The Impact of Façade Design on Daylighting Performance in Office Buildings

The Case of Beirut, Lebanon

Sawsan Mohamad Saridar

A thesis submitted for the degree of
Doctor of Philosophy
in the
School of Architecture, Planning, and Landscape
at the
University of Newcastle upon Tyne

August, 2004

To,

My parents

and

in loving memory of my grandmother

Abstract

An energy shortage arose in Lebanon during and after the civil war (1975-1990). 62% of the national electricity generation is consumed by building stock, of which 7% is consumed in the commercial sector. Given the acute shortages and increased consumption, there is a need to rationalise the use of energy in the building sector.

There is growing evidence that buildings which adopt passive design solutions, such as daylighting and natural ventilation, have good energy performance and show higher occupant satisfaction. Daylighting can be a good contributor to energy efficiency in the buildings of Beirut, where the climate is typically Mediterranean and daylight is available 12 hours per day on average.

During the last century, the development of façade configurations and the widespread adoption of international design trends in Beirut, particularly in office buildings, changed the energy consumption pattern. The lack of any building regulations that considered the potential of daylighting led to an underestimation of the impact of façade design on the internal environment and building energy behaviour.

The aim of this study is to develop design guidelines for office building façade configuration and plan morphology that will contribute to the best use of daylighting, with associated potential energy savings, in Beirut.

To achieve this, the study has three main parts. Firstly, the literature relating to daylighting design principles, glazing façades and human comfort in workspaces is reviewed in order to identify design parameters and variables that are significant for daylighting performance in office buildings. Thereafter, the seven historical phases of architectural development in Beirut are identified. Examples of office buildings from each phase are evaluated for their daylighting efficiency, in accordance to four parametric levels describing the 'Building Shape, 'Window/Façade' and Window/Office' relationships, and the 'Shading Devices' used. Finally, the lighting behaviour of 14 selected case studies is simulated using ADELINE. Electrical lighting consumption and the possible savings due to the implementation of different lighting control strategies are calculated. The simulation outputs are validated by empirical energy data. Finally design guidelines for the best practice in the office buildings of Beirut are produced, by coupling the evaluation of daylighting design variables and energy savings measures.

Acknowledgements

Now, staring at a blank page, I do not know what to write in my acknowledgements. The first thing that came into my mind is Aristotle's statement: *' The roots of education are bitter, but the fruit is sweet'*. The product of this research cannot be measured only by the amount of work I have done, or the number of pages I have written; it is the amount of experience and knowledge I have earned during these years. The '*movement from darkness to light*' has been easier with the help of many people who have been a source of stimulation, inspiration and motivation to me.

I must first thank my supervisor, ***Professor Hisham Elkadi.*** He really does deserve the greatest of thanks, since he has provided me with an incredible amount of support, encouragement and guidance both in the writing of this thesis and the work which preceded it.

It is to ***my parents***, however, that I feel I owe the most. They have been wonderful over the years, and never raised an eyebrow when I claimed that my thesis would be finished `next month'...for almost a year. They have always given me the confidence to believe that I could do anything I set my mind to, and after years of wondering if it was true, I can look at this thesis and believe it is. I have accomplished what, at times, seemed almost too large to conceive. My parents are extraordinary people, and it is my greatest hope that I have inherited some of their exceptional generosity, faith and love.

I cannot forget my ***uncle Mohamad,*** and my brothers ***Hussam*** and ***Hisham*** who have been tremendously generous, caring, supportive and loving people with me. Thank you for being there during every single step of my life.

A very special word of gratitude must to my best friend ***Dr. Nawal Al-Hosany***. She is the sister that I never had. She has also enriched my work through the helpful discussions we have enjoyed.

Rima El-Hassan and ***Nassra Al-Dhaheri***, have been very generous with me. I thank them for sharing the good times and the bad. We have walked this way together, and I pray to God that we shall reach the end having achieved our best.

Special thanks go to ***Firas Mourtada***, ***Dr. Georges Arbid*** and ***Khaled Azhari,*** for their time and the data they provided so very generously.

Finally, thanks to all ***my friends*** in Newcastle and Beirut for their continuing love and support.

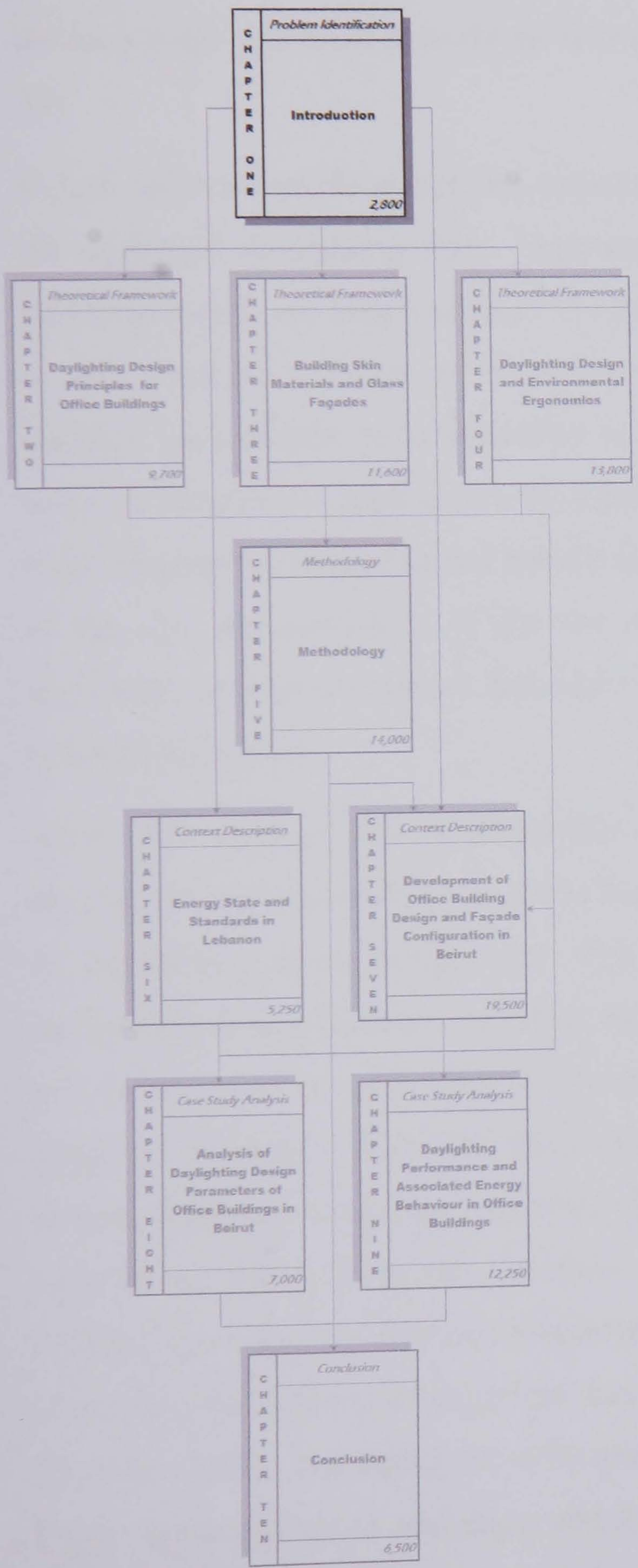
Table of Contents

List of Figures

List of Tables

INTRODUCTION

1



Chapter One

1. Introduction

1.1 Overview

"*Architecture cannot exist but with light. We take it too much for granted and forget its true value. We abuse light with intensive and careless solutions and by substituting it too often by too much unnecessary artificial lighting. Today further to feeling, we have both the knowledge and tools to make an even greater and creative use of it*" (Tombazis, 1998: 29).

Before effective artificial lighting became available, it was particularly important to get the design of daylighting right. Organised knowledge of good daylighting practice for buildings has a very long tradition. The Romans were the first to discuss good daylighting in the classical writings of Vitruvius. Throughout history, architectural forms and building technologies have responded to bioregional forces in ingenious and resourceful ways. A bioregional approach to daylighting has involved the ways that design can grow from, respond to, engage in and benefit from the life forces of a specific region. The track of the sun, the conditions of the sky, the climate and the nature of the site are the significant bioregional forces that have shaped architecture and influenced daylighting (Guzowski, 2000).

After 1900, daylight was in competition with the various forms of artificial light. The development and availability of cheap fluorescent electric lighting accelerated the neglect of daylighting as a design aim. This led to architectural impoverishment of the daylighting design tradition based on the interaction of form and daylight (Baker *et al.,* 1993), having as its nadir the development of "Burolandschaft" in 1960s Germany. This design movement is commonly known as office landscaping, where buildings could be of infinite depth allowing large expanses of open floor space and more even distribution of light in the space. Over the last three decades, renewed interest in the utilisation of daylight has been apparent and primarily justified by the high cost of fossil fuels and the realization that sources of electricity have a finite life, these being quoted as most cogent (Phillips, 2002). The energy used by artificial lighting in buildings is a major part of the energy consumption in buildings, and it is recognized that reduction in the emissions of carbon dioxide, as well as the reduction of greenhouse gasses will have an important effect in reducing global warming (Hens *et al.*, 2001; Li *et al.*, 2003). Greater use of daylight can also lead to a reduction in the use of electrical energy, and assist significantly in the battle to solve the energy problem.

Yet, the emphasis on daylighting within the context of sustainable design still tends to focus on a particular set of environmental issues related to energy and natural resources. However, it is impossible to judge the need for daylight and sunlight in engineering terms alone. Daylighting is not simply about the wise and rational use of light within a particular bioregion, but a set of design considerations to illuminate a distinct set of human activities (Guzowski, 2000).

Daylighting is an intriguing aspect of design in which environmental, aesthetic and human factors come together. According to Guzowski (2000: xxvi), 'daylighting should be explored from different perspectives and addressed by different people during the design process. "Building scientists" study the energy and environmental impacts of daylighting, "designers" explore its formal and aesthetic implications and "behaviourists" address the human implications of daylighting'. The human factor is at least of equal importance. Daylight is believed to be essential in providing a pleasant visual environment, contributing to a feeling of wellbeing and often resulting in improved productivity (Phillips, 2002; Baker *et al.*, 1993 and Clements-Croome, 2000). Accordingly, in some countries such as the Netherlands and Germany there are regulations determining that in a work situation, the staff must not be located further than six metres from a window (Ander, 2003).

1.2 Daylighting in Office Buildings

The interest in daylighting returned in the late 1970s, after the energy crisis. It was re-discovered as an efficient way to reduce energy consumption in buildings with predominantly daytime occupancy such as offices, educational buildings and factories. This is particularly the case in areas of buildings where daylight is available (i.e. where illuminances are roughly 2 to 5% of the simultaneous outdoor illuminance for overcast conditions). Daylight brings enough light to meet the lighting requirements of 50 to 70% of the occupancy period in the temperate zones of the earth, and even more around the equator (CIE, 1970).

Energy for artificial lighting in offices can account for up to half of their primary energy use (Burton, 2001). Since office work takes place largely during daytime, a large proportion of this energy can be eliminated by using daylight. The theory of electric lighting savings due to daylight is well understood, and theoretical models have been developed to predict energy savings using different window designs (Sullivan *et al.*, 1992). Many studies have shown that the use of daylight can introduce energy savings in the range 35 – 75% of lighting costs, provided that the artificial lighting is controlled in such a way as to take the increased daylight level into account (Burton, 2001; Bodart *et al.*, 2002).

Although the potential for reducing energy costs and environmental emissions is substantial, daylighting's most powerful impact is on the building's occupants. Buildings are constructed for people. One hour of salary is equivalent to the cost of 1 year of lighting energy for that worker (Leslie, 2003; Bodart *et al.*, 2002). Therefore, the strongest economic argument for daylighting may be the worker's improved productivity, increased job satisfaction or reduced absenteeism, each of which can easily offset the initial investment in daylight systems (Li *et al.*, 2003; Heschong *et al.*, 2003 and Mullins, 1998).

1.3 Daylighting Office Buildings vs. Energy State in Beirut

Following the local problems that started in Lebanon in 1975, the electricity sector has suffered serious damage and continuous energy shortages. In 2002, the yearly reserved power shortage reached 525GWh. In addition, since Lebanon is a non-oil producing country and 91.3% of its power production is thermal, combustibles must be imported from the international market in order to meet the local energy demand. In 1999 imported energy bills represented 13% of the country's total imports, and 5.7% of the GDP (Chedid *et al.*, 2004).

The building sector remains the largest consumer of energy compared with other sectors. According to a UNDP / GEF study (2000), commercial and residential sector consumption constitutes 70% of the national electricity generation, while in contrast only 11% is used by the industrial sector. There is therefore a vital need to rationalise energy use in the building sector, and to improve the emerging environmental policies in Lebanon.

Daylighting can be a good contributor to energy efficiency in the buildings of Beirut, where the climate is typically Mediterranean and the average daylight duration varies from 10 hours in winter to 14 hours in summer days. There are no recorded data of global horizontal illuminance in Beirut (33° 49' North latitude and 35° 29' East longitude), but the nearest location where daylight has been measured may be considered as a reference point to reveal daylight availability. In the eastern Mediterranean, daylight data were collected at the Israeli meteorological service at Bet Dagan which is located at 32° North latitude and 34.49° East longitude. This work was part of the International Daylighting Measurement Program. The global horizontal illuminance (in lux) was measured in the Tel Aviv area for the typical office working hours of 8:00 to 18:00. This shows that most of the time the illuminance level is over the value of 10 000 lux, including most of the working hours throughout the year (Capeluto, 2003).

Whatever the availability of daylight outside the building, the penetration of daylight into the building depends on many design parameters; among them the depth of the room from the window wall, ceiling height, internal reflectances, window orientation, shape and size, and the optical properties of the glazing. The development of façade configuration and the spread of international design trends in Beirut during the last century, predominantly in office buildings, have changed the daylighting flow pattern of the indoor spaces. In turn, energy consumption patterns have also changed. This is due to the lack of enforced building regulations or codes that consider the potentials of daylighting, which in turn may provide ideal opportunities for an appropriate, energy-conscious building design.

1.4 Aims and Objectives

The aim of this research is to assess the daylighting performance of office building façade configuration and plan morphology that contributes to the best use of daylighting and associated potential lighting savings in Beirut. This study examines the 'Lebanese Energy Standard for Buildings' project currently under development by the United Nations Development Programs (UNDP) and the General Directorate of Urban Planning. This investigation is to propose some additional recommendations emphasising the role of daylighting, which have been marginalised by the conducted project, to improve potential energy savings.

The main objectives of the study can be divided into three main groups. The first group deals with the development of a preliminary design evaluation tool to assess the daylighting performance of office buildings in Beirut. The second category of objectives considers the historical review of office building design trends in Beirut during the last century, with emphasis on the development of their façade design and their impact on daylighting performance. The investigation of the impact of office building design variables on the buildings' energy behaviour and potential lighting savings, are the last set of objectives. The three groups of objectives can be further explained as follows:

1. Objectives related to the development of a preliminary design evaluation tool:
   - To identify the main façade design variables that have influence on daylighting availability and flow pattern in internal spaces.
   - To investigate the relative importance of different variables that draw relationships between the aperture properties and the related window-wall and daylit area in the studied context.
2. Objectives related to the historical review of office building trends in Beirut and daylighting performance:
   - To outline the historical phases of architectural development of office buildings in Beirut.
   - To review the development of façade design and plan morphology of offices in Beirut.
   - To identify the daylighting variables that have been considered or neglected by architects in the design and construction of office buildings in Beirut throughout the last century.
   - To evaluate the daylighting performance of office buildings in Beirut in all historical phases.
3. Objectives related to lighting consumption and potential savings
   - To examine the potential lighting savings in the studied context resulting from daylight and electric light integration with automated switching controls or dimming systems.
   - To identify the main variables that have influence on the potential lighting savings.

1.5 Thesis Structure

The structure of the thesis and a brief description of chapters contents are illustrated in Figure 1.1. The diagram explains the six different stages of the research, and the links between the chapters. The problem identification (the 'why' question) is followed by the review of literature and theories related to daylighting and façade design in an attempt to assess daylighting performance and related energy behaviour in office buildings in Beirut. The methodology stage identifies the methodology of this research has been conducted. The studied context is reviewed in the following stage. The analysis and investigation of the case studies constitute the fifth stage of the research, followed by the concluding remarks and recommendations.

Chapter One presents and justifies the topic of the study. The first section of the chapter represents an overview of the importance of daylighting as a design feature in buildings. It also highlights the renewed interest in daylighting design as a significant solution to assist both the energy crisis and global warming. Section 1.4 states the aims and objectives of the research. The structure of the thesis is described, and the contents of the chapters are summarized.

Chapter Two begins by defining daylighting and its characteristics in the built environment. This is followed by a review of the architectural design variables and factors used to assess daylighting. These variables are classified in three different scales: the micro scale, the meso scale and the macro scale. Section 2.3.1 goes through all the variables of the micro scale in detail. These variables are of great importance for this study, as they draw the relationship between the window properties and the room façade and area respectively. Section 2.3.2 reviews the variables of the meso scale (or the building scale). The macro scale is briefly reviewed in Section 2.3.3, as the impact of urban planning is not a main concern of this study.

Chapter Three will firstly define the building envelope. Subsequently, Section 3.3 reviews the physical and optical properties of different envelope materials that have bearing on daylighting. As the window, or more specifically the glazing, is the interface of the building with the natural environment and the main source of daylighting, advances in the various technologies of glazing are reviewed in Section 3.4. The literature review in Chapters Two and Three is to identify the variables necessary to assess the impact of façade design on daylighting performance.

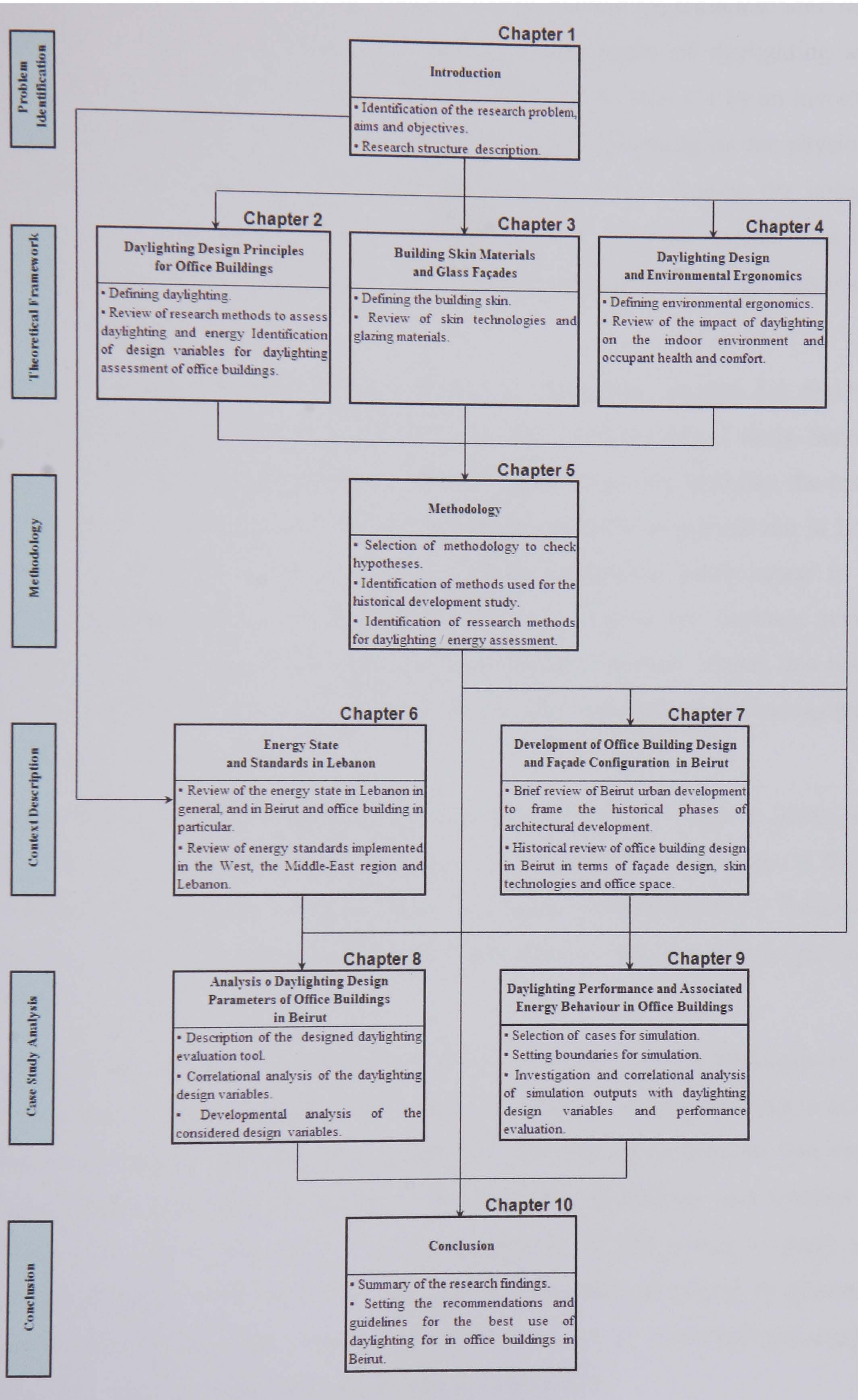


Figure 1.1. The thesis structure diagram.

Chapter Four introduces the definition of environmental ergonomics, and its main components. Section 4.3 reviews the physical characteristics of daylighting and the anatomy of the visual system. This review is followed in Section 4.4 by an investigation of visual comfort requirements, and the implications of daylighting on the physiological and psychological aspects of office occupants in Section 4.5. Finally, the impact that daylight has upon mood and productivity is discussed in the final section. This chapter aims to highlights the human implications of a sustainable approach to daylighting in the built environment.

Chapter Five describes the methodology used in the thesis. Section 5.1 reviews the theories of research methods in general, and their link to the conducted study. Section 5.2 reviews the methods and approaches used in previous researches, studying the historical development of architecture and daylighting design evolution in general and in Lebanon in particular. Research methods used to assess daylighting performance in office buildings are discussed in Section 5.3. Section 5.4 includes the literature review of available daylighting simulation tools, and describes the selection criteria that helped to select ADELINE software used to estimate the lighting performance and energy potential savings of the case studies.

Chapter Six reviews the state of energy in Lebanon in general, and in Beirut and the building sector in particular. It also discusses energy conservation awareness in the World and the implemented or developed energy standards, predominantly in Lebanon. The chapter is prefaced by some background information on the geographic and climatic conditions in Beirut.

Chapter Seven reviews the emergence and development of office buildings in Beirut. The alteration of façade typology and urban morphology of office buildings and their impact on daylighting performance is emphasised. Section 7.2 reviews the first true signs of urbanization that began to appear in Beirut during prehistory, and resulted in the emergence of commercial and / or office use structures. The period of study and the historical phases of architectural development are therefore identified in section 7.2.2. Examples of office buildings from each identified phase are described and analysed in Section 7.3, where their daylighting efficiency is discussed.

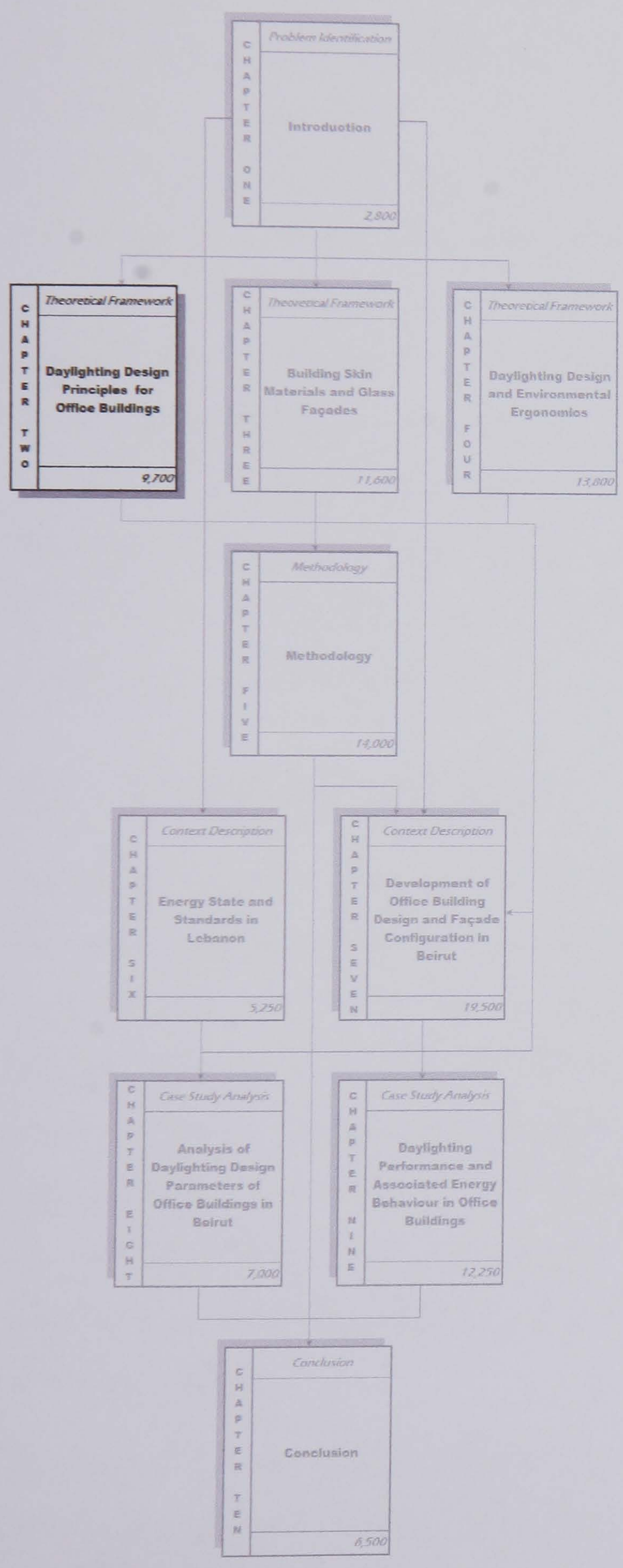
Chapter Eight aims to draw a more detailed and comparative view of office building architecture in Beirut, and identify the façade and plan design variables that have been considered most significant for daylighting performance in the studied context. Firstly, Section 8.2 examines the correlation of the considered design variables with daylighting performance evaluation. The following section reviews the development of each daylighting design variable and the daylighting performance evaluation of the design parametric levels during the last century.

Chapter Nine aims to identify the considered variables, describing façade configuration and office plan layouts which have implications on the energy performance of the building. This chapter is divided into three major sections. Section 9.2 discusses the criteria for the selection of cases for simulation. The following section sets the boundaries for the simulation. In Section 9.4, the simulation outputs are investigated and analysed in accordance with daylighting design variables as discussed in Chapter 8. A summary of the findings is given in the last section of the chapter.

Chapter Ten provides a summary of the thesis findings. Attempts are made in this chapter to set recommendations and guidelines for the best use of daylighting in office buildings in Beirut, and which could enhance the potential energy savings studied in the 'Lebanese Energy Standards for Buildings' project.

DAYLIGHT DESIGN PRINCIPLES FOR OFFICE BUILDINGS

2



Chapter Two

2. Daylighting Design Principles for Office Buildings

2.1 Introduction

Daylighting is important. It can permit a more flexible building façade design strategy, and enhance more energy-efficient and greener building development (Li *et al.*, 2002). Many studies have indicated that there is great potential for the reduction of energy demand in non-domestic buildings, by exploiting natural light more effectively (Knight, 1998 and Li et al, 2002). Numerous books, reports and magazine articles have been written about daylighting designs. Some have presented the merits of daylighting, while others have discussed various design strategies. However, it is often difficult to extract from these publications the underlying principles used to create a good daylighting design solution. In particular, there are not enough data about the optimum use of daylighting in the eastern Mediterranean region. This chapter will not restate the merits of daylight, nor provide an in-depth technical discussion of any particular issue. Instead it will focus on a few basic principles and schemes used to assess daylighting in buildings. This is preceded by definitions of 'daylight' and 'daylighting' in general, and what daylighting can mean to people in the built environment.

2.2 Defining Daylighting

As a noun, *daylight* or *natural light* describes all direct, diffuse and reflected light from the sun in the daytime. This includes sunlight (direct from the solar disk), skylight (whether clear sky, partly cloudy, cloudy or overcast sky), and sunlight and or / or skylight reflected from other surfaces such as the ground, other buildings or bodies of water (Ternoey, 1999 and Steffy, 2002). As a verb, *daylight* or *daylighting* is the choice, act, art, science or practice of using daylight as the primary daytime illuminant in a room or building. From the environmental perspective, the definition of daylighting also includes the inherent ability to turn off electric lighting when not needed in the daytime (Ternoey, 1999).

As noted from the reviewed literature, daylighting means different things to different people and may be considered from different perspectives. View, health, illumination and sustainability are criteria that are likely to drive the reasons for daylighting being introduced into a building, and how it is handled as a design and engineering element.

2.2.1 Daylighting and View

People like to be able to have a view out of buildings they use for any length of time, such as their homes or work places. To have a view means that the building's occupants are visually connected with the outdoors, through windows or other architectural openings. According to Rennie *et al.* (1998), views in urbanised areas should be analysed in three layers: the upper (distant) layer extended from the sky down to the skyline; the middle layer, which includes the fields, hills or buildings; and the lower (close) layer which overlooks the foreground (i.e. plants, paving, and people). Views which include all three layers are the most satisfying. View offers psychological benefits to users. View also acts as a distant focus for eye muscle relaxation, from time to time during the day (Ternoey, 1999 and Rennie *et al.*, 1998). Referring to the British Standard (BSI, 1992): 'all occupants of a building should have the opportunity for the refreshment and relaxation afforded by a change of scene and focus… Unless an activity requires the exclusion of daylight, a view-out-of-doors should be provided irrespective of its quality'. The size of the window needed to give an adequate view depends on how far one is from the window. Critical minimum window sizes recommended by the British Standard daylight code (BSI, 1992) for deep rooms with a window on only one wall are given in Figure 2.1 (BSI, 1992):

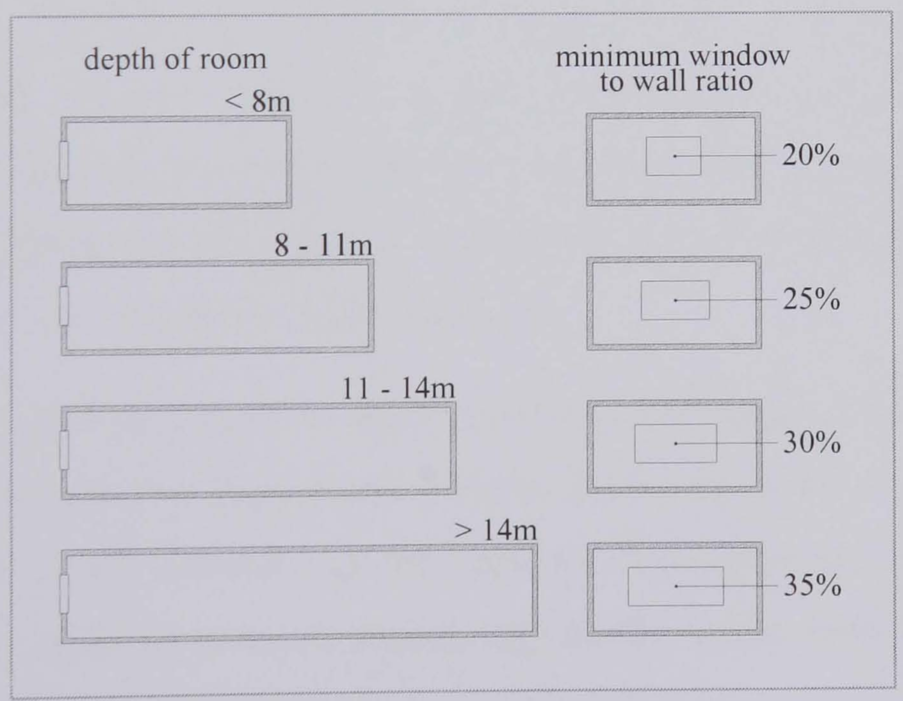


Figure 2.1. Minimum window size recommended by BSI to provide adequate view in deep rooms.

2.2.2 Daylighting and Healthy Environment

Daylight has significant health benefits. Capra (1982) suggests that human health is integrally related to the environment: '... our experience of feeling healthy involves the feeling of physical, psychological and spiritual integrity, of a sense of balance among the various components of the organism and between the organism and its environment.' Daylight is one of many important environmental factors. Daylight is involved in the setting of the "biological clock" and its associated circadian rhythms, and in the production of vitamin D. Of particular significance to the architect, the lack of daylighting in deep offices can negatively affects occupants of deep-plan artificially lit buildings. Although adequate for visual tasks, artificial illumination is insufficient to trigger the necessary physiological response. An extended study of the significance of daylight for health will be found in Section 4.5 of Chapter Four.

2.2.3 Daylighting and Illumination

It seems almost unnecessary to explain that daylighting can be used to provide illumination and to reduce electric lighting loads. Yet although many buildings admit daylight to their interiors, surprisingly few actually use it for illumination. Guzowski (2000) stated that a quick survey of the typical office buildings in any city will show how infrequently electric lights are switched off, dimmed, or in any way correlated with the available daylight. Hundreds of thousands of electric lamps burn needlessly as daylight streams through the windows. Daylight can provide much of the light needed to perform many of today's living and working tasks. However, poor design is more often the reason for not using daylighting for illumination. In some cases, its use may simply be a question of the routine of turning on electric lights each day.

Thick buildings, excessively large or small windows, inadequate solar access and lack of control can all contribute to inappropriate illuminance levels, glare, excessive heat gain or heat loss and poor visual comfort. All the variables that assess daylighting performance and their impact on building users are extensively studied in the following sections of this chapter, and in Chapters Three and Four.

2.2.4 Daylighting and Sustainability

Sustainable development is '*the ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own* *needs'* (The World Commission on Environment and Development, Brundtland Commission 1987). Referring to Steffy (2002), the very essence of sustainability is to attempt to achieve as much as possible with a little as possible, particularly with natural and renewable resources. Daylight offers just such a means. Success of daylighting as a sustainable practice is very sensitive to the integration and interaction of the various building designs, materials and systems (e.g. window dimensions, glazing systems, lighting systems, control systems, monitors, etc.). Accordingly, despite the many human and aesthetic benefits that derive from using daylighting for illumination, health and view, it's most evident ecological benefit is to reduce peak energy demand and subsequent environmental impacts.

In conclusion, the previous review showed that the benefits of daylighting a building are far-reaching. These benefits are summarized in the diagram illustrated in Figure 2.2.

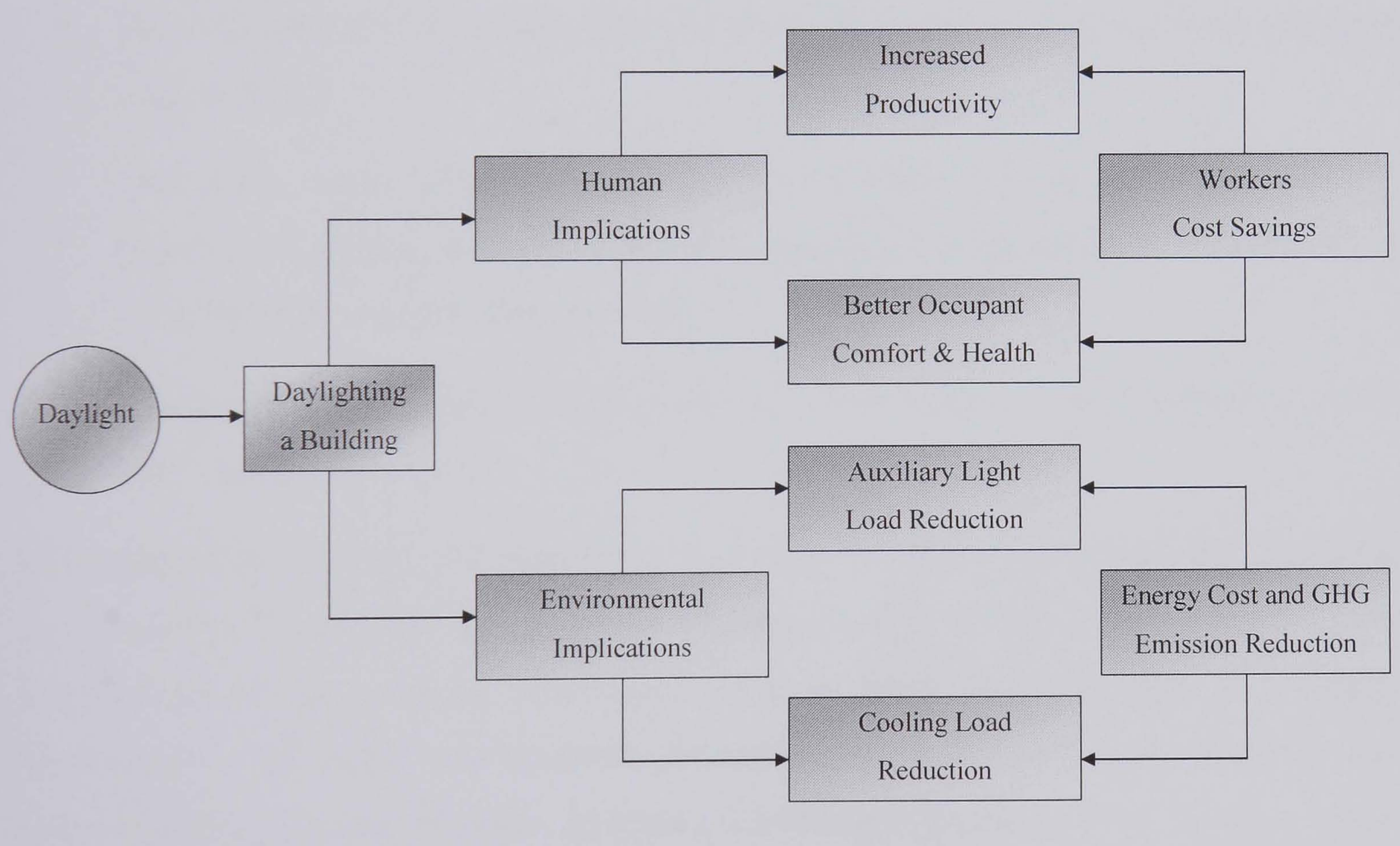


Figure 2.2. Benefits of daylighting to a building

2.3 Assessing Daylight in Buildings

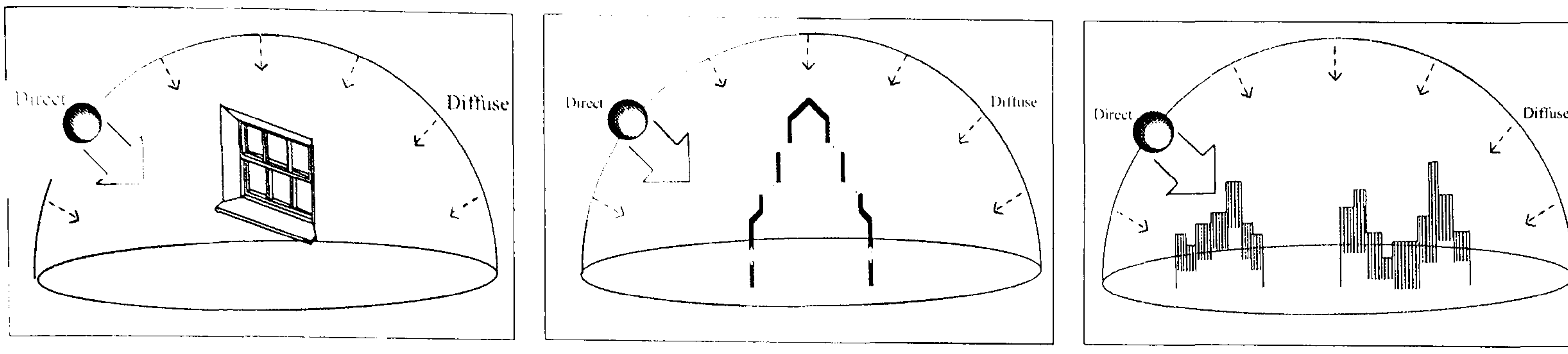
According to Littlefair (1996), the building envelope can be thought of as a light fitting designed to control the quantity and quality of light to achieve an effective daylighting design. The building envelope should therefore achieve the following key aims:

- Increase daylight levels towards the rear of deep rooms,
- Improve the daylight within a space and therefore its appearance,
- Control direct sunlight so that it can be an effective working illuminant, and
- Reduce glare and discomfort for occupants.

To achieve the stated aims, a set of design variables may be examined. BRECSU (1997) classified these design variables into three different levels underneath a simple and useful model, the dome of the sky:

- The micro scale, which deals with architectural detail of the fenestration elements (Figure 2.3a),
- The meso scale, where the interest is concentrated upon the significance of openings within the external fabric of the building and the effect of building depth on daylight penetration (Figure 2.3b),
- The macro scale, where considerations are at the level of town planning or the urban block (Figure 2.3c).

This framework is adopted by this study, to review basic daylighting design principles. The variables of each scale are revised in a separate section of this chapter. Section 2.3.1 goes through all the variables of the micro scale in detail. These variables are of great importance in this study, and establish the indicators for the case study selection and analysis in the following chapters. Section 2.3.2 reviews the elements of the meso scale. The macro scale is reviewed but only briefly in Section 2.3.3, as the impact of urban planning is not a main concern of this study. The set aim is to examine only the impact of building envelope and window design on daylighting performance.



a- The Micro Scale b- The Meso Scale c- The Macro Scale

Figure 2.3. Classification of different scales for studying daylighting in buildings (BRECSU, 1997).

2.3.1 The Micro Scale

In the micro scale, the actual design of the building's daylit areas is based upon the geometric relationships between the room or space being daylit and the size, shape, location and orientation of the various daylight apertures that provide the room's daylighting illumination. In general, any space can be daylit using side-lighting (vertical aperture), top-lighting (horizontal aperture) or even angled lighting (inclined aperture). Side lighting is normally the main method of whatever provides natural lighting to multi-storey buildings such as office blocks, which are the concern of this study.

Proportional relationships between daylighting concepts and the room or the space being daylit were grouped by Robbins (1986) into three sections:

- Spatial proportions, which draw relationships between size and volume in the room (or building),
- Aperture proportions, which illustrate the aperture characteristics as a daylight fitting and its proportion from the external wall,
- Spatial / Aperture proportions, which interpret the relationships between aperture and room dimensions.

The following section, 'aperture proportions', will describe the characteristics of sidelit apertures. Section 2.3.1.2 reviews the spatial / aperture proportions required for optimum daylighting performance in offices. Spatial proportions such as the width, length and ceiling height of the room are considered. These proportions are basic to the architectural theories of office space design. They are further reviewed as part of the building form and volume in the meso scale (Section 2.3.2).

2.3.1.1 *Aperture Proportions*

In this section, the different scenarios of aperture location, aperture shape, window height, window orientation and window / wall proportions are reviewed. The aim of this review is to set the variables of the aperture characteristics as part of the window wall, and their impact on daylight propagation inside the indoor space.

2.3.1.1.1 Aperture location

Spaces can be daylit by sidelight windows unilaterally, bilaterally, multilaterally or by complete glazing façade(s).

In a room that is unilaterally daylit, where daylight is received through apertures placed in a single side wall, the illumination level decreases until it reaches the opposite wall (Figure 2.4a). Accordingly the effective depth (width) of a room in high latitude regions, where there is a substantial number of overcast days, should be limited to a maximum of two and one half times the height from the floor to the window head (Rule of Thumb). This is not the case in Lebanon, where clear days are more prevalent and reliable. According to Flynn (1992), this ratio can be increased to 3.5 in lower latitudes.

Bilateral daylighting occurs when daylight apertures are located on opposite walls of a room, generating two primary lighting zones (Figure 2.4b). Large open plan offices and rooms having views to the exterior and to an interior courtyard or atrium are possible examples of bilateral rooms.

Multilateral daylighting occurs when daylight apertures are placed on more than one non-opposing walls of a room, which generates three or more primary lighting zones (Figure 2.4c). Multilateral rooms are generally located on the corners of buildings.

With a complete glazing façade, daylight apertures are placed along the whole external façade(s) generating two primary lighting zones (Figure 2.4d).

Comparing the four room schemes illustrated in Figure 2.4, daylighting from complete glazing produces a bigger zone of high illuminance than the other schemes. Unilateral daylighting with a room depth of more than 2.5 – 3.5 the height of the aperture head is the worst scenario for window location in relation to daylight propagation. Therefore, this classification of aperture location is adopted in this study.

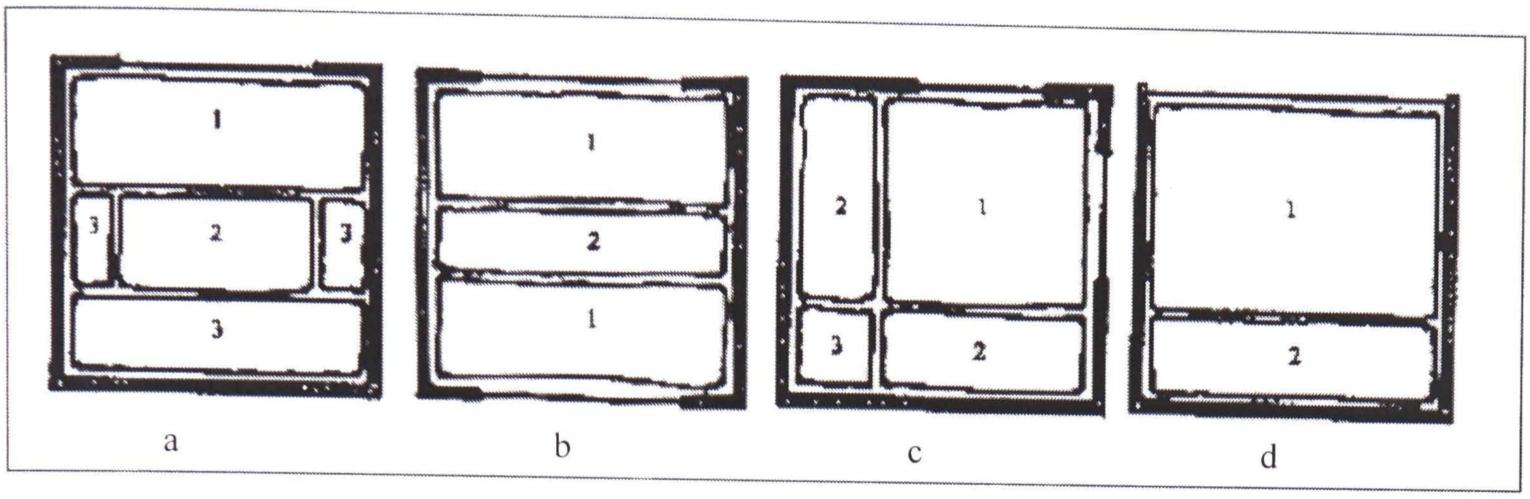


Figure 2.4. Plans illustrating lighting zones (1: higher illuminance level , 2: less illuminance level and 3: lower illuminance level) : a- unilateral; b- bilateral; c- multi-lateral; d- complete glazing (Robbins, 1986).

2.3.1.1.2 Window shape

The next variable of the window as a daylighting component is its shape. The shape of a window affects light distribution and the quality of the view (Figure 2.5 and Figure 2.6). The variation of window Coefficient Shape CS (length / height) produces four window shape categories:

- Horizontal windows: CS < 0.5. Illumination levels are parallel to the window wall, with little difference in light distribution and with little glare.
- Intermediate windows: 0.5 < CS<2.0.
- Vertical windows: 2.0 <CS. Illumination is perpendicular to the window wall, producing various luminous distributions. It offers better illumination in the zones farthest from the window.
- Totally glazed wall.

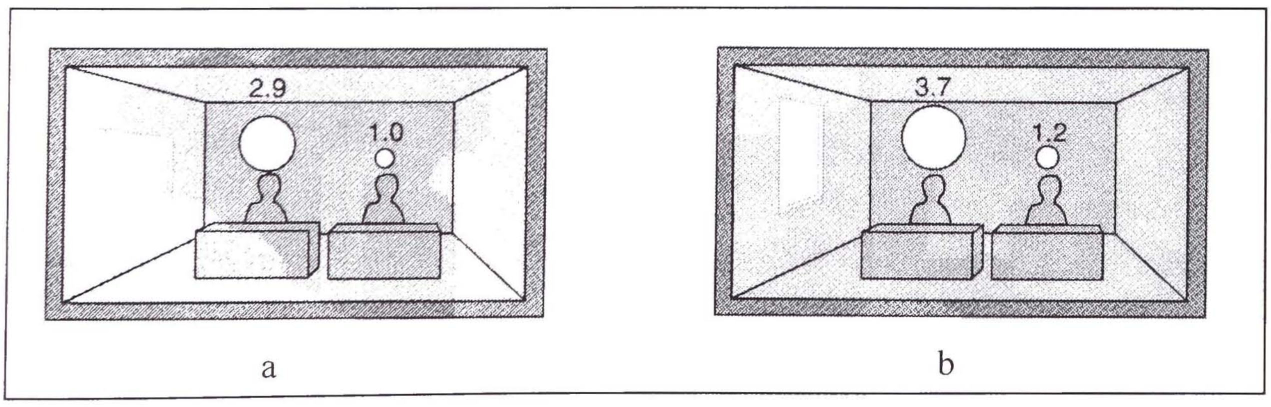


Figure 2.5. A vertical window (b) has a better effect on daylight penetration than a horizontal window (a) of the same area (O = daylight factor (%) on the desk; Rennie *et al.*, 1998)

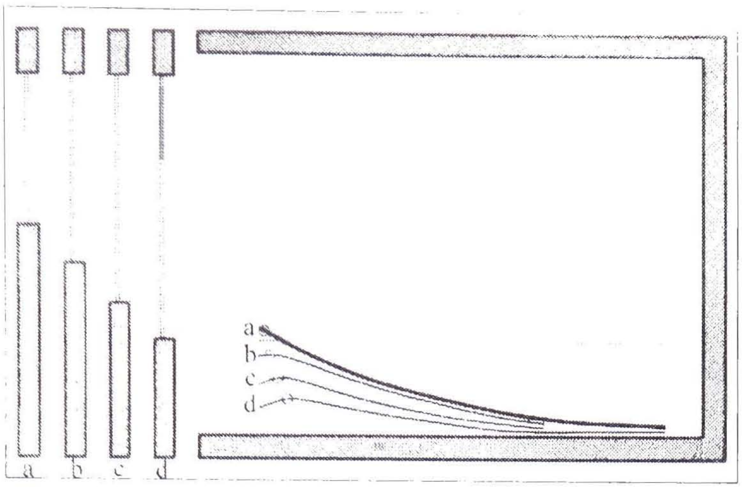


Figure 2.6. Effect of window shape on illumination level (Robbins, 1986): a-vertical, b-c- intermediate, and d- horizontal.

2.3.1.1.3 Window sill height

The height of the window from the finished floor will dictate the depth of penetration. Broadly speaking, the higher up the window is placed the greater the daylight factor will be. This is because the light from a higher window comes from a higher and therefore brighter part of the sky, and it reaches the working plane at a steeper angle. Window position may be classified as follows:

- Low window (SH < 75cm): when Sill Height SH is lower than the working plane, and reaches down to the floor (Figure 2.7d and Figure 2.8a).
- Intermediate window (75cm ≤ SH ≤ 160cm): where the sill height is just above the working plane and below eye level. (Figure 2.7b, Figure 2.7c and Figure 2.8b).
- High window (SH > 160): where sill height is above eye level (Figure 2.7a and Figure 2.8c).
- Window wall.

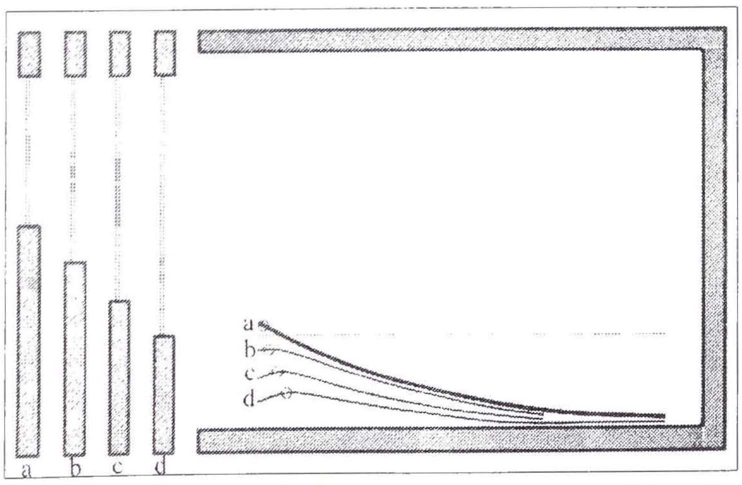


Figure 2.7. Effect of window sill height on illumination level (Robbins, 1986): a- high, b-c- intermediate, and d- low.

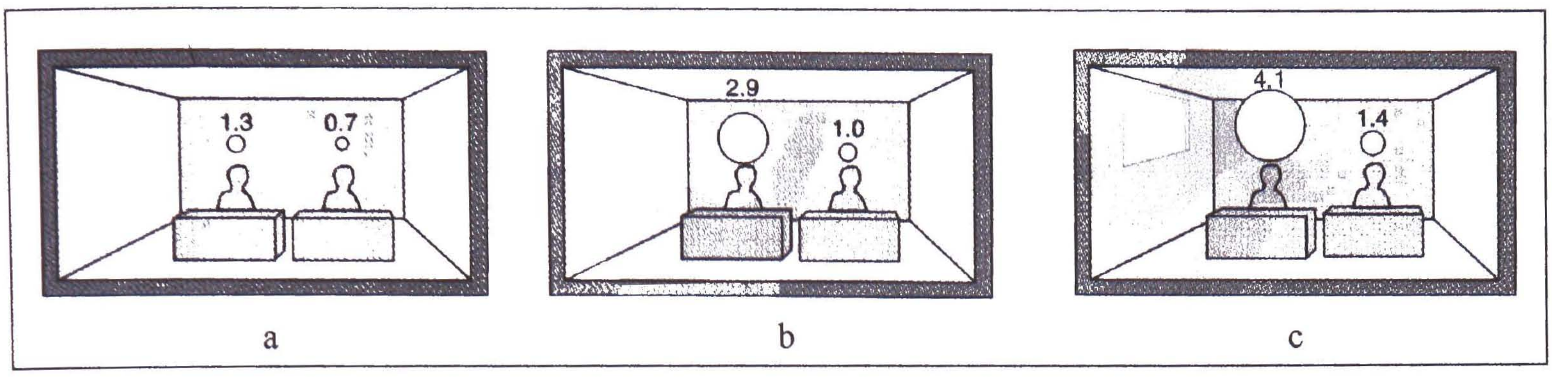


Figure 2.8. Effect of the height of the window head on the daylighting factor (O = daylight factor (%) on the desk below; Rennie *et al.*, 1998).

2.3.1.1.4 Window orientation

With regards to the orientation of a window, reference must be made to geographical orientation since the sun's path can have great influence on natural illumination (Figure 2.9). When analysing daylight at a given location, there are three basic components to consider: direct sunlight, which impinges intermittently on the east, south or west exposures of the building in the northern hemisphere; skylight, which impinges simultaneously and somewhat more consistently on all exposures of a building; and reflected light from the ground and nearby man-made structures. Each of these components varies widely with the time of day, time of year, geographic location and prevalent atmospheric conditions.

The south face generally affords the greatest quantities of light. This is particularly true during winter months where sunlight is lower in the northern hemisphere (Figure 2.9). The south-facing window produces high luminosity, variable illumination and high energy gain.

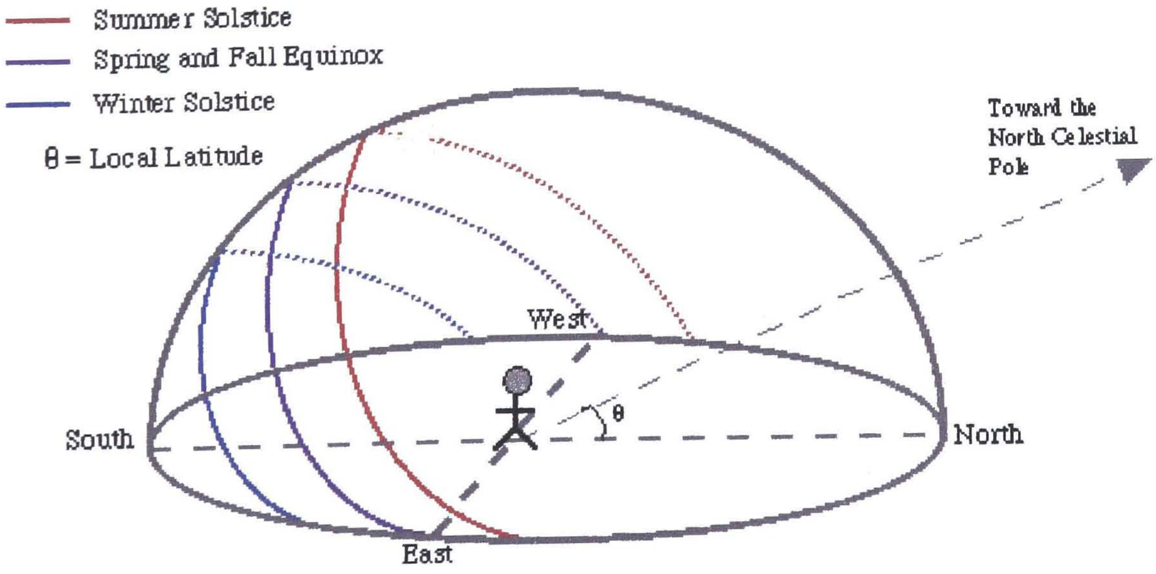


Figure 2.9. The sun's path in the northern hemisphere (Larson, 2004).

Because of the low angle of the sun during morning and afternoon hours, exposure to the east and west present the most difficult problem related to direct sunlight penetration and glare control. From this point of view, east and west facing windows are considered as being equivalent since the general effect produced is the same, although occurring at different times of the day. The low solar angle in the east and west is hard to control without covering the window completely; thus east and west facing windows will have a low luminous level, and the illumination will vary greatly during the day. High-energy gain will be caused in the summer, but will be lower in the winter.

In the north, skylight and reflected light from the ground are the dominant sources of light. Therefore, the north-orientated window produces low luminosity, constant illumination and poor energy gain.

Given these characteristics, it is possible to classify window orientation as follows:

- East and west facing windows
- North facing windows
- South facing windows

2.3.1.1.5 Exterior wall area to window area relationship

In this section, variables that relate window dimensions to exterior wall area are reviewed. These variables also consider some properties of glazing such as visible light transmittance and shading coefficient, which will be extensively studied in Chapter Three.

2.3.1.1.5.1 Window to wall ratio

The Window to Wall Ratio (WWR) is the product of **net glazing area** divided by the gross exterior wall area.

The net glazing area obstructed by glazing bars depends on the framing material and its design. Thus it can be calculated by multiplying the area of aperture by the correction factor for the frame, which depends on the window framing design and its percentage in the aperture area. Table 2.1 illustrates some values for the correction factor for frames.

Within the morphological box developed by Baker *el al.* (1993)and explained later in Chapter 5, WWR has been categorized as follows:

- $0.00 \leq WWR < 0.15$
- $0.15 \leq WWR < 0.30$
- $0.30 \leq WWR \leq 1.00$

In the study by Baker *et al.* (1993), there is no clear explanation or justification of this categorization. For this research, the adopted WWR classification will be according to the figures calculated in the studied context.

Type of window	Typical correction factor
Metal patent glazing	0.9
Metal Frame: large pane	0.8
Wooden Frame: large pane	0.7
Wooden Frame: small pane	0.6

Table 2.1. Correction factor for frames (BRE, 1986).

2.3.1.1.5.2 Daylighting aperture ratio

The choice of glazing affects the daylight, solar heat gains and heat loss through a window. These are measured by the Visible Transmittance VT, the total solar transmittance or Shading Coefficient, and the thermal transmittance or U-Value. The 'Effective Aperture' size EA (Ander, 2003) or Daylighting Aperture DAR (Lam *et al.*, 1999) is an additional ratio that affects daylight penetration and performance in the micro scale. It is the product of the window to wall ratio WWR multiplied by the visible transmittance of the glazing system used; DAR = WWR x VT. In other words, it is the product of the exact glazing area divided by the gross exterior wall area. If however the glazing has a VT of 0.50 the opening will transmit only half of the light striking, and the 'effective aperture' will be half the actual size of the opening. Table 2.3 gives the values for visible transmittance of some common types of glazing.

When the daylighting aperture is around 0.18, daylight saturation may be achieved (Ander, 1995). Additional glazing area will increase the cooling load more than the lighting load. This circumstance led to the following room classification for 'Effective Aperture' DAR (Ander, 1995):

- $0.00 \leq DAR < 0.16$ poor lighting
- $0.16 \leq DAR < 0.20$ adequate lighting
- $0.20 \leq DAR \leq 1.00$ high illumination with high cooling load

In Ander's study (1995), the context relevance of the revealed DAR classification and consequent daylighting and thermal performance is not clarified. Thus the classification of DAR adopted in this research, like WWR, will be made according to the calculated figures in the studied context.

2.3.1.1.5.3 Solar aperture

In the previous sections daylight aperture was defined as a window design factor to control the availability of indoor daylight, which in turn aims to control the electric lighting energy and cooling requirements arising from heat gain from the artificial lighting. On the other hand the building envelope, primarily the glazing, is a main source of solar heat gain, and is thus a major variable in determining the peak demands and energy consumption of a building. The shading coefficient of the glazing (SC) dominates solar gains. Lam *et al.* (1999) defined Solar Aperture SA (SA = WWR x SC) as a factor that indicates the proportion of incident solar energy that enters the indoor space as heat gain (Lam *et al.*, 1999).

This variable is therefore an indicator of solar gains. Accordingly, solar aperture is not considered in the daylight performance evaluation tool proposed later, which aims to quantify daylight availability in internal spaces.

In Lebanon the building regulations do not recommend a specific exterior wall area to window area relationship such as window to wall ratio, daylighting aperture or effective aperture. The recommended window area is calculated with respect to the room area only. Each room should have a minimum window area equal to 1/10 of the room area (i.e. Fenestration Factor ≥ 0.10; this variable is discussed in the following section) and open onto an 'extended vision field' equal to 450cm x 550cm (Figure 2.10). This regulation does not consider the frame ratio nor the visible transmittance of the glazing material to be used. Indeed, there are no codes that control the glazing materials to be used. On the contrary they only establish minimum limits for opening areas, ignoring the negative impacts of excessive daylight such as glare and heat gain.

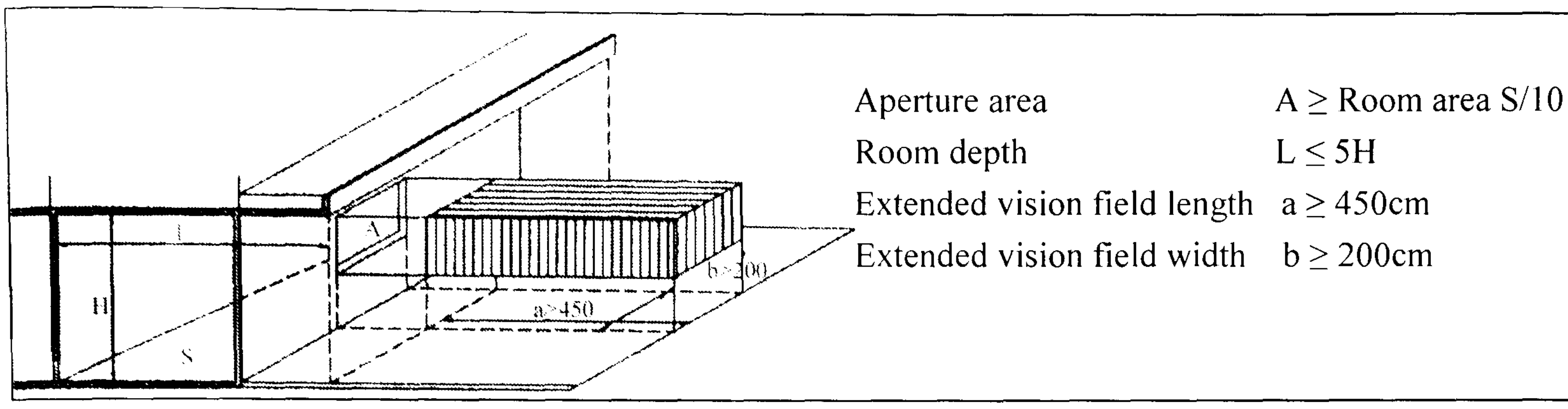


Figure 2.10. Lebanese building regulation setting the relation between window area room area, room depth and recommended 'extended field of vision'.

2.3.1.2 *Spatial / Aperture Proportions*

In this section, the relation between the spatial and aperture proportions is considered. For an optimum daylighting design in terms of light intensity and distribution, the size, height and width of the window have to rule the room or office space dimensions, and vice versa.

2.3.1.2.1 <u>The limiting depth rule</u>

In Section 2.3.1.1.1 it was mentioned that in a space that is daylit unilaterally, daylight penetration to the opposing wall is the lowest. This depends on the depth of the room. To obtain a room that is successfully daylit unilaterally, the British Standard Daylight Code (1992) suggests that the depth (L) of the room should comply with the limiting depth rule or criterion of uniformity, which is

$(L/w) + (L/h) \leq 2/(1-R_b)$, where:

> L = depth of the room from window to back wall.
>
> w = width of the room measured across the window wall.
>
> h = height of window head above floor.
>
> R_b = area-weighted average reflectance in the back half of the room (about 0.5, for a typical office).

Figure 2.10 shows how in the Lebanese building regulations, the room depth should not exceed five times the height of the room. This limiting depth rule depends only on the room height, and does not consider the window height or the width of the room. In this research, the limiting depth rule equation is used in the daylighting performance evaluation tool, described later in Chapter 5, in order to investigate its applicability in the studied context.

2.3.1.2.2 Room area to window area relationships

In this section, variables that relate window area to daylit space area are reviewed. These variables also consider some glazing properties, such as visible light transmittance and correction factor for frames.

2.3.1.2.2.1 The fenestration factor

As previously mentioned, the size of the window plays an important role on the quantity and quality of daylight penetration into building spaces. When a room is daylit through more than one window, a relation between the sum of surfaces of all the windows and the area of the room should be considered. 'Fenestration Factor' is the ratio of the total window surface to the area of the room illuminated by the window.

Baker *et al.* (1993) define 'Fenestration Factor' $FF = A_G / A_R$, where:

A_G = total net glazing area

A_R = total area of the room

According to Baker *et al.* (1993), the relationship between the 'Fenestration Factor' and the mean daylight illumination in a room is approximately linear. The following classification can be made (Baker *et al.*, 1993):

- $0.00 \le FF < 0.01$ illumination is very low
- $0.01 \le FF < 0.04$ illumination is low
- $0.04 \le FF < 0.10$ illumination is medium
- $0.10 \le FF < 0.25$ illumination is high
- $0.25 \le FF \le 1.00$ illumination is very high

As a general rule, high or very high fenestration can cause problems of thermal control and glare. Providing low or very low fenestration can produce excessively low illumination levels, especially where predominately overcast skies.

The above classification of fenestration factor and the implications for illumination levels are subject to question, because the considered ratios seem to be unreasonable (e.g. a

$20m^2$ room with $1m \times 1m = 1m^2$ window has FF = 0.05; the opening is too small to consider illumination to be medium). In addition, the fenestration factors calculated for the considered case studies from Beirut are higher than 0.1. This does not mean that illumination is high in all cases. Accordingly, fenestration factor classification will be further linked to office building practice in the studied context.

2.3.1.2.2.2 The glazing ratio

According to Fontoynont *et al.* (1997), when designing the dimensions of a window with respect to the space to be daylit, the most useful parameter is the 'exact glazing area', and this needs to be adjusted for the transmittance of the glazing. Some tinted or diffusing glazing used today may have a transmittance of less than 50%. The glazing area needs correction to take this into account, to give more accurate figures for daylight availability in the lit space.

Therefore the ratio of the 'exact glazing area' to the floor area, called Glazing Ratio (GR), is of great interest. Typically in the range from 0.05 to 0.3, GR quickly gives some idea of the general brightness of the space over the year, and also the sensitivity of the space to outdoor climatic conditions (Fontoynont *et al.*, 1997).

Accordingly, glazing ratio will be considered in the daylighting performance evaluation tool described in Chapter 5. The classification of glazing ratios is made according to the calculated values in the studied context.

2.3.1.2.2.3 Uniformity ratio

The uniformity ratio represents also another variable in the micro scale. It draws the relationship between daylighting factor and room depth. The uniformity ratio UR is the ratio of the level of daylight at the back of the room to that at the front of the room.

$UR = DF_B / DF_F$, where:

DF_B = Daylight Factor at the back of the room

DF_F = Daylight Factor at the front of the room

In the BRE Digest (1986), Average Daylight Factor ADF was taken as the arithmetical average of all the sky components (direct light components, external reflection components and internal reflection components, Figure 2.11) for side-lit interiors as follows:

ADF = (W/A) (Tθ / (1-R^2)), where:

ADF = average daylight factor

W = net window area

A = area of all surfaces of the room, including the window

T = visible transmittance of the glass (with a subtraction to correct for dirt using the 'Dirt correction factor', which depends on the tilt of the glazing, the frequency of cleaning and the atmosphere (Table 2.2 and Table 2.3).

θ = visible sky angle, in degrees (defined in Figure 2.12)

R = average reflectance of room surfaces (Table 2.4).

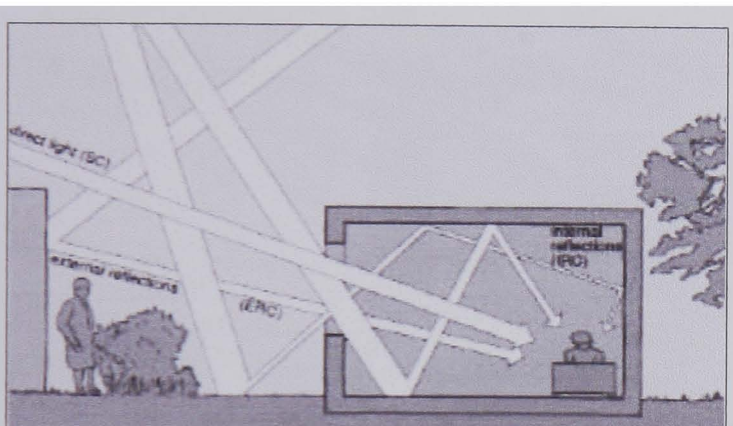


Figure 2.11. The main components of skylight (Littlefair, 1996).

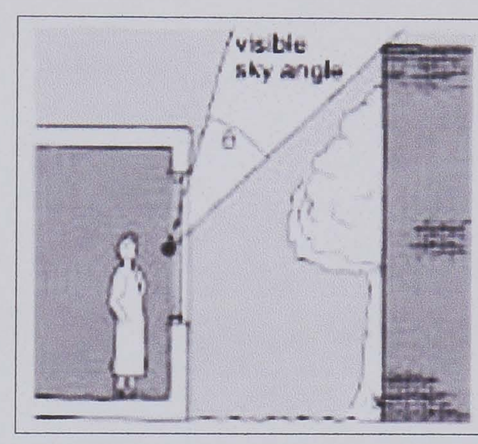


Figure 2.12. Visible sky angle θ (Littlefair, 1996).

Angle of Glazing	Clean Atmosphere	Urban Atmosphere	Industrial Atmosphere
Vertical	0.9	0.8	0.7
Sloping	0.8	0.7	0.6
Horizontal	0.7	0.6	0.5

Table 2.2. Typical dirt correction factor adopted in daylighting calculations (Tregenza, 1998).

Type of Glazing	Visible Transmittance	Solar Transmittance * with internal shading	U-Value ($W/m^2\ ^oC$)
No glazing and no shading	1.00	1.00	-
Single	0.87	0.47*	5.6
Double Clear	0.75	0.45*	2.8
Double Low E Standard float glass	0.65	0.40*	1.8
Double Tinted	0.30	0.30*	2.8
Double with int. light shelf	0.55		
Double with internal and external light shelf	0.40		
Double with prismatic film	0.55		
Double with solar control mirrored louvres	0.3		
Double with coated prismatic glazing	0.3		

Table 2.3. Approximate visible transmittance, solar transmittance and U-value for various glazing types (when they are clean) (Rennie, 1998).

Another formula, proposed to calculate the daylight factor DF at a reference point lit by daylight from the side was suggested by Hopkinson *et al.* (1966). This formula is as follows:

$DF = ((10(W)(H)^2) / ((D)(D^2+H^2))) + ((4(G)(R)) / (F- (1-R)))$, where:

DF = daylight factor, %

W = width of window, m

H = height of window above the workplane, m

D = distance from window wall to reference point, m

G = glass area, m^2

R = wall reflectance, %

Deep narrow rooms seemed too dark at the back, even if the daylight factor is adequate. This is because the uniformity ratio is too small. Following the study by Rennie *et al.* (1998), these were proposed (Figure 2.13):

- If the uniformity ratio = 2% / 10% = 0.2, the room will have good uniformity of illumination.

- If the uniformity ratio = 1% /10% = 0.1, the room will have moderate illumination.
- If the uniformity ratio = 0.5 / 10% = 0.05, the room will be too dark at the back.

Daylight Factor or Average Daylight Factor is mostly used in regions where overcast skies prevail most of the year. This is not the case in Lebanon. The average daylight factor has meaning only if an appropriate sky model is used.

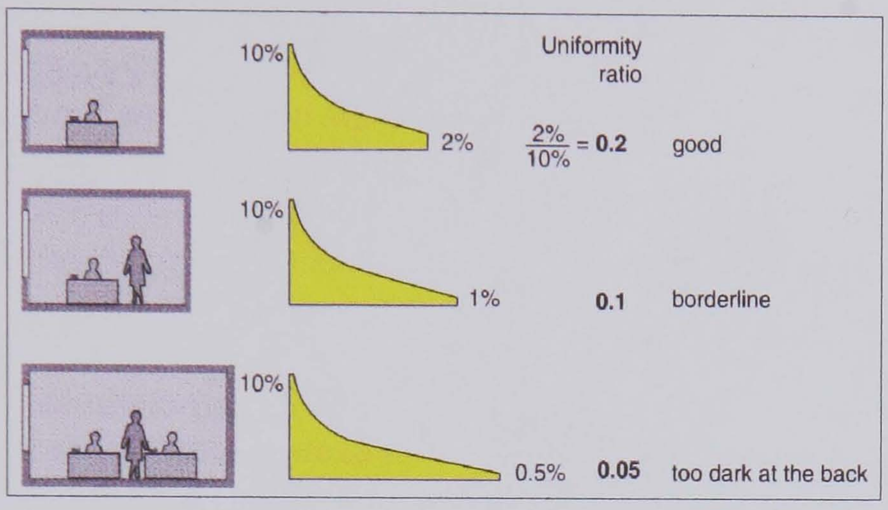


Figure 2.13. The uniformity ratio classification (Rennie *et al.*, 1998).

2.3.1.3 *Reflectance of Room Surfaces*

The reflectance values of room surfaces will have great impact upon the performance of a daylit space. Reflectance is a property of the surface material, and is independent of the amount of light that reaches the surface. By definition, the reflectance R is the fraction of incident light that is reflected back by a surface and which varies from zero to one. Consequently, the reflected beam depends on the surface material. A specular reflector reflects a ray in the same plane as the incident ray. A diffuse reflector is a matt surface that scatters light evenly in all directions (Figure 2.14). No real surface is either entirely specular or diffusing. For lighting calculations in buildings it is usually enough to assume that diffuse reflection is dominant, and that a single value for a particular material describes its total reflectance. The reflectance R of coloured surfaces is given approximately by a simple function of the Munsell value (Tregenza, 1998): R = ((value (value-1) /100). Table 2.4 presents the typical reflectance of some room surfaces. For the lighting simulations of case studies presented in Chapter 9, the reflectance of walls, ceilings and floors are obtained from the ADELINE building material library.

Lam (1986) states that in the majority of buildings, the ceilings and upper walls are likely to be the only areas that can be depended upon to be good light-reflecting surfaces. Therefore, the use of high reflectance ceiling materials maximises the intensity and effectiveness of reflected daylight. The next most important surface is the back wall, followed by the sidewalls and finally, the floor (Figure 2.15).

Material	Reflectance	Material	Reflectance
Ground:		Carpet (cream)	0.4
Snow	0.8	Wood (light veneers)	0.4
Sand	0.3	Wood (medium colours)	0.2
Paving	0.2	Wood (dark)	0.1
Earth (dry)	0.2	Quarry tiles	0.1
Earth (moist)	0.1	Window glass	0.1
Green vegetation	0.1	Carpet (deep colours)	0.1
Other external materials:		Paint colours, with Munsell ref:	
White glazed tile	0.7	White N9.5	0.85
Portland stone	0.6	Pale cream 5Y9/2	0.81
Medium limestone	0.4	Light grey N8.5	0.68
Concrete	0.4	Strong yellow 6.25Y8.5/13	0.64
Brickwork (buff)	0.3	Mid-grey N7	0.45
Brickwork (red)	0.2	Strong green 5G5/10	0.22
Granite	0.2	Strong red 7.5R4.5/16	0.18
Window glass	0.1	Strong blue 10B4/10	0.15
Tree foliage	0.1	Dark grey 5Y4/0.5	0.14
		Dark brown 10Y3/6	0.10
Materials used internally:		Deep red purple 7.5RP3/6	0.10
White paper	0.8	Black N1.5	0.05
Stainless steel	0.4		
Cement screed	0.4		

Table 2.4. Reflectance of some common diffusing materials (Tregenza, 1998).

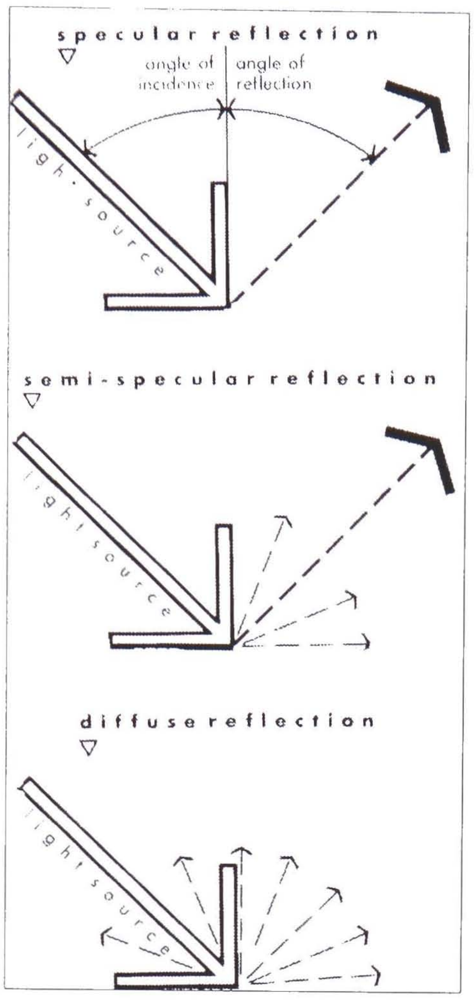


Figure 2.14. Light reflection: (1) specular (polished, glossy surface), (2) semi-specular (etched, honed, brushed surface) and (3) diffuse reflection (matte, textured surface).

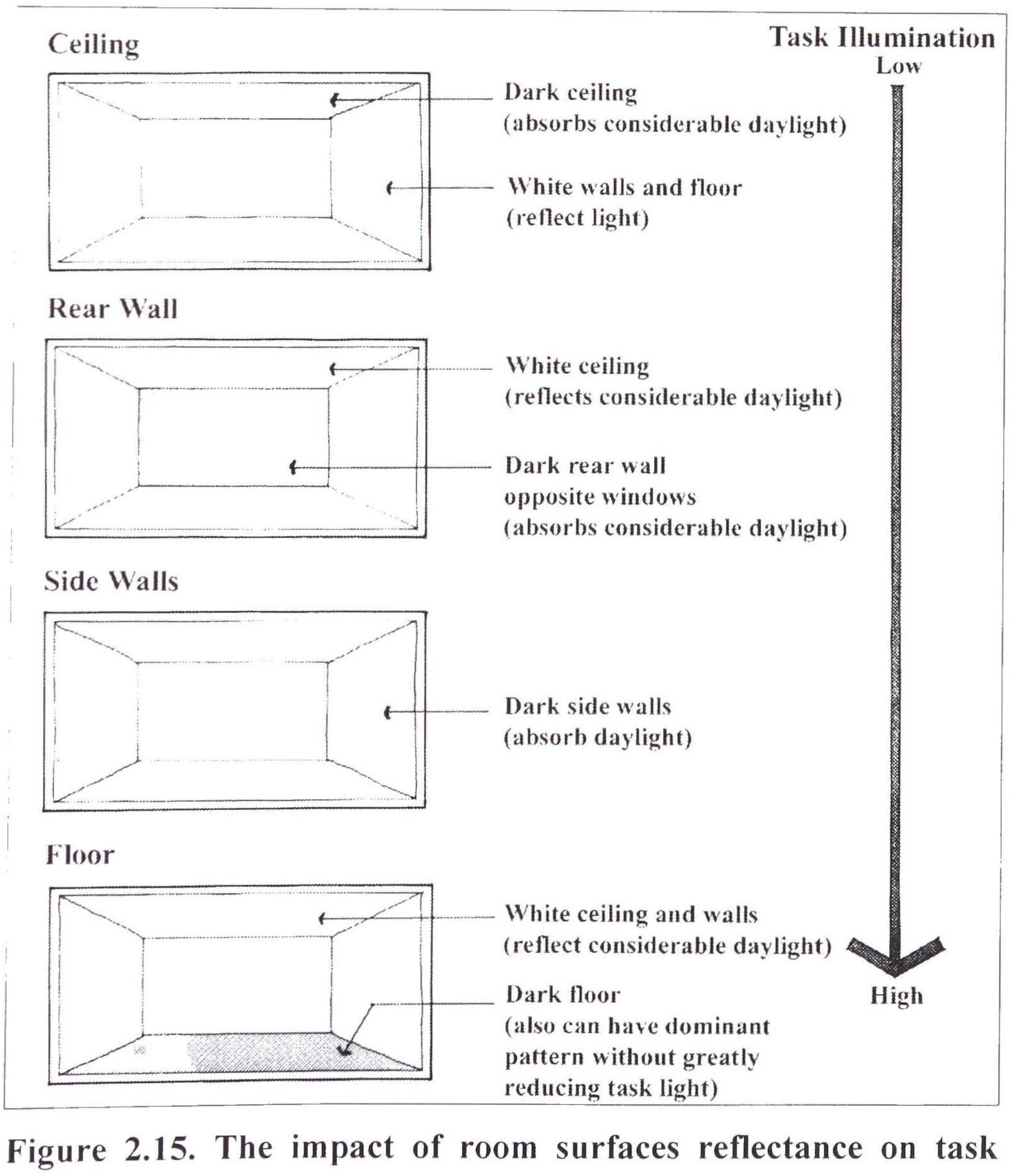


Figure 2.15. The impact of room surfaces reflectance on task illumination (Evan, 1983).

2.3.1.4 *Shading Strategies*

Shading or sunlight control strategies are mechanisms or devices capable of altering the effects of a window. These devices may be:

- Fixed: not operable by the user. Generally do not require significant maintenance
- Moveable: adaptable to different conditions. May be directly controlled by the user or operated automatically.

Shading devices may also be internal or external devices, or sunlight control integrated within glazing panels. Glazing that uses such technology is reviewed in Chapter 3. Exterior systems are typically more effective than interior systems for blocking solar heat gain. Exterior devices are attached to either the building skin or an extension of the skin itself to keep out unwanted solar heat.

2.3.1.4.1 Control elements

Referring to Baker *et al.* (1993), sunlight control devices may be categorized into 5 different groups as follows: separator surfaces, flexible screens, rigid screens, solar filters and solar obstructers. All the elements included in these five groups and their characteristics are described in the following sections

2.3.1.4.1.1 Separator surfaces

Separator surfaces are elements of a transparent or translucent material which separate two light environments, permitting light to pass through while not admitting air, and sometimes obstructing the view. Such division surfaces can be conventional or simple, optical, prismatic and active (Figure 2.16).

Simple divisions made of wooden or metal frame supporting transparent surfaces (e.g. clear glass, laminated glass, polycarbonate, acrylic or polyester, etc.) allow view and light to pass through (Figure 2.16a).

Optical divisions modify the characteristics of the radiation passing through it (Figure 2.16b). They diffuse and redirect natural light or control its intensity, depending on the specific treatment of the division. Some of these treated surfaces may not be variable, in which case they have the disadvantage that light intensity is controlled in the same way throughout the year. In some cases views to the exterior are limited or distorted. Optical divisions are made of a wooden or metallic frame supporting treated surfaces such as permanently coloured glass, mirrored glass, translucent or embossed glass, and glass with thermochromic or holographic films.

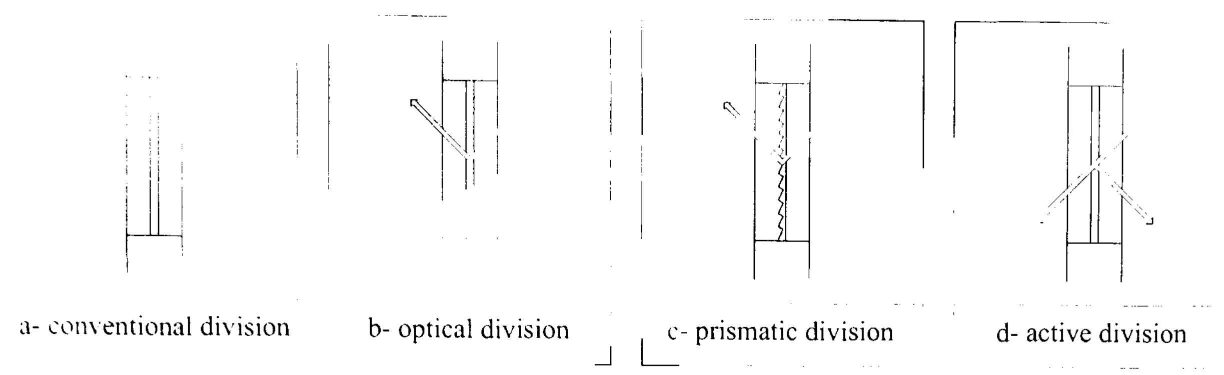


Figure 2.16. Types of separator surfaces used to control sunlight.

Prismatic division redirects light because of the prismatic panel that changes the beam direction depends on the angle of incidence (Figure 2.16c). Its poor visual transparency restricts its use. The material used is rigid enough to be fixed without framing. It may be made of glass, polycarbonate, acrylic or polyester in various shapes. The survey in the studied context shows that this control strategy has not yet been used in the office buildings of Beirut.

Active division is an active control element that changes the optical absorption properties by applying an external electric field (Figure 2.16d). Daylight intensity is controlled by active division, according to the interior conditions required. This is a complex multi-layer structure, made of high technology materials that make the cost very high and this discourages its use, especially in Lebanon where import costs make it even more expensive.

2.3.1.4.1.2 Flexible screens

These elements partially or totally obstruct direct sunlight and diffuse sunlight, allowing natural ventilation. They can be opened or closed to control views. Awnings and curtains are flexible screens applied on the external and internal sides of the window, respectively (Figure 2.17).

An **Awning** is a control element made of opaque or diffusing flexible material placed on the exterior of an aperture to obstruct or diffuse direct solar radiation (Figure 2.17a). It provides a decreased and less contrasting light level in the zone close to the awning, and full or partial shade for the window as required. It may be drawn down flush with the window-wall surface, or protruding to the exterior. It may also roll up or be drawn sideways. Awnings are usually made of canvas or flexible plastic materials. They are used most in residential buildings in Beirut, seldom in office buildings.

Curtains have the same properties as awnings, but are placed on the interior of the aperture (Figure 2.17b). They are made of cloth or flexible plastic materials, providing full or partial shade for the window. Curtains have been used in some offices in Beirut but plastic louvers, described later, are more popular.

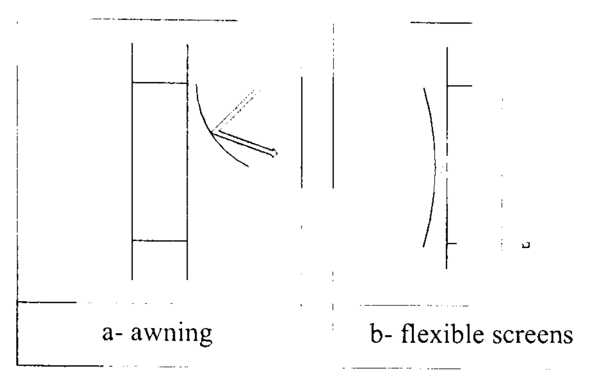


Figure 2.17. Type of flexible screens used to control sunlight.

2.3.1.4.1.3 Rigid screens

Rigid and opaque elements redirect and / or obstruct direct solar radiation falling upon a glazing opening, and are normally fixed structures which cannot be regulated (Figure 2.18). Overhang, lightshelf, sill, fin and baffle are the most common shading devices or rigid screens in general use, and in particular in the office buildings of Beirut.

An overhang is part of the building itself, protruding horizontally from the façade above the opening (Figure 2.18a). It protects the zones close to the openings of the building. Horizontal overhangs are effective in the south façade and somewhat useful on the east and west façades, but have no function on the north. When used in the east or west orientation, an overhang does not provide shading in early morning and late afternoon because of the sun's path. Overhangs can be constructed from a variety of materials such as concrete, metal, wood, etc.

A lightshelf is usually placed horizontally above eye level in a vertical opening, dividing it into an upper and a lower section (Figure 2.18b). Solar radiation falling on the upper surface of the lightshelf is redirected to the interior ceiling. It thus provides shade in summer and makes the interior light distribution uniform. Lightshelves are made of different materials, the upper surface having a reflective finish such as mirror glass, aluminium or some other highly polished material.

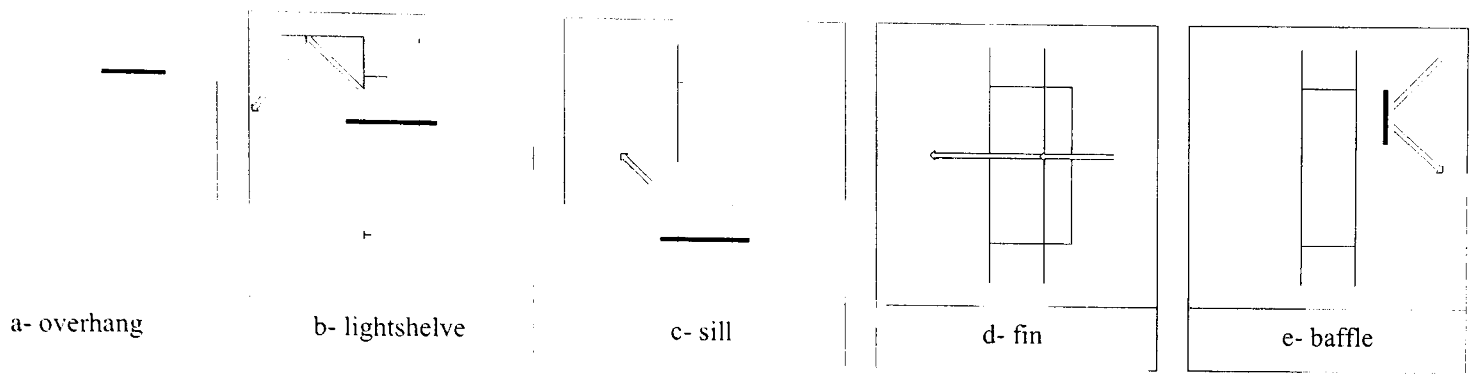


Figure 2.18. Types of rigid screens used to control sunlight.

A sill is defined as an element placed horizontally at the bottom of a window opening. It can reflect and redirect daylight that strikes it, in order to increase the light level in the interior space (Figure 2.18c). Like lightshelves, the upper surface of a sill may be of any high reflection material such as mirror, aluminium, other highly polished surface or even glossy paint.

Fins are external control elements placed vertically on the sides of the opening (Figure 2.18d). Daylight falling laterally on the fin is reflected and redirected to the inside. Depending on its location, direct solar radiation may be avoided and possible interior discomfort reduced. It provides a lower and possibly more homogeneous internal daylight flow pattern, by reducing light at the opening. It is particularly appropriate for shading oblique low angle sun falling at the sides facing east and west. Fins can be made from a variety of materials such as concrete, metal, wood etc.

A baffle is a fixed, single opaque or translucent element which protects the aperture from direct solar radiation at certain angles, and may reflect daylight to the interior (Figure 2.18e). It may provide a lower and possibly more homogeneous internal daylight flow pattern, avoiding the entry of direct solar radiation in the zone close to the opening or increasing lighting in the interior zones.

2.3.1.4.1.4 Solar filters

Solar filters cover the entire surface of an opening, protecting the interior spaces against direct solar radiation whilst allowing ventilation (Figure 2.19). They can be fixed or adjustable. Jalousie, louvers and brise-soleil are common types of solar filters.

A jalousie is an exterior or interior element composed of slatted screens placed over the whole window (Figure 2.19a). It permits the control of direct solar radiation, and regulates the entry of daylight. The slats may be fixed or movable. When movable they may be adjusted according to the sun's angle and shading requirements. This device can be moved along the opening, drawn to the side, or rolled up to the top. The slats are usually made of wood, plastic, aluminium, stainless steel etc. Fixed jalousies were used in the multi-use buildings during the early decades of the 20th century in Beirut, and adjustable jalousies that could be rolled up to the top were common in 1950s and 1960s office buildings. Nowadays they are rarely used in office buildings in Beirut.

Louvers are a series of exterior or interior slats (also called Venetian blinds) which may be fixed or adjustable. They usually cover the whole opening (Figure 2.19b). Depending on the orientation of the slates, direct solar radiation which falls upon the louvers may be obstructed and / or reflected, or redirected to the interior zone. Horizontal louvers are usually located on southern façades, and vertical louvers on eastern and western façades. Slats can be made of painted or galvanized steel, anodised aluminium, PVC, wood, fabric, etc. PVC and fabric internal louvers are the mostly common shading device used in contemporary office buildings.

A **brise-soleil** or egg-crate is defined as an exterior, fixed structure covering the opening or a larger area (Figure 2.19c). The open structure permits the passage of daylight and air. Depending on the geometric design, the structure will obstruct direct solar radiation at certain sun angles. A brise-soleil may be made of wood, metal, concrete and other construction materials. This shading was mostly used in 1950s and 1960s office buildings in Beirut.

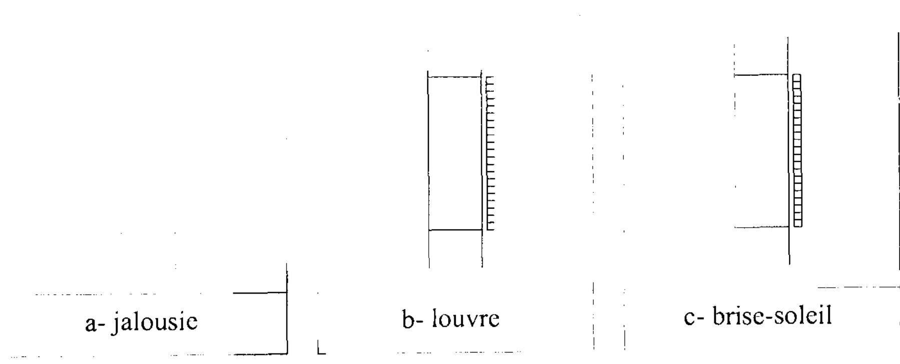


Figure 2.19. Types of solar filters.

2.3.1.4.1.5 Solar obstructers

Elements composed of opaque, adjustable surfaces which cover the whole of an opening are called solar obstructers.

Shutters are the most common type of solar obstructers. They may be fixed on the interior or exterior of the opening (Figure 2.20). They provide a continuous opaque surface that can be made of wood, aluminium, PVC etc. Shutters can be folded or drawn towards the side of the openings. When closed, the interior is visually and in part thermally isolated from the exterior. Shutters are not common in the office buildings of Beirut.

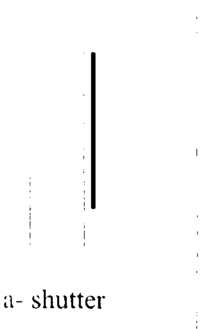


Figure 2.20. Types of solar obstructers

2.3.1.4.2 Measuring external shading devices

External shading devices in façades of office buildings in Beirut include overhang and side-fin projections around windows. In the reviewed literature, the characteristics of a shading device are described mostly by their projection ratio or projection factor. Overhang ratio and relative solar heat are two other factors that describe the performance of external shading devices, in accordance to their orientation and the solar heat gain coefficient of the window respectively. These three factors are adopted in this study. The following section will define these factors.

2.3.1.4.2.1 Projection ratio

The characteristics of a shading device are described by the overhang projection ratio (OPR), or the side-fin projection factor (SPR), depending on the type of shading device concerned (Wan *et al.*, 2004). The projection factor depends upon the ratio of the overhang length or fin depth, and its height from the windowsill or distance from the opposite-side jamb, respectively. The projection ratios of overhang and side fin are defined in Figure 2.21.

2.3.1.4.2.2 Overhang ratio

In the *'The non-residential manual for compliance with the 2001 energy efficiency standards'* produced by the California Energy Commission (2001), overhang factor is required to describe the shading devices used in non-residential buildings. This factor is more precise than the projection ratio described in the previous section, as it takes into consideration the orientation of the considered opening and associated shading devices. Overhang ratio (OVR) is defined by the following formula:

$$OVR = 1 + a*PR + b*PR^2$$

Where PR = projection ratio

a = -0.41 for north façade, -1.22 for south façade and -0.92 for east/west façade

b = 0.2 for north façade, 0.66 for south façade and 0.35 for east/west façade

a and b are orientation correction factors which can be also adopted in the studied context, as the geographical centres of California and Beirut are approximately on the same latitude (36° 57.9'N and 33° 49'N, respectively).

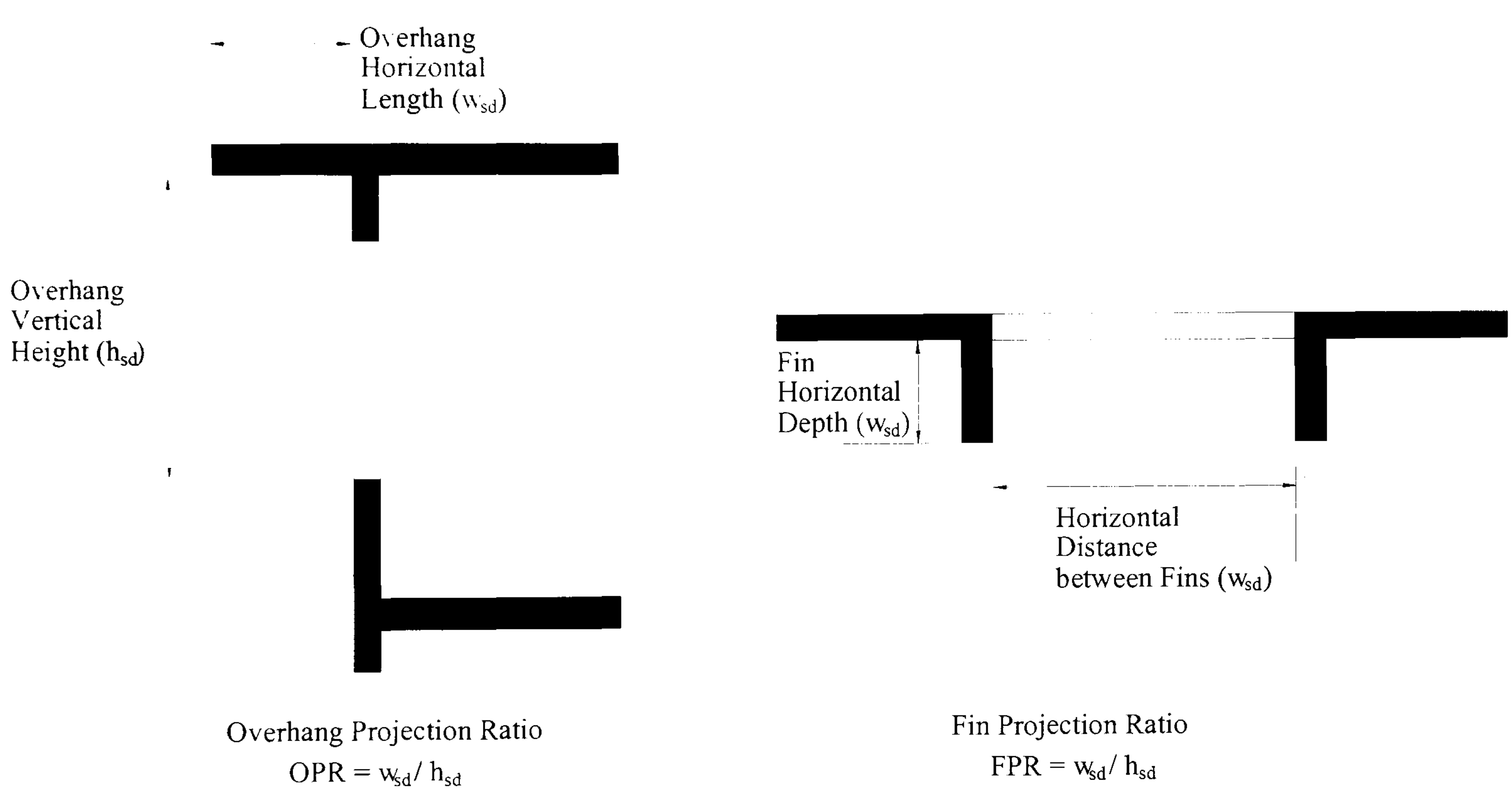


Figure 2.21. Definition of projection ratio of overhangs and fins.

2.3.1.4.2.3 Relative solar heat gain

Relative solar heat gain (RSHG) is another factor considered in the non-residential energy standards of California (California Energy Commission, 2001) to describe the performance of fenestration. This factor is essentially the same as the solar heat gain coefficient ($SHGC_{win}$) of the opening, except for the external shading correction. It is calculated by multiplying the SHGC of the fenestration by the overhang ratio (OVR): $RSHG = OVR * SHGC_{win}$.

2.3.2 The Meso Scale

Besides the variables of the micro scale studied in the previous section, the extent of this reduction depends upon a number of variables in the meso scale. Building form, building size, building orientation and the size and location of light openings in the building envelope are the essential variables of a daylit building. Hence it is reasonable to anticipate that the design to make use of daylight in a building will affect some of the building's overall spatial relationships.

2.3.2.1 *Building Form*

In the early design stages, the building shape has primary impact on daylighting performance. As a general rule, daylighting is a function of the exposure of interior spaces to the sky dome. Therefore, in a multi-storey building the exposure to the sky dome becomes a function of the narrowness of the plan. The integration of air-conditioning systems solved the problem of ventilation in deep plan office buildings, and led to an increased use of artificial lighting due to the increased average distances to the exterior walls. To utilise daylighting effectively in multi-storey buildings, "finger" plans may be used as a solution where conditions make a straight, narrow plan undesirable. Consequently the envelope area increases, and with a well studied space between "fingers" or wings there is better daylight penetration (Figure 2.22). The courtyard plan is the most compact variation of the finger plan, and creates the most self-obstruction of the skydome. The advantage of the geometry of the courtyard is that while the opposite wall obstructs the skydome, it also obstructs low-angle direct sunlight; reducing the problem of glare and the need for the addition of overhangs. Moore (1991) indicated that the lighting performance of an atrium is very similar to that of a courtyard of similar dimensions, because the same skydome obstructions are present. However, they do have major thermal differences. In temperate climates, the atrium remains habitable in the winter at the expense of the considerable heat gain that occurs in summer time.

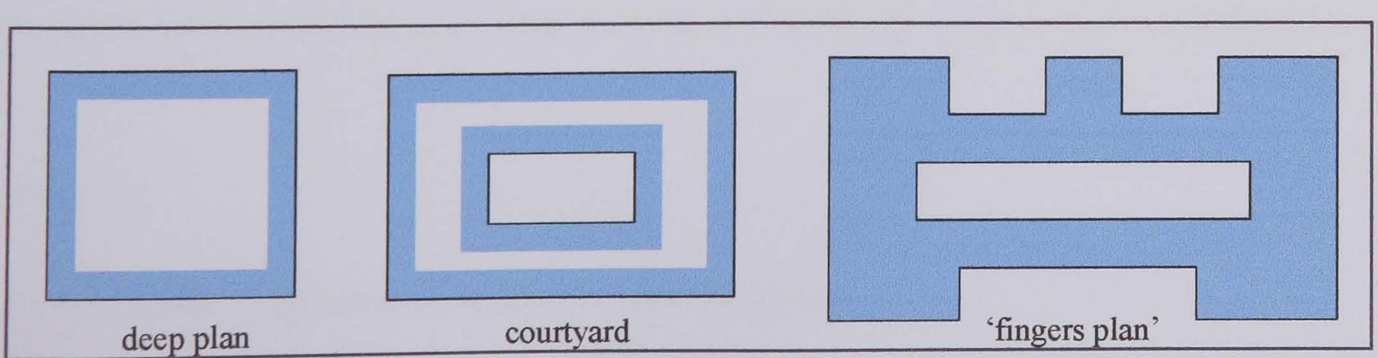


Figure 2.22. Articulated building forms showing increased daylighting perimeters and hence daylighted zones.

Figure 2.23 illustrates the primary energy consumption of the four different forms mentioned previously, which have the same floor area and assuming 40% of their external walls are glazed. In their case studies analysis, Rennie *et al.* (1998) investigated the relationship between building depth and energy consumption. The authors' key conclusion was to avoid deep-plan buildings, as air conditioning and electric lighting may double energy consumption. Narrow buildings use less energy, as potential savings in electric lighting and ventilation are higher. Courtyard buildings perform rather less well than narrow buildings, because they have less daylight. Atrium buildings perform similarly to courtyard buildings, but daylight is poorer due to losses at the roof.

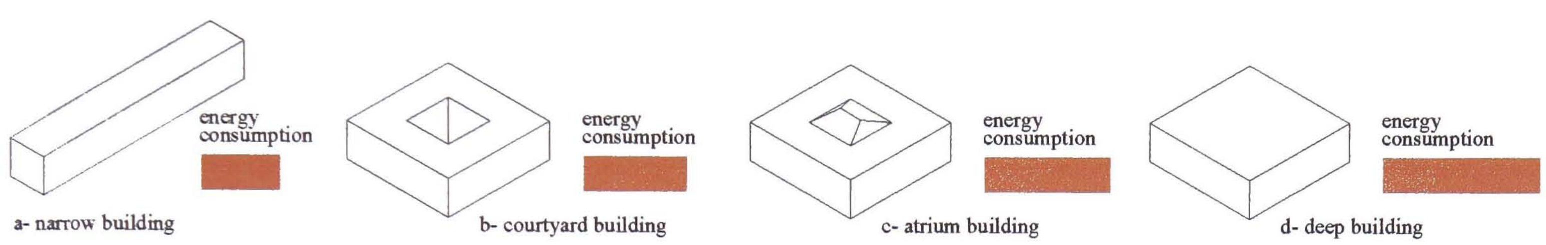


Figure 2.23. Building forms and energy consumption (Rennie *et al.*, 1998).

The literature reviewed earlier showed that building shape could be an indicator of the energy consumption in it. The two morphological features that affect energy consumption are the building's compactness and its porosity ratio, which indicates the existence of any form of void such as a courtyard or atrium. Compactness is a scale-invariant measure of a perfectly symmetrical object of the same area (i.e. a circle, for which compactness equals 1; Barr *et al.*, 2001). As an object's shape deviates from perfect symmetry, its compactness ratio increases (i.e. it becomes less compact; Figure 2.24). Barr *et al.* (2001) defined compactness ratio (CR) by the following equation:

$$PR = P^2 / 4\pi * A$$

Where P = perimeter of the building layout

A = building floor area

The porosity ratio (PoR) is the void-volume to building-volume ratio (Barthakur *et al.*, 1999):

$$PoR = Vv / V$$

Where Vv = volume of void (courtyard, atrium)

V = total building inner volume

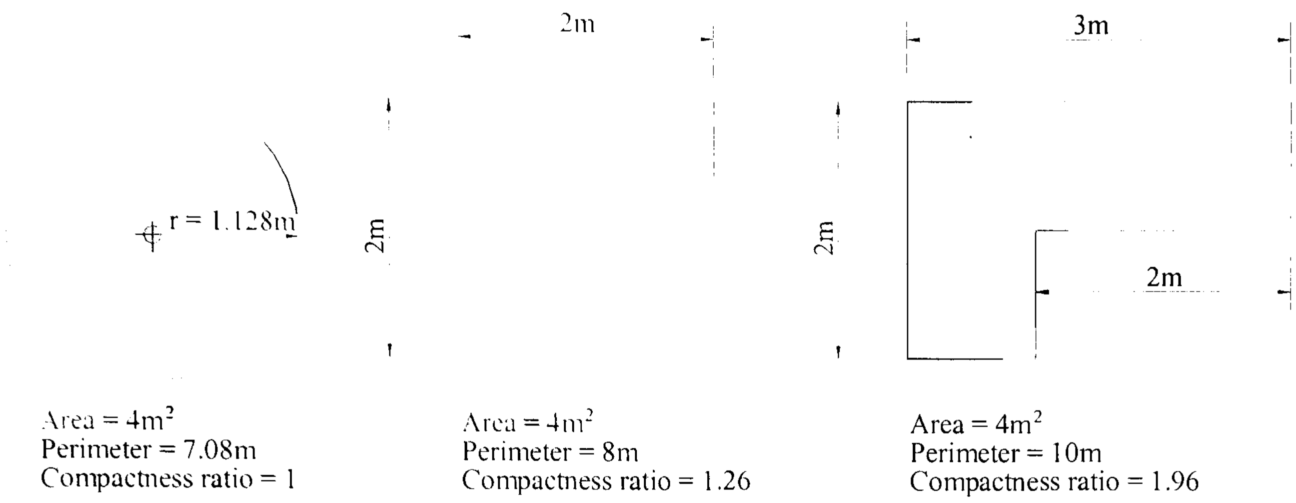


Figure 2.24. Compactness ratio as an indicator of building forms having same area

2.3.2.2 *Building Size*

In the meso scale, Robbins (1986) described two basic spatial relationships that can be used to assess the impact of building size upon daylight availability in internal spaces. Shape coefficient and envelope to floor area ratio draw the relationship between the three dimensions of the building's volume, total envelope area and total floor area.

2.3.2.2.1 Shape coefficient (C_f)

$C_f = V / S_e$

Where, V = total building inner volume, excluding the ground and lowest floors

S_e = total envelope area, excluding the ground and lowest floors

Shape coefficient is smaller for daylit buildings than for non-daylit buildings.

2.3.2.2.2 Envelope area to floor area ratio (ů)

$ů = S_e / A_T$

Where S_e = total envelope area (not including the ground and lowest floors)

A_T = total building floors area

Envelope to floor area ratio is typically larger in daylit buildings.

Shape coefficient and envelope to floor area ratio will be considered to assess building size in the case studies. In the daylighting performance evaluation tool described in Chapter 5, these two variables are classified according to the calculated values in the studied context.

2.3.2.3 *Wall to Aperture Ratio, WAR*

The following variable of daylighting design, to be considered in the meso scale, is the Wall to Aperture Ratio WAR of a building façade. Wall to aperture of a façade is defined as follows (Baker *et al.*, 1993): WAR $= S_a / S_f$

Where S_a = total apertures' surface area

S_f = total façade surface area

The analysis by Rennie *et al.* (1998) showed that increasing glazing areas from zero to around 20% saves an enormous amount of primary energy in office buildings in the south of the UK, as daylight replaces electric lighting. However, increasing glazing area beyond 30% saves little extra energy, as heat losses from the glazing increase (Figure 2.25). The optimum glazing area for saving energy is around 30 to 50% (varying with orientation and type of glazing), but overheating is a risk with areas greater than 50% other than in north-facing rooms.

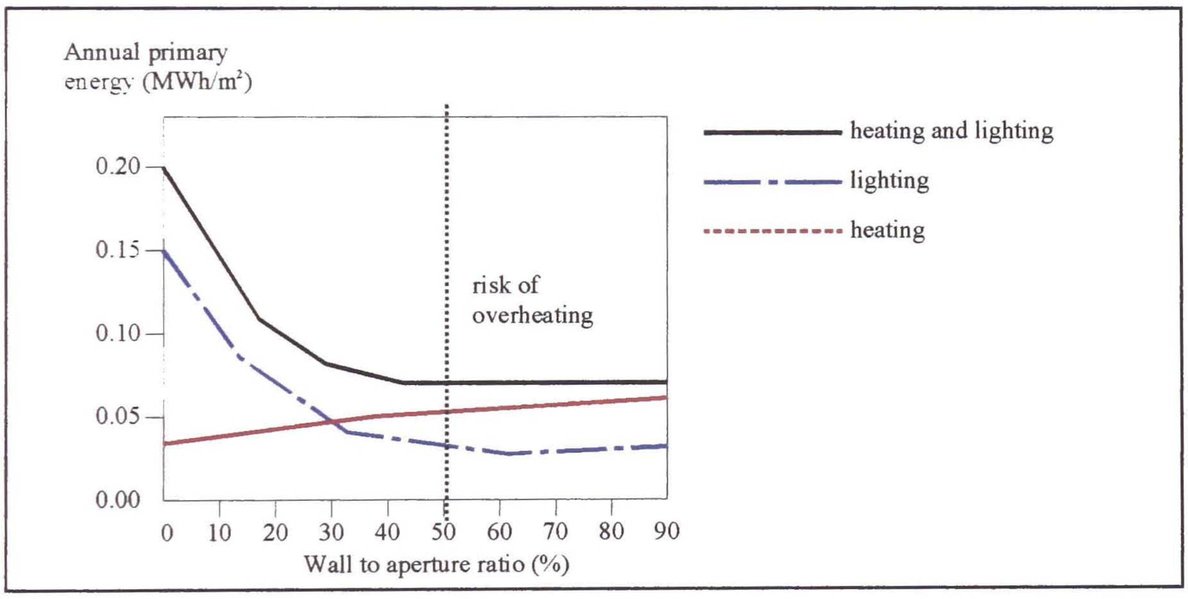


Figure 2.25. Effect of wall to aperture ratio on primary energy consumption (the graph is for a south-facing double-glazed office in the south of the U.K., with single glazing) (Rennie *et al.*, 1998).

According to the previous study by Rennie *et al.* (1998) and to Baker et al. (1993), when considering calculated values in the studied context window to wall aperture ratios may be categorised as follows:

- From 0.00 to 0.25
- From 0.25 to 0.40
- From 0.40 to 0.55
- From 0.55 to 1.00

2.3.3 The Macro Scale

When a new building is erected on a site, it should allow adequate skylight and sunlight to reach existing or possible future adjacent buildings. Furthermore, it should be ensured that the new building itself has adequate skylight and sunlight. For this reason, the building should be considered both in relation to the site in terms of the impact of the building and its relationship with other buildings. Aspects such as aesthetics, over-shading, self-shading, climatic variations, vegetation, man-made and natural obstructions should be examined to avoid negative effects on existing and new buildings. In other words the site should be considered holistically, and not the building in isolation. Accordingly, a number of matters should be taken into consideration at the macro level. Nevertheless, this study aims to compare office building designs in Beirut irrespective of their location, in order to examine the impact of their façade configuration and plan morphology on daylighting performance. Therefore, an overview of the macro scale variables is given in the following sections.

2.3.3.1 *Urban Space Layout*

Spacing and grouping of building and landscape features in a layout will affect the availability of sunshine, as well as wind conditions on site. They can also have important implications for thermal comfort and energy use indoors. The mix of buildings and site densities, the layout of access roads and the shape and size of plots all have a bearing on daylighting and energy performance inside any building.

Baker *et al.* (1993) related the layout of urban blocks to building orientation, and classified urban space layouts into seven categories as illustrated in Figure 2.26. Besides building orientation, larger gaps between buildings allow greater penetration of sunlight and skylight. In this categorization of urban space layout, small urban blocks (Figure 2.26a) provide the least penetration of daylight to internal spaces, compared with the detached towers layout (Figure 2.26g). In detached towers, the buildings' façades are free on all four sides, and the distance between the towers is large enough for daylight to reach even the lower floors. The satellite picture in Figure 2.27 shows that the urban space of Beirut is made up of small urban blocks. In addition, buildings constructed in Beirut since the 1950s (office buildings and residential buildings) are at least 7 storeys. It can be concluded that buildings in Beirut may have little access to sunlight and skylight, and more consideration should be given to improve daylight penetration to the internal spaces.

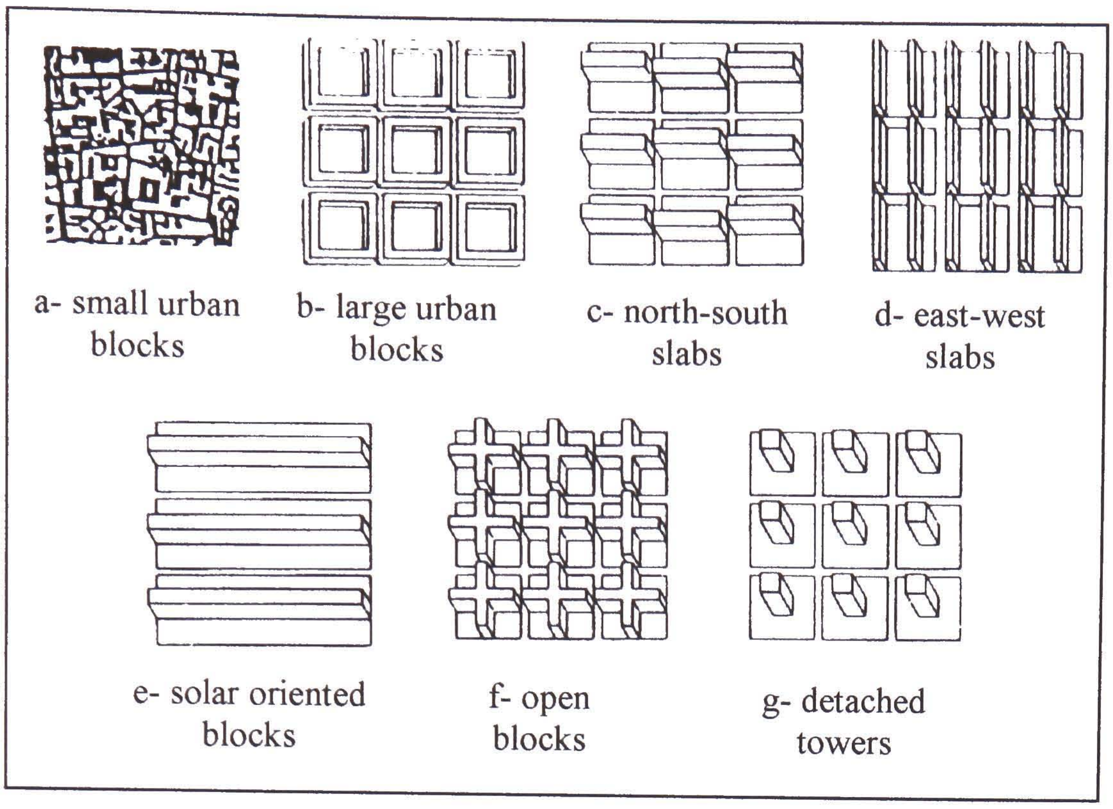


Figure 2.26. Urban blocks layout classification (Baker *et al.*, 1993).

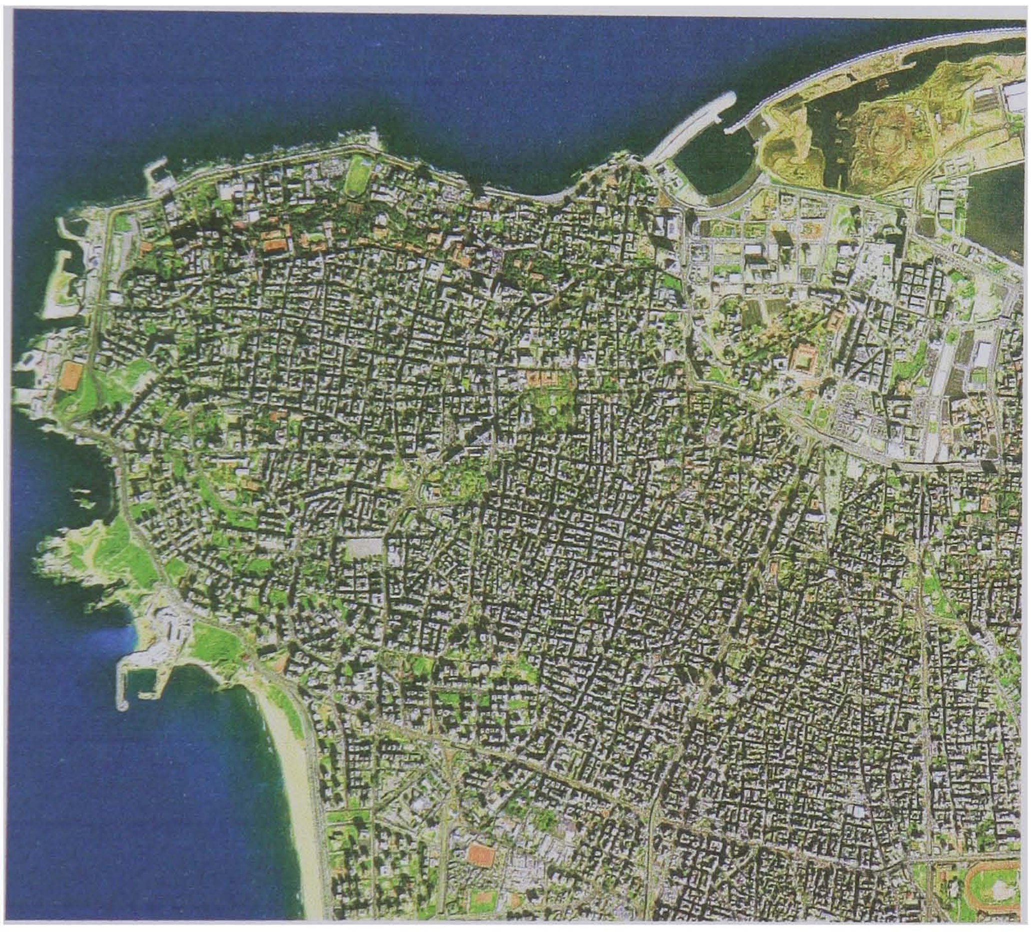


Figure 2.27. Satellite picture of Beirut taken in March, 2002 (Saliba, 2004).

2.3.3.2 *Overshadowing*

Overshadowing occurs when the sun's rays directed towards a surface are obstructed by adjacent buildings or landscape elements. These results in total loss of the direct component of solar radiation during the period when the sun is hidden from view, and a reduction in the amount of solar radiation reaching the building surfaces affected. Both site slope and geographic latitude have considerable influence on overshadowing.

Minimising overshadowing, both on building surfaces and on the ground around buildings, is an important design objective during site and layout planning.

Yannas (1994) explained that 'For any point on a surface, its view of the sun becomes obstructed when the altitude angle of the obstruction object – the obstruction angle θ – exceeds the solar altitude angle'. He defined the obstruction angle θ by the following equation:

$\tan\theta = H / X \rightarrow X = H / \tan\theta$, where:

> θ = obstruction angle in °.
>
> H = obstruction height, in m.
>
> X = distance between the obstruction central axis and the affected surface, in m (Figure 2.28).

Robins (1986) concluded that generally, an obstacle that blocks no more than 10% of the field of view does not have a major impact on daylighting. Obstructions that cover more than 10% of the field of view necessitate moving the aperture, removing the obstruction, or adjusting the design or design requirements to take the aperture's reduced performance into account.

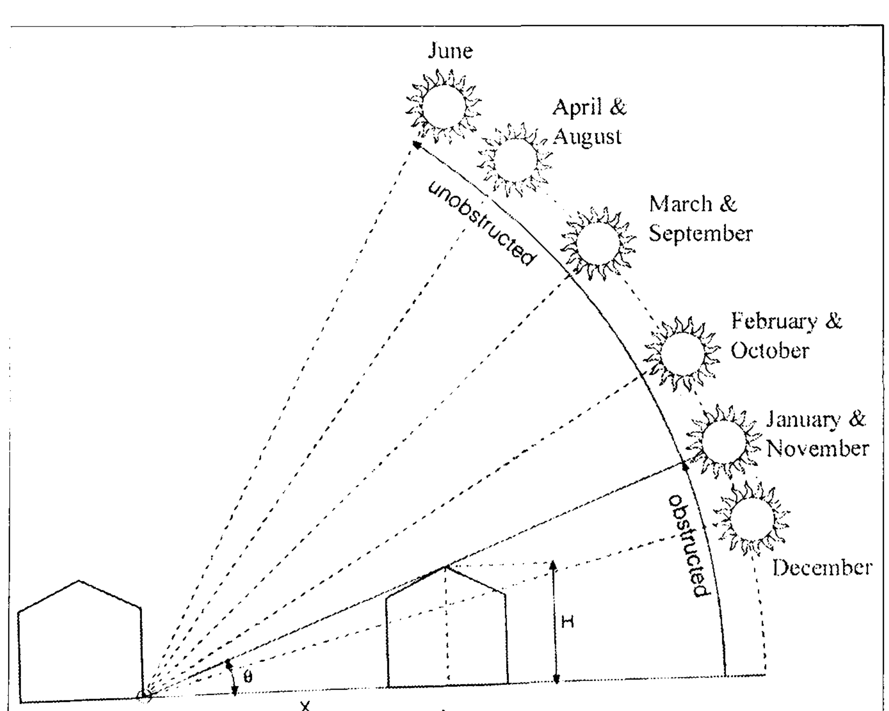


Figure 2.28. The obstruction angle compared with altitude angle.

Complete freedom from overshadowing is rarely possible in high density, urban areas. The spacing required to avoid overshadowing may be larger than feasible for the size and existing or planned density of the site, or the site may be subjected to some unavoidable overshadowing (as is the case in most built-up areas). Baker *et al.* (1993) classified the obstruction angle (or profile angle) values as follows (Figure 2.29):

- Profile angle less than 30°: almost complete obstruction
- Profile angle between 30° and 60°: medium obstruction
- Profile angle between 60° and 90°: no obstruction.

Figure 2.30 shows that the building envelope regulation recommended by the Lebanese building regulation for buildings constructed in urban areas may lead to completely obstructed façades, as the profile angle can be lower than 30°. The overshadowing of building surfaces is more than possible in the buildings of Beirut.

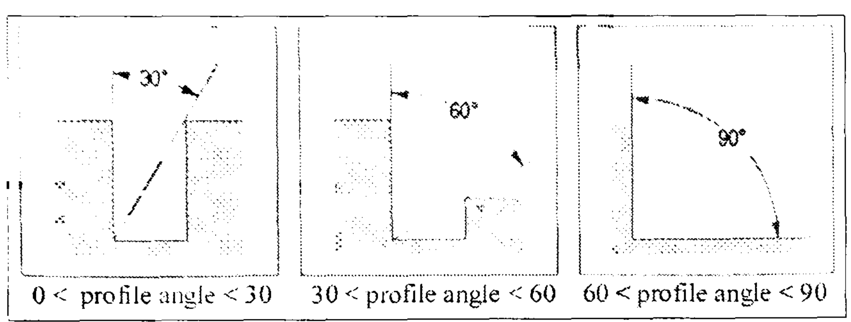


Figure 2.29. Obstruction or profile angle classification.

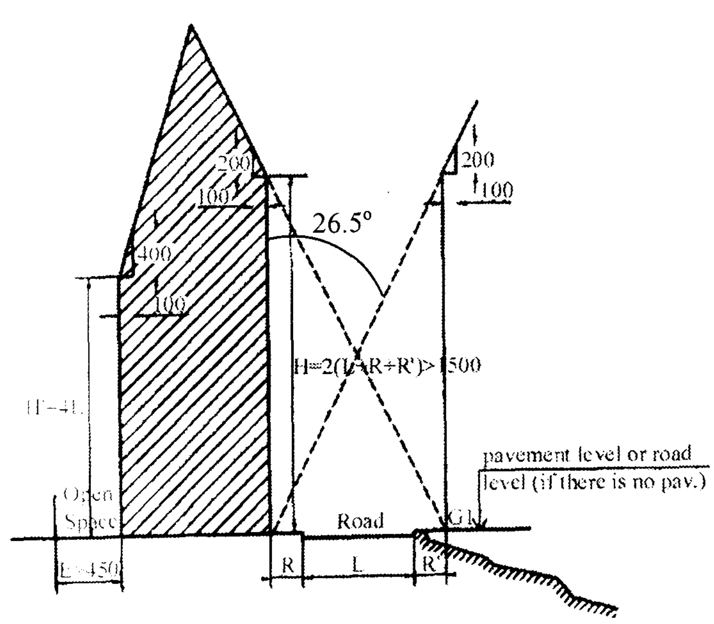


Figure 2.30. The building envelope regulation applied to street façades (Order of Engineers et Architects, 1995: 25).

2.3.3.3 *Façade Reflectance*

Off-site obstructions such as adjacent buildings often block a significant portion of the field of view. 'Any obstruction, on or off-site, that blocks more than 50% of the field of view should be considered as a possible reflecting light source. Large obstructions that cover less than 50% of the field of view can also reflect daylight into a building.'

(Robbins, 1986). Façade reflectance of adjacent buildings has a considerable effect on daylighting performance. If a surface is very reflective (over 60%), it may be a major source of glare. Extremely bright surfaces (reflectivity over 85%) should be avoided when planning and designing a daylighting system. Baker *et al.* (1993) classified façade reflectance into three groups:

- High reflectance, where reflectance is more than 85%
- Mean reflectance, between 60% and 85%
- Low reflectance, less than 60%.

In the lack of any regulation that control façade reflectance in Lebanon, and with the trend for excessive use of glazing in office buildings, highly reflective façades may be problematic in Beirut where the sky is clear throughout most of the year.

2.4 Conclusion

Many studies have demonstrated that the proper use of daylighting has a great impact on energy load. To achieve good daylighting, a number of building design variables must be studied. This chapter has reviewed some daylighting principles, and concluded that any study of daylighting performance in building should be made in accordance with three scales: the micro, meso and macro scales. The micro scale reviews the effect of aperture variables upon the internal space. The micro scale variables are divided into two principal kinds of relationship; the relationship between the window and the window-wall (or external wall), and the relationship between the window and the internal space. The meso scale evaluates the impact of the building façade and volume on the internal daylit spaces. The macro scale assesses the relationship of the building with its built environment. The macro scale will not be considered in the later analysis, as building designs will be compared irrespective of their built environment. Nevertheless it has been noted that the urban morphology of Beirut and the Lebanese building regulations do not give cognisance to the access of daylight to interior spaces.

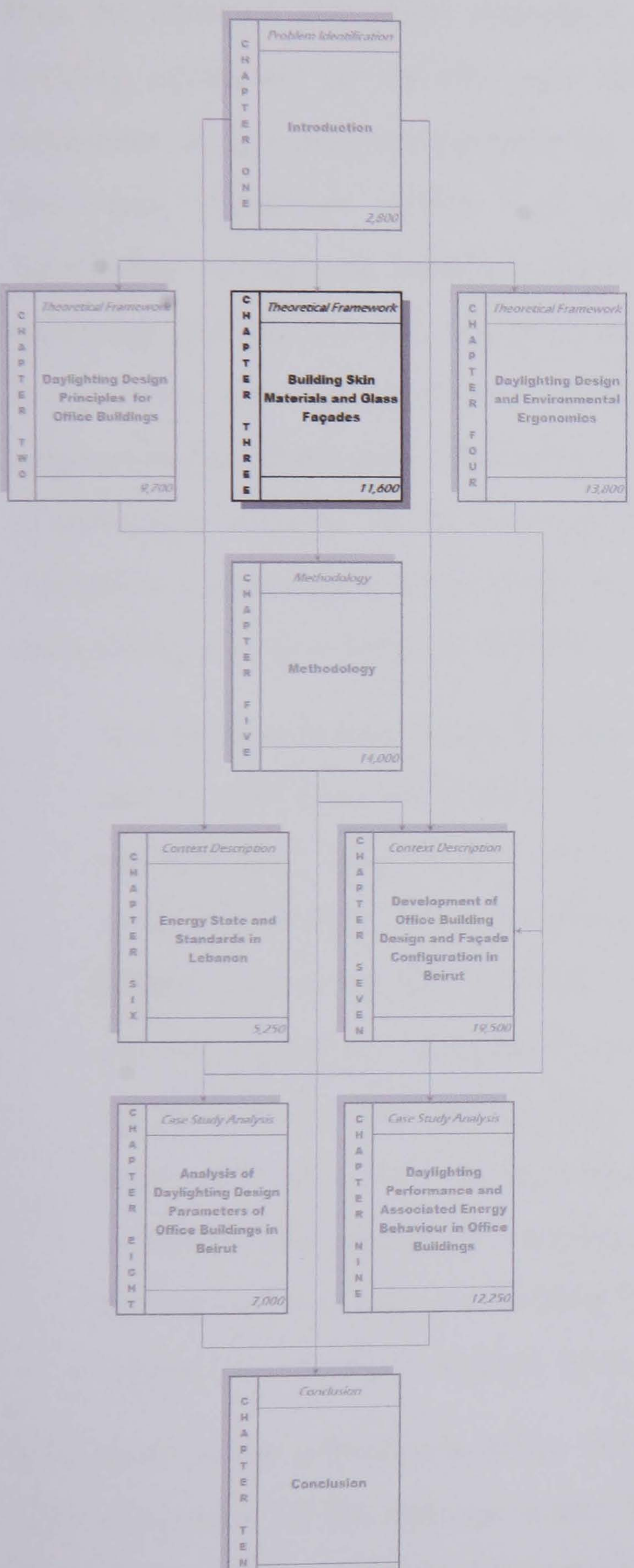
Finally, following the review conducted in this chapter, the design variables to be considered and adopted in this study for the assessment of daylight in buildings are listed in Table 2.5.

Parametric Level of Analysis	Variables			
	Name	Code	Formula	Related Factors Definition
Building Shape (Meso Scale)	Compactness Ratio (CR)	A	$CR = P^2/4\pi A$	P = total building perimeter A =building floor area
	Shape Coefficient (C_f)	B	$C_f = V/Se$	V = total building inner volume S_e = total envelope surface area
	Envelope to Floor Area Ratio (û)	C	$\hat{u} = S_e / A_T$	S_e = total envelope surface area A_T = total building floors area
	Porosity Ratio (PoR)	D	$R_P = V_v / V$	V_v = total volume of inner void V = total building inner volume
Window / Façade Relashionship (Micro Scale - Aperture proportions)	Wall to Aperture Ratio (WAR)	$E_{N, S, E W, Av}$	$WAR = S_a/S_f$	S_a = tatal apertures' surface area S_f = total façade surface area
	Aperture Location (AL)	$F_{N, S, E W, Av}$		Unilateral, bilateral, multi-lateral and complete glazing
	Window Shape Coefficient (C_{ws})	$G_{N, S, E W, Av}$	$C_{ws} = L_w/H_w$	L_w = window length H_w = window height
	Window Sill Height (H_{ws})	$H_{N, S, E W, Av}$		H_{ws} is measured in meter
	Window to Wall Ratio (WWR)	$I_{N, S, E W, Av}$	$WWR = A_g/A_w$	A_g = net glazing area A_w = gross exterior wall area
	Daylight Aperture Ratio (DAR)	$J_{N, S, E W, Av}$	DAR = WWR x VT	WWR = window to wall ratio VT = glazing visible light transmittance
Window / Office Volume Relationship (Micro Scale - Spacial/Aperture proportions)	Daylight Buffer Zone (DBZ)	$K_{N, S, E W, Av}$		DBZ is measured in meter
	Room Limiting Depth Rule (LD_r)	$L_{N, S, E W, Av}$	$LD_r = (l/w) + (l/h)$	l = av. room depth ; w = av. room width h = hight of window head above floor
	Office Average Area (A_r)	$M_{N, S, E W, Av}$	$A_r = l * w$	l = typical office depth w= Typical office deth
	Fenestration Factor (FF)	$N_{N, S, E W, Av}$	$FF = A_g/A_r$	A_g = net glazing area A_r = typical office total area
	Glazing Ratio (GR)	$O_{N, S, E W, Av}$	$GR = A_g * VT / A_r$	A_g = net glazing area VT = glazing visible light transmittance A_r = typical office total area
Shading Devices (Micro Scale - Shading Strategy)	Projection Ratio (PR)	$P_{N, S, E W, Av}$	$PR = w_{sd}/h_{sd}$	w_{sd} = width of the overhang or depth of the vertical fin. hsd = height from window sill to the bottom of overhang or distance between side fins.
	Overhang Ratio (OVR)	$Q_{N, S, E/W, Av}$	$OVR = 1 + a*PR + b*PR^2$	PR = overhang projection ratio a = -0.41 for north façade, -1.22 for south façade and -0.92 for east/west façade b = 0.2 for north façade, 0.66 for south façade and 0.35 for east/west façade
	Relative Solar Heat Gain (RSHG)	$R_{N, S, E W, Av}$	$RSHG = OVR x SHGC_{win}$	OVR = Overhang ratio $SHGC_{win}$ = solar heat gain coefficient of the window

Table 2.5 . List of variables that should be considered to assess daylighting in buildings

BUILDING SKIN MATERIALS AND GLASS FAÇADES

3



Chapter Three

3. Building Skin Materials and Glass Façades

3.1 Introduction

Three decades ago, when office work was based on what seemed to be the everlasting technology of the telephone and the typewriter, the architect's tasks were relatively easier than the situation that exists nowadays. As a consequence of developing technology, building occupants are making new demands for their well-being which influence workspace design, and consequently the façade design and its performance. In the past few years, significant strides have been made in the design and engineering of "intelligent" workplaces, buildings that not only accommodate major advances in office technology but also provide a better physical and environmental setting for the occupants. In particular, now that computer workstations and video display terminals have become common in the office environment, the proper lighting of these environments has become of increasing concern. As an early indication of the problem, Button *et al.* (1993: 13) referred to a statement by Peter Roger in 1979, in which he revealed the important role of the building skin as a dynamic and effective information medium:

> *It is no good having a sophisticated mechanical services system for a building and a poor skin performance. It is only even partially effective to have a sophisticated mechanical services installation and high quality fixed performance skin. A time responsive, variable quality skin system is the only logical answer to this problem. A building becomes a chameleon, which adapts. A properly equipped and responsively closed building would monitor all internal and external variables, temperature, hygrometry and light levels, solar radiation etc... to determine the best energy equation given these conditions and modify the building and its internal systems accordingly. It is not too much to ask of a building to incorporate, in its fabric and its nervous system, the very basic vestiges of an adaptive capability.*

In addition to the advances in office technology, the energy crisis of the 1970s together with recognition of the damage human beings are causing to the biosphere are factors encouraging a return to natural lighting and ventilation in buildings, following the use of sophisticated mechanical service systems. In respect of daylight, it is therefore useful to think of the building envelope in general as a 'light fitting' (Guzowski, 2000), and the window as 'luminaire' (Mills, 1996) that must be properly designed to control the quantity and quality of the light it filters. As part of the building envelope, windows are sources of light and have distinct optical characteristics and implications for visual comfort. Of course, they are also sources of natural ventilation, heat gains and losses. Although the field of daylighting is as old as architecture itself, recent advances in window technology have opened up new opportunities for controlling lighting requirements in buildings.

The aim of this chapter is to investigate the evolving configuration of building envelope and glass façade in the architecture of daylit office buildings. Providing a clear definition of building envelope and façade is an essential prerequisite to the discussion carried out in this chapter. The physical and optical properties of different envelope materials that have bearing on daylighting are discussed. As the window, or more specifically the glazing, is the interface of the building with the natural environment and the main source of daylighting, the many types and advanced technologies of glazing are reviewed in Section 3.4. Finally, the chapter will set the boundaries for the variables to be included in the case studies analysis in Chapters 7 and 8.

3.2 The Building Envelope and Technology

'Building envelope', 'building skin' and 'building façade' are the terms most often used in the literature to describe the enclosure of indoor spaces of a building. The following section illustrates the various definitions of these terms. Sections 3.2.2 and 3.2.3 review the development of façade design, from being traditional to the concept of an 'intelligent' or 'smart' skin able to interact automatically with outdoor environmental changes.

3.2.1 Definition

'Building envelope' and 'building skin' which include walls, windows, doors, roofs and floor surfaces, aim to compare the building façade to an envelope or human skin that protects the 'inside' from external conditions.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 1985) defined the building envelope with more emphasis on its thermal function, as being the 'group of elements that enclose conditioned spaces through which thermal energy may be transferred to or from the exterior, or to or from unconditioned spaces'.

Stein *et al.* (2000) extended the restricted description of the building envelope as being a set of two-dimensional exterior surfaces. They described it as a transitional space, 'a theatre where the interaction between outdoor forces and indoor conditions can be experienced'. This transition space is a place where people indoors experience something of what the outdoors is like at that moment, as well as where people outside get a glimpse of the functions within. The more suited the outdoors to comfort, the more easily indoor activity can move into this transition space. The authors added that building envelope has a fourth dimension, which changes with time. Seasonal changes have a marked effect on the transition space, and consequently have an effect on the environmental aspects of the indoor spaces.

Powler *et al.* (1990) compared the envelope of a building with the skin of the human body, the 'building skin', which is called upon to perform a multitude of simultaneous functions in a relatively thin dimension. These functions can be energy related (e.g. to control heat loss from the interior of the building) or non-energy related (e.g., to present an aesthetic position). Powler *et al.* (1990) stated that the building envelope always plays the role of building façade to 'communicate important cultural and social information such as sense of grandeur and permanence'. Harris *et al.* (1998) and Wigginton *et al.* (2002) wrote that while applying the biological metaphor of the human skin to achieve human comfort it seems appropriate to describe this enveloping membrane as an 'intelligent skin', emphasising its close relationship to the epidermis. Architecture has been described by Ted Kruger (1994) as 'our collective epidermises'. He describes a building as our 'our second skin'.

Alternatively, Tombazis (1996) revealed that 'the more the design of buildings becomes bioclimatically conscious, the more the behaviour of these buildings tends to become skin dominated'. The author continues by comparing the multi-layered building skin to the different layers of the skin of animals or human beings, that can serve more than one purpose at the same time such as shading, movement of air, filtering of light, regulating the inner temperature, etc.

The previous review of building envelope, skin and façade definitions shows that there is no clear distinction in the use of these terms. Building envelope has the same role as the skin that covers the human body (Powler *et al.*, 1990), and those of animals and plants (Tombazis, 1996). The use of 'building skin', however, has become more prevalent in bio-climatically conscious architecture. In energy studies, the term 'façade' is used specifically when referring to the exterior surfaces of a building envelope (Guam Energy Department, 1995). In this thesis the three terms are used with no distinction to describe the outer parts of a building, which consist of opaque walls and glazed openings.

3.2.2 Traditional Façade

Traditional façades have well-defined regional characteristics, which make the building environmentally responsive. Climate sensitivity, culture and local construction materials are the major factors that influence regional differences in façade design (Lechner, 1991). Stein *et al.* (2000) identified two opposing concepts for designing traditional building envelopes. These are the open frame, and the closed shell. The latter concept, also named 'barrier- dominated' (Stein *et al.*, 2000), is mainly used in harsh environments, where environmental conditions are undesirable. In this case the building envelope acts as a barrier, and windows are no more than carefully selected punch holes to limit contact with the outdoor environment. On the other hand, in the open frame concept the building envelope acts as a connector with the external environment. This is usually applied when external conditions are very close to the desired internal environment. In contrast to the 'barrier-dominated' approach, where no or only limited contrast between the external and the internal is required, the 'connector-dominated' concept allows direct contact between the two environments (Stein *et al.*, 2000). The 'closed shell' concept has been widely applied in hot arid and cold climates. The 'open frame' concept has been used in both hot, humid, and temperate climates.

Since the building envelope is thought of as 'a barrier between the internal, controlled environment, and external, perhaps undesirable conditions' (Koenigsberger, 1980), the selection of envelope materials and the façade design should be considered as the selective pathway for a building to work with the climate, responding to daylighting, heating, cooling and natural ventilation needs.

The climatic conditions and space usage affect the rate at which a building gains or loses heat, and the availability of daylight to provide adequate lighting levels for the activities conducted in it. Hot/dry, hot/moist, temperate or cold climates thus suggest different design strategies. Specific designs and materials should take advantage of, or provide solutions for the given climate.

Referring to the DOE (2003), buildings in hot/dry climates with significant diurnal temperature swings should have thick walls constructed from envelope materials with high thermal mass, such as adobe and masonry. Openings on the north and west façades should be limited, and southern openings should be large enough to exclude direct sun in the summer and admit it in winter. In hot/moist climates, where night-time temperatures do not drop greatly below daytime highs, lightweight materials with little thermal capacity are preferred. In some hot/moist climates materials such as masonry, which functions as a desiccant, are preferred. Large openings protected from the summer sun should be located primarily on the north and south sides of the envelope to catch breezes or encourage stack ventilation. As for temperate climates, as is the case in Lebanon, the thermal capacity of materials for buildings is based upon the specific location and the heating/cooling strategy employed. Walls should be well insulated. Openings in the skin should be shaded during hot times of the year, and unshaded during cool months. In a cold climate, the floor plan should be as compact as possible to minimize the area of building skin, which should not be constructed with high thermal mass materials because they will lengthen the time required to reheat the space to a comfortable temperature.

3.2.3 Intelligent Envelope

The world 'intelligent' relates to the procession of intellectual faculties which provide a capacity for understanding. It was first used to describe buildings at the beginning of the 1980s. The American term 'smart' is also used, to imply the same kind of abilities in materials, structures and buildings. The word 'intelligent' has been also associated with building façade, and indicates the dynamic, almost living capability of a façade to adapt to changing daily or seasonal conditions in order to achieve a reduction in the building's consumption of primary energy. According to Compagno (1999), the 'intelligent' expression with respect to façade indicates an ability to respond to changing environmental conditions according to the time of day or year, in such a way as to reduce primary energy needs for heating, cooling and lighting and thus make a contribution to environmental conservation.

Wigginton *et al.* (2002: 44) defined the intelligent skin as 'an active manipulator of the external elements and responsive to internal conditions, with the ability to adjust itself automatically to provide optimum comfort by self-regulated amendments to the building fabric. It is assumed that this is achieved with the minimum use of energy, and minimal reliance upon imports. The intelligent building fabric becomes a flexible, adaptive and dynamic membrane, rather than a statically inert envelope. Information is gathered through different sensors, and behaviour is modified in response'.

Skelly (2000) identified the many variables to which intelligent façade should respond. He divides these variables into three categories:

- weather: There are no two identical days. In fact, temperatures and solar radiation levels can vary significantly from hour to hour and from minute to minute.
- context: No two sites are the same, and even on the same site the microclimate and obstructions imposed on one façade can be dramatically different from those imposed on another.
- occupants: No two individuals are alike; each has different preferences, depending on experience and various other psychological factors.

Wigginton (1996) indicated that to achieve a 'smart', 'intelligent', or 'thinking' envelope, the following components should be integrated during the building envelope design:

- computer systems and control systems that predict, analyse and respond,
- neural systems which feel and communicate, and also think themselves;
- proliferating variable multi-state materials which can perform in accordance with the needs both of the building as a whole, and of localized parts of it.

In a later survey which covered twenty two case studies, Wigginton *et al.* (2002) identified twelve different features that make a building intelligent. These features are: building management systems, learning ability, environmental data, responsive artificial lighting, daylight controllers, sun controllers, occupant control, electricity generators, ventilation controllers, heating and ventilation controllers, cooling devices and double skin.

Compagno (1999) considered that an appropriate façade design for a building is reached using a combination of many criteria. The first main criterion is the number of glazed skins incorporated in the design; here the terms used are single-skin façades and multiple-skin façades. The second criterion is the positioning of the solar control devices.

Consequently, a building façade is described to be, for example, a single-skin facade with exterior or interior shading, or with integrated shading devices incorporated in the cavity between the panes.

To conclude, in both traditional façade and intelligent envelope schemes the role of the building envelope is to provide a comfortable indoor environment for the building's occupants. The difference between them is that the intelligent envelope is no longer perceived as a three dimensional exterior surface only, but it has a fourth dimension which is 'time'. The term 'intelligent' indicates the dynamic, almost living capability of the façade to adapt to the external environmental conditions at each time of the day or season (Compagno, 1999), rather than a statically inert envelope. In both façade schemes, the control of daylight and solar radiation control constitute a major component of the façade design, which is the concern of this study.

3.3 The Window as Part of the Building Envelope

The skin, independent of the building shell, is made up of three main groups of elements: the opaque elements, the transparent elements, and the translucent elements (The European Commission: DGXVII, 1999).

The opaque elements are the solid elements of the building envelope, walls, foundation, floor, ceiling and roof. They perform both heating and cooling functions through the use of thermal mass insulation and protection of the internal environment from air infiltration. Conversely, opaque materials have no impact on daylighting transmission

Translucent materials allow the transmittance of light, but the light is scattered or diffused and objects cannot be seen through these materials. Translucent insulation materials sandwiched between sheets of glass in a conventional frame can replace traditional windows where light but not vision is required. Thermal insulation values are very much better than for those of glass.

The transparent or glazing elements are often the most interesting and complex factor in sustainable buildings. They are more dynamic in responding to short and long-term changes in interior and exterior conditions. They have more complex functions such as daylighting, as well as providing views and communication with the outside; heating through the controlled use of solar gain, and cooling by shading and ventilation. External shading, daylight enhancing devices and solar control blinds can play a significant role in filtering heat and light at a building's skin, particularly when used in combination with glazing selection and ventilated façade strategies that integrate natural processes.

Since daylighting in buildings is the main goal of this study, the properties of transparent elements are reviewed extensively and a brief interest is taken in translucent materials. Sunlight falling on a window is made up of visible light, near infrared energy (heat) and ultraviolet light. Solar radiation that strikes the aperture glazing surface are either absorbed by the glass, reflected back to the outside, or transmitted into the building (Figure 3.1).

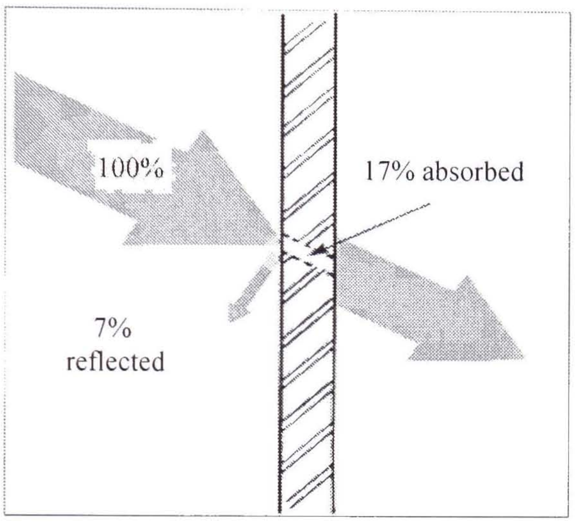


Figure 3.1. Sunlight striking a window can be transmitted, reflected or absorbed.

Today, new technologies help to resolve the historic problem of the trade-off between windows that reflect unwanted solar gains in summer and those that admit the maximum amount of useful light (Figure 3.2). Alternatively, for buildings that need heating, glazing technologies should minimise heat loss through the window (Figure 3.3). The wide range of high performance glazing products may respectively be capable of providing improved solutions for the use of daylight, transforming the window into a net source of useful light, and regulating solar heat loss and gain. This is done by altering the properties and specifications of the glazing to respond to the environmental conditions. Accordingly in the following section it has been considered important to go through the glazing parameters, before reviewing all types of glazing products and the new glazing technologies.

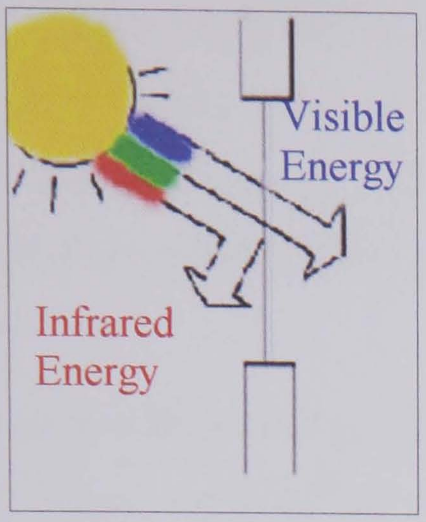


Figure 3.2. Performance of glazing material that admits visible light and excludes unwanted heat gain.

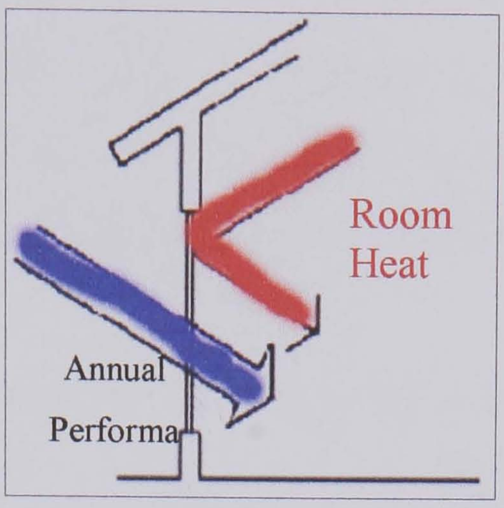


Figure 3.3. Performance of glazing material that admits visible light and wanted heat gain with minimal heat loss.

3.3.1 Window and Glazing Optical and Thermal Performance Parameters

New glazing technologies have been developed to harness solar energy and natural forces, and to diminish the thermal and energy consequences of windows. Thus the three main areas of interest are the determination of the heat transfer through the window, the solar gain through the window and the light distribution behind the window. These quantitative and physical parameters that describe and evaluate the properties of glazing relatively to the incident solar radiation are usually listed in product literature. Considering them all leads to a good selection for maximum comfort and energy efficiency, while preserving view and other design intentions for the fenestration. These parameters are defined as follows:

3.3.1.1 *Light Transmittance*

The nature of light, and the variation in transmission and absorption experienced by different materials has resulted in different types of glass that vary in performance and uses. The performance of glass as a transmitter is a result of its selective transmittance across ultraviolet, visible light and near infrared wave bands, which is specified by the following factors: ultraviolet transmittance, visible light transmittance and infrared transmittance.

3.3.1.1.1 Visible light transmittance

Visible Light Transmittance factor (VLT) is the amount of the visible portion of incident radiation that penetrates a window, expressed as a percentage (Button *et al.*, 1993). A typical clear glass has a visible light transmittance of 60% to 80%, between about 400 and 2500nm.

Glazing with a high visible transmittance provides a good sense of connection with the exterior, while admitting useful daylight. Daylight can offset the need for electric lighting, and save a significant amount of energy while creating a pleasant indoor environment.

High visible transmittance glazing can sometimes introduce a glare problem. When the window and the area immediately adjacent are far brighter than surrounding areas, the contrast is difficult for our eyes to handle. Low transmittance glazing, while reducing glare, creates 'gloomy' interiors, diminished view, and little daylight.

The PG&E Energy Centre (2000) recommended in one of its fact sheets that while using high transmittance glazing, visual comfort could be achieved through careful sizing and placement of windows, light coloured interior surfaces, movable window coverings, and light-diffusing deep sills and baffles.

3.3.1.1.2 Ultraviolet transmittance

Ultraviolet Transmittance (UVT) is another parameter of glazing that indicates the percentage of incident ultraviolet radiation that passes through the glazing (Energy Source Builder, 1994). Ultraviolet radiation (UV) is responsible for sunburn (of people and plants) and contributes to fabric fading and artwork damage. Most manufacturers provide the percentage of UV transmittance for their glazing. When interior finishes or artworks need protection, low ultraviolet transmittance glazing is preferred.

3.3.1.1.3 Infrared transmittance

Infrared Transmittance (IRT) measures the percentage of incident infrared radiation for wavelengths of 750nm and upwards (Wigginton, 1996). The range of selectivity of transmission between light and heat is limited by the fact that 53% of the energy in solar radiation is in the visible spectrum (3% ultraviolet and 44% near infrared). For energy-saving and suitable solar filtering, the window material transmittance should have the lowest value in the infrared spectrum and the highest value in the visible sector of the solar spectrum (Correa *et al.*, 2004). According to Wigginton's studies in 1996, it proved impossible to decrease the total radiation transmittance without reducing light transmittance (Figure 3.4). Most recently, a study by Correa *et al.* (2004) showed that the peak transmittance values for Cu_2O selective coatings glazing lie within the visible spectrum, producing a window of high luminous transmittance. Figure 3.5 shows that with copper-based coatings it is possible to block 40–50% of the infrared radiation, while only 25–40% of the visible radiation is blocked (75–60% transmittance).

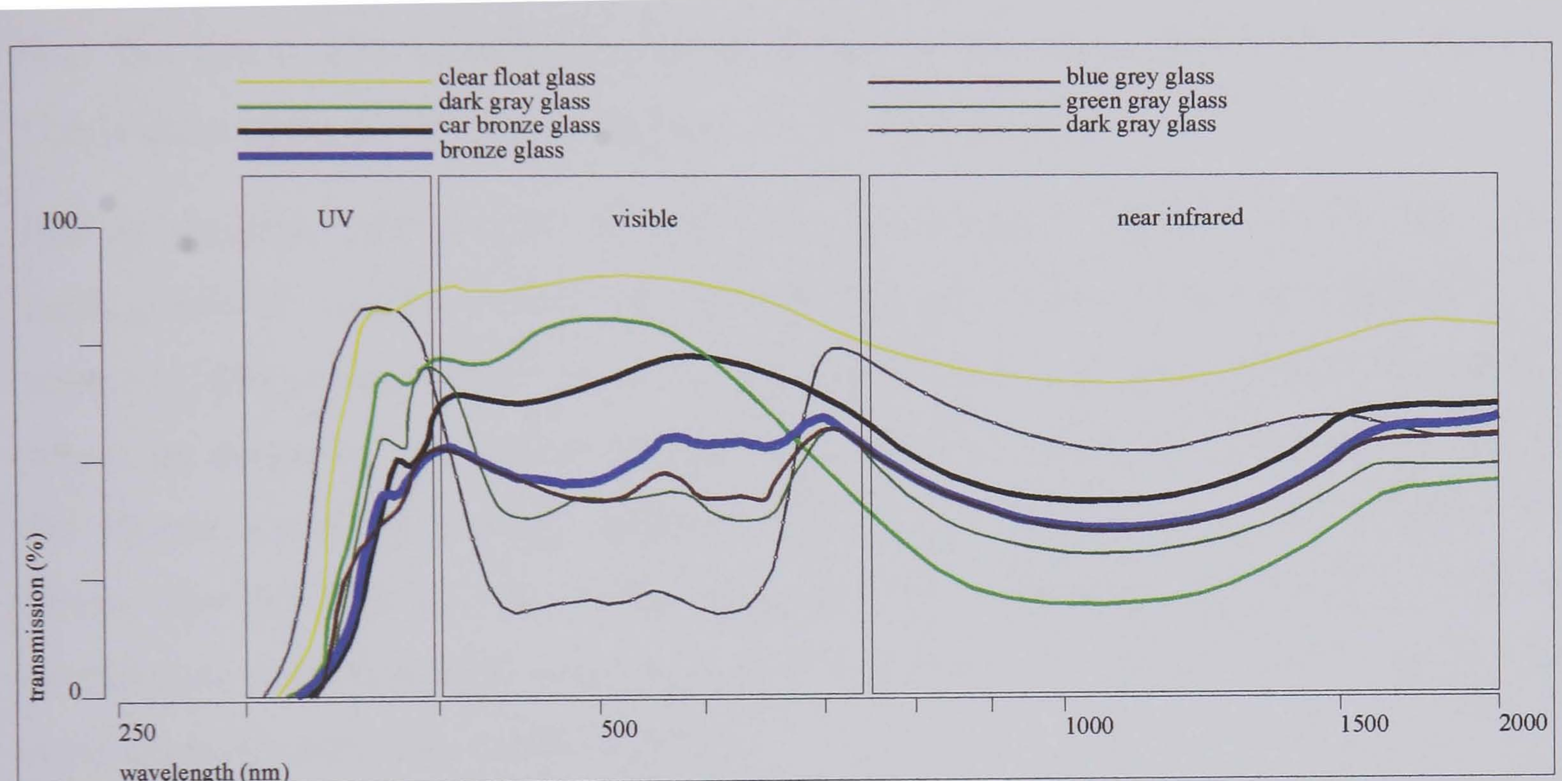


Figure 3.4. Comparative spectral transmittance of six typical tinted glasses with clear glass (Wigginton, 1996).

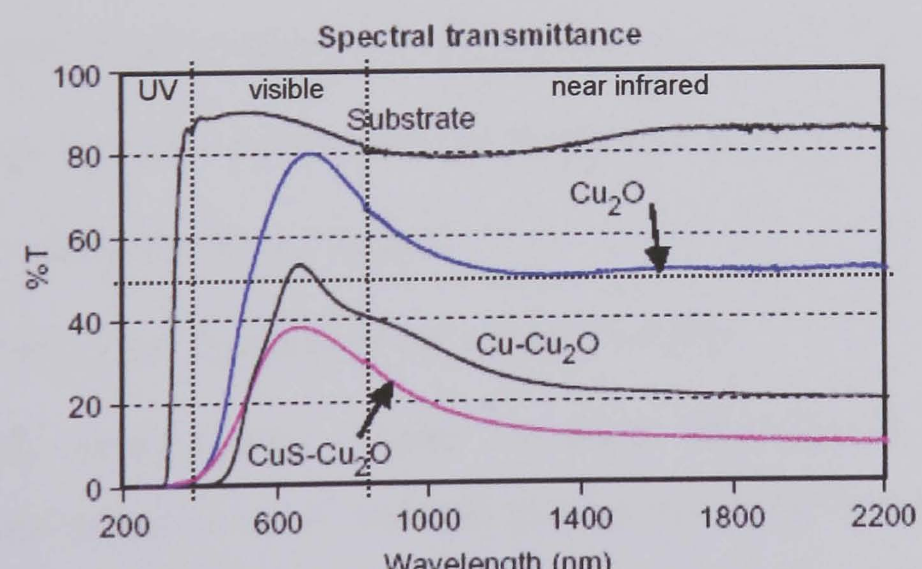


Figure 3.5. Spectral transmittance of three different kinds of copper-based glazing (Correa *et al.*, 2004).

3.3.1.2 *Thermal Transmittance*

The thermal transmittance or ***U-value*** of a material is 'the overall coefficient of heat transfer from air to air. It is the time rate of heat flow per unit area under steady conditions from the fluid on the warm side of the barrier to the fluid on the cold side, per unit temperature difference between the two fluids' (ASHRAE, 1989). The SI unit of U-value is $W/m^2.°C$. Manufacturers usually present the energy efficiency of windows in terms of their U-value for the entire window unit, including the frame.

Heat loss can be also quantified in terms of thermal resistance, abbreviated to ***R-value***. This is the reciprocal of U-value: R-value = 1 / U-value $m^2.°C/W$.

Just as windows are sources of light and have distinct optical characteristics and implications for visual comfort, they are also sources of heat gains and losses. The U-value of glazing therefore has great impact on the heat and cooling demands of buildings, which are dependent on climate and vary seasonally. According to Hutchins (1997), in any climate where the average outdoor temperature is consistently above or below the human 'comfort band', a low U-value is an advantage. The selection of glazing material to minimize unwanted solar gains in summer as well as heat losses in winter should not simultaneously squander valuable daylight.

According to Givoni (1998), any window system depends on four independent factors which change its thermal transmittance and resistance. These factors are:

- The existence and number of air spaces between glazing types
- The properties and / or treatments of the glazing material and surfaces
- The gas which fills the air spaces
- The materials and detailing of the window's frame.

Based on Mills' study (1996), Figure 3.6 traces the relation between the visible transmittance and the U-value of multiple glazing materials. In this comparative study, Mills (1996) illustrates that visible transmittances may vary from roughly 0.2 to 0.8 over the entire range of insulating values. There is therefore no identified relationship between U-values and visible transmittance. Figure 3.6 supports the notion of Givoni that the thermal transmittance of glazing is improved by the number of air spaces; i.e. quadruple glazing has lower U-values than triple, double and single glazing assemblies. On the other hand, low-e coatings give better thermal performance to glazing than tinted glazing. The impact of tints and coatings on glazing is examined in detail, in Section 3.4.1

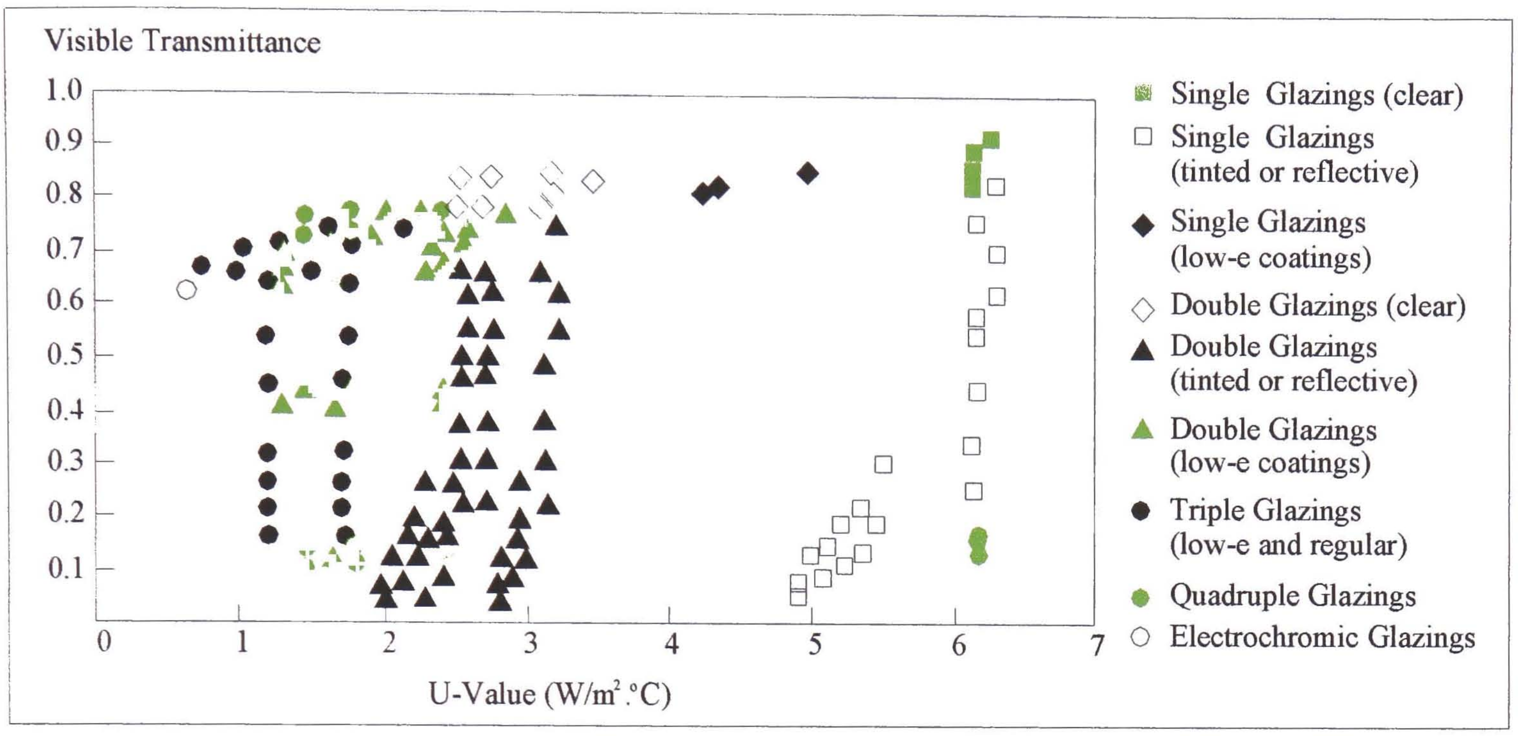


Figure 3.6. Over a range of thermal transmittance, U-Value, windows vary considerably in their visible transmittance (Mills, 1996).

3.3.1.3 *Shading Coefficient*

The American Society of Heating and Refrigerating and Air-Conditioning Engineers (ASHRAE, 1986) defined the Shading Coefficient (SC) as 'the ratio of solar heat gain through fenestration, with or without integral shading devices, to that occurring through unshaded 1/8 inch (3mm) thick clear double strength glass.' To minimize heat gain and air conditioning load, glazing with low shading coefficients are thus preferred. SC values range from 1.0 for clear glass to 0.08 for heavily reflective glass. A standard insulated glass unit (IGU) has a SC value of about 0.87. Figure 3.7 illustrates the variation in visible transmittance and shading coefficients for various glazing products. This diagram shows a clear linear relationship between the two glazing properties. The shading coefficient correlates positively with visible transmittance; i.e. the integration of shading devices decreases the amount of light transmitted through glazing; and accordingly visible light transmittance decreases.

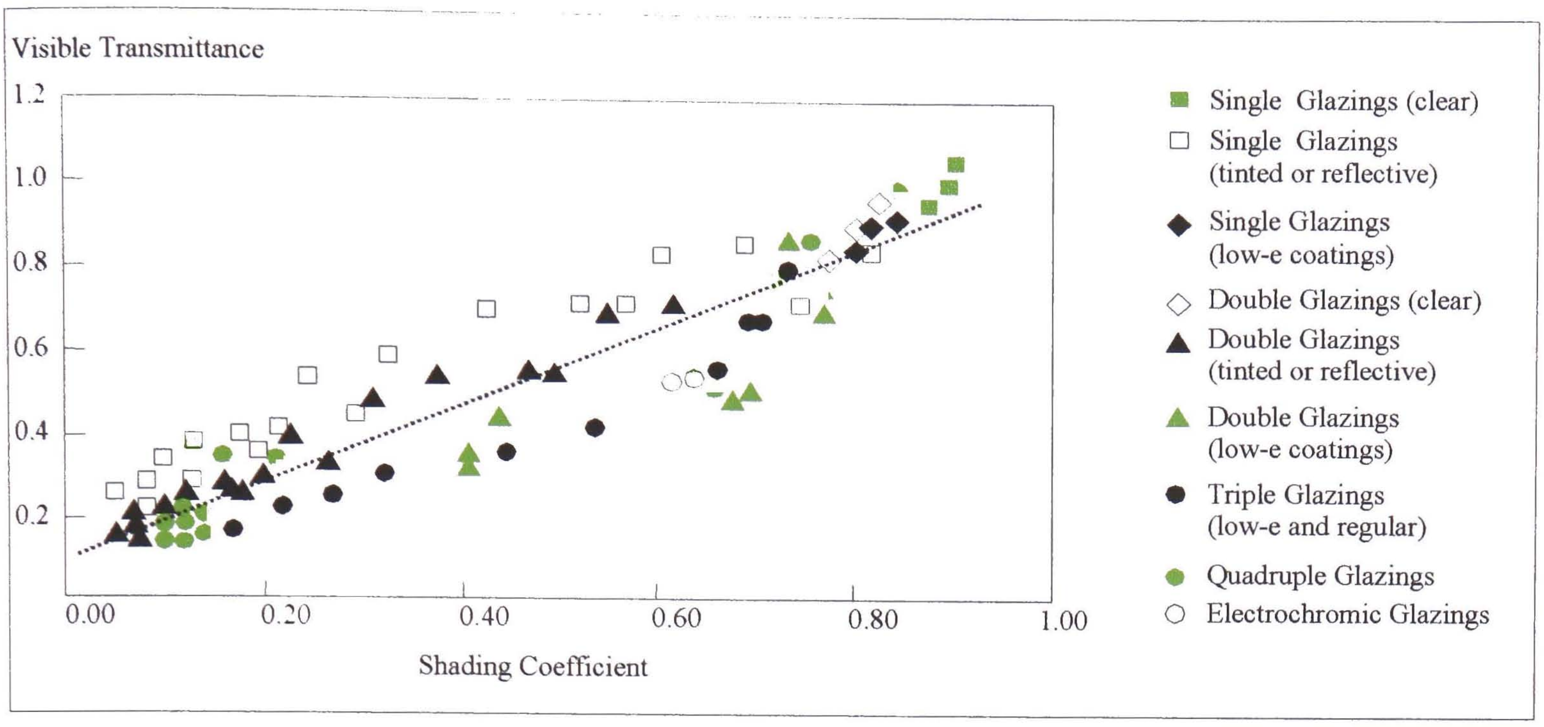


Figure 3.7. Over a range of shading coefficient, windows vary considerably in their visible transmittance (Mills, 1996).

In 1986 Sweitzer *et al.* from Laurence Berkley Laboratory suggested the **Ke factor** (Givoni, 1998) which has also been termed the **coolness index** (Button *et al.*, 1993) or efficacy factor (ESR, 2000). Ke is the ratio of visible transmittance to shading coefficient:

Ke = VLT / SC, where:

Ke = Ke factor or coolness index or efficacy factor

VLT = visible light transmittance

SC = shading coefficient

This factor is one of the criteria that evaluate the window's performance. It is helpful in selecting glazing products for different climates, in terms of those that transmit more heat than light and those that transmit more light than heat. The higher the number, the better the glass filters heat from the sun's daylight (Givoni, 1998 and ESR, 2000).

Based on Mills' work (1996), Figure 3.8. illustrates the relationship between coolness index and U-value. The relationship of shading coefficient to visible transmittance ratio with U-value is quite similar to the one between visible transmittance and U-value. This is due to the fact that visible transmittance and shading coefficient correlate positively. On the other hand, there is a clear distinction between the 4 groups of glazing in Figure 3.8. categorized according to their U-value. Group I includes electrochromic glazing, quadruple glazing, low-e triple glazing, and low-e double glazing. The thermal transmittance values range from 1 to 2, and the average coolness factor is approximately

1.1. The glazing types of this group have very well managed solar heat gain and good visible transmittance. The U-values of clear, tinted or reflective double glazing can vary between 2 and 3, and their coolness index can range between 0.2 and 1.2 (Group II). Clear, tinted or reflective single glazing types (Group IV) have the same range of coolness index but their thermal transmittance is the highest, approximately 6 $m^2.°C/W$. Tinted glazing can have lower coolness index and U-value depending on the tint colour. (Group III).

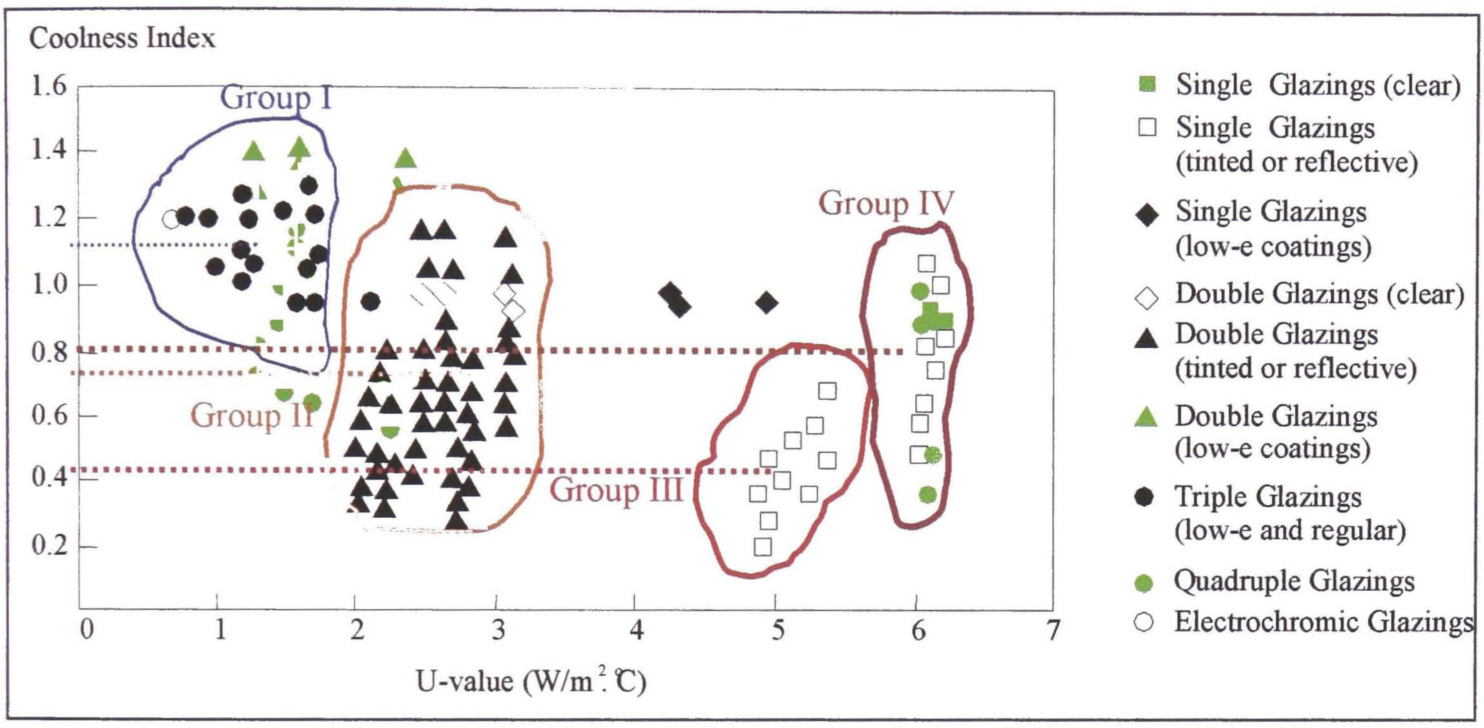


Figure 3.8. Over a range of U-value, windows vary considerably in their coolness index.

Solar Heat Gain Coefficient (SHGC) is now gradually replacing 'Shading Coefficient' SC in product literature as the key solar parameter. The solar heat gain coefficient also indicates how much solar heat is blocked by the window, but it is slightly different from the shading coefficient. It expresses the amount of solar heat that penetrates the window compared with the amount that strikes the outside. The relationship between SGHC and SC is as follows: SHGC = SC*0.87 (ASHRAE, 1985).

The SHGC is a ratio between 0 and 1. SHGC = 0 means none of the incident solar gain is transmitted through the window as heat, and SHGC = 1 means all of the incident solar energy is transmitted through the window as heat.

Typically windows with low SHGC values are desirable in buildings with high air conditioning loads, while windows with high SHGC values are desirable in buildings where passive solar heating is needed.

Thus the SHGC is a significant factor in improving the thermal comfort of occupants in building interiors, especially in the east, west and south façades where solar heat gain is considerable.

The Advanced Building Technologies and Practice Organization (2000) recommends **Light-to-Solar Ratio (LSR)** as a common measure of the performance of glazing units. This is the ratio of visible light transmission (VLT) divided by the solar heat gain coefficient (SHGC) for the glazing system.

LSR = VLT / SHGC, where:

LSR = light-to-solar ratio

VLT = visible light transmittance

SC = solar heat gain coefficient

LSR is a similar measure to coolness factor, and is approximately equal to 1.15*Ke since SHGC=0.87*SC. High values of LSR are recommended in buildings where daylighting is desirable with a minimal solar heat gain. The highest possible ratio is approximately 2.0. Clear glazing units have a value close to 1.0, while a good spectrally selective glazing system would have a value greater than 1.7.

3.3.1.4 *Visible Light Reflectance*

The visible light reflectance indicates, as defined by PG&E Energy Centre (1997), 'to what degree the glazing appears mirror-like, both inside and out; measures the percentage of light striking the glazing that is reflected'. The numbers are listed for inside, outside or both. While all smooth clear glass is naturally somewhat reflective, visible reflectance can be increased by glazing treatments such as metallic coatings. A higher visible reflectance represents a more mirror-like appearance, a darkened view and reduced daylight transmittance. To avoid the "mirrored" look outside reflectance should be lower than 10 to 15%.

Glass internal light reflectance and glass external light reflectance are parameters to be considered in addition to light transmittance, where view in and view out are imperative (Button *et al.*, 1993). Standard clear insulating glass has an exterior daylight reflectance of 16% and an exterior solar reflectance of 14%.

Multiple types of glazing are obtained by altering the optical and thermal performance parameters mentioned in 3.3.1. The following section will review the most common types of glass and glazing technologies.

3.4 Window Glazing Systems

Choosing the right glazing material is critical to successful daylighting. Until recently, clear glass was the primary glazing material used in windows. Although it allows a high percentage of daylight to enter buildings, it has very little resistance to heat flow. During the past two decades, however, glazing technology has changed a lot. Research and development into types of glazing have created a new generation of materials that offer improved window efficiency and performance of buildings. All types of glazing, and the advances made to enhance daylighting design energy performance are reviewed in the following sections. Following Guzowski (2000), this review is divided into three main approaches:

- Glazing assemblies and glass technologies
- Daylighting systems within the glazing cavity
- Integrated glazing and shading systems.

3.4.1 Glazing Technologies

Over recent decades, a variety of glazing assemblies and glass technologies has been developed that use the characteristics of the glass as means of responding to environmental conditions.

There are nine basic types of glazing that are important for daylighting and solar heating and cooling applications because of their distinctly different behaviour in the three regions of the radiation spectrum (ultraviolet, visible and near infrared). These are:

- Clear glazing
- Fritted and laminated glazing
- Tinted glazing
- Reflective glazing
- Low emissivity (Low-e) glazing

- Applied Films
- Spectrally selective glazing
- Switchable glazing or smart glazing
- Photovoltaic

3.4.1.1 *Clear Glazing*

Clear glass transmits the highest amount of all the wavelengths of the solar spectrum. Compared to other glazing types, Figure 3.9 shows that clear glazing has the highest values for visible transmittance and shading coefficient, and the lowest values for coolness index. It is often the best choice where clear view and a maximum daylight penetration are recommended. On the other hand, clear glass absorbs most of the infrared radiation (long wave radiation) that causes the highest solar heat gain into the building, and which increases the cooling load in summer. However, such glass is the most suitable for solar heat collection in winter.

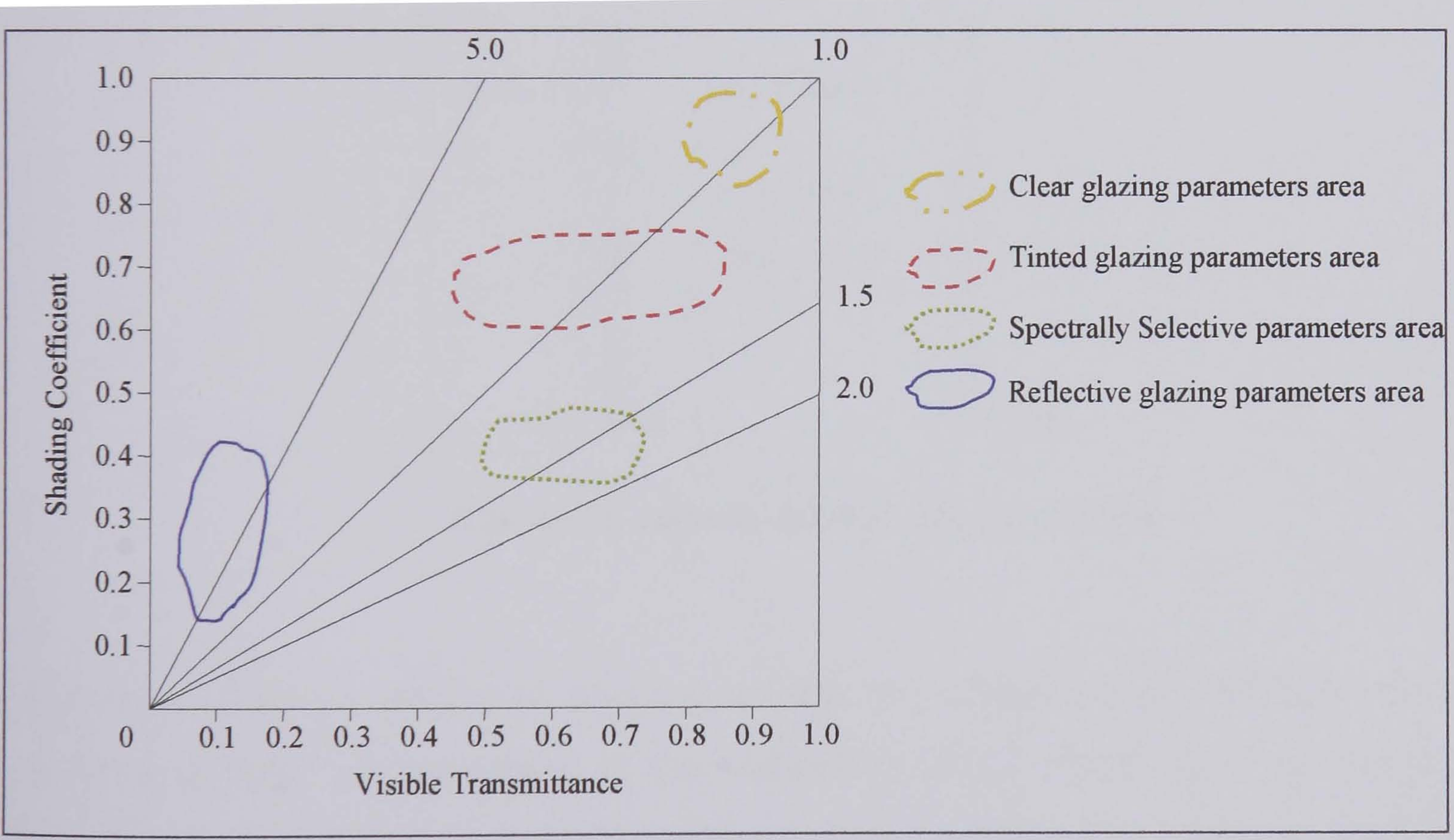


Figure 3.9. Clear glass compared to other types of glazing in terms of visible transmittance, shading coefficient and the Ke indicated by the diagonal lines (PG&E Energy Centre, 1997).

Sand is the most important raw material in the manufacture of glass. Standard clear glazing always contains a small amount of impurities, mostly iron oxide (approximately 0.1%), which produce a faint green colour tint that can bee seen on the edge of the pane.

The visible transmittance of 6mm clear glass is 0.85, and the infrared transmission coefficient is 0.70. This varies according to the glass thickness (Wigginton, 1996).

A clear 'white' glass is achieved by chemical cleaning of the base materials. The percentage of iron oxide is therefore less, which increases the visible light transmittance slightly as well as the heat transmittance.

3.4.1.2 *Fritted and Laminated Glazing*

Fritted and laminated glazing systems are important products in terms of shading sunlight, reducing thermal gains, responding to glare and providing privacy (Guzowski, 2000). Fritted glass is manufactured by adding ground-glass particles, called frit, which are oven-dried and fired onto the glass, creating integral shading through a translucent overlay. Standard or custom frit patterns can be applied to a variety of glazing assemblies that includes additional selective films, insulation, air gaps and inert gas infills (Figure 3.10).

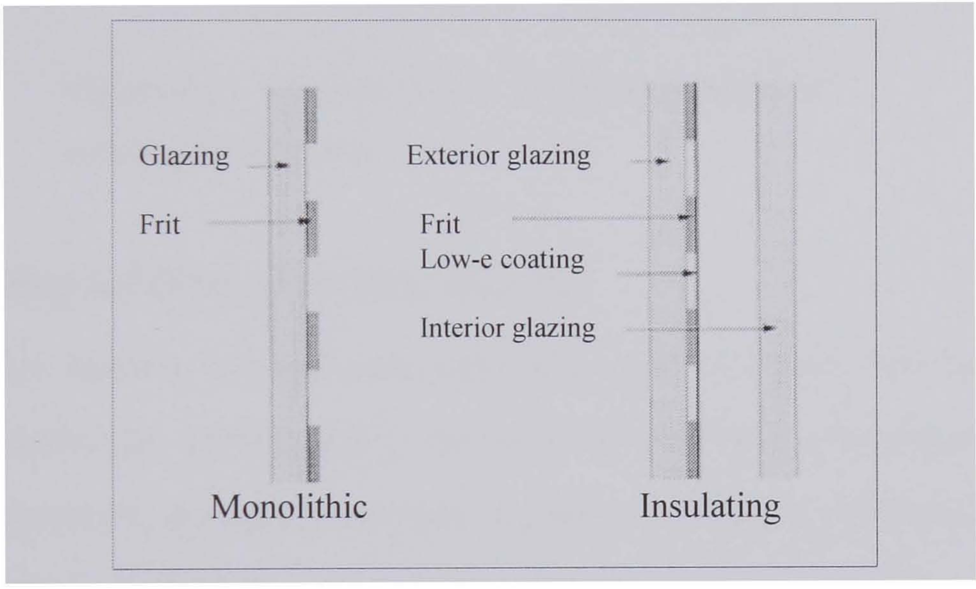


Figure 3.10. Multiple fritted glazing construction.

Frit glass offers no options to adjust or modify the daylighting for different uses or qualities of light. The advantages of this technology are the simplicity of an integrated shading device with low maintenance. The drawbacks are that it is static and cannot be altered to meet the changing daylight conditions or needs, to provide views, or to connect to the site. Potential glare at the window should also be considered, because the diffuse light captured on the surface of the frit can become a potential source of glare or a troubling light source within the room. In addition, fritted glazing by itself has no effect on the U-value of the window.

Laminated glass consists of a tough plastic interlayer made of polyvinyl butyral (PVB) bonded between two panes of glass under heat and pressure. Once sealed together, the glass "sandwich" behaves as a single unit and looks like normal glass. The PVB in laminated glass helps reduce solar energy transmittance to reduce cooling loads. Selective films, air gaps, tinting, infills and insulation allow reduced solar gains and provide shading within the glazing assemblies (Figure 3.11).

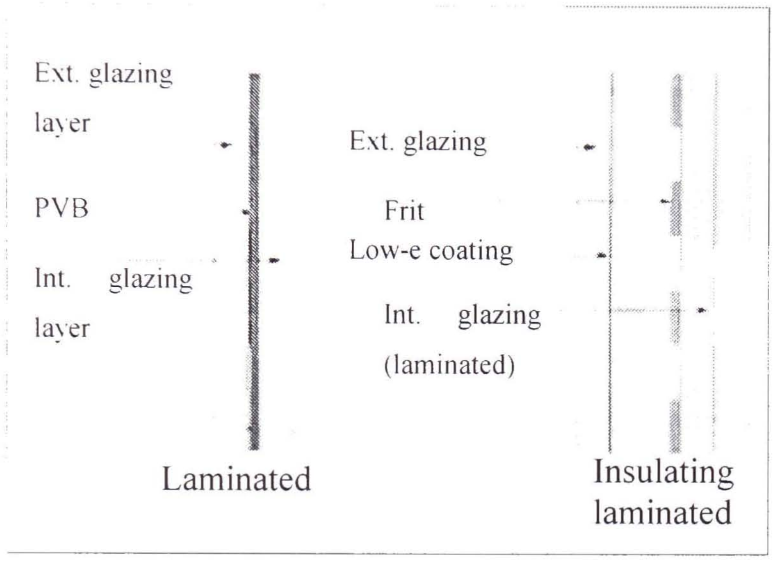


Figure 3.11. Laminated and insulating laminated glazing construction

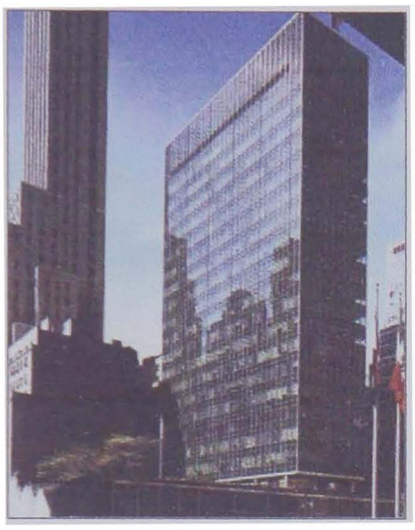
3.4.1.3 *Tinted Glazing (or Heat Absorbing Glazing)*

Tinted glazing, also known as heat-absorbing glazing, is where the basic clear glass formulation is modified by adding small amounts of additional materials into the mix. These additional materials are used to produce glasses that have different light and solar radiant heat transmission characteristics, coupled with different colours. These types of glass are rarely appropriate for daylighting purposes, because they reduce light transmission and distort the colour of the view. They block heat transmission through bulk absorption in the glass itself. Unfortunately this also causes the glass temperature to rise, increasing the radiation coming off the window into the conditioned space.

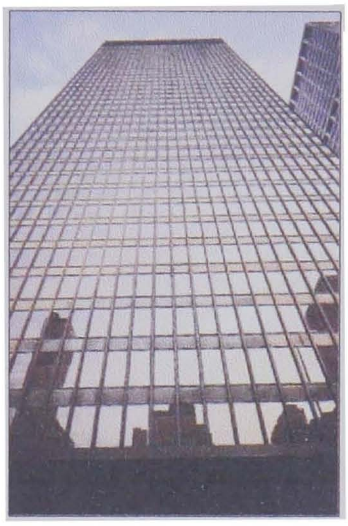
Typical colours are green, bronze, grey and blue. The first tinted glasses used in buildings were green. Figure 3.12a shows the Lever House building in New York (date of construction: 1951 – 1952), where green tinted glazing was used for the first time (Wigginton, 1996). The body-tinted green glass is based on putting back the iron oxide that was removed in the first purification process to get 'clear white' glass. The addition of iron oxide, which is done in carefully defined quantities, is very good for absorbing photons towards the near infrared and thus reduces the transmission of solar heat.

After green glass came bronze glass, used for the first time at the Seagram building of 1954 – 1958 (Figure 3.12b). The bronze tint is produced by the addition of Selenium oxide to the glass mélange. These green and bronze tints were subsequently joined by the grey range. A variety of chemicals such as cobalt oxide, nickel oxide and selenium are added to the iron oxide, to produce slightly different greys.

Blue tinted glass is obtained by the addition of cobalt oxide. Blue and green tinted windows, compared to the other colour tints, offer greater penetration of visible light and slightly reduced heat transfer (Table 3.1).



a-



b-

Figure 3.12. An early use of: a- green heat absorbing glass at Lever House building, New York (1951-1952); b- pink gray glass at Seagram building, New York (1954-1958).

Glass type	Visible Light Transmittance	Infrared Transmittance
6mm clear	0.82	0.70
6mm green	0.66	0.46
6mm blue	0.50	0.46
6mm grey	0.39	0.42
6mm bronze	0.46	0.46
6mm dark grey	0.18	0.58
10mm grey	0.23	0.25
10mm bronze	0.30	0.29

Table 3.1. Visible light transmittance and Infrared transmittance of typical range of body tinted glasses (CIBSE, 1999).

As explained previously, the addition of chemicals to clear glass makes tinted glass that absorbs shortwave radiation and thus reduces heat gain to the inside of a building.

However, depending on coincident internal and external climatic conditions, the energy stored as heat may be re-radiated into the space as the temperature outside begins to fall in the late afternoon. At this time, the internal equipment and casual gains tend to be at a peak. Thus summer overheating can be more severe than would have occurred otherwise with clear glass, and winter heat gain may occur too late in the day to be of any use. To conclude, studies have shown that the tints used can have two additional effects (Federal Energy Management Program, 1998):

- Longwave light transmission is reduced resulting in an increased need for artificial lighting, and larger window areas to achieve the same level of daylight.
- The psychological effect of looking at the world through brown, grey or green glass can be disturbing, and has been suggested as a contributory factor in building-related health problems.

3.4.1.4 *Reflective Glazing*

Reflective glazing is created by depositing very fine semitransparent coatings made of thin layers of metals or metallic oxides on the surface of the glass, producing a mirror like appearance. This type of coating or 'film' is usually reflective in the infrared regions as well as the visible regions. They have a better shading coefficient than tinted glazing, which can reach as low as 0.11 (Energy Source Builder, 1994), but light transmittance is very low. Table 3.2 illustrates the properties of several types of coated glass.

Developments in surface chemistry and coating technology have led to a wide range of coated glass. The surface characteristics of glass can be modified to give a wide range combination of light and solar radiant heat transmission characteristics, including colour variety. Reflective coatings can be incorporated in multiple glazing and, in some cases, are applied as a minimum specification in combination with another glass as a sealed double-glazing unit.

Because reflective glazing reflects light along with solar infrared radiation, it should not be used in windows that are designed to collect daylight. It is however commonly applied in hot climates, where solar control is critical. The reduced cooling energy demands achieved may be offset by the need for additional electrical lighting.

A new selectively reflecting glazing is available, however; it reflects more of the shortwave infrared than visible light. Reflective glazing is more often used when solar heat gain must be reduced rather than when daylighting is desired. Neither normal reflecting nor selectively reflecting glazing is appropriate in buildings where solar heating is desirable in the winter.

Glass type	Visible Light Transmittance	Infrared Transmittance	Shading Coefficient
6mm silver	0.09	0.08	0.26
6mm bronze	0.09	0.06	0.27
6mm blue	0.18	0.15	0.28

Table 3.2. Visible light transmittance, infrared transmittance and shading coefficient of typical range of coated glazing types (CIBSE, 1999).

3.4.1.5 *Low Emissivity (Low-E) Glazing*

Introduced in 1989, low-e glazings have special coatings that reduce heat transfer through windows. Low-e coatings are similar in behaviour to reflective coatings, but are selected for their low emission and reflection of longwave rather than shortwave heat. Such coatings are defined as those which are predominantly transparent over the visible wavelength (300 to 700 nm) and reflective in the longwave infrared. The thermal properties of these glasses can be tailored to give good solar control. At the same time they admit significantly more daylight than conventional tinted glasses, and have lower heat loss in winter. They are used in double and triple glazed units, which may be filled with a low conductivity gas such as argon to achieve very high thermal resistance whilst preserving good levels of solar and visible light transmittance. Table 3.3 lists the properties of some low-e glazing assemblies (Hutchins, 1997).

When applied inside a double-pane window, low-e coating is either placed on the outer surface of the inner pane (surface 3, Figure 3.13b) of the glass or on the inner surface of the outer pane (surface 2, Figure 3.13c). In the first case, the low-e coating reflects heat back into the building space while in the second case, heat radiated from surface 2 is reflected back and therefore less heat is lost to the external environment. This same coating will slightly reduce heat gain during the cooling season.

Glass type	Gas Fill	Visible Light Transmittance	Infrared Transmittance	U-value ($W/m^2.°C$)
Single	-	0.90	0.86	6.4
Double glazed unit (DGU)	air	0.81	0.76	2.9
Double glazed unit, low-e	air	0.74 – 0.78	0.62 – 0.71	1.8 - 2.2
DGU, low-e porolytic heat mirror	argon	0.75	0.72	1.9
DGU, low-e sputtered noble metal heat mirror	argon	0.75	0.58	1.1
DGU, low-e sputtered noble metal heat mirror	xenon	0.76	0.58	0.9
DGU, low-e sputtered solar control	argon	0.66	0.34	1.2
Triple glazed unit, 2 low-e	argon	0.62 – 0.67	0.49 - 0.58	0.8 - 1.1
Triple glazed unit, 2 low-e	krypton	0.63	0.55	0.7

Table 3.3: Optical and thermal performance of glazing units using low emittance coatings (Hutchins, 1997).

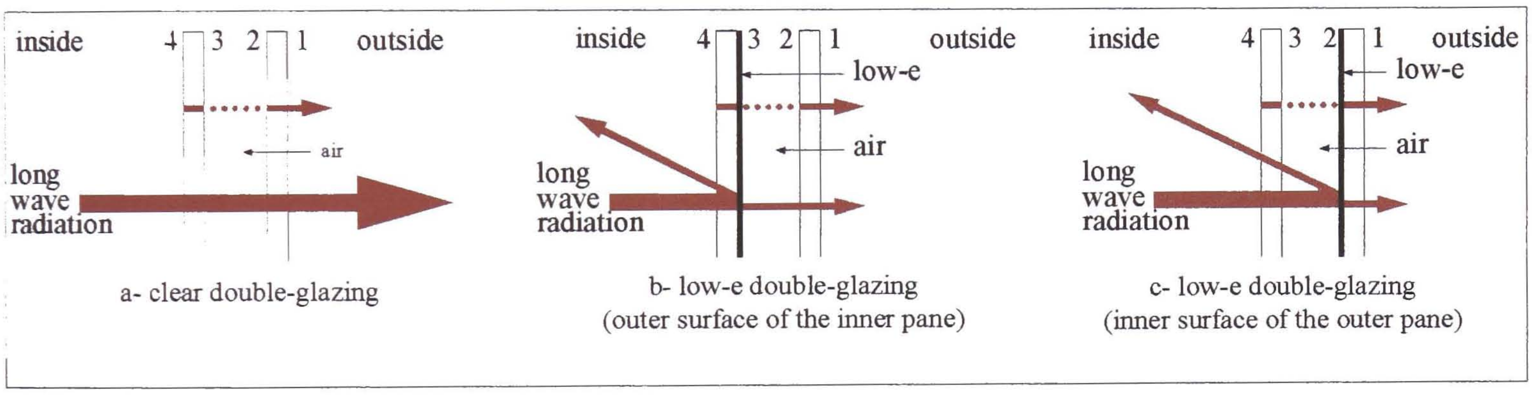


Figure 3.13. Transfer of heat through low-e double-glazing systems. The dots signify conduction.

The low-e coatings are thin, and almost invisible. There are two types:

- multilayer dielectric/metal/dielectric,
- highly doped semiconductor films.

The multilayer materials are more 'tuneable' while the doped materials tend to be more durable. In multilayer films, typical dielectric materials are indium oxide, tin oxide and zinc oxide. Silver is the metal most commonly sandwiched between these dielectric materials, which are very reflective to longwave radiation and the visible spectrum (Wigginton, 1996).

Low-e films are applied in either soft or hard coats. Soft-coat low-e films have a limited shelf life. When exposed to air and moisture, they are degraded and easily damaged. Therefore they are carefully applied by manufacturers in insulated multiple-pane windows. Hard low-e coatings, on the other hand, are more durable and can be used in add-on applications. However the energy performance of hard-coat, low-e films is slightly poorer than that of soft-coat films.

3.4.1.6 *Applied Films*

Applied solar control films, also known as adhesive-backed films, are a common retrofit technology. They are available to give the same effects as the various forms of tinted glazing, reflective, absorbing and low-e types. Their main advantage is that window films are relatively inexpensive, and can be readily installed in most existing buildings to control solar gain. They typically darken a window and give a mirror-like look to the glass, particularly the films that offer the highest degree of solar control. The advantages of films include solar heat reduction; glare reduction, UV reduction, increased shatter resistance and some improvement in insulation value. The disadvantages of these films are loss of daylight and winter solar heat, and poor control of glare from the sun.

Window films are multilayer assemblies of coatings and polyester films, as shown in Figure 3.14. These films are attached to the insides of existing single or double glazed windows by an adhesive backing. Typical films have a total thickness of 0.025 to 0.1 millimetres. Exterior grades are also available. They may give better thermal performance when applied to tinted glass or double-glazed units. Exterior application is also practical for inaccessible rooflights (Littlefair, 1999).

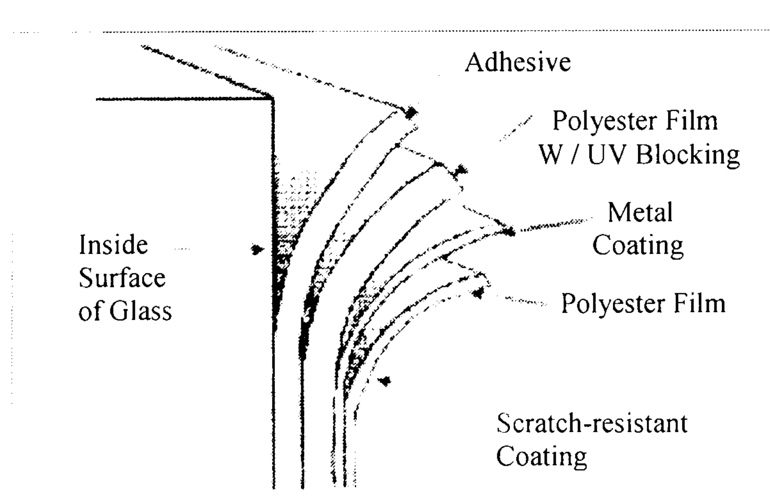


Figure 3.14. Multilayered film assembly.

3.4.1.7 *Spectrally Selective Glazing*

In a report produced for the U.S. Department of Energy, spectrally selective glass is defined as 'a window glass that permits some portions of the solar spectrum to enter a building while blocking others' (Federal Energy Management Program, 1998).

Spectrally selective glazing has been available since the 1980s. It is achieved through the use of thin film, noble metal low-e multiplayer coatings which are commonly termed 'cold mirrors' or 'cool daylighting glazing' (Hutchins, 1997). These coatings filter out from 40% to 70% of the heat normally transmitted through clear glass, while allowing the full amount of light to be transmitted (DOE and NREL, 1993). Spectrally selective coatings can be applied on various types of tinted glass, to produce "customized" glazing systems capable of either increasing or decreasing solar gains according to the aesthetic and climatic effects desired (Figure 3.15).

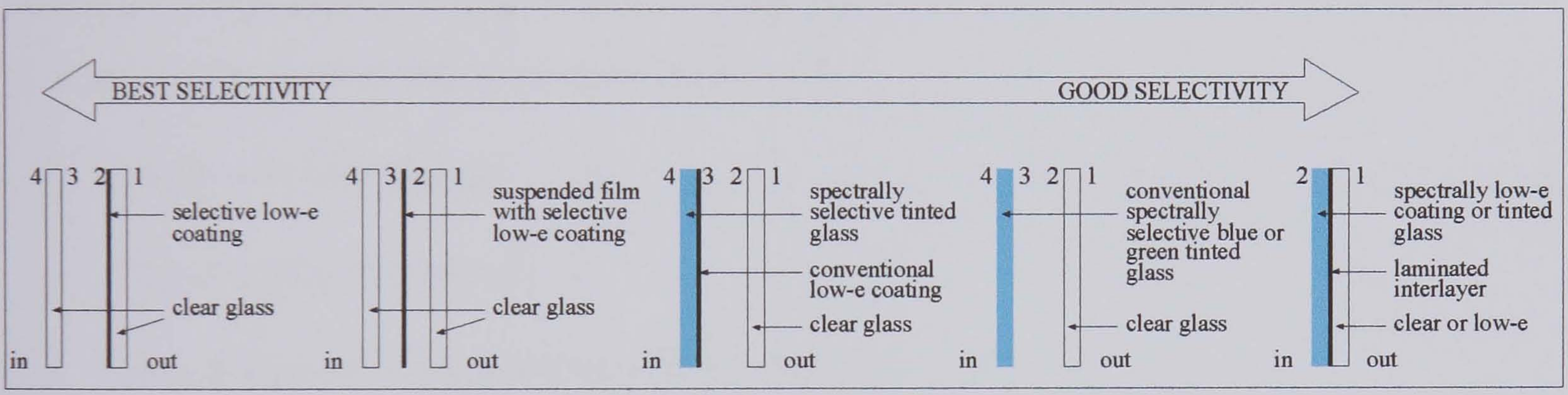


Figure 3.15. Spectrally Selective Window Assemblies (DOE and NREL, 1993).

This high-performance glazing admits as much daylight as possible, while preventing transmission of as much solar heat as possible. The energy performance of spectrally selective glass is illustrated by its ability to control solar heat gains in summer, preventing loss of interior heat in winter, and allowing occupants to reduce electric lighting use by making maximum use of daylight. Spectrally selective glazing significantly reduces building energy consumption and peak demand (Federal Energy Management Program, 1998).

Therefore, spectrally selective glazing is best suited to buildings that require high light levels and have a long cooling season. Buildings in cool climates are not well suited to spectrally selective glazing, because of the large reduction in winter solar heat gain. DOE and NREL (1993) claim that simulations have shown that advanced glazing with spectrally selective coatings can reduce the electric space cooling requirements of new homes in hot climates by more than 40%.

3.4.1.8 *Switchable Glazing or 'Smart' Glazing*

Glazing materials that are responsive to hourly, daily and seasonal climatic changes are known as optical switching materials. These coatings can control the flow of light or heat in and out of a building window, thus performing an energy-management function. They inherently provide a change in the glazing optical properties under the influence of light, heat or an electrical field, or by their combination. Depending on the design, the coatings can control glare, modulate daylight transmittance, limit solar heat gain to reduce cooling loads and improve thermal comfort

Switchable glazings, not yet mature products, change their properties such as shading coefficient and visible transmittance in response to a signal. There are six categories, defined by the mechanisms that make them work:

1. Angle selective glazing
2. Liquid crystal assemblies
3. The chromogenic phenomenon which includes:
    - photochromic glazing assemblies,
    - thermochromic glazing assemblies,
    - electrochromic glazing assemblies
4. Holographic diffractive films
5. Prismatic glazing
6. Photovoltaic.

3.4.1.8.1 Angle selective glazing

Angle selective glazings are used in window apertures to admit or reflect incident light depending on the angle of incidence. Generally it is desirable to reflect high elevation light to avoid a high illuminance and glare level near the window, and to admit low elevation light (which contains the view) and the useful daylight that penetrates deeply into a room (Reppel *et al.*, 1998). Daylight is reduced, but some winter solar gain may enter. This structure has a minimal effect on the ability to see through the glass from inside the building, as the angle at which radiation strikes the glass is different from the angle at which we look out.

Angular selective transmittance coatings are recent in their development. These coatings were first prepared at the University of Technology, Sydney. In principle, they are composed of a microscopic louvered grid structure created on a 0.28mm thick polymer film by a process of photopolymerisation, producing an oriented dendritic thin film structure. The orientation of the dendrites can be controlled and varied by the deposition procedure. Evaporation, steered cathodic arc and sputtering techniques are being investigated (Hutchins, 1997). Solar radiation is transmitted more easily when the radiation is incident in directions along the axes of the dendrites, than when it is incident perpendicular to the columnar structure.

In Japan, Nippon Sheet Glass introduced its 'Angle 21' products using a polymer with an oriented column microstructure. This varies in its transmittance from specular transmittance to diffusing scattering, depending upon the angle of the light beam. The polymer molecules can be oriented so as to give an angular dependent crystal structure, and this has been achieved for dispersed liquid crystal films; this opens up the possibility of switching the angles electrically, to produce molecular Venetian blinds.

On the other hand, the angle selective function can be obtained from the very high light deflecting power of a laser cut panel (LCP) as illustrated in Figure 3.16 with LCPs as panels in a louver window (Reppel *et al.*, 1998). The panels may be used in windows as a moveable louver system to provide sunlight rejection with the panels in the open louver position (Figure 3.16, A), or as a light re-directing system with the panels in the closed louver position (Figure 3.16, B).

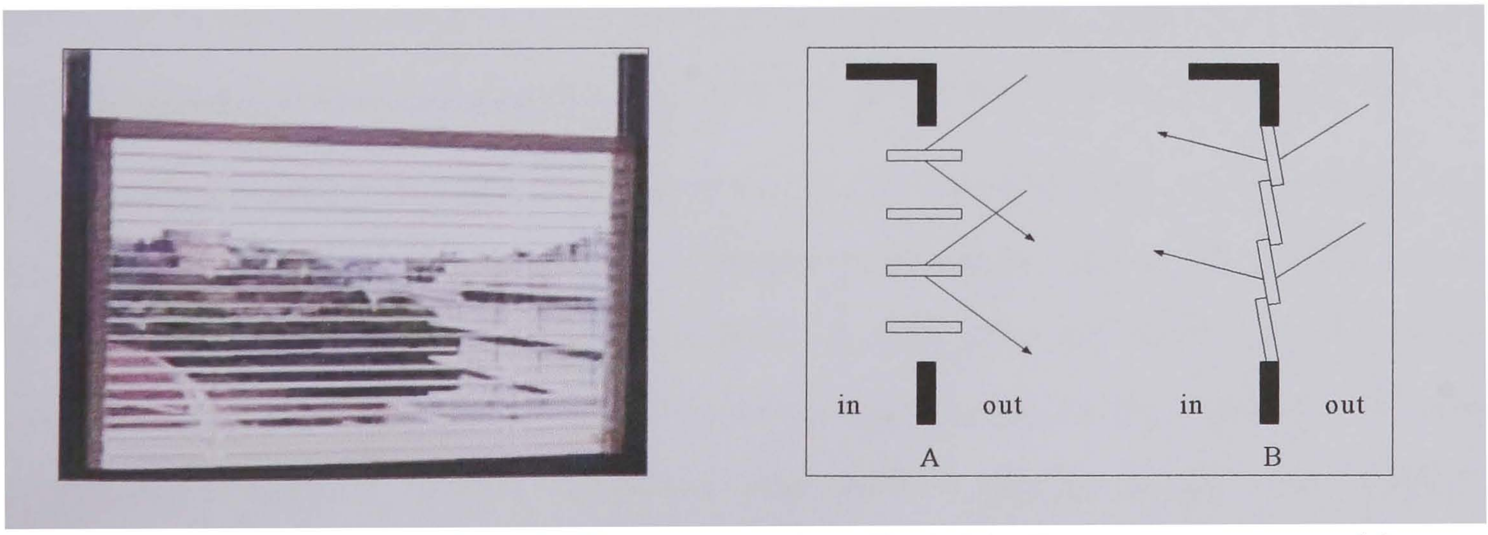


Figure 3.16. In louver or Venetian form LCP panels may be adjusted to the open, summer position to reject light or to the closed, winter position, to admit light (QUT, 2000).

3.4.1.8.2 Liquid crystal assemblies

Liquid crystals are based on the use of materials with a rod-like molecular structure, which adjust the way light is transmitted depending on the alignment of the rods. Typical materials are only a few nanometres long, which can be aligned for distances measured in thousands of nanometres. Most crystals types are smectic at low temperature, nematic when warmed and eventually become ordinarily fluid when warm enough.

Liquid crystal systems (LC) work on the principle that liquid crystal molecule chains can be influenced electrically to permit the transmission of polarised light. Liquid crystal devices are transparent in the presence of an electric field applied across two transparent electrodes or polarizers which align the liquid crystal molecules in the direction of the field (Figure 3.17). In this state the system is able to transmit light, as long as the electrical field is maintained. Without any applied voltage, the molecules are randomly oriented and the incident light is scattered. To maintain a clear state the voltage has to be continuously applied.

Liquid crystal systems are divided into two types: those which use polarizers, and those which do not. The polarised LC systems tend to be optically inefficient, with a maximum light transmittance of 35% (Wigginton, 1996). The commonest type of liquid crystal systems is the twisted 'nematic' (thread), in which the polymers form chains that rotate between polarising plates (Figure 3.18). The degree of rotation is controlled during manufacture. LC systems with no polarizers can transmit light much more effectively than polarized ones. Typical devices of non-polarizers systems are polymer dispersed liquid crystal (PDLC), or 'nematic' curvilinear aligned phase crystal (NCAP). In the NCAP schemes, the liquid crystals are within an index-match polymer medium integrated between two sheets of indium-tin-oxide electrode film. When the current is switched off, the window is transformed into a translucent opal white surface; when on, the glazing is totally transparent because of liquid crystal droplets alignment with the electric field.

The main disadvantage, however, of LC layers is the fact that they are non-transparent when no voltage is applied across them. Therefore continuous application of the electric field is required, which make the system expensive. Referring to Hutchins (1997) 'liquid crystals do not appear promising candidates for use as energy saving windows'. Relative to his study, Hutchins (2000) suggested that such a system might have effective application in glare control and privacy, as a substitute for conventional shading devices.

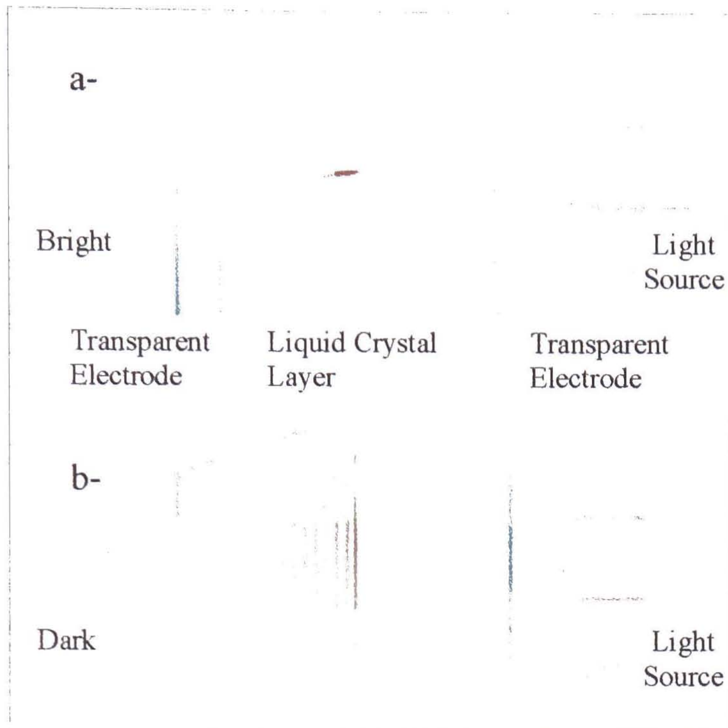


Figure 3.17. The action of liquid crystal systems: a- applied voltage, b- no voltage

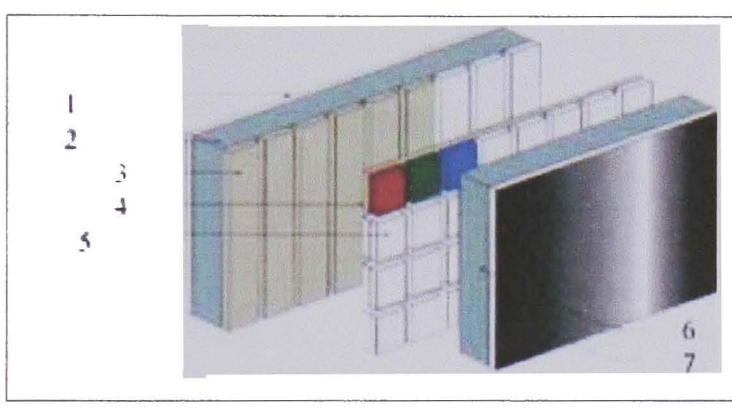


Figure 3.18. the twisted nematic liquid crystal construction: 1- polarizer, 2- substrate, 3- vertical electrode, 4- horizontal electrode, 5- colour filters, 6- substrate, and 7- polarizer.

3.4.1.8.3 Chromogenic glazing assemblies

Variable transmission has been the subject of a great deal of research, and the development of thin film coatings has permitted a wholly different category of materials to be created resulting from the capacity of a film to carry an electric current. This work has been progressing for several decades and chromogenics, the science of colour change in glasses, became in the 1990s a consolidated worldwide area for research and development.

Known as chromogenic glazings, these materials selectively control the spectral aspect of radiation. Chromogenic or optical switching windows enable windows to alter their transmittance in response to temperature (thermochromic) or light (photochromic) fluctuations, or in response to small electrical currents (electrochromic).

3.4.1.8.3.1 Photochromic glazing

Photochromic materials change their properties in response to light; the light transmission decreases automatically in response to exposure to ultra-violet or shortwave visible light. Photochromism is one of the oldest switching ideas, and reference to it is reported as far back as the 1880s (Wigginton, 1996; Hutchins *et al.*, 2000). In 1937, the scientist R H Dalton noted a phenomenon relating to the already known behaviour of glass containing copper, and which turned red when heated. Dalton discovered that exposure of such glazing to short-wave ultraviolet radiation before reheating led to this colour change happening more quickly at a lower temperature. The process was patented in 1943.

The importance of photochromic glass is that the darkening phenomenon derives from the chemistry of the glass itself, rather than from a coating. The chemical structure of photochromic glazing consists of the removal of oxygen, the combination with hydrogen, or lessening the positive valency by adding electrons to a glass containing copper or silver halides. This technology has been used for years in sunglasses, and is apparently beneficial. Nevertheless photochromism can operate inappropriately in a window, when the need for light in the interior is often independent of the brightness outside (Wigginton, 1996). These glasses are suitable for glare control, but not so much for solar heat gain as they tend to reduce only the visible portion of the spectrum (Figure 3.19); when photochromic materials change their transmittance, the absorptivity is increased causing the glass to absorb more heat. For example, a photochromic window may darken on a cold sunny day when more solar heat gain is desirable.

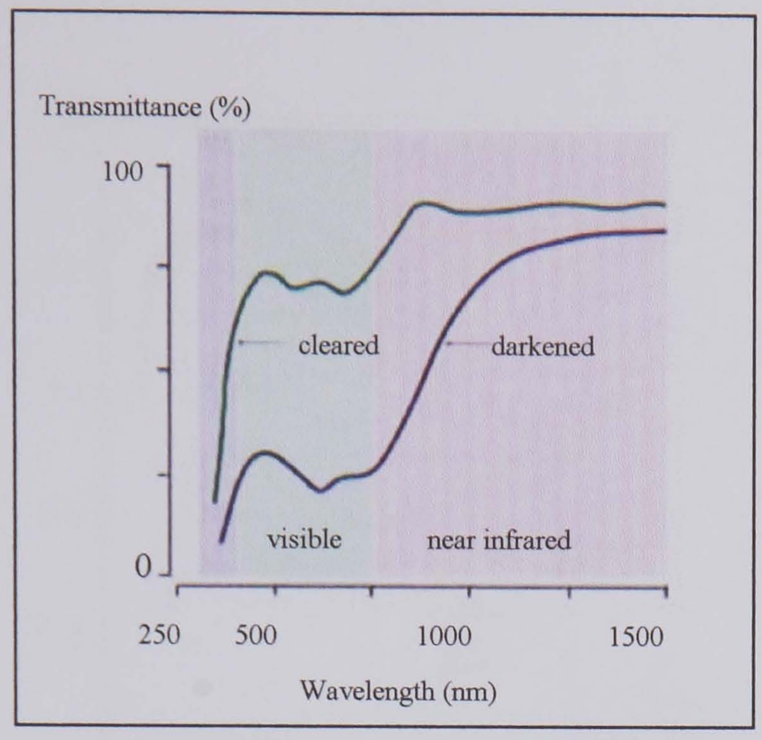


Figure 3.19. Photochromic glass spectral transmission. In this example, VLT is reduced by two-thirds (Wigginton, 1996).

3.4.1.8.3.2 Thermochromic glazing

In thermochromic materials, temperature induces a phase alteration turned out by a chemical reaction. Thermochromic glazing mainly consists of liquid or gel polymers sandwiched between layers of glazing. With cooler temperatures, the polymers in the film elongate into diameters smaller than the light's wavelength, allowing light to pass freely through the film. However, when the film warms to about 24°C, or to the programmed transition temperature, the polymer diameters become greater than the light's wavelength. As a result the molecules curl up, join together and reflect the light back.

Thermochromic windows are designed to block solar gain. A drawback to these systems is that they reduce the transmission of visible light. Typical visible transmission values lie between 0.8 – 0.9 and 0.1 – 0.5, and solar energy transmission values lie between 0.8 – 0.9 and 0.05 – 0.04 (Compagno, 1996). Figure 3.20 shows the optical properties of a typical thermochromic glazing, where the thermochromic film is 1mm in thickness.

Elmahdy *et al.* (1988) state that the possibility of thermochromic liquids leaking from the glazing unit can affect the long-term stability of these materials.

Again, as with photochromic materials, thermochromic glazing is not versatile in response. Daylight or view may have a higher priority for the occupant, at least temporarily, than any reduction in solar gain.

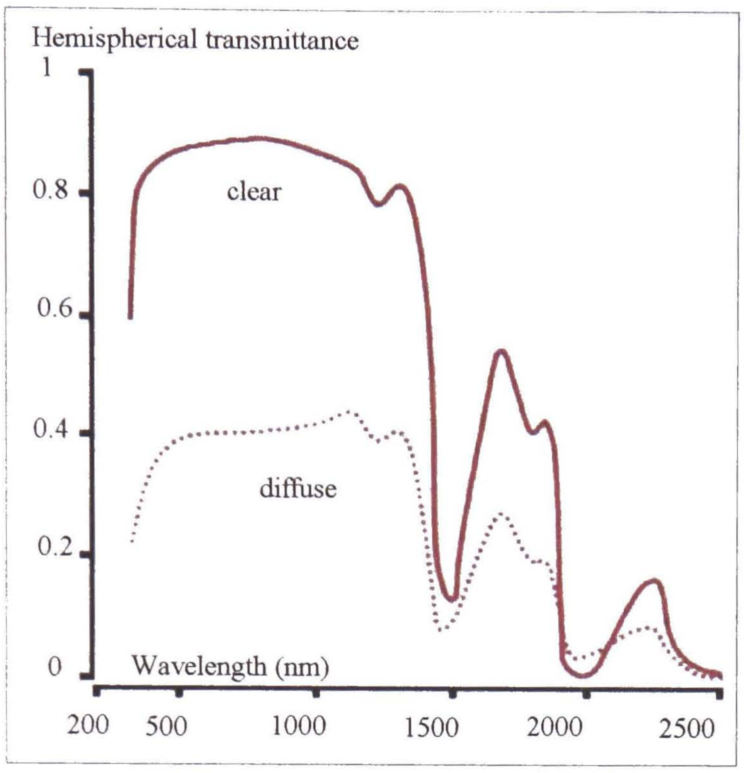


Figure 3.20. Optical properties of a typical thermochromic glazing, 1mm thickness thermochromic material (Wigginton, 1996)

3.4.1.8.3.3 Electrochromic glazing

Considered the most suitable chromogenic technology for energy control in buildings, electrochromics are the subject of intensive research. Electrochromic glazing changes thermal and optical performance by the action of an electric field that runs on a very low voltage (1 – 3V), and changes back when the field is reversed. Electrochromic devices can be found in two forms, the open system and the closed system. These are presented in Figure 3.21 (Wigginton, 1996).

Electrochromic devices essentially consist of five thin film layers successively deposited on a transparent substrate (normally glass). Two transparent conducting thin films, commonly indium tin oxide (ITO) or fluorine-doped tin oxide (SNO_2F), serve as the electrical conductors. The active electrochromic thin film or ion storage film is separated from the counter electrode by a transparent ion-conducting layer (electrolyte). In the case of tungsten oxide (WO_3), under the condition that it is at a negative potential with respect to the counter electrode, ions are transported from the counter electrode through the electrolyte and are inserted into the WO3 lattice (Figure 3.22). The injection of ions and electrons into the electrochromic film creates the conditions for a change of colour in the presence of light. A deep blue colouration results.

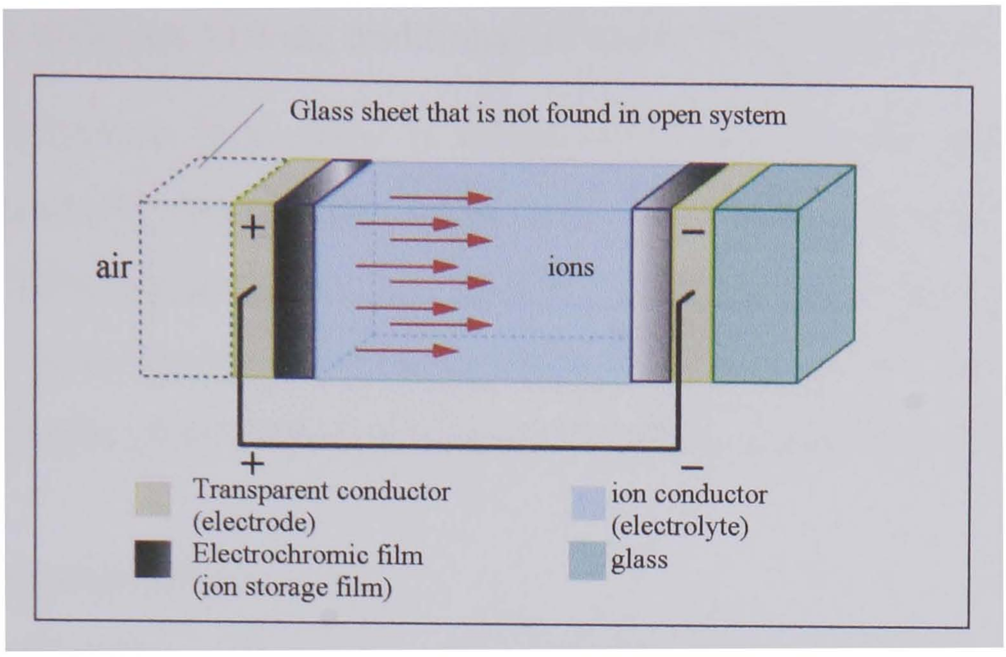


Figure 3.21. Schematic representation of multilayer thin films that constitute the electrochromic devices: the open system excludes the presence of an outer glass sheet where transparent electrode is open to the air (Wigginton, 1996).

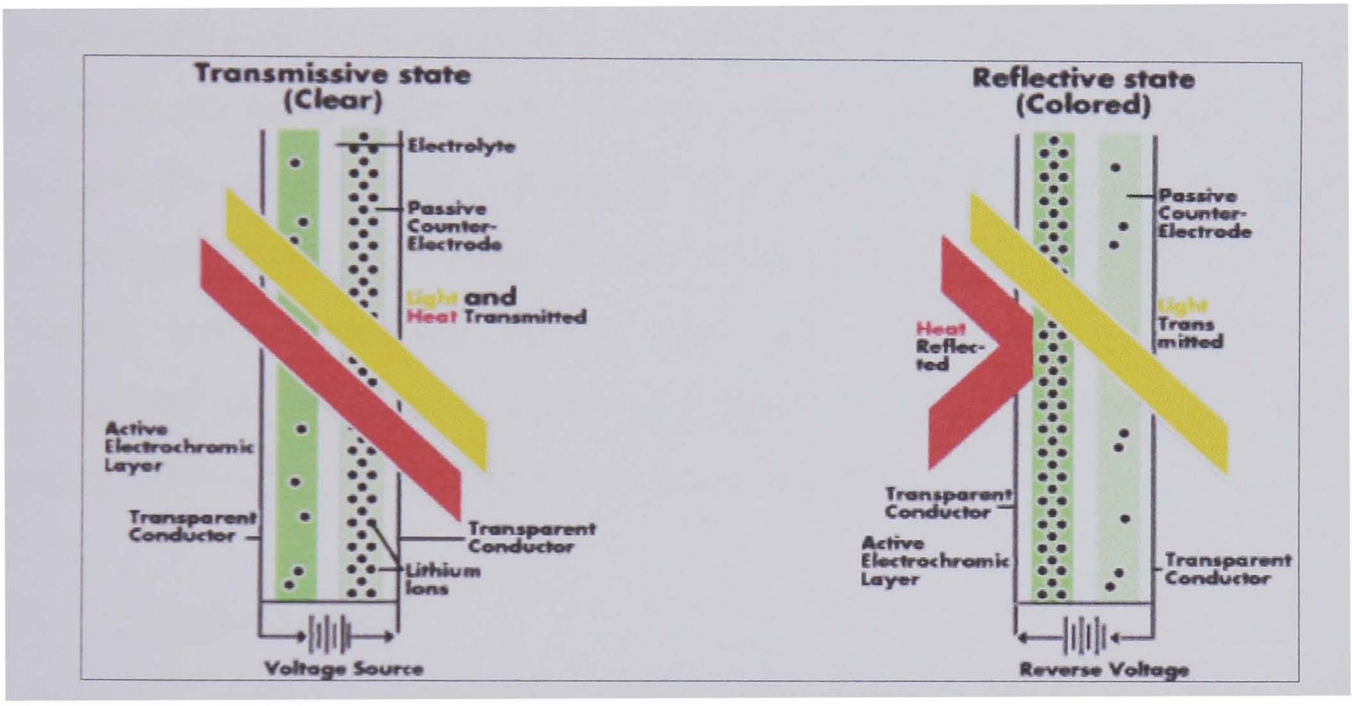


Figure 3.22. Cross section of prototype five-layer electrochromic coating, in clear and coloured states (layers not to scale) (Mills, 1996).

Mills (1996) stated that the electrochromic glazing developed by the Centre's Building Technologies Program permitted shading coefficients that could be adjusted from 0.98 to 0.36, with visible transmittances from 0.85 to 0.13. With such properties, Mills was able to say firmly that such windows make designers free from the historical rule-of-thumb that energy use eventually increases as a function of ratio of window-to-wall areas. His research shows that, even in very hot climates, energy use can decline steadily with increasing window area if electrochromics are used with daylighting controls, whereas conventional windows inevitably increase energy use as their size increases. Potential uses for electrochromic technology include privacy, daylighting control and solar control in windows and skylights, making traditional window shades and blinds obsolete.

Another electrochromic technology is called suspended particle display (SPD). This material contains molecular particles suspended in a solution between the plates of glass. In their natural state, the particles move randomly and collide, blocking the direct passage of light. While in an electric field, the particles align rapidly and the glazing becomes transparent. This type of switchable glazing can block up to about 90 percent of light.

3.4.1.8.4 Holographic diffractive films

Holographic diffractive films are two-dimensional or three-dimensional (volume holography) recordings of laser light patterns created on high-resolution photographic film, which is then laminated between two panes of glass. The diffraction lattice deflects light only from a predetermined angle of incidence, which means that the holograms can be electronically controlled to track the sun or the changing angle of light across the sky. In practice, this type of system produces good results for only a narrow range of solar incidence angles (Littlefair, 1996). In side windows, holographic diffractive films act in the similar way to mirrored louvers, thus there is less solar glare control. Colour dispersion can be avoided by applying gratings of some different, special frequency (Littlefair, 1996). Therefore a clear view out is possible.

3.4.1.8.5 Prismatic glazing

The principle underlying prismatic glazing is the alteration of incoming daylight by means of refraction and reflection. Typically, prismatic glazing comprises glass sheets that are flat on one side and faceted on the other, in the form of long parallel prisms. The prismatic sheet controls light and heat by reflecting the energy, instead of absorbing it. Prismatic systems can be utilized to redirect diffuse light from near the sky zenith towards the back of the room, which would otherwise receive no direct skylight.

There are two primary types of prismatic glazing: sunlight directing prisms, and sunlight excluding prisms:

Sunlight directing prisms work on the same principles as the mirror systems. Figure 3.23a shows typical ray paths through a schematic prismatic sheet. Usually, the prismatic panel is installed inside a double glazed unit, and located in a clerestory type system since refraction distorts and obscures view to the outside. According to Ruck (1989), this arrangement offers transmission efficiency between 50 to 70%, depending on the solar altitude. For energy efficiency and occupants' comfort, the glazing needs to be adjusted seasonally to optimise deep daylighting onto the ceiling surface by controlling the direction of reflection.

Sunlight excluding prisms feature in a system whereby the aim is to reject direct sunlight while admitting skylight from near the zenith (Figure 3.23b). The tilted prismatic sheet has one face of each prism silvered, so that light from the areas of sky where the sun could be will be reflected back outside. Diffuse light from higher altitudes is admitted and refracted onto the ceiling by the inner, vertically fixed prismatic sheet. This system allows glare-free lighting into the depth of the room, and is particularly useful where Visual Display Units are used.

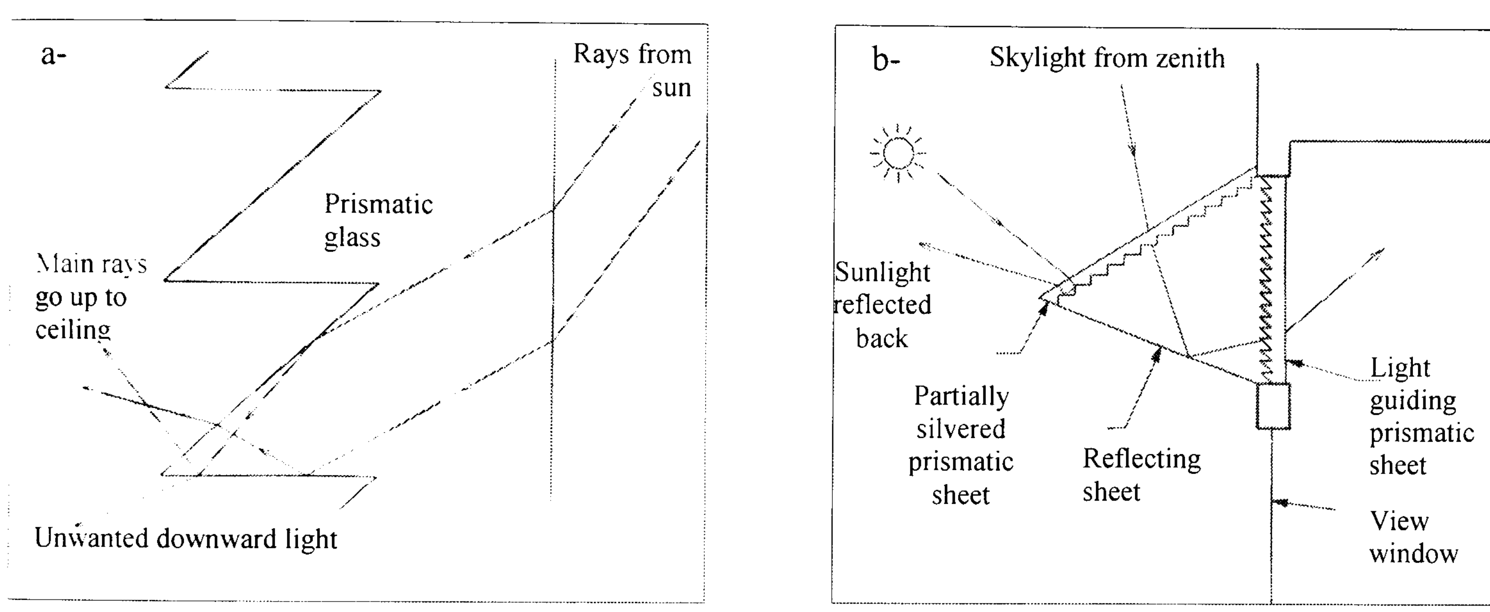


Figure 3.23. Prismatic glazing systems: a- sunlight directing prisms and b- sunlight excluding prisms (Littlefair, 1996).

3.4.1.9 *Photovoltaic*

Layers with photovoltaic modules enable the active use of solar radiation by turning it into electrical energy; they can also represent a form of passive solar protection. The most well known photovoltaic products are silicon solar cells, available in three types: monocrystalline, poly- or multi-crystalline, and amorphous, i.e. non-crystalline solar cells.

The monocrystalline solar cells are opaque, blue, or dark grey to black, and they have a high efficiency (14 – 16%) (Compagno, 1996). The polycrystalline solar cells are mostly blue or opaque. Crystalline solar cells are produced as 0.4mm thick disks, in sizes from 10 x 10 cm to 15 x 15 cm. These disks are then put together to form modules and embedded with resin in the cavity in a laminated glass unit. According to composition, the result can be either a transparent, translucent or non-transparent module. Light transmission through transparent and translucent modules can be set from 4% to 30% according to the choice of spacing.

3.4.2 Daylighting Systems within the Glazing Cavity

While the preceding section focused on the characteristics of the glass itself, this section focuses on the opportunities of the glazing cavity to accommodate additional levels of daylighting response. The glazing cavity can range from a narrow slot between the glass panes to a large three-dimensional volume. The way in which this space may be used may range from the modest insertion of diffusers, shading and insulation, to a more elaborate integration of daylighting and passive solar systems.

3.4.2.1 *Inert Gas Fills*

Traditionally, the space between glazings was filled with air. Air is a very good insulator, as long as it is still. Wide gaps (more than 12.5mm) tend to increase natural convection (heat transfer from moving air). Thus further decreasing heat transfer between two layers of glass requires using a gas with a thermal conductivity lower than that of air. Manufacturers have introduced the use of argon and krypton or xenon gas fills, with measurable improvement in thermal performance. Argon is inexpensive, non-toxic, non-reactive, clear and odourless. The optimal spacing for an argon-filled unit is the same as for air, about 11-13 mm. Krypton has better thermal performance, but is more expensive to produce. Krypton is particularly useful when the space between glazing must be thinner than normally desired, for example 6 mm. The optimum gap width for krypton is 9mm. A mixture of krypton and argon gases is also used as a compromise between thermal performance and cost.

3.4.2.2 *Transparent Insulation Material (TIM) Fills*

Transparent insulation materials (TIM) are an additional device used to reduce heat losses. The advantage of TIM over traditional insulation lies in their high transmission of incident light and near infrared radiation.

Various transparent and translucent materials can be used for transparent insulation, such as glass, acrylic glass (PMMA), polycarbonate (PC) and quartz foam, in varying thickness and structures. To protect them from the effects of weather and mechanical stress, these layers are sandwiched between two panes of glass.

A division into generic types of geometric media in the structure simplifies their classification. The first group consists of a build-up of several layers, arranged behind one another parallel to the glass surfaces and enclosing separate air spaces. This type of TIM of fill is known as 'parallel plate structure' and comprises stretched films (Figure 3.24c). This arrangement entails higher reflection losses, an effect which can be partly reduced by the use of antireflection coatings. The second group of TIMs is of structures arranged perpendicular to the exterior surface, such as louvers (or parallel slats), honeycombs and capillaries, which divide the cavity into small air cells (Figure 3.24a). This type has the advantage of lower optical losses, as the incoming beams are reflected several times from the parallel surfaces and transmitted in a forward direction. This opens up the possibility of increasing levels of natural daylight at the back of deep rooms.

The third group is cavity or capillary structures that are made up of many small plastic or glass tubes (Figure 3.24b). The plastic tubes, of acrylic (PMMA) or polycarbonate (PC), have a diameter of 1 – 4 mm, depending on whether light-scattering properties or higher radiation transmission are desired.

The fourth group consists of quasi-homogeneous structures, such as aerogels and xerogels which have microscopic cavity structures (Figure 3.24d). An aerogel is a highly porous filigree structure of 2 – 5 % silicate and 95 – 98% air, interspaced. Dawson (1995: 21) describes the benefits of this technology: "the advantage of aerogel as both insulator and translucent screen lies in its cellular structure. Its pores' dimensions are smaller than the wavelength of solar radiation, and too small to allow the free movement of air molecules which transmit heat ... regardless of season and climate, an even temperature can be maintained across the interior of the room." This group has high radiation transmission and thermal insulation properties with a fairly high daylight transmittance of 45% (Guzowski, 2000).

Xerogel is very similar to aerogel, but cheaper because it needs no special drying process during manufacture. As its structure is less homogeneous and the air spaces are larger, xerogel has better radiation transmission but worse thermal insulation properties than aerogel.

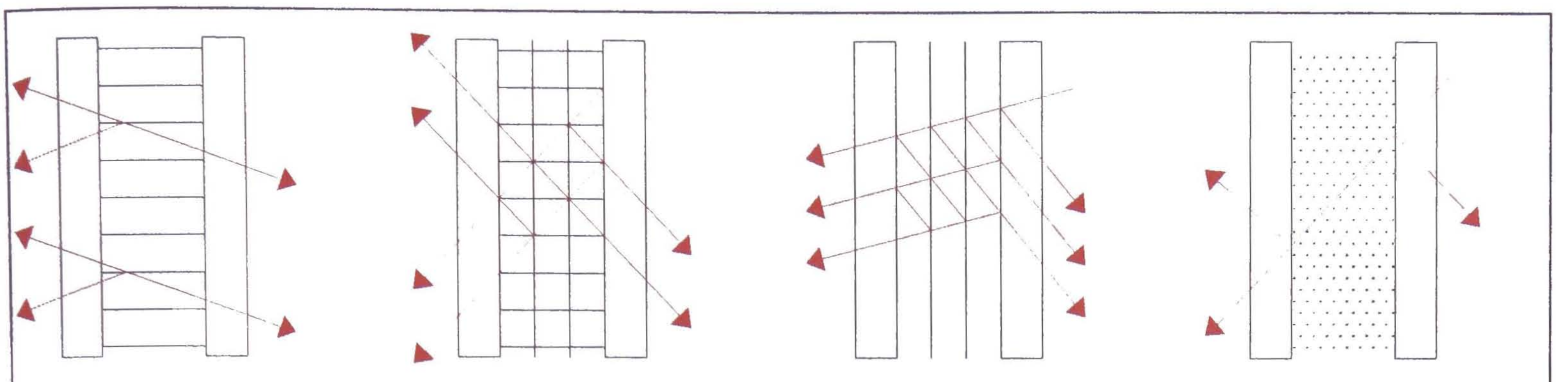


Figure 3.24. Transparent insulation material fills: generic types (Wigginton, 1996).

3.4.3 Integrated Glazing and Shading Systems

As glazing technologies have evolved during the past decades, so have shading devices. The integration of external and internal shading systems with new glazing assemblies expands the opportunities for daylighting inside building envelope. Shading usually consists of micro Venetian blinds, which can be operated by magnets or a small electric motor.

3.4.3.1 *Mid-Pane Blinds*

'Mid-pane blinds' have several advantages. They provide better protection from the sun's heat, as the heat that is absorbed by the blind is more likely to be emitted to the outside. They do not take up space inside the building, and can be less obstructive to occupants (Littlefair, 1999). Difficulty of access, cleaning and maintenance are the main disadvantage of such a system. Only tilt blind position can affect the view out, and reduce daylight on dull days.

Rollers and pleated blinds can also be installed inside double-glazing.

3.4.3.2 *Mid-Pane Fixed Reflective Louvers*

Fixed louver systems have curved slat profiles, and they are installed inside double-glazing to cut maintenance. Figure 3.25 shows a proprietary system with seasonally varying shading performance. In summer, sunlight is reflected back but in spring, autumn and winter it is admitted and redirected.

Inevitably, slat design is a compromise between view, daylight admission and glare.

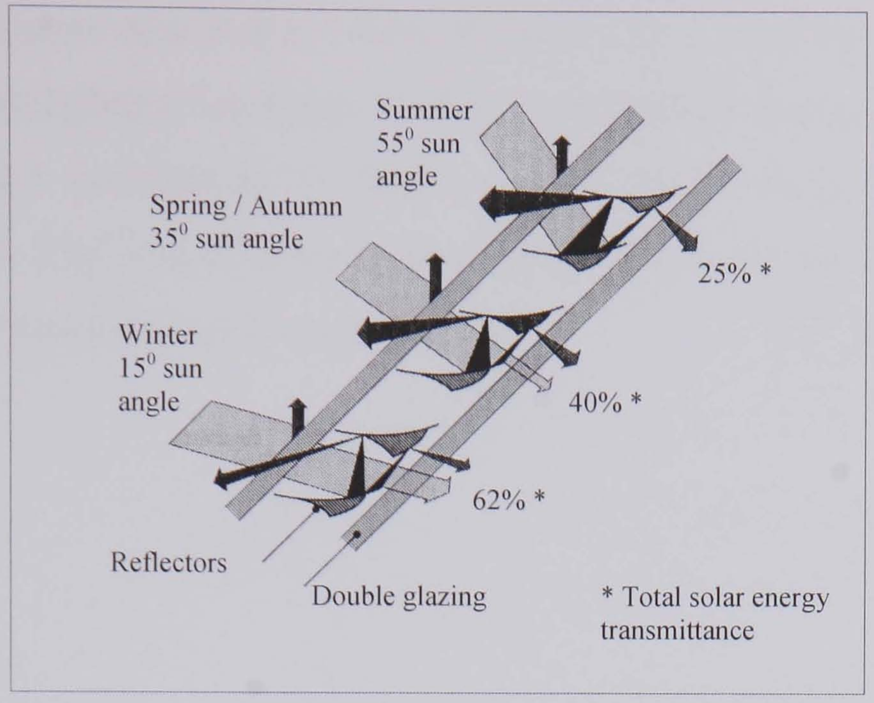


Figure 3.25. Cross section through curved slat louver system (Littlefair, 1999).

3.5 Conclusion

This chapter reviews the glazing properties, after offering a range of definitions for the term building 'envelope' or 'skin'. The literature review focuses on the envelope elements that have greatest impact on daylighting performance inside building spaces, which are mainly glazing assemblies. In addition, this chapter sets out a study of the impact multiple glazing systems on thermal and energy performance. Advances in the various technologies of glazing are reviewed. This review begins by looking at the properties of clear glazing, passing through several kinds of glazing tinting, coatings, films and filling system specifications, ending with a description of glazing with integrated shading devices. These solutions tend to become increasingly responsive to the environment as additional layers are added, and greater variability and changeability are included in the systems. It is apparent that there are a large number of available glazing systems, each with its own advantages and disadvantages.

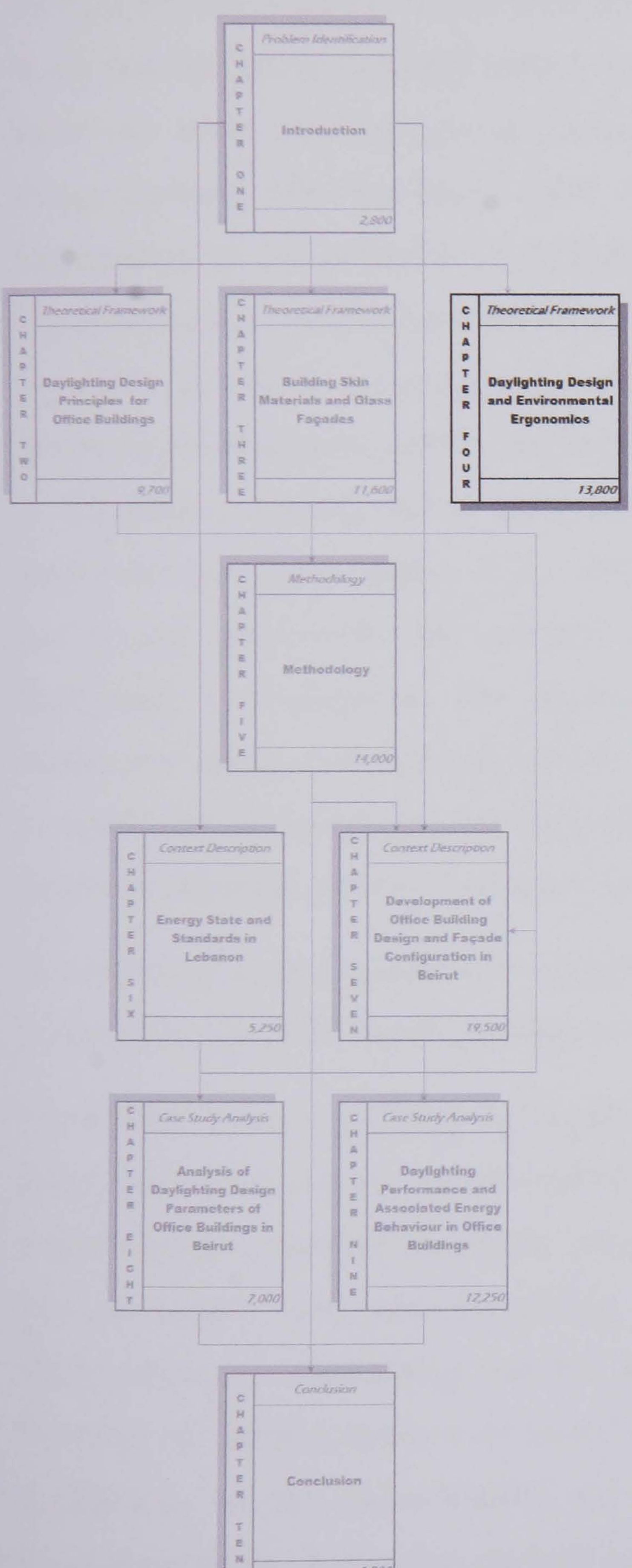
From this review, Table 3.4 lists the discussed types of glazing with a brief description of their daylight, view, solar control and thermal performance, as well as their energy behaviour, possible control and cost. These factors are relevant to the climatic conditions in Lebanon. It can be concluded from this table that there have been many advances in glazing, which can be used to improve daylight performance as well as thermal performance. At the same time, some of these technologies are still under development and their cost is relatively high, especially in Lebanon. Advances in low-e glazing, for which the cost remains reasonable, seem to have much promise for maintaining the balance between daylighting use (high visible transmittance) and solar heat gain control (low U-values), and contributing to improvements in the energy efficiency of office buildings in Beirut. The cost of other technologies, such as electrochromic and specular selective glazing limits their use in such situations.

Glazing Type	Daylight Penetration			View			Solar Control			Solar Heat Gain			Solar Heat Loss			Energy Performance			Control			Cost		
	VLT			Transparancy	**Colour**		SC SHGC			U-Value			U-Value			Ke LSR								
	High	Aver.	Low	**Good**	Aver.	Bad	**Good**	Aver.	Bad	High	Aver.	Low	High	Aver.	Low	**Good**	Aver.	Bad	Autom.	Yes	No	High	Aver.	Low
Single Clear	•			•					•	•					•		•				•			•
Double Clear	•			•					•		•			•			•				•			•
Fritted glazing		•			•			•	•		•			•			•				•			•
Laminated glazing		•		•				•			•			•			•				•			•
Tinted		•	•			•		•		•					•			•			•		•	•
Reflective			•			•	•			•	•			•	•		•				•		•	•
Low-e	•			•			•			•				•		•					•		•	
Applied films			•			•	•					•			•		•				•			•
Spectrally selective coatings	•			•			•					•	•			•					•		•	
Angle selective		•				•	•					•		•		•			•			•		
Liquid crystal assemblies			•			•	•					•					•		•			•		
Photochromic	•		•	•		•		•			•			•			•		•			•		
Thermochromic	•		•	•		•		•		•					•		•		•			•		
Electrochromic	•		•	•		•		•		•					•	•			•			•		
Holographic defractive films	•			•				•			•			•		•			•			•		
Prismatic glazing	•		•			•	•				•			•			•		•			•		

Table 3.4. A summary listing of the reviewed glazing types with a brief description of their performance to daylight, view, solar control, and thermal behaviour , as well as their energy behaviour, possible control and cost.

DAYLIGHTING DESIGN AND ENVIRONMENTAL ERGONOMICS

4



Chapter Four

4. Daylight Design and Environmental Ergonomics

4.1 Introduction

After the introduction of artificial light, daylight moved to a lower level of priority in architecture. This led to a different approach, where daylight openings at most only fulfilled the user's need to have a view. However, for a large number of leading architects in the first half of the twentieth century such as Le Corbusier, Frank Lloyd Wright, Louis Kahn and Alvar Alto, daylighting remained one of the main considerations in building design (Lechner, 1991 and Parry, 1994). The energy crisis of the mid 1970s led to the re-examination of the potential of daylighting to save energy. At first only the energy implications were emphasised, but more recently daylighting has also become valued for its ability to satisfy physiological, biological and psychological needs. Some recent studies in environmental studies and ergonomics have ascertained the role of daylighting in affording a suitable indoor environment for office occupants, with the benefit of improved productivity (Baker *et al.*, 1993; Boyce, 1997 and Norris *et al.*, 1997). In the last decade, productivity has emerged as another compelling economic rationale for daylighting in workspaces. The argument is that over the life cycle of a building, cumulative energy costs are very modest when compared to the cumulative salaries paid to employees. If daylighting can improve employee productive gains, these productivity gains can offset the costs of almost any daylighting systems (Norris *et al*, 1997).

The objective of this chapter is to identify the range of effects that daylighting design in buildings has upon the health, comfort and productivity of workspace occupants.

The chapter starts by defining environmental ergonomics, and its main components that affect the indoor environmental conditions and worker comfort; i.e. indoor air quality, noise, vibration, thermal conditions, privacy and space design and, as well as windows with associated view and daylighting. The following sections review the physical characteristics of daylighting and the anatomy of the visual system. This review is followed by an investigation of visual comfort requirements, and the implications of daylighting on the physiological and psychological features of office occupants. Consequently, the impact that daylight has upon mood and productivity are discussed in the final section.

4.2 Environmental Ergonomics

Human beings do not respond to the environment in a way that is monotonically related to direct measures of the physical environment. There are human characteristics that determine human sensitivities and responses. The relationship between a human and his workspace environment has been widely studied under the newly developed science of ergonomics. Different standards, mostly established by the International Standards Organisation (ISO) and more recently the European Standards Organisation (CEN) aim to manipulate and organise this relationship (International Organisation for Standardisation, 1995; and European Committee for Standardization, 1998).

The research conducted here is directed more toward environmental ergonomics, and more precisely to study the impact of the lighting environment on health and the visual system, and the function of lighting in the workplace. Section 4.2.1 defines ergonomics and investigates the main factors of environmental ergonomics as an integral part of that discipline.

Environmental ergonomics factors are briefly investigated in Section 4.2.2. Lighting design recommendations, and the impact of inadequate lighting will be extensively discussed in Section 4.4.

4.2.1 Ergonomics Definition

The word "Ergonomics" comes from two Greek words "ergon", meaning work, and "nomos" meaning "natural laws" (Pheasant, 1998). Hywell Murell first used this term in 1949 as a result of the meeting of a working party, at which it was resolved to form a society for 'the study of human beings in their working environment'. It should be pointed out that Prof. Wojciech Jastrzebowski used the name 'ergonomics' first, in an article published in 1857 in Poland (Oborne, 1995). In 1961, the International Ergonomics Association (IES) was created which, according to Dul *et al.*, (1991) represents ergonomics societies active in 40 countries or regions, with a total membership of some 15,000 people.

Any job setting is characterised by an interaction between the following three parameters:

- a worker with attributes of size, strength, range of motion, intelligence, education, prospects, and other physical and mental capacities

- a work setting consisted of different tools, furniture and other physical objects
- a work environment shaped by climate, lighting, noise, vibration and other atmospheric qualities.

Ergonomics, or the term 'human factors' often used by Americans, aims to set good criteria for creating the best interface between worker, work setting and environment. It is a science concerned with human work, which aims to "design the job to fit the worker, and the product to the use" (Pheasant, 1998). A concise definition would be that ergonomics aims to design the work environment, appliances, technical systems and tasks in such a way as to improve human safety, health, comfort and performance (Kroemer *et al.*, 1997). User friendliness, human based technology and human factors are all synonymous terms for the basic notion, that is to get the best out of people.

Accordingly ergonomics is a multidisciplinary field of study, and which is considered a combination of physiology, anatomy, and medicine as one branch; physiological and experimental psychology as another, and physics and engineering as a third. It is divided into two general categories: industrial ergonomics and office ergonomics. Since the wide spread introduction of computer screens into modern offices, office ergonomics has become a more popular concern than it ever was in the factory (Vischer, 1996 and Anshel, 1998). Office ergonomics has covered all aspects of an office job, from physical stresses to environmental factors that can affect hearing, vision, and general comfort and health. Physical stress producers on office workers such as repetitive motions, vibration, excessive force and awkward positions, all frequently linked to ergonomic disorders, have been widely covered by researchers during recent decades (Oborne *et al.*, 1983; Karasek, 1990; Oborne, 1995; Kroemer *et al.*, 1997 and Pheasant, 1998).

A range of ergonomic subjects is covered by international ISO standards of the International Standardisation Organisation (ISO), European EN-standards of the Comité Européen de Normalisation (CEN), as well as national standards, for example in the United States (ANSI) and Britain (BSI) (Dul *et al.*, 1991). BS EN ISO 9241-5:1999, for example, deals with the ergonomic requirements for office work with visual display terminals (VDTs), workstation layout and postural requirements.

4.2.2 Environmental Factors in Ergonomics

Environmental ergonomics is concerned with all physical environment components that can have effects on the health and safety, comfort and the performance of people. It forms an essential consideration of any user-centred approach to systems and product design and assessment. These environmental physical components may include electromagnetic radiation and light, dust, heat and cold, noise, vibration, humidity, gases and others. The International Standards Organisation, (ISO) and more recently European Standards Organisation (CEN) have made significant contributions in the area of environmental ergonomics.

This research is more directed toward the significant contribution of daylighting and lighting conditions to office occupants' health and comfort. Nevertheless, in order to judge the lighting conditions, Hygge *et al.* (1999) raised the importance of evaluating other 'valued aspects' of indoor environments. In the post-occupancy evaluation study (POE) performed within the IEA SHC task 21 / ECBCS Annex 29, *Daylight in Buildings* (1995-1999), nine environmental factors were considered. These factors are temperature, light, ventilation and indoor air quality, windows, general environment (colours, carpet, decoration), noise and vibration, privacy, space and view out. Accordingly, a brief discussion is confined in this section to the factors of indoor air quality, noise, vibration, heat and cold, general environment, privacy and space design. Windows, view out and the effects of daylight on human comfort and health are extensively investigated in the following sections.

Indoor air quality

Many studies have found a clear relationship between dissatisfaction with air quality, health complaints and falls in perceived productivity (Cheong *et al.*, 2001; Fanger, 2001; Oseland *et al.*, 1999 and The European Commission, 1999). Indoor air contaminant materials are particulates, gases and vapours that may be generated due to the nature of the indoor space, by the occupants and their activity in the space, or brought in from outdoors (ASHRAE, 1997). Deterioration of the indoor air quality is due to the following (Kroemer *et al.*, 1997):

- Release of odours (smoke, body odour, equipment)
- Formation of water vapour
- Release of heat
- Production of carbon dioxide
- Air pollution, either entering from outside or generated by activities within the room.

In addition, with the increase in the use of organic solvents, interior finishes emitting volatile organic compounds (VOCS), cleaning agents, and office appliances, indoor air pollution has become a serious concern (The European Commission, 1999).

According to Michel (2001), indoor air quality is directly determined by the performance of the ventilation system. Indoor environments must be adequately ventilated in order to maintain the correct balance of respiratory gases (oxygen, carbon dioxide), to remove or dilute unpleasant odours, tobacco smoke and potentially hazardous chemical or biological contaminants, and remove excess of heat. Appropriate ventilation rates should be set to prevent discomfort from draughts, while ensuring the appropriate delivery of fresh air. Current ventilation standards recommends a ventilation rate of 8 – 12 l/s per person, i.e. 0.8 – 1.2 l/s m^2 assuming 1 person per 10m^2, and 0.6 – 0.9 l/s m^2 assuming 1 person per 14 m^2 (CIBSE, 1997).

A 1999 World Health Organization report suggested that up to 30% of new and remodelled buildings worldwide may be the subject of excessive complaints related to indoor air quality. Different studies have shown that poor indoor air quality is of the main common contributors to sick building syndrome and building-related illnesses, and are accompanied by headaches, congestion, fatigue, lack of concentration and even rashes (Beachler *et al.*, 1991; Rostron, 1997 and WHO, 1999).

Noise

Like indoor air quality studied previously, the acoustics of the building environment heavily influences work performance in offices (Muneer *et al.*, 2000). For this reason, it is important to have windows with appropriate acoustic properties to prevent any unwanted sound or noise to distract occupants' comfort and work performance.

The simplest definition of noise is that of any disturbing sound which is undesired by the recipient (Pheasant, 1987 and Oborne, 1995). Grandjean (1988) defined noise more precisely, as follows: "Sound only becomes burdensome if the person affected feels that it is discordant, i.e. if it does not harmonise with his intentions at the particular moment." Noise in offices may originate from transportation, communal activities, office machines such as photocopiers or printers, and other sources.

Concentrated mental activity, or jobs at which understanding of speech is important, are 'noise sensitive' occupations and even if the noise level is comparatively low, it can be disturbing. Noise levels, usually expressed in dB (A) that may be expected in offices are shown in Table 4.1 (Kroemer *et al.*, 1997). Although, the aim is always to reduce noise levels below a certain maximum, at the same time the level should not drop below 30 dB (A), otherwise unpredicted irrelevant noise becomes extremely obvious (Dul *et al.*, 1991).

Type of office	Average L_{eq} in dB(A)
Very quiet, small offices and drawing offices	40-45
Large, quiet offices	46-52
Large, noisy offices	53-60

Table 4.1. Usual noise levels in offices (Kroemer and Grandjean, 1997)

The principal effects of noise are:

- Hearing damage or loss (either temporary or permanent) due to a noise level greater than 80 dB(A) on average over an 8-hour working day (Figure 4.1).
- Interference with verbal communication
- Interference with the performance of mental work
- Annoyance.

Various other British (e.g. BS 5330) and international standards (e.g. ISO 1999-1975) deal with noise and measurements. Ergonomic aspects of noise have been widely covered by Kroemer *et al.* (1997), Oborne (1995), Oborne *et al.* (1983) and Singleton (1982).

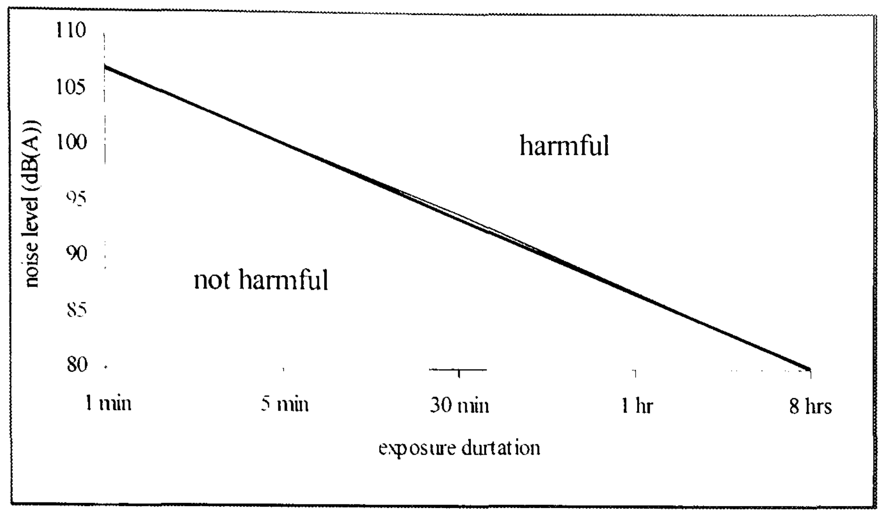


Figure 4.1. Constant noise levels affecting hearing system and contributing to its damage (Dul *et al.*, 1991).

Vibration

Vibration in a building originates from both outside and inside. ASHRAE (1997) identifies outside vibration that may result from blasting operations, road traffic, overhead aircraft, underground railways, earth movements and weather conditions. As for vibration sources inside buildings, these include door closing, foot traffic, moving machinery, elevators, HVAC systems and other building services.

In any discussion of vibration, a distinction has to be made between whole body vibration and hand arm vibration. In whole-body vibration, the whole body is brought to vibration via the feet (in standing work) or via the seat (in seated work). Three variables are important in assessing vibrations: their level (expressed in m/s^2), their frequency, measured in cycles per second (expressed in Hz) and the exposure duration. Figure 4.2 shows the limit for various combinations of exposure time and average vibration level, for work-body vibrations in standing and seated work.

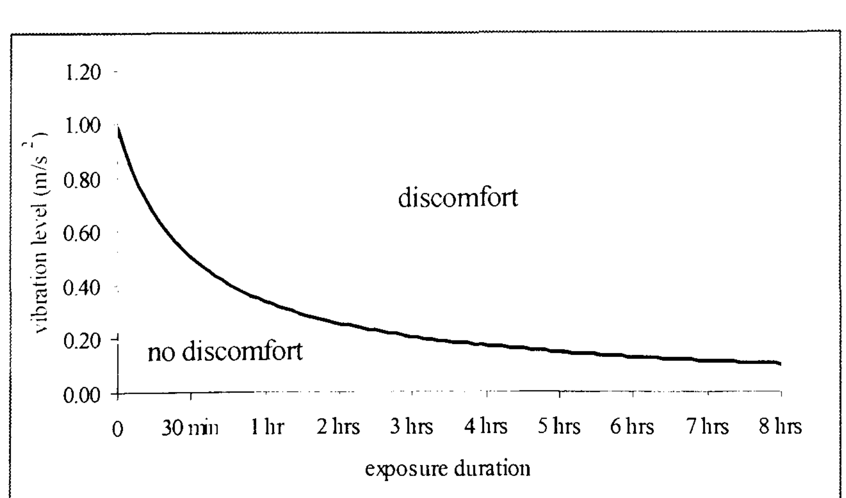


Figure 4.2. Body vibration results in discomfort, depending on exposure duration and average vibration level (Dul *et al.*, 1991).

Low-frequency body vibration (less than 1 Hz) can produce a feeling of seasickness. Body vibration between 1 and 100 Hz, especially between 4 and 8 Hz, can lead to chest pains, difficulties in breathing, back pain and impaired vision (Dul *et al.*, 1991 and Pheasant, 1987). The possible consequences of hand-arm vibration frequencies between 8 and 100 Hz are reduced sensitivity and dexterity of the fingers, 'vibration white finger', as well as muscle, joint and bone disorders.

Standards relating vibration to health and comfort were first produced in 1978, by the International Organisation for Standardisations. ISO Standards 2631 and 7962 are attempts to provide standardised information. Despite acceptance of these standards by many countries, mainly European countries and the USA, several studies (Oborne, 1983; Oborn, 1995 and Kroemer *et al.*, 1997) have criticised these standards and demonstrated that many of the recommendations are not supported by empirical data.

Thermal environment and human comfort

Humans are homeotherms, which means that they attempt to maintain the internal temperature of the body within an optimum range (around 37°C). The body has no means of storing heat, so any heat generated by the body has to be dissipated. Thermal comfort is therefore related to the thermal balance between heat gains due to the metabolism of the body, and heat losses from the body to the environment. Figure 4.3 indicates the breakdown of the heat-loss mechanism in typical conditions: 20% by evaporation, 35% by convection, and 45% by radiation.

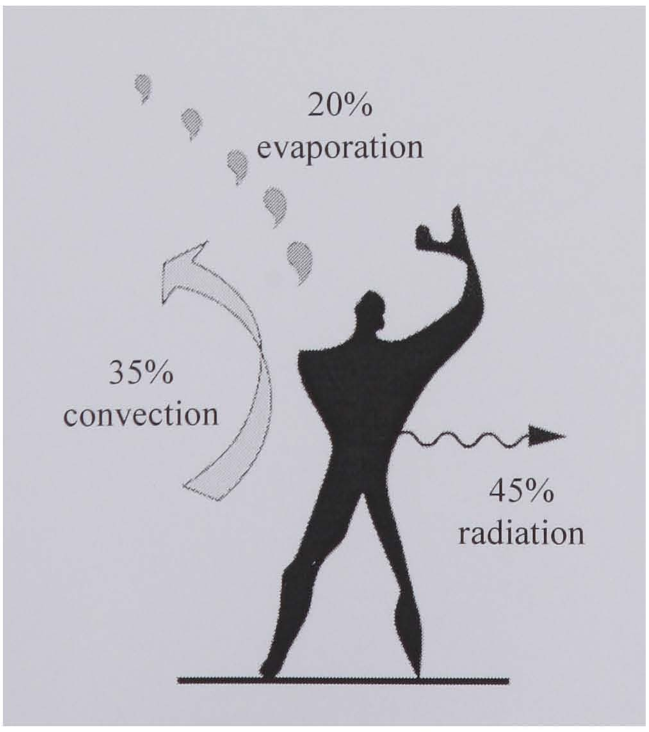


Figure 4.3. Heat loss from the body in typical conditions.

ASHRAE (1997) and ISO (1995) defined thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment". ASHRAE, (1999) for example, set up general design criteria to provide thermal comfort by limiting internal design conditions (mean temperature and relative humidity) and the air movement within certain ranges. Similarly, ISO 7730 recommends temperatures of 22 ± 2° C in winter and 24.5 ± 1.5° in summer, a relative humidity of 40% to 50%, and air movement below 0.15 m/s in winter or 0.25 m/s in summer. On the other hand, according to Baker *et al.* (2000), providing temperature and relative humidity within limited ranges does not guarantee thermal comfort. Comfort is a far more holistic experience, being dependent upon the interaction of many environmental aspects and the ability of the occupant to determine those options. Figure 4.4 illustrates the seven main factors that should be quantified in order to assess human response to thermal environments. Three depend on the individual; they are metabolism (Table 4.2), clothing worn by the occupants (Table 4.3), and occupant activity that affects skin temperature. The other four are linked to the surrounding environment. The environmental parameters are respectively (a) surface temperature of the walls and other surfaces in the room or the mean radiant temperature, (b) relative humidity, (c) room / air temperature, and (d) air velocity. Most of the causes of discomfort can be explained by the long-term imbalance of losses and metabolic gains, or extreme values of one of the environmental parameters. Therefore, a number of thermal indices have been developed for describing the interaction between the seven previously mentioned parameters, and evaluating the feeling of thermal comfort an occupant is likely to experience in the space.

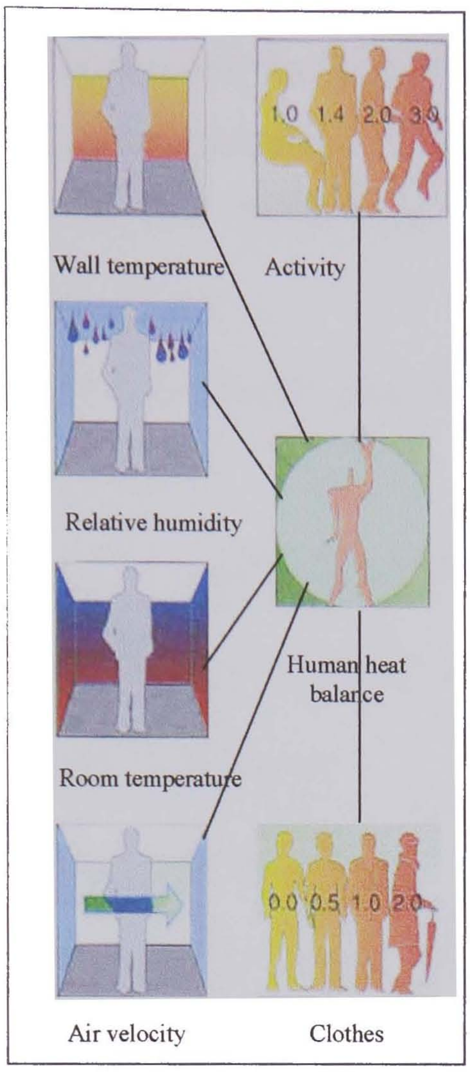


Figure 4.4. Parameters that affect human thermal comfort (The European Commission, 1999).

Activity	Production of metabolic energy M	
	W/m²	met
Rest – lying	46	0.8
Rest – sitting	58	1.0
Office work	70	1.2
Housekeeping	117	2.0
Tennis	290	5.0
Squash	406	7.0

Table 4.2. The metabolic energy produced in some example activities.

Clothing	Cloth thermal resistance C	
	m²K/W	Clo
Naked	0.00	0
Shorts	0.02	0.1
Summer wear	0.08	0.5
Winter wear inside	0.16	1
Winter wear outside	0.23	1.5

Table 4.3. Thermal resistance due to some example clothes.

Fanger (1970) suggested three conditions for comfort; these are that the body is in heat balance, and that the mean skin temperature and sweat rate are within limits required for comfort. Conditions required for heat balance can be derived from a heat balance equation: $M \pm C \pm K \pm R - E = S$, where:

M is the heat generated by the body's metabolic processes (particularly physical work)

C is the heat lost or gained by conduction (through solid media)

K is the heat lost or gained by convection (by air currents)

R is the heat lost or gained by radiation

E is the heat lost by the evaporation of sweat

S is the total quantity of heat lost or gained by the tissues of the body.

When $S = 0$, the body is in thermal equilibrium and body temperature remains steady at the 'normal' level of approximately 37°C.

Mean skin temperatures and sweat rates that are acceptable for comfort have been derived from empirical investigation (Fanger, 1970). In addition, Fanger (1970) developed the Predicted Mean Vote index (PMV), which is a practical approach to assessing thermal environments for the comfort of the occupants. PMV predicts the mean vote, on a seven-point thermal sensation scale (Table 4.4), of a large group of occupants in a room. The scale ranges from +3 (corresponds to 'hot') through 0 (corresponds to 'neutral' and is the value for comfort) to -3 (corresponds to 'cold'). The PMV index has been adopted as the International Standard method for assessing thermal comfort (ISO, 1995).

Thermal Feeling	**PMV**
Cold	-3
Chilly	-2
Fresh	-1
Optimal comfort temperature	0
Mild	+1
Warm	+2
Hot	+3

Table 4.4. The PMV thermal sensation scale.

Optimal operative temperature, the predicted percentage of those dissatisfied (PPD), and the comfort charts are other thermal indices that have been developed. The operative temperature is defined as the uniform temperature of a black radiative enclosure, in which the occupant exchanges the same quantity of heat through radiation and convection as he or she would in a non-uniform real space. The PPD is an indication of the percentage of people susceptible to feeling too warm or too cold in a given thermal environment. It can be deduced from the PMV. A readily accessible way of presenting the relationship between thermal comfort parameters, or thermal index and the other parameters is by means of comfort charts. In one such graphical method, lines show the optimal operative temperature as a function of metabolism (activity level) and clothing for a given PMV and relative humidity (Figure 4.5, Goulding *et al.*, 1992).

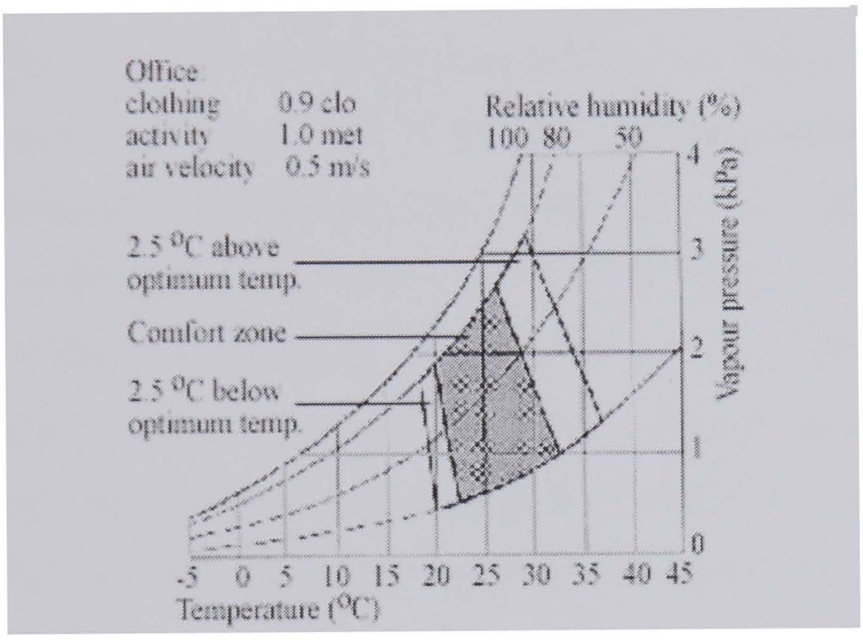


Figure 4.5. Diagram identifying the comfort zone in office space as a function of temperature, vapour pressure and relative humidity, at specific clothing conditions, activity and air velocity (Goulding *et al.*, 1992).

Thermal comfort is considerably affected by transparent and translucent openings, as well as the overall thermal resistance of the external envelope. Windows do not only permit daylight, but also let in excessive solar gains that can cause unbearable overheating. Therefore the size and position of the window, the type or types of glazing, and the window construction must be all carefully considered in this respect. Any window design should ensure that the daylighting design does not cause thermal discomfort, and aids visual comfort.

Space design, privacy and general environment

Research has shown that the physical layout and design of a work setting, the amount of workspace available, and the nature of furnishings can all affect worker behaviour (Noyes, 2001; Clements-Croome *et al*, 2000; Laing *et al*, 1998 and Duffy *et al*, 1993). The design of the physical aspects of a workplace can create certain psychological conditions, e.g. a feeling of privacy or crowding, and of status and importance; or the converse, a perception of anonymity and unimportance.

Windows, view out and daylighting

In offices, the psychological benefits of windows have been found to be even greater than the physical benefits of which occupants themselves are well aware (The European Commission, 1999 and Norris *et al.*, 1997). Windows provide sunlight, daylight and view to the indoor environment. It is important that the provision of a view, and the delivery of daylight be clearly differentiated. People often use the terms 'view' and 'daylighting' interchangeably, but the view function of windows is very different from the natural lighting function. The provision of daylight alone (e.g. through skylights) does not often satisfy the occupants' desire for views. It is generally found that people prefer almost any view out, to no view out. The views most preferred are those that include sky, horizon and ground (IESNA, 1999).

Several countries have recognised that views are more than an amenity. In Germany, windows are expected near workstations. In Finland, where the few daylight hours in midwinter occur entirely during the workday, daylighting availability in workplaces is made mandatory by building regulations. The Netherlands also require windows in workplaces. Indeed, daylighting should be viewed not as a "privilege', but as a "right" that ensures the physical and psychological well-being of occupants (Gusowski, 2000).

How does daylight figure in people's strong desire for windows? According to Nemeskeri *et al.* (1995), Norris *et al.* (1997) and the IESNA (1999), people have a great preference for windows in their work environments primarily because of the associated views. This is not general; Ruys (1975) found that the top-rated objection to windowless offices was not lack of a view, but lack of daylight. Many empirical studies that asked people which light source they would like to illuminate their work area, have revealed a strong preference for daylight (Christoffersen *et al.*, 1999; Vischer, 1996 and Cuttle, 1983). In a twin study by Cuttle (1983) 85.7% of 138 office workers surveyed in London, and 83.2% in New Zealand indicated that daylight was their preferred working illumination. Adding to this, sunshine reaching into interiors was expressed as being desirable by 93% of interviewed households, 91% of hospital patients and 73% of office workers (Ne'eman, 1974). In an early survey by Markus in 1967, 86% of 400 interviewed office workers who occupied nine floors of a twelve storey building in Britain, preferred sunshine in the office. In Sunderstrom's study (1986), occupants were given the choice between daylight in summer only, winter only and year round. They wanted it all year round. The results showed that 96% of the office workers surveyed preferred to work by daylight all year round.

As part of this research, a POE of daylight in office buildings has been conducted. 76 office users responded to the questionnaire illustrated in Appendix VI. As part of this questionnaire, occupants were asked specify whether they preferred to work in natural light, artificial light or a combination of the two light sources. The results showed that 85% prefer to have daylight and artificial light in their working space, 14% prefer daylight alone, but only 1% have a preference for artificial lighting. In the same survey, occupants were asked how important it was for them to have a window in their workplace. The results show that 94.5% of respondents believe windows to be a very important requirement in their workplace.

In the POE of daylight conducted by the IEA (1999), good lighting and comfortable temperature were the two indoor environmental aspects most wanted by workspace users. The desire for windows and a view out had a much lower rating (Figure 4.6). The same question has been asked in the questionnaire used in the POE survey of office buildings in Beirut. The results of both surveys are illustrated in Figure 4.7, in which the importance of light, view, and windows to workspace occupants (from all the scores recorded by the POE) represent 38% in Britain and 37% in Beirut. The use of side windows to provide view and natural lighting to the workspace is usually accompanied by higher heat loss / gain, which increases the importance of controlling the internal temperature (22% in Britain and 19% in Beirut, Figure 4.7), especially in highly glazed office buildings.

Therefore, it can be concluded that a properly daylit office space in Beirut is, bearing in mind the accompanied thermal penalties, of 56-60% significance for the design performance of the workspace environment. Ventilation (7-13%), noise (9-11%), privacy and space design (7-8% each), and the general environment (4-10%) can be considered as 'secondary' indoor environmental aspects in providing satisfaction and comfort to the occupants of office buildings.

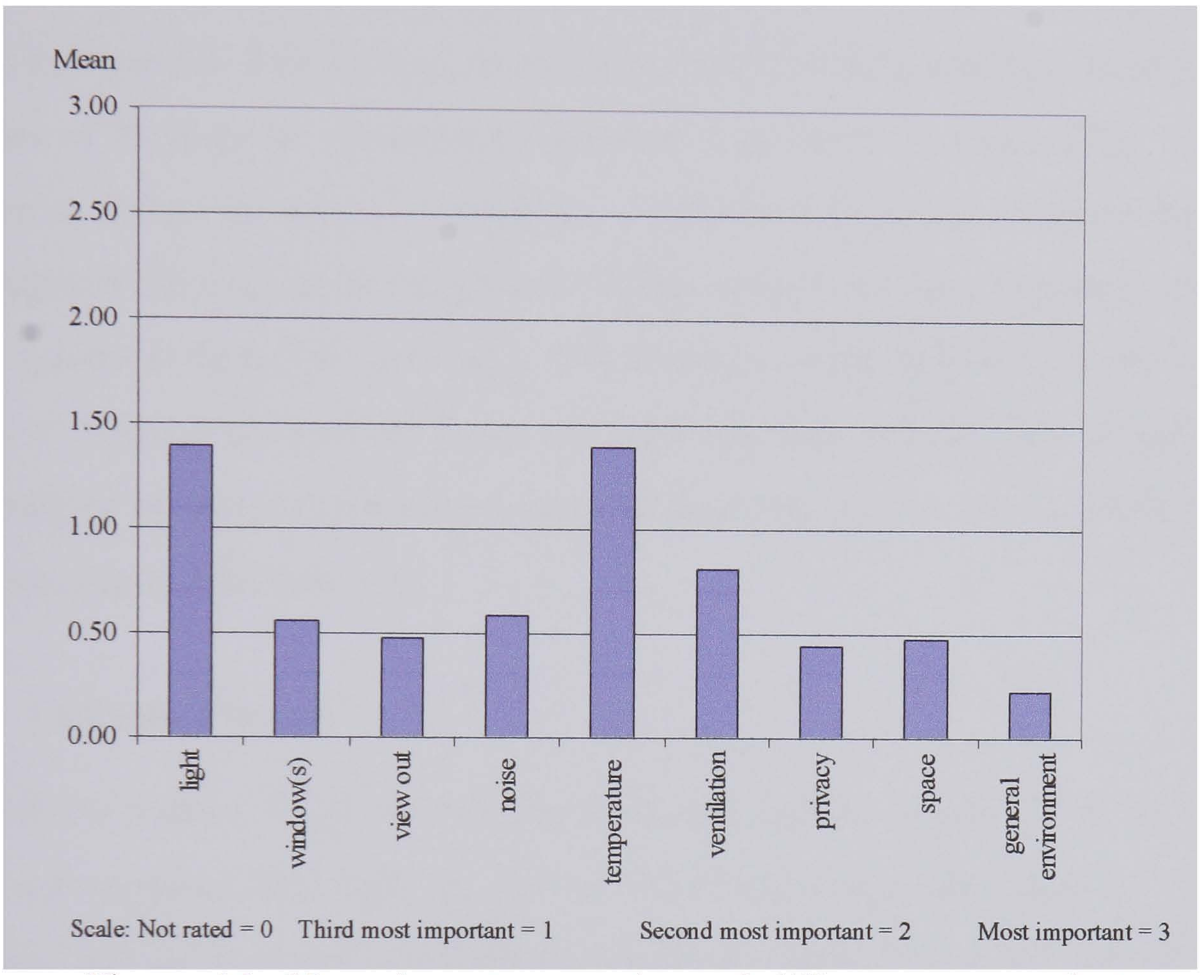


Figure 4.6. Mean importance ratings of different aspects of the workplace (IEA, 1999).

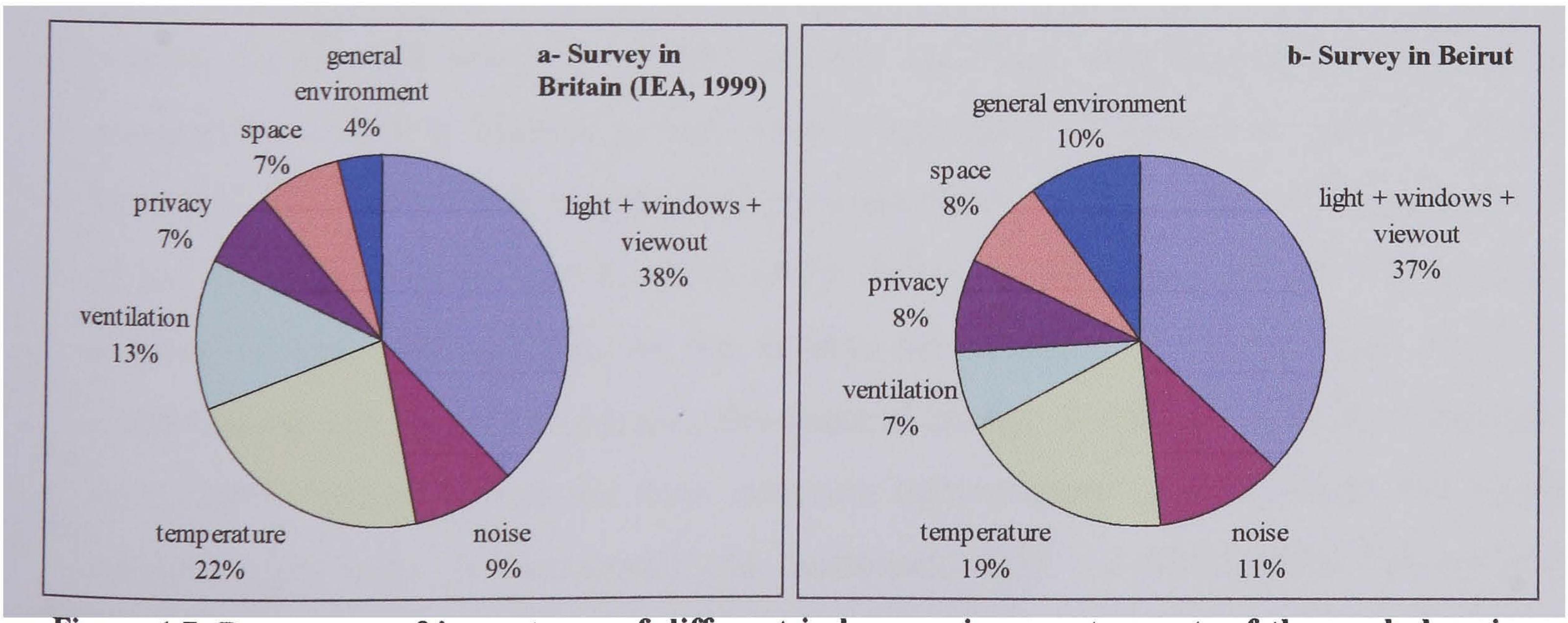


Figure 4.7. Percentage of importance of different indoor environment aspects of the workplace in a- Britain (IEA, 1999) and b- Beirut.

4.3 Daylighting vis-à-vis the Human Visual System

The provision of windows accompanied with good daylighting and view out, as well as the thermal aspect, have been proved to be the most significant aspects for workspace environment and users' satisfaction. Daylighting design is not a solely a matter of providing the required quantity of light at the task position, although this is a certainly a major criterion in the design process. Daylighting in workspaces is a problem revolving around how people feel in, react to and function in various settings. Lighting is not only a problem of biology or physiology, but also a problem of psychology. Accordingly, to develop or define successful daylighting it therefore important to understand how people feel, respond and act with lighting. A better understanding of lighting physics and the visual system is therefore necessary. The concern in the following study revolves around the users' biological needs for light, and their reaction to light. This review is the prelude to a detailed investigation of the impact of daylight on the visual comfort and health of office occupants (Section 4.5).

4.3.1 Lighting Physics

The IESNA defines 'light' as visually evaluated radiant energy (Stein *et al.*, 2000). This definition suggests that light is first of all energy; secondly, that it is transmitted by radiation, and lastly that it is a form of radiant energy to which the eyes are sensitive. The sun is of course the dominant lighting source, and emits a continuous spectrum of energy. If light is considered as a wave, it has a frequency and a wavelength that determines its colour. The human eye, considered as a photochemical device, can only perceive a very narrow wavelength band of electromagnetic radiation that ranges from 380 to 760 nanometres which is known as the 'visible spectrum' (Figure 4.8). Starting with the longest wavelengths (red), visible light proceeds through the spectrum of orange, yellow, green, blue, indigo and violet to arrive at the shortest visible wavelengths. 'White light' is a more or less even mixture of the various wavelengths of visible light. Figure 4.9 interprets the colour composition or the spectral energy distribution (SED) of daylight at noon (D65 illuminant) and the most common light sources used in offices, the standard tungsten light bulb (A illuminant) and fluorescent light (F2 illuminant). The horizontal axis describes the colours (wavelengths), and the vertical axis the amount of light (relative energy). Figure 4.9 shows that daylight at noon on a clear day in June has a generally horizontal curve, that reflects the uniform mixture of the various colours of the visual spectrum. Only violet light is present in less quantity. Tungsten lamp light has an almost exponentially rising curve, while fluorescent light consists of both broad and sharp peaks, typically sharp peaks at 440 and 530 nm, and broad peaks at 400 and 590nm. Therefore, each light source has different composition of various wavelengths of the visible spectrum, and artificial light sources have different colour composition than daylight, which affects the colour appearance of the perceived object.

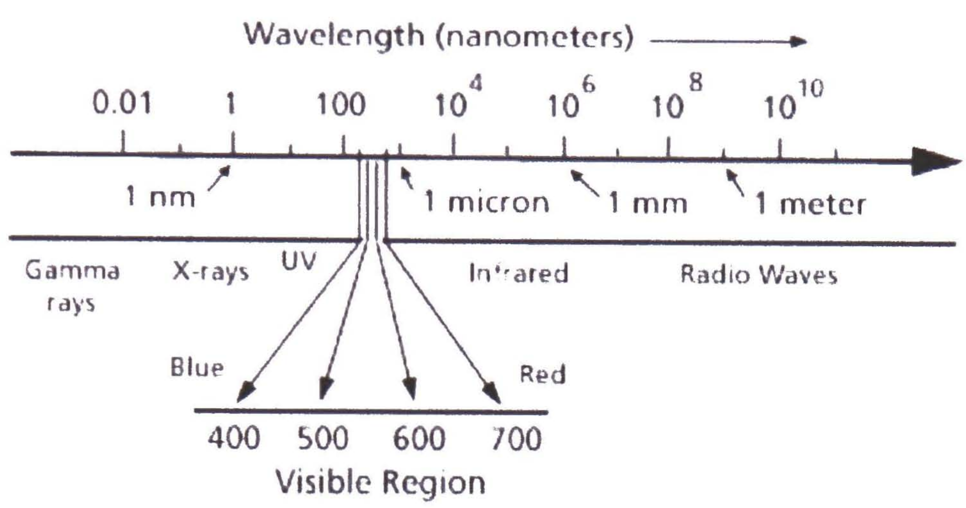


Figure 4.8. A schematic diagram of the electromagnetic spectrum which encompasses the visible region of light (ACEPT, 1999).

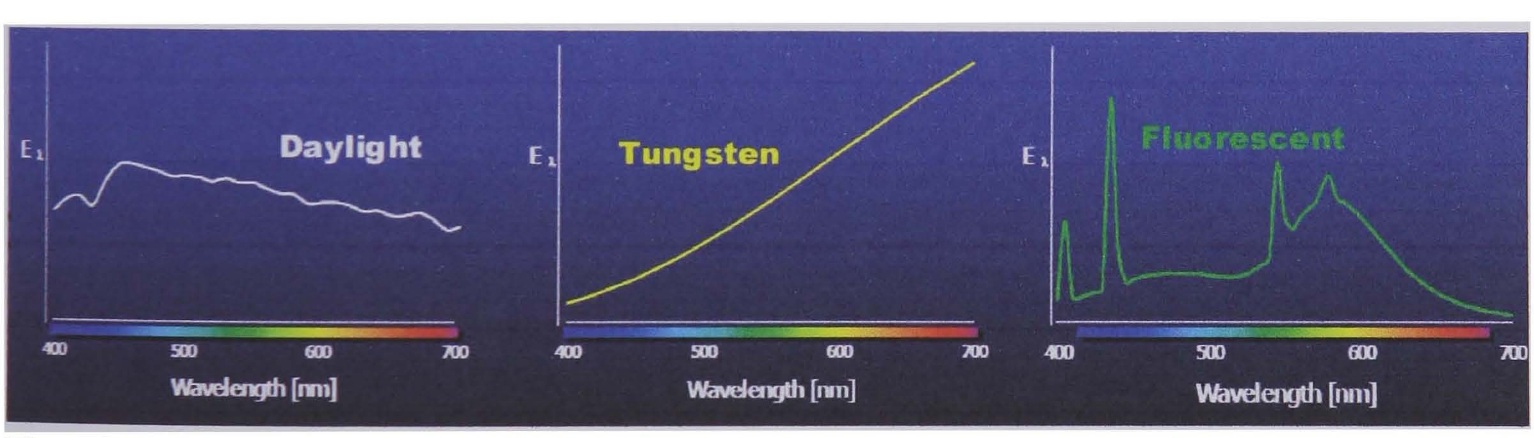


Figure 4.9. The spectral energy distribution of daylight at noon on a clear day in June, standard tungsten light bulb and fluorescent light (HunterLab, 2001).

However, the anatomy of any lighting system in a room does not consist only of the light source, being natural or artificial with additional components like ballasts, luminaires and controls. The lighting system is a complicated interaction between the lighting source, the environment, human vision and the task. The environmental components have been studied in Chapters 2 and 3. The following section will examine human vision and its response to light in order to see the task.

4.3.2 The Visual System and its Response to Daylight

Figure 4.10 delineates the process of seeing. The first prerequisite is a source of visible radiant energy that can be the sun, a flame, or any of the electric light sources. The second requirement is some kind of modifier that reflects or transmits the light to the eye, which is the third component of the seeing process. The modifier can be a window, a page of a book, a computer screen, etc. It is called a modifier because most of the time it alters the spectral character of the radiation emitted from the source; by way of illustration, white light viewed through red glass will appear red, because red light is mostly transmitted and the light of the other colours is mostly absorbed. Consecutively, the eye plays the role of receiving the light 'message' from the spatial and temporal relationships of objects, and converting radiant energy in the form of electrical signals. The brain is ultimately the interpreter link in the seeing process. It receives signals from the optic nerve, decodes them, and thus provides the viewer with perception and understanding of the object being viewed.

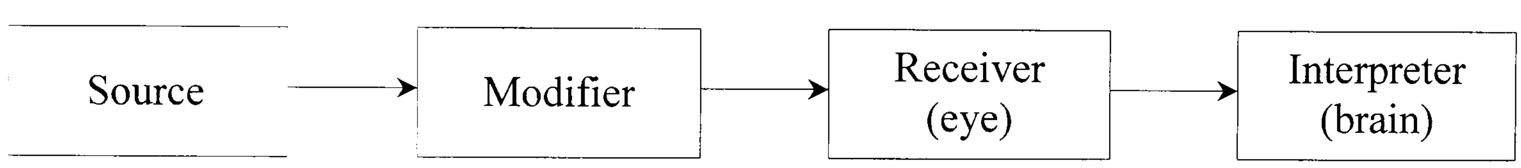


Figure 4.10. The process of seeing.

The anatomy of the human eye consists of two specialised interacting sets of components: the optic components (cornea, crystalline lens, pupil and vitreous humour), and the neural components which are composed of the retina and the optic nerve (Figure 4.11). Light from an object (such as a paper on a desk) enters the eye first through the clear cornea and then through the pupil, the circular opening in the iris. Next, the light is converged by the crystalline lens to a point immediately behind the lens; at that point, the image becomes inverted. The light progresses through the gelatinous vitreous humour and, ideally, back to a clear focus on the retina, the central area of which is the macula. In the retina, light impulses are changed into electrical signals and then sent along the optic nerve and back to the occipital (posterior) lobe of the brain, which interprets these electrical signals as visual images.

The sclera and choroid are the two outer jackets of the eye and its lining. The sclera maintains the eye in nearly spherical shape, and about 25 mm in diameter. In front, it comprises the white of the eye. The choroid is the black coating which lines the sclera. It absorbs all stray light inside the eye and thus makes vision more distinct, serving the same function as the black interior of a camera.

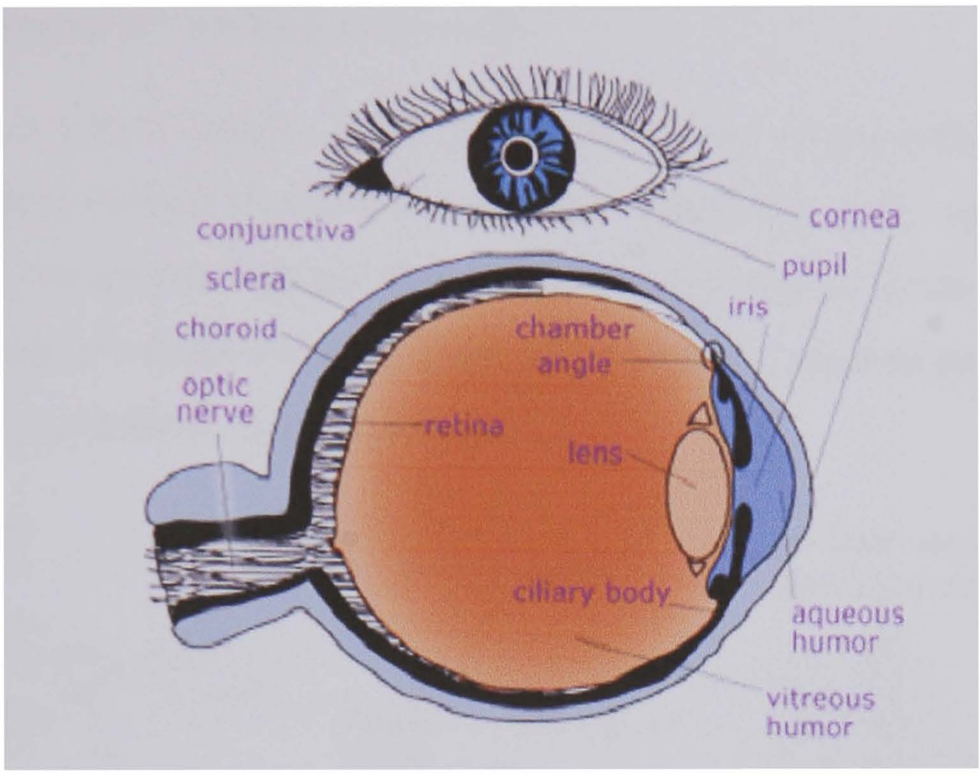


Figure 4.11. Horizontal cross-section through the human eye.

Accommodation

Objects at different distances from the eye are focused on to the retina by adjusting the curvature of the convex lens, a process called accommodation. The closest distance at which objects can be focused is called the near point. The near point recedes from about 100 to 750 mm during the course of a working life time, due to hardening of the convex lens. The lens in the eye is an elastic structure that changes shape in order to focus things near or far onto the retina. This is accomplished via contraction of the ciliary muscles that hold the lens in place. When these muscle fibres contract the lens, being elastic, springs into a more convex shape allowing a focused image of near objects. This is a process requiring energy since muscular effort is necessary, and therefore it can be tiring.

Adaptation to light intensity

The eyes are designed to be stimulated by light and to control the amount of light entering the eyeball. The process by which the visual system changes its sensitivity depends on the luminance prevailing in the visual field, which can create glare discomfort as illustrated in Figure 4.12. The process that takes places as the visual system adjusts itself to the brightness or the colour of the visual field is called adaptation. The term is also used, usually qualified, to denote the final state of this process. For example 'dark adaptation' denotes the state of the visual system when it has become adapted to a very low luminance. A dark-adapted person is one who has spent sufficient time in the dark for his eyes to be optimized for working in the dark.

Light-adapted is a term usually implying the completion of the adaptation process to a visual field bright enough to guarantee photopic vision. The time required to adapt to a lower luminance is greater than that to a correspondingly higher luminance, particularly if the former involves a transition from cone to rod vision. Complete dark adaptation from photopic vision can take as long as an hour.

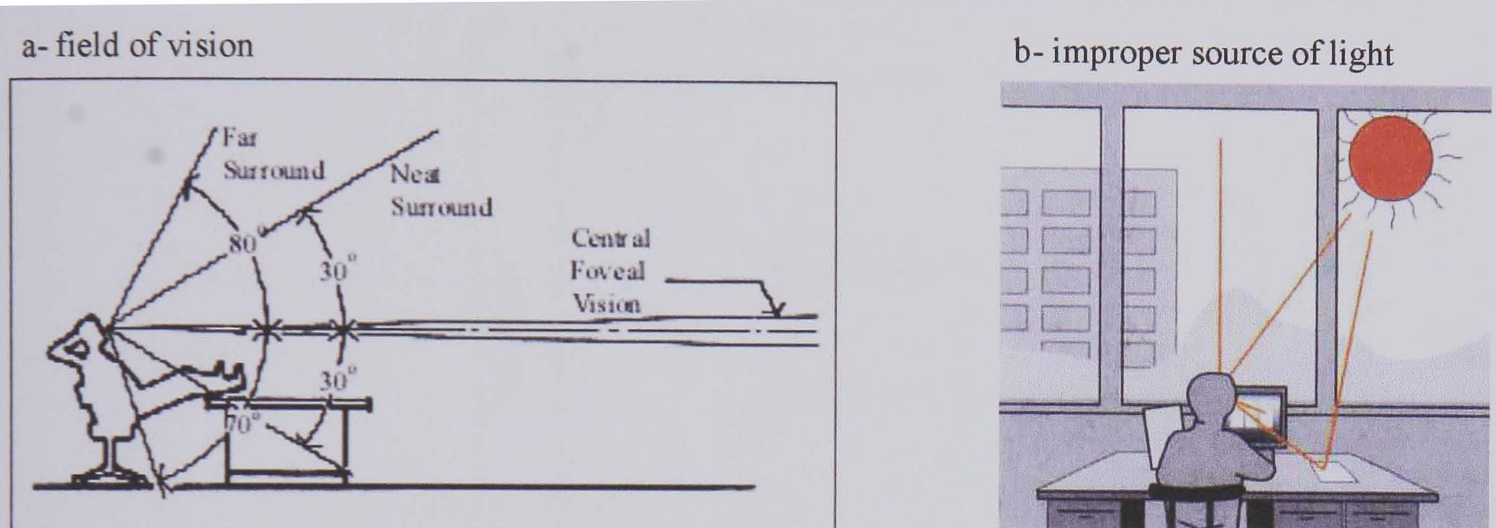


Figure 4.12. A bright light source in the field of vision, like direct sun or bright patches of sky and reflection of these in other surfaces can cause severe glare.

The eye tends to seek a state of equilibrium that is appropriate for general brightness conditions; luminance perception is normally limited to within a brightness range up to a factor of 1000 (Baker *et al.*, 1993). This constant adjustment involves some photochemical actions. In a quick first step, some change is achieved by increasing or reducing the iris opening, which directly increases or reduces the amount of light that can enter the eye. In a second step, the receptive cells on the retina (rods and cones) of the eye change their actual sensitivity. The latter is a slower process. It may take a few minutes before the visual system is fully adjusted to the new situation.

Cone vision provides acute vision at daytime (photopic) level of illumination, whereas rod vision allows for the high degree of sensitivity that is essential for seeing when light levels are low (scotopic). The sensitivity of our eyes can be measured by determining the absolute intensity threshold, that is, the minimum luminance of a test spot required to produce a visual sensation (Kolb *et al.*, 2000). Figure 4.13 shows that the photopic system adapts relatively quickly, and reaches its most sensitive level after approximately 7 minutes in the dark. The scotopic system starts out less sensitive than the photopic system, and adapts more slowly (Bean, 2004).

If the illumination change is relatively slow this adaptation to dark or light conditions is fairly smooth, but with fast changes in illumination the well-known experience of temporary blindness results. An example of 'quantitative' adaptation can be observed by a person walking from full sunshine into a building. The environment in the building will appear almost pitch black at first. A few minutes later, the person can again distinguish details.

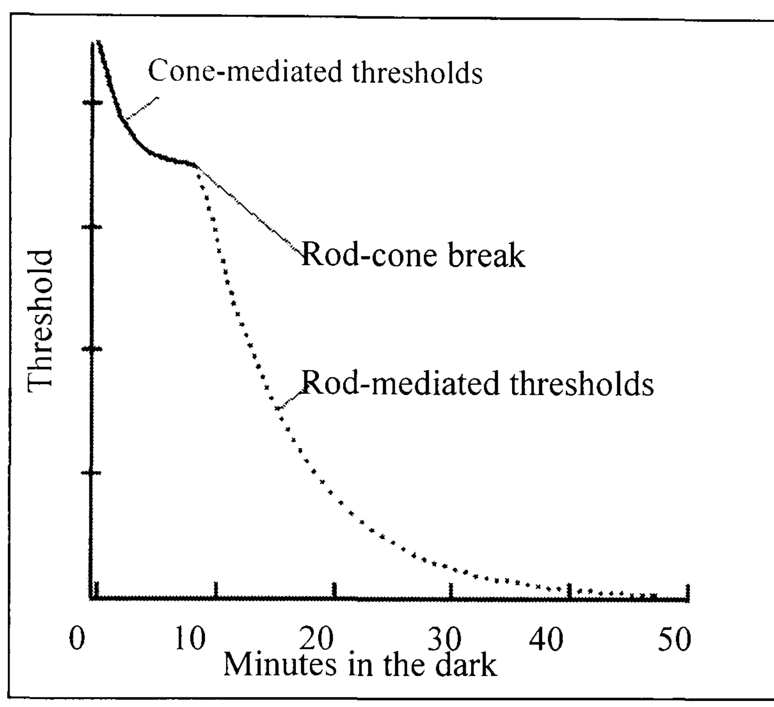


Figure 4.13. The dark adaptation stimulus time (Bean, 2004).

Chromatic vision and adaptation

Normal colour vision is referred to as trichromatic vision. Three kinds of pigments, present in the three classes of cones are responsible for the human perception of colour. These colour receptors, concentrated in the central (foveal) portion of the eye, are commonly referred to as the red, green and blue cones. Each cone contains a different pigment, and each pigment has a different spectral response curve. Figure 4.14 illustrates the three spectral response curves for each pigment overlapping across the visible spectrum. Each spectral response curve is shifted with respect to the others along the wavelength continuum, so that each has a different maximum sensitivity. The peak or maximum sensitivities occur at 570, 535, and 445 nm (Belcher *et al.*, 1997).

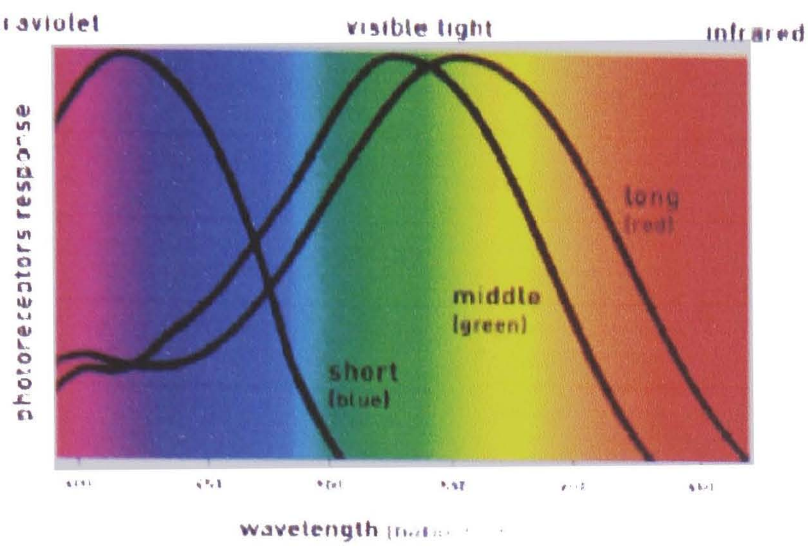


Figure 4.14. Cones colour sensitivity across the visible spectrum (HunterLab, 2001).

Colour adaptation refers to the process by which some colour sensations are altered by continuous exposure to others. For example, looking at a bright red stimulus for a few minutes and then at a yellow stimulus will cause the yellow to appear green. Gradually, the eye will recover from the adaptive effects of the red field; the yellow cones will gradually become dominant over the red cones and, after few minutes, the field will again appear as normal. Along with this adaptation, there will also be a reduction in brightness and changes in saturation. Such effects have important implications for office workers who may have to spend a long time looking at a coloured display such as a computer screen.

Visual acuity

Visual acuity, or sharpness of vision, is defined as a measure of the ability of the eye to distinguish subtle detail. It can be measured as the size of the smallest detail the eye can perceive at a given distance (Hopkinson, 1996; Baker, 1993 and March, 1999). This size is usually expressed as a visual angle (a = 2438 h/d, Figure 4.15) in minutes, with the visual acuity number being the reciprocal of the minimal visual angle, and which is expressed in minutes of arc (Belcher *et al.*, 1997). Therefore, the larger the angle required to see an object, the poorer the visual acuity, and hence the smaller the visual acuity number. Increasing the visual angle is achieved by bringing objects closer to the subject. In addition, the visual angle increases with increasing illuminance, subject to the law of diminishing returns. According to March (1999), typical values would be 0.25 (a = 4') at 100 lux, 0.5 (a = 2') at 300 lux, 1.0 (a = 1') at around 2000 lux.

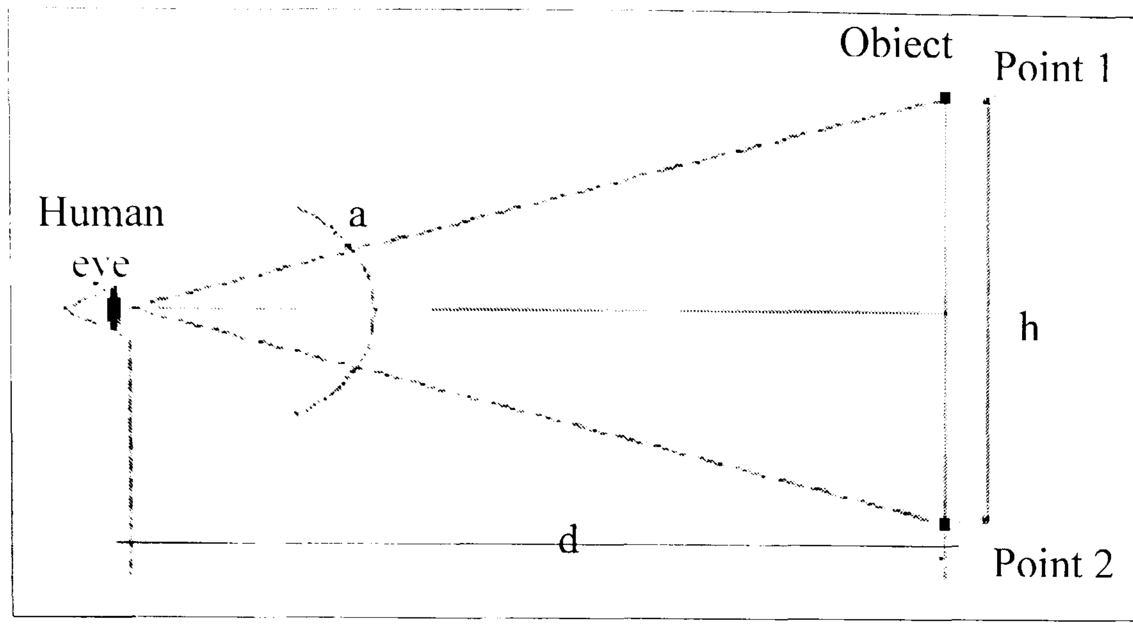


Figure 4.15. The visual acuity angle definition (March, 1999).

Based on many investigation results, Stein *et al.* (2000) and Lechner (1991) determined the three main components of visual acuity. The three components are obviously the object or task, the lighting conditions and the observer. Stein *et al.* (2000) categorised the variables that affect the three components of any seeing task as of primary or secondary importance. Listed below are the variables affecting each of the seeing task elements:

I- The Task:

Primary Factors:

(a) Size

(b) Luminance (brightness)

(c) Contrast, including colour contrast

(d) Exposure time

Secondary Factors:

(e) Type of object

(f) Degree of accuracy required

(g) Task: moving or stationary

(h) Peripheral patterns

II- The Lighting Conditions:

Primary Factors:

(a) Illumination levels

(b) Disability glare

(c) Discomfort glare

Secondary Factors:

(d) Luminance ratios

(e) Brightness patterns

(f) Chromaticity

III- The Observer:

Primary Factors:

(a) Condition of the eyes (both health and age)

(b) Adaptation level

(c) Fatigue level

Secondary Factors:

(d) Subjective impressions; psychological reactions

Assuming a good lighting environment (low glare, acceptable luminance ratios, and white light plus a normal pair of unfatigued eyes), visual acuity is, therefore, primarily dependent on the task variables listed from I (a) to I (d).

It can be concluded that the achievement of good lighting conditions, quantitatively (listed item II (a)) and qualitatively (listed items II (b) through II (f)) contribute to visual comfort and eye adaptation to light and visual acuity. These lighting factors will be extensively reviewed in the following Section (4.4) of this chapter.

4.4 Visual Comfort Parameters in Daylit Offices

In the mid 1970s, as the energy crisis peaked, efforts to conserve energy necessarily increased. The first strategy used to reduce lighting consumption was 'delamping', or in other words, reducing overall lighting levels by reducing the number of lighting fixtures. This illuminance reduction produced uneven distributions of light. Energy was saved, but comfortable lighting conditions declined (Benya *et al.*, 1977; Chase, 1977 and Florence, 1976). Numerous studies have ascertained that good and comfortable lighting conditions in a space are not simply dependent on the quantity of available light, but on a number of lighting factors which must be explored (Veitch, 2001; Stein *et al.*, 2000; Veicher, 1996a; Megaw *et al.*, 1983 and Boyce, 1981). Despite ongoing discussions throughout the 1980s, defining and debating lighting quality remains a continuous issue among lighting communities (Veitch *et al.*, 1996b). Renewed interest in lighting quality emerged in the early 1990s, in parallel with the development of energy codes and standards. The luminance conditions generally agreed as useful descriptors of the lit environment are: illuminance (horizontal and vertical), luminance of room surfaces, uniformity across tasks, luminance distribution within rooms, glare, spectral power distribution, and flicker (Rea, 2000; CIBSE, 1994 and NUTEK, 1994). All these factors, except for spectral power distribution and flicker are skin / window related and should be considered when daylighting offices. These cited parameters are considered in the following sections (Section 4.4.1 to Section 4.4.5).

4.4.1 Illuminance in Daylit Offices

Illuminance is the measure of luminous flux density at a surface, i.e. the luminous flux incident per unit area. The light may come from the sun, lamps in a room or any other bright source. The unit of measurement is the lux, defined as 1 lux = 1 lumen per square meter; the lumen being the unit of luminous flux. This quantity was formerly known as the illumination value or illumination level (CIBSE, 1994).

Illumination levels in the open vary between 2000 and 100000 lux during the day, whereas at night artificial light levels between 50 and 500 lux are normal (Kroemer *et al.*, 1997). The human eye responds to a very wide range of illumination levels, from a few lux in a darkened room to approximately 100000 lux outside under the midday sun.

To ensure lighting conditions under which a task can be performed comfortably, with normal speed and accuracy, a minimum illuminance level for a specific task needs to be determined. Most developed nations, including the UK, the USA, Australia, Brazil, China, France, Germany, Denmark, Sweden, Japan and others have their own published lighting standards. The IESNA Lighting Handbook (IESNA 2000), the Code for Interior Lighting (CIBSE, 1994), and the Illuminance Selection Procedure from the European Committee for Standardisation (CEN, 1998) contain tables or flow charts from which this illuminance level can be obtained. Table 4.5 shows a minimum horizontal work surface illuminance of approximately 500 lux for reading and writing tasks, and 300 lux for tasks at the computer and VDU. These values correspond with those given in several standards (e.g. Din 1990, CIBSE 1994 and IESNA 2000), which are extensively investigated in the following sub-section of this chapter.

Extensive studies on preferred light levels conducted by Begemann *et al.* (1994 and 1995) indicate that the set minimum illuminance levels might not be accepted by the users of the room. This research showed high preference for illuminance levels with an average of 1900 lux for horizontal tasks as well as VDU tasks. Similar results are shown in a review conducted by the Illuminating Engineering Society (IESNA, 2000) and CIBSE (1994). Judgements of optimum illuminance increased with age and task contrast. Most subjects preferred 1000 lux with high contrast, 1800 lux with low contrast. Nonetheless, the work of the SLG (Schweizerische Lichttechnische Gesellschaft) in 1983 showed a general tendency to increased satisfaction with lower illuminance levels, followed by a decrease in satisfaction at the highest illuminance (Figure 4.16; Velds, 2000). Also, in a recent study of preferred desktop illuminance carried out by researchers from Liverpool University and the BRE, it was found that people want to work under a widely variety of illuminance levels, often well below the standard levels (Carter *et al.*, 2000). This study found that people work under vastly dissimilar lighting conditions, with illuminance levels that varied from a minimum of 6 lux to a maximum of 804 lux.

Under daylighting conditions, Tenner *el al.* (1997) showed minimum acceptable illuminance levels of 900 lux. Osterhaus and Selkowitz (1992), on the other, concluded that 500 lux is an acceptable illuminance level for many office tasks, which coincides with the standards for reading and writing tasks.

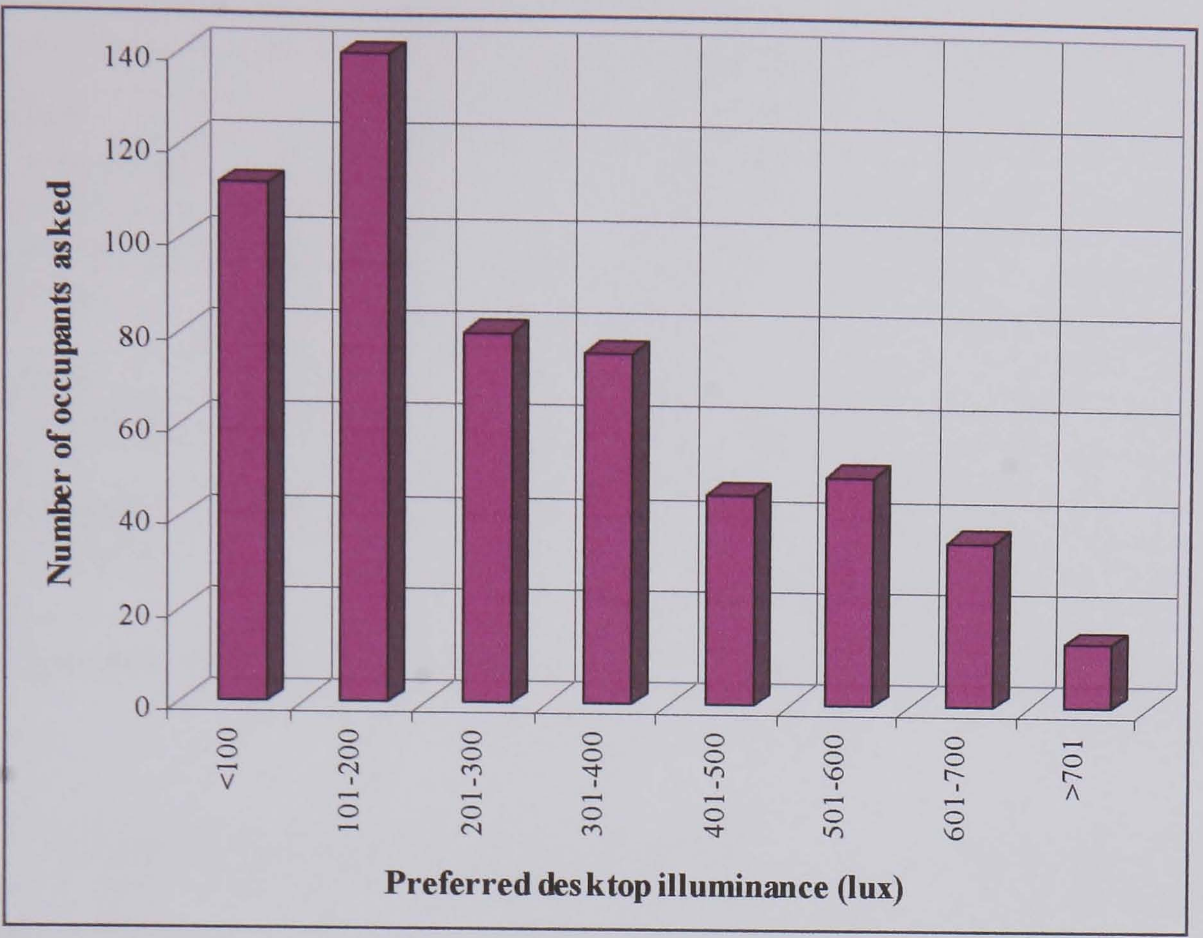


Figure 4.16. Preferred desktop illuminance levels recorded for 564 occupants throughout 12 tested offices (Carter *et al.*, 2000).

4.4.1.1 *Illuminance Recommendations in Daylit Offices*

The British lighting standards were prepared by the Lighting Division Technical Committee of the Chartered Institute of Building Service Engineers (CIBSE). The Code for Interior Lighting published in 1994 is a revision of the lighting standards that have been adopted since 1984 (CIBSE, 1994). This code was also reprinted in 1997 with some amendments. The method of use adopted in the CIBSE code is to determine the recommended average illuminance level, called the standard maintained illuminance, from the detailed and extensive listing of specific tasks illustrated in Table 4.5.

In addition, task size and contrast, task duration and exposure time, and the error risk are modifying factors to be considered to derive the design of maintained illuminance from the standard maintained illuminance listed in Table 4.5. This derivation is done through the flow chart illustrated in Figure 4.17 (CIBSE, 1994), which aims to specify the proper illuminance level in accordance with the working task that is to be accomplished in the space under design. Five questions about the task are asked. The standard maintained illuminance (ranging from 200 to 750 lux) increases or decreases according to the answers.

	Standard maintained illuminance (lux)
Offices	500
General offices	300-500
Computer work stations	300-500
Conference rooms, executive offices	500
Computer and data preparation rooms	300
Drawing offices	
General	500
Drawing boards	750
Computer aided design and drafting	300-500
Print rooms	300
Banks and building societies	
Counter, office area	500
Public area	300

Table 4.5. Standard maintained illuminance recommended in office spaces (CIBSE, 1994).

Standard maintained illuminance (lux) from Table 4.5.	**Task size and contrast**		**Task duration**		**Error risk**	**Design maintained illuminance (lux)**
	Are task details unusually difficult to see?	Are task details unusually easy to see?	Is task undertaken for an unusually long time?	Is task undertaken for an unusually short time?	Do errors have unusually serious consequences for people, plant or product?	

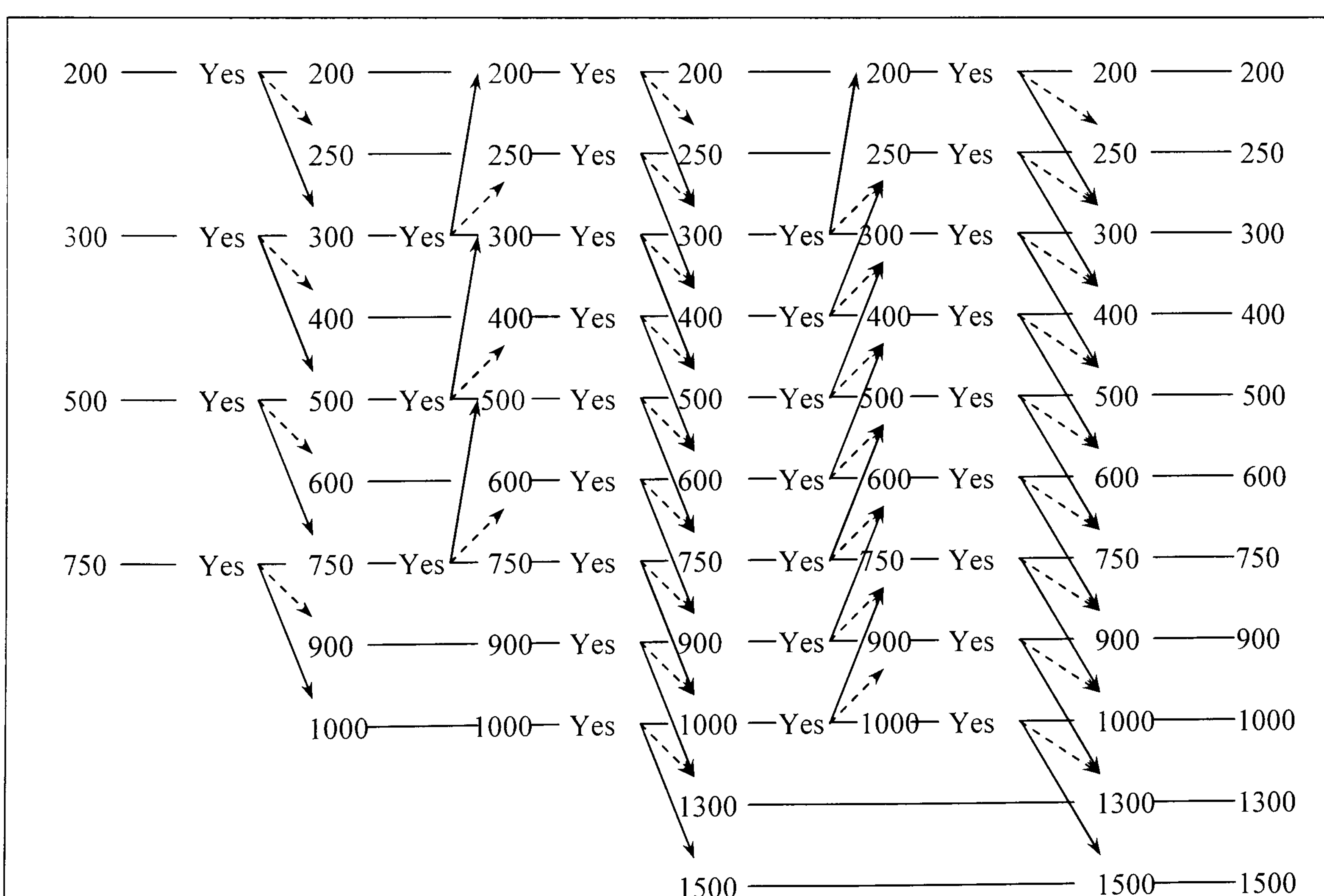


Figure 4.17. Design maintained illuminance flow chart (CIBSE, 1994).

Concerning recommendations for daylighting in the British standards, where the sky is typically overcast, the illuminance is measured in terms of average daylight factor; if electric lighting is not normally to be used during daytime hours the average daylight factor should be not less than 5% and not less than 2% if supplementary lighting is used. This method cannot be applicable in Lebanon where the sky is typically clear.

In 1979, the IESNA established nine illuminance categories, "A", the lowest set of recommended illuminance, through "I" the highest. This classification is based on the description of the visual task, irrespective of the application. The 2000 IESNA Lighting recommendations employ the same approach but reduce the categories to only seven, organised into three sets of visual tasks: orientation and simple, common, and special. The recommended illuminance levels are no longer provided without reference to a specific application. Every application in the Design Guide, first published in 1993, has a specific recommended illuminance (horizontal, vertical, or both). Table 4.7 illustrates the recommended illuminance levels of specific applications in office spaces. These illuminance levels increase roughly logarithmically with increasing task difficulty, by combined changes in task contrast and task size. The calculation procedures for contrast and task size were explained by Rea (2000).

<table>
<tr><td colspan="3">Orientation and Simple Visual Task: found in public spaces where reading and visual inspections are only occasionally performed. Visual performance is largely unimportant.</td></tr>
<tr><td>A</td><td>Public spaces</td><td>30 lux</td></tr>
<tr><td>B</td><td>Simple orientation for short visits</td><td>50 lux</td></tr>
<tr><td>C</td><td>Working space where simple visual tasks are performed</td><td>100 lux</td></tr>
<tr><td colspan="3">Common Visual Tasks: found in commercial industrial and residential applications. Visual performance is important</td></tr>
<tr><td>D</td><td>Performance of visual tasks of high contrast and large size</td><td>300 lux</td></tr>
<tr><td>E</td><td>Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size</td><td>500 lux</td></tr>
<tr><td>F</td><td>Performance of visual tasks of low contrast and small size</td><td>1000 lux</td></tr>
<tr><td colspan="3">Special Visual Tasks: very specialised, including those with very small or very low contrast critical elements. Visual performance is of critical importance</td></tr>
<tr><td>G</td><td>Performance of visual tasks near threshold</td><td>3000 to 10000 lux</td></tr>
</table>

Table 4.6: Determination of illumination categories (Rea, 2000).

Tasks	Horizontal Illumination Category	Vertical Illumination Category
Filing	E	C
General and private offices		
Open plan office: Intensive VDT use	D	B
Open plan office: Intermittent VDT use	E	B
Private office	E	B
Libraries	D	B or D
Lobbies, lounges, and reception areas	C	A
Mail sorting	E	A
Copy rooms	C	A

Table 4.7: Recommended horizontal and vertical illuminance for office space tasks (Rea, 2000).

Regarding appropriate light levels for VDT workplaces, Mahnke (1993) found some degree of controversy. The authors reported that the Swedish National Board of Occupational Safety and Health recommends 200 to 300 while at the other extreme, the Canadian Defence and Civil Institute of Environmental Medicine recommends 810 to 1075 lux. According to Rea (2000), the Illuminating Engineering Society of North America recommends 300 to 500 lux horizontal illuminance and 50 lux vertical illuminance. Furthermore, a 1983 publication distributed by a German governmental agency (Bayerisches Staatsministerium für Arbeit und Sozialordnung) specifies 300 to 500 lux (Mahnke, 1993).

It can be concluded from the previous review that 300 to 500 lux is the horizontal illuminance in office spaces most often recommended by different codes and studies. For this study, these illuminance levels are adopted later in the simulation of the case studies.

4.4.2 Human Perception to Luminance Ratios

Section 4.4.1 described the necessary and recommended amount of light or illumination levels to assure visual comfort in workspaces. Although a particular light level may fall on a body, this is not to say that the observer 'sees' that level. Depending on their surface characteristics, different bodies absorb and reflect different amounts and qualities of light. In this case, the term used to define the amount of light reflected from the body's surface is its luminance or brightness, which refers in simple terms to the amount of light falling on the body multiplied by the proportion of light which the body reflects (its reflectance).

In the metric system, luminance is measured in units of candela per m^2 (cd/m^2). In the English-speaking world the terms millilambert (mL) and footlambert (ftL) are still used to measure luminance. The following equations can be applied 1 cd/m^2 = 0.292 footlambert, and 1 footlambert = 3.5 cd/m^2.

Excessive differences in brightness between objects or surfaces in the in the visual field are undesirable. For a particular level of adaptation, the eye can only cope with a limited range of brightness for good and comfortable visibility. Table 4.8 shows a few examples of how people experience differences in brightness, expressed as the luminance ratio which is the brightness of one object divided by the brightness of another. If the luminance ratio in the normal field of view is too large, then from bright sources there will be glare, which will cause visual discomfort or disability; but in very dark areas it will be difficult to see, as shown in Figure 4.18.

Luminance Ratio	Perception
1	None
3	Moderate
10	High
30	Too high
100	Far too high
300	Extremely unpleasant

Table 4.8. Human Perception of a few luminance ratios (Dul *et al.*, 1991).

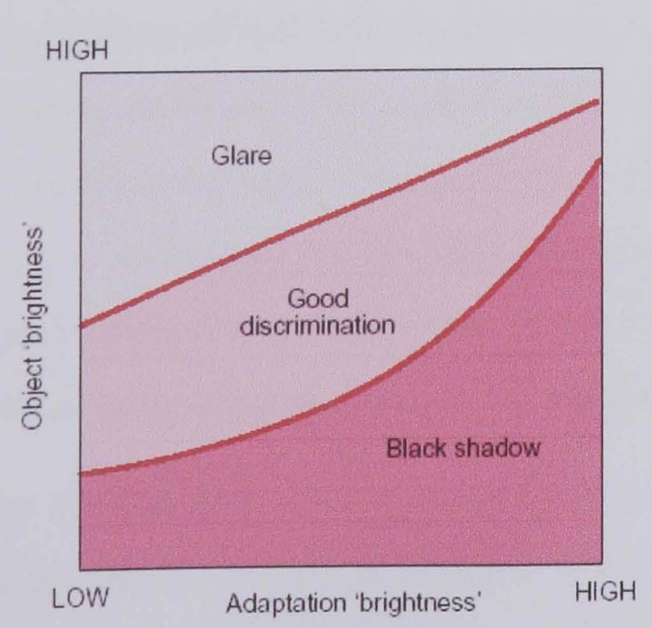


Figure 4.18. The general effect of visual adaptation and object brightness on visual discrimination (BRECSU, 1999).

The visual field can be divided into three zones: that of the task area, the adjacent surroundings, and the wider surroundings (Figure 4.12). Stein's (1992) recommendations for maximum luminance ratios to achieve a comfortable environment are presented in Table 4.9. The brightness of the task area should not be three times smaller than of the close surroundings. The brightness of the task area should not differ from that of the wider surroundings by more than a factor of ten. Differences in brightness that are too small should also be avoided, because this makes a room look dull (Dul *et al.*, 1991and Hopkinson *et al.*, 1970).

1 to 1/3	Between task and adjacent surroundings
1 to 1/10	Between task and wider darker surroundings
1 to 10	Between task and wider lighter surroundings
20 to 1	Between luminaires (or fenestration) and surfaces adjacent to them
40 to 1	Anywhere within the normal field of view

Table 4.9. Recommended maximum luminance ratios (Stein, 1992).

Extracting the preferred luminance ratios from the literature is a difficult task. Each study has chosen a different set of photometric measurements, in the absence of a common protocol for describing the luminous environment. Recalculations have been made to convert some of the published values to common ratios. These are summarised in Table 4.10. Several reports included illuminance values or illuminance ratios, but these could not be converted to luminances without the associated reflectance values. Rea *et al.* (1990) varied their task to adjacent surrounding luminance ratios by varying the reflectance of the adjacent surroundings while keeping the task reflectance constant, for a variety of wider surrounding luminance and task contrast conditions, using a horizontal paper-based numerical verification task. The authors found that the task to adjacent surrounding luminance ratio had a very small effect on visual performance, and no effect on ratings of the readability of the task. The wider surrounding (or background) luminance and task contrast both affected visual performance and readability ratings.

Accordingly, reflectance figures have been recommended for workspaces. Stein (1992) suggested that reflectances of 50, 30 and 80% for walls, floor and ceiling respectively, and 35% for furniture, establish a fairly high eye adaptation level so that direct glare resulting from excessive luminance in the field of view is minimised.

In the last two decades the advent of computers in offices has changed the primary task from the horizontal to the vertical plane, and raised new research questions about acceptable luminance ratios between computer screen and paper documents. Kokoshka *et al.* (1985) examined the speed of data entry for a wide range of task: screen luminance ratios, and found no effects up to 20:1. The results suggested that more extreme ratios might reduce performance. Schemidtke (1980) pointed out that the range of display luminance is also a function of the overall illumination levels used. Thus, in normal office environments with illumination levels between 100 and 1000 lux, a range of luminances between 10 and 150 cd/m^2 would be required.

Investigation	**Luminance (cd/m²)**	**Task:wall luminance ratio**	**Ceiling:wall luminance ratio**	**Wall maximum: minimum**
Tregenza *et al.* (1974)		2 to 1	1.6 to 1	
Van Ooyen *et al.* (1986 1987)		3.3 to 1		
VDT work (wall)	20-45			
Other tasks (wall)	30-60			
Miller (1994)	75			3 to 1
Miller (1995)				
Direct / indirect systems			1:3 through 3:1	
Parabolic direct systems			1:5 through 3:1	
Loe *et al.* (1994)	5		1:1	161 to 1
Berrutto *et al.* (1994)				
Free choice	117-179			
Restricted power use	60-109			

Table 4.10. Summary of recommended luminance ratios and luminances for office use spaces.

4.4.3 Brightness Patterns in Daylit Offices

In the list of characteristics in 4.3.2, pattern of luminance is included among the secondary factors of lighting conditions. Lighting designers may consider luminance distribution across vertical and horizontal surfaces to be synonymous with lighting quality. Brightness patterns are the patterns of light and shadow in a space resulting from the method of illumination, which the human visual system detects and interprets. If the pattern allows occupants to see what they want and creates the desired atmosphere, then one might say that it is of good quality.

A single source produces sharp shadows, while a luminous ceiling or a completely indirect illumination system produces almost completely diffuse light. Diffusion is the degree to which light is shadowless, and is therefore a function of the number of directions from which light intrudes upon a particular point. Diffusion can be judged by the depth and sharpness of shadows. A room with well-diffused illumination resulting from multiple sources and high room surface reflectances yields soft multiple shadows that do not obscure the visual task.

In the case of daylighting, diffusing sunlight by shading devices is important to provide a distributed pattern of light on the vertical and horizontal surfaces of the room, and the task level.

4.4.4 Sources of Glare in Offices

Glare is to light, as noise is to sound. Just as noise is unwanted acoustic energy, glare is unwanted luminous energy. The CIE defines glare as 'the condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or extreme contrasts' (Baker *et al.*, 1993). Hopkinson *et al.* (1966) defined glare, in general terms, as a condition of eye adaptation that is unfavourable to good sight. It causes discomfort and impairment of vision.

Glare is a complex phenomenon which involves the understanding of many issues, such as the length of time that the glare source is present, the luminance ratio between the glare and its surroundings, and the requirements of the visual tasks in the room. It is typically caused by windows provoking bright sunlight in the field of vision, as well as lamps; and surfaces appearing too bright in comparison with the general background.

It is possible to distinguish between direct and reflected or indirect glare. When the discomfort glare is caused by light sources in the field of vision, it is known as direct glare. More explicitly, the factors involved in producing direct glare are the luminance, size and position of each light source in the field of vision, plus the adaptation level of the eye (Stein *et al.*, 1992); i.e. in daylighting conditions, the size and position of the window in relation to the working surface or VDT may cause discomfort glare. When glare is produced by specular surfaces that reflect bright areas, this is known as veiling reflections or reflected glare. Baker *et al.* (1993) differentiate between reflected glare and veiling reflections, which both make part of 'indirect glare'. Reflected glare is caused by shiny or glossy surfaces reflecting images of light sources into the eyes. Veiling reflection occurs when small areas of the visual task reflect light from a bright source (windows or light fixtures), reducing contrast between the task and the immediate surroundings.

Glare from windows can arise in various ways. The common source of glare is the sun itself; sunlight creates the most severe glare problems, because of its intensity. This is common in Lebanon, where clear sky with sunlight is quite typical for almost half of the year. Reflected glare may come from a bright patch of sky, a bright patch of sunlight inside the room or by reflection from a building opposite. This is common in Beirut because of the high building density and the common use of reflective glazing in office buildings. Even when sunlight is excluded, windows can produce serious uncomfortable glare when they are in the field of view. High luminance ratios between the window and adjacent surfaces may occur, unless care is taken to reduce luminance variations. According to a recent study (IESNA, 1999), increased interior electric lighting may be required to reduce glare from windows if it is not otherwise controlled, thus increasing energy consumption when daylighting is used.

Lighting professionals distinguish between two types of glare, and either can occur without the other. The two types are disability glare and discomfort glare (Rea, 2000; IESNA, 1999; CIBSE, 1999 and Baker *et al.*, 1993). These are discussed in the following sections.

4.4.4.1 *Disability Glare*

Disability glare is that which reduces the ability to see details. It does not necessarily cause visual discomfort. For example, excessive reflections from shiny white paper can cause disability glare while reading. Such conditions also occur when a person has a direct line of view to a bright object, such as a window or a light fixture. If this disability persists after the immediate cause is removed, the condition is called 'successive glare' and is due to the time necessary for the process of adaptation and readjustment. The eye must constantly adjust from the task to the higher luminance, resulting in eye fatigue.

Under daylight conditions, the influence of the sky through the window can have a disturbing effect. Such conditions can be experienced when looking at a wall surface adjacent to a window, or when attempting to see details of an object set against a highly reflective surface in which it is mirrored by the source of light.

The disabling effect of glare can be reduced by reducing the luminance of the light source, while at the same time increasing the luminance of the object, or a surface by a better light distribution, and by the use of lighter colour (Baker *et al.*, 1993).

In practice all these conditions may arise from the same glare source, but with interior lighting to high or moderate levels the usual cause of complaints is the discomfort rather than the disability glare. Discomfort glare, a visual comfort feature, is therefore one of the key aspects that should be taken into consideration when evaluating the lighting quality of a daylighting design.

4.4.4.2 *Discomfort Glare*

If there is no direct interference with vision, but discomfort, annoyance, irritation or distraction, the condition is called 'discomfort glare' (Hopkinson *et al.*, 1970). Discomfort glare occurs with the presence of excessive bright sources in the field of view. The sources may be too bright with respect to darker surroundings, or be uncomfortably bright in absolute terms. According to Cakir *et al.* (1998), if a person stays in such a room for an extended period, this type of glare leads to premature fatigue and to lowered performance, reduced activation and well-being.

A study by Chauvel *et al.* (1982) deals with the issue of daylight as a source of discomfort glare, with reference to skylight but not to direct or reflected sunlight. The main conclusion of this study is that 'discomfort glare from a single window (except for a rather small one) is practically independent of size and distance from the observer, but is critically dependent on the sky luminance'. This luminance can be as high as 10000 cd m^2, even on overcast days, and much higher if bright sunlit clouds are visible. Serious problems may occur when there is unrestricted use of daylight. If the users are not prevented from glare, their performance will be reduced or the lighting situation might of necessity be altered. The latter aspect has a significant influence on energy savings.

A quantitative assessment of discomfort glare can be given by the expression of the 'glare constant' G (Baker *et al.,* 1993): $G = K.P. (L_s^{1.6} . \omega^{0.8}) / L_b$

Where: K is a constant depending on the units employed

P is a 'position factor' depending on the position of the source with respect to the line of sight

L_s is the luminance of the source

L_b is the field luminance

ω is the solid angle subtended by the source.

The values of glare constant derived from the previous formula are found to correspond, as illustrated in Table 4.11 (Hopkinson *et al.*, 1970). Thus, if the glare constant for a given situation were evaluated as 60, the degree of glare would be between 'just uncomfortable' and 'just acceptable'.

Glare Constant	Criterion of glare discomfort
600	Just intolerable
150	Just uncomfortable
35	Just acceptable
8	Just perceptible

Table 4.11. Glare constant criterion scale (Hopkinson *et al.*, 1970).

The most often cited prediction of the degree of discomfort glare due to the sky being visible through a window, is the Daylight Glare Index (DGI) (Hopkinson, 1972; Chauvel *et al.*, 1982 and IEA, 2000). This is the function of the source, location, intensity, surrounding luminance and direction of view. It is calculated from the 'Cornell large source glare formula':

$$DGI = 10 \text{ Log } (K. (L_s^{1.6} . \Omega^{0.8}) / (L_b + 0.07 . \omega^{0.5} . L_s)$$

Where: K is a constant depending on the units employed

L_s is the luminance of the source

L_b is the field luminance

ω is the solid angle subtended by the source

Ω is the solid angle subtended by the source, modified to take into account the position in the field of view.

The numerical representation of subjective evaluation according to the DGI scale is shown in Table 4.12.

Glare Criterion	DGI
Intolerable	>28
Just intolerable	28
Uncomfortable	26
Just uncomfortable	24
Acceptable	22
Just acceptable	20
Noticeable	18
Just noticeable	16

Table 4.12. DGI multiple criterion scale (Fisekis *et al.*, 2002).

4.4.5 Daylight and Chromaticity

The ability to see colours properly is another aspect of lighting quality. Light sources vary in their ability to accurately reflect the true colours of people and objects. This is due to their spectral energy distribution (SED). As has been shown in Figure 4.9, daylight (compared to the most common artificial light sources in offices, incandescent and fluorescent lamps) has a uniform mixture of the various colours of the visual spectrum, which makes it the best source of light for good colour rendering. This is because a light source may alter the perception of colours to match the spectral composition of the light. Therefore, objects may vary in colour appearance depending upon the light source. This is another reason for the reconsidering the use of daylight as a light source in offices to improve the lighting quality, especially for professions where colour appearance is important.

The colour rendering index (CRI) scale is used to compare the effects of a light source on the colour appearance of its surroundings. A scale of 0 to 100 defines the CRI. A higher CRI means better colour rendering, or less colour shift. CRIs in the range of 75-100 are considered excellent, while 65-75 are good. The range of 55-65 is fair, and 0-55 is poor. (U.S. EPA Green Lights Program, 1995a).

4.5 Light and Health

Despite the fact that current lighting 'standards' are not based on health and well-being, but on task performance and energy use (Zilber, 1993), it is important to point out that with more understanding of the effects of daylight, the emphasis is shifting from vision alone to biological needs. An innovative project by Brainard (1995) explored the human biological and behavioural impacts, and the related energy implications of electric lighting systems in architecture. Brainard pointed out potential conflicts between the amount of light needed for biological response, current illuminance recommendations by the Illuminating Engineering Society of North America, and energy-efficiency design. He suggested that the low levels of illuminance recommended for some tasks are equivalent to biological darkness. Brainard (1995: 16) explained, "*It would be unconscionable to suggest that we waste any of our valuable energy resources. We should all conserve energy and preserve the ecology of our environment. In the process, we also should be careful not to waste human productivity, health, and well-being. Ultimately, we need to determine energy efficient strategies for lighting that provide optimal visual stimulation as well as optimum biological stimulation*".

In the last decade, there has been an expansion of research efforts directed to understanding the biological impact of light on humans (Mahnke *et al.*, 1993; Zilber, 1993 and Cakir *et al.*, 1998). This is being pursued simultaneously at the biochemical, cellular, organism and epidemiological levels, and includes researches on circadian rhythms, hormone regulation and immunological levels, psychological response, and human growth and development. The luminous environment can no longer be considered as merely a visual issue. The light humans are exposed to, during both the day and the night, interacts with some of the more fundamental biological processes of the body.

There are in fact a number of well recognised medical symptoms of daylight deprivation: irritability, fatigue, reduced immune function, insomnia, depression, alcoholism, suicide, vitamin D deficiency, calcium deficiency, neurotransmitter and hormonal deficiencies, rickets, jaundice and osteoporosis, through to more elusive conditions such as seasonal affective disorder (SAD). Other health issues directly or indirectly related to the visual comfort and the quality of light in the built environment include building-related illness (BRI) and sick building syndrome (SBS). Some of these are reviewed in the following section.

4.5.1 Lighting and Vision Syndromes

The most common complaints caused by visual work in poor conditions are eyestrain in various forms, muscular aches and pains, and more general reactions such as fatigue, irritability, and headaches (Baker *et al.*, 1993 and Breeding, 1997). Eyestrain is the most frequently mentioned problem caused by lighting, or the lack of it. Eyestrain may indeed be the result of trying to overcome difficult viewing conditions such as those presented by visual display units, but the strain is only a temporary discomfort and does not damage the eye (Baker *et al.*, 1993). Eyestrain can be caused by one or more of the following conditions: inadequate illumination; glare; flicker; uncorrected refractive errors (need for eyeglasses); and the non-ergonomic positioning of the visual task (Baker *et al.*, 1993 and Zilber, 1993).

In Cuttle's study (1983), nearly 60% of the respondents agreed with the position that 'daylight causes less harmful effects to your eyesight and / or general health'. When asked to qualify this, people identified daylight as being beneficial and electric light as deleterious, in the long term. Heerwagen *et al.* (1986) confirmed and widened Cuttle's findings. When asked to evaluate daylight vs. electric light as regards general health, 79% of their respondents chose daylight, 3% electric light, while 15% felt both were equal. When asked to evaluate the question of visual health, 73% of the subjects preferred daylight, 9% electric light, and 9% saw no difference.

4.5.2 Daylight and Chronobiology

The positive reaction of people to windows and daylit environments, and their defensive reaction to electric lighting may simply be the manifestation of an awareness of daylight's potential to directly influence physiological processes. Early survival clearly depended on the awareness of, and response to daylight's seasonal and diurnal cycles. This explains the very early evolution of the chronobiological system, whose primary function is the regulation of the sleep/wake cycle. Moderate disruption of chronobiology can lead to jet lag; more serious disruption can lead to serious performance reductions and the short and long term health problems evidenced amongst shift workers.

The most serious and widespread disruption of chronobiology is evidenced by those who suffer from SAD, or seasonal affective disorder. SAD is characterized by a recurrent annual depression, with the onset during winter followed by an elated mood in spring.

According to Terman (1986: 356): "affected individuals show clinical depression, accompanied by oversleeping, overeating, decreased work productivity, and social withdrawal."

SAD is related to the availability of daylight: an IESNA study (1993) concluded that there is a north-south pattern of SAD in the United States, with far more people reporting SAD symptoms at the highest latitudes (greater than 30%) than the southern end of the country (less than 5%). It would seem likely that in Beirut (33° 54' N latitude, approximately the same as California which is located in the south-east of the US), the percentage of people affected by SAD will be small. Daylight is available for 10 -14 hours daily throughout the whole year, and overcast skies prevail only 15% of the year (Ministry of Public Affairs and Transport, 1966).

4.5.3 Sick Building Syndrome in Windowless Offices

In recent years, it has become apparent that the occupants of buildings suffer a number of relatively minor illnesses where there is no apparent cause, yet it has been established that these are caused in some way by the building. The symptoms are varying degrees of irritation of the eyes, nose, throat or skin, plus general symptoms such as lethargy and headaches. Because these illnesses may happen in the building or elsewhere, it was initially difficult to show that they could be caused by the building (WHO, 2000).

Many different terms have been used to describe the phenomenon of reported high incidence of illness, or feelings of being unwell, suffered by people for no apparent reason in certain buildings; these include "building sickness", "sick office syndrome", "tight-building syndrome" and "office-eye syndrome". In 1982 the World Health Organization agreed the term "Sick Building Syndrome" (SBS), and this is now the most widely used (WHO, 2000).

Since the causes of SBS have not been identified, the best way of finding out if there is a problem is to look at the frequency of complaints or symptoms of illness (WHO, 2000). Figure 4.19 shows the relevant section of a questionnaire proposed by Cakir *et al.* (1998). It asks for symptoms which depend not only on lighting but also on environmental factors, and those which can also be connected to personal factors such as poor eyesight. The same question has been asked within the POE survey conducted in office buildings in Beirut. The results (shown in Figure 4.20) indicate that the frequency of SDS symptoms complaints is the lowest for people who are less than two metres distant from the window. Workers who have no access to windows complain the most about rapid fatigue, headache, burning eyes and dry eyes. The frequency of burning and dry eyes is lowest for people sitting 4-6 metres away from the window. The reason might be that the occupants are less affected by discomfort glare coming from windows.

Do you suffer from particular disturbances of your health and well being?

	Very strong	strong	moderate	barely	not at all
concentration weakness	☐	☐	☐	☐	☐
rapid fatigue	☐	☐	☐	☐	☐
sleepiness	☐	☐	☐	☐	☐
irritability	☐	☐	☐	☐	☐
visual impairments	☐	☐	☐	☐	☐
headaches	☐	☐	☐	☐	☐
dry eyes	☐	☐	☐	☐	☐
burning eyes	☐	☐	☐	☐	☐

Figure 4.19. Questions on Sick Building Syndrome symptoms.

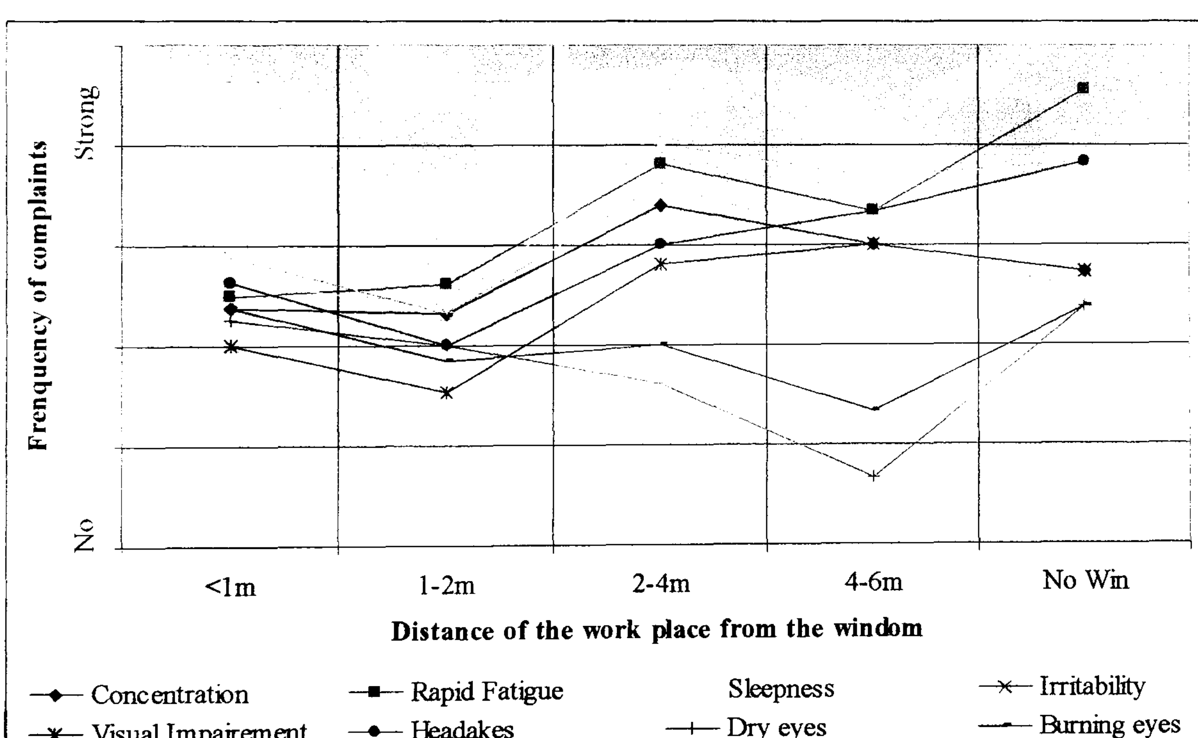


Figure 4.20. Complaints frequency of SBS symptoms as a function of the distance of the workplace from the window, in office buildings in Beirut (after Cakir *et al.*, 1998).

WHO (2000) identified that a lack of natural light may also be a contributor to SBS. Tests have shown that those seated near a window tend to suffer less from SBS, although the link is not clear. The necessity of having access to daylight can also be seen from one of the most striking results of the Light and Health studies (Cakir *et al.*, 1998). Figure 4.20

shows the same results in office buildings in Beirut, which suggest an additional reason for the significance of this study. Figure 4.21 shows that regardless of the specific office task, all symptoms of sick building syndrome depend on the distance of the workplace from the next window. Near windows, working with VDTs causes no more problems than conventional office work. Subliminal flicker from fluorescent tubes has been shown to contribute towards headaches and eye-strain, and elimination of the flicker has been shown to reduce the symptoms (WHO, 2000).

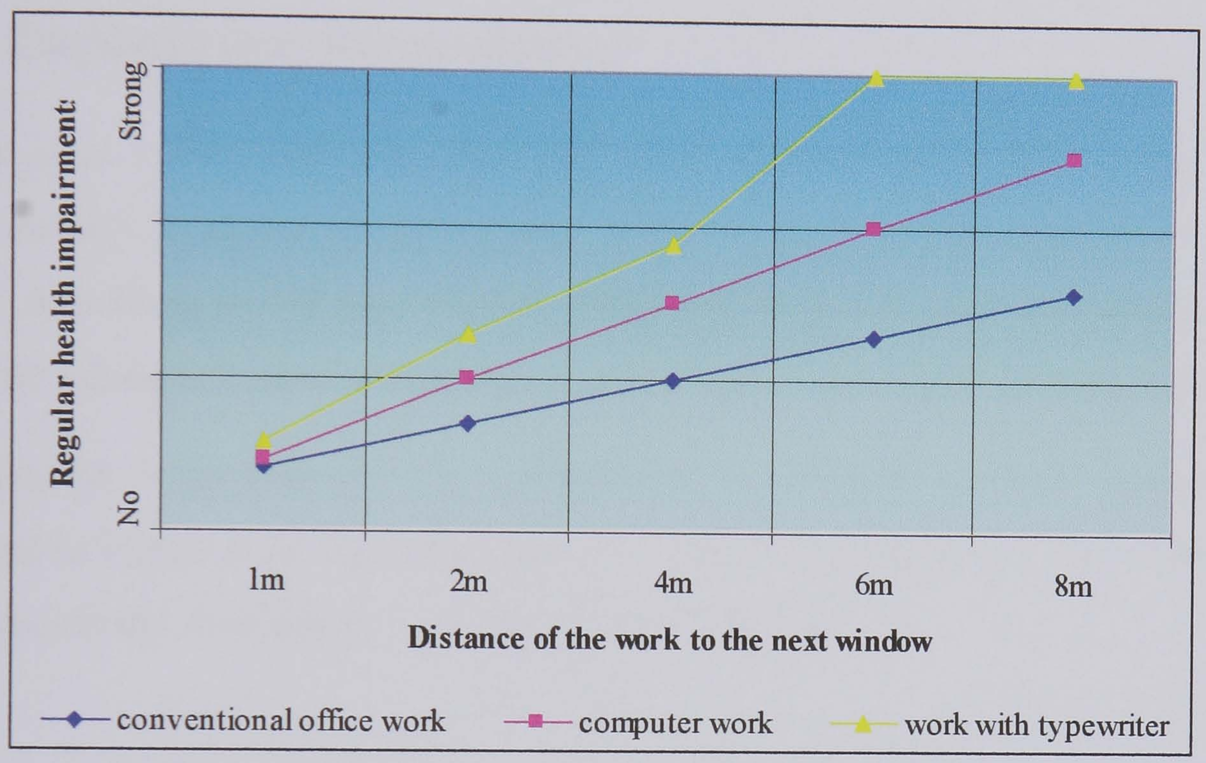


Figure 4.21. Increase of SBS symptoms as a function of the distance of the workplace from the window (after Cakir *et al.*, 1998).

4.6 Daylight and Occupant Behaviour (Psychology)

Stress is an individual psychological and physiological response to a situation that threatens well-being. Stress is a recognisable part of most people's workspace experience and it exercises a powerful role on an employee's mood, thinking, behaviour and physical health, all of which can influence his or her performance.

According to Norris *et al.* (1997), windows reduce stress and thereby improve the prospect for better performance. While daylight clearly plays a part in the stress-reducing function of windows, research has mostly not attempted to separate out its functions. What little there is, suggests a potentially powerful role.

In Keep's research (Keep *et al.*, 1980) of windowed vs. windowless intensive care units (ICU), the windows were translucent thus eliminating view as a variable. Nonetheless he discovered that disorientation, hallucination, loss of memory and delusions were still significantly less common in the windowed but viewless ICU. The implication is that daylight alone provides critical information, perhaps about time and weather patterns, to the patients which in turn led to stress reduction. Butler and Biner (1989) found that 80% of their respondents wanted windows in their office because it gave them information about time and weather. This outranked task performance (76%), mood (73%) and sunlight (70%).

4.7 Daylight and Productivity

Leaman *et al.* (2000) define productivity as the ability of people to enhance their work output through increases in the quantity and / or quality of the product or service they deliver. According to DiLouie (2000a), productivity is a measure of human performance on the job taking into account comfort, satisfaction, safety, speed and accuracy.

According to Sundstrom (1987), productivity is affected by many factors. These are presented in Figure 4.22; the environment is only one small factor. The effect of lighting, more specifically daylighting, may be difficult to determine.

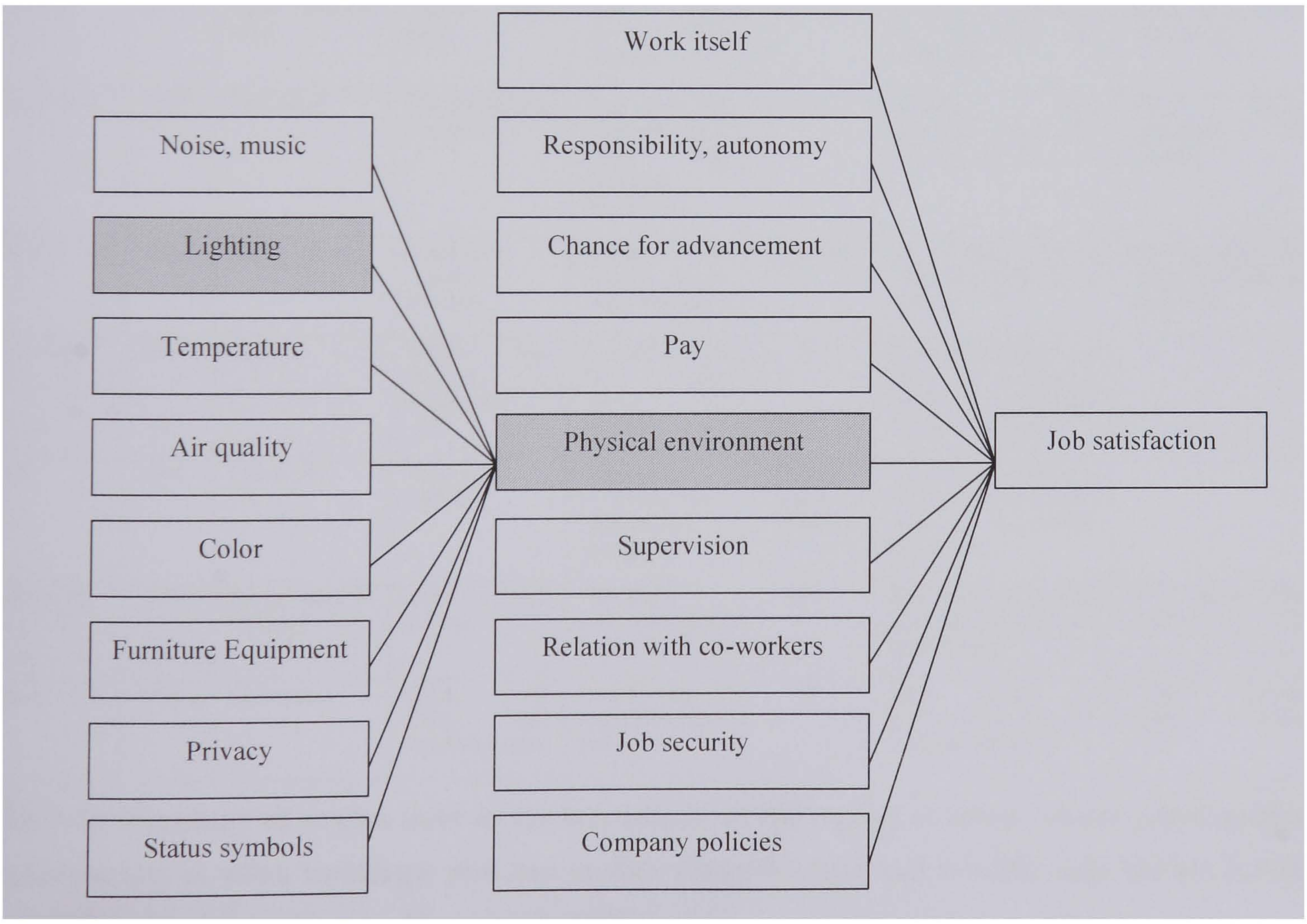


Figure 4.22. Aspects of the physical environment affecting job satisfaction (Sundstrom, 1987).

The impact of the indoor environment on office workers has been of interest to building science researchers for many decades. Most studies have looked at whether changes in specific environmental conditions can be related to measurable changes in worker performance and productivity. Some of the recent laboratory and field studies most relevant to this work are summarized in Table 4.13. This table delineates some of the worker performance (outcome) metrics that have been examined in recent office related studies, along with the explanatory variables (inputs) considered. Many studies which have focused on different aspects of the indoor environment have not controlled the potential influences from electric illumination or daylight, and vice versa.

Researcher	Year	Study type, Location	Key inputs	Key outcome	# of subjects	Findings	Comments
Kroner and Stark-Martin	1994	Field, old and new buildings. West Bend Mutual	Ventilation, thermal comfort	# of insurance forms processed	300	2-3% increase due to workstations, 12-14% increases due to 'improved building'	Daylight contribution in new space not accounted for
Federspeil *et al.*	2002	Field, HMO incoming call Centre	Ventilation, thermal comfort	Call handling time	100	No significant relationship to variation to performance	Variation in exposure to daylight not accounted for
Milton *et al.*	2000	Field, Polaroid Corp.	Ventilation	Absenteeism, health changes	501 or more	Increased ventilation associated with reduced absenteeism	
Myatt *et al.*	2002	Field, Polaroid Corp.	Indoor CO_2 level	Sick leave among office workers	294	No association between sick leave and CO_2 differential	Follow-up to Milton study above
Boubreki *et al.*	1991	Laboratory	Electric lighting conditions	Data entry and cognitive tasks, mood and alertness assessment	15	Different light conditions have no effect on outcomes	Electric lighting considered in isolation
Aizlewood *et al.*	2002	Field	Ventilation, relative humidity	Health and comfort in an office building	unknown	No significant effect on symptom prevalence or comfort	Only ventilation and relative humidity are considered
Boyce *et al.*	1997	Field	Window size, sunlight penetration	Emotional state of office workers, self reports	40	Only small amounts of sunlight penetration promote positive feelings of relaxation	
Veitch	1990	Laboratory	Acoustics, lighting	Reading, comprehension, personality assessment	48 male and 52 female	Significant interaction between noise levels with personality assessment	
Figueiro *et al.*	2002	Filed, software company	View and daylight	Occupancy rates, time spent on tasks	141	Workers in offices with views or daylight stay on task more	Pilot study, few controls
Wargocki *et al.*	2000	Laboratory	Indoor air quality and ventilation rates	Performance of simulated office tasks	90	Better indoor air quality associated with higher productivity	Three studies, changed 'pollution load'

Table 4.13. Summary of studies done in the last decade on the impact of indoor environment quality on productivity in office buildings; previous studies where daylight and window were the key inputs are shaded (California Energy Commision, 2003)

For decades, the prevailing hypothesis concerning light and productivity was of the "more light, better sight" school of thought (DiLouie, 2000). The higher the light level at the task, the greater the visual acuity, hence the greater efficiency and accuracy of the worker. Nevertheless, California Energy Commission (2003) found that daylight illumination levels are not significant for the visual acuity tests or long term memory test. The other desirable component of basic lighting design was to keep unwanted glare from the field of view, and distribute light uniformly. After 1970 a new dimension to lighting quality research began, as John Flynn explored visual comfort and preferences in the total luminous environment rather than simply the quantity of illumination on the workplane. According to Muneer *et al.* (2000), it is difficult to produce confident relationships between daylight level and improvements, detriments to work output and quality. On the other hand, a recent study completed by California Energy Commission in 2003, which aimed to better understanding the comfort and productivity related issues with daylighting in office spaces, found that daylight illumination levels were significant and positive when predicting better performance in one test of mental function and attentiveness.

What is clear, however, is that people prefer daylit environments and enjoy the benefits associated with windows. Occupants who are content with their environment find it easier to channel their attention to work tasks; distractions are reduced and work productivity is increased. The California Energy Commission (2003) found that an ample pleasant view was consistently found to be associated with better office worker performance, which on the other hand was reduced by glare from windows. This idea is also supported by the literature review conducted by Norris *et al.* (1997) on the daylighting and productivity relationship.

It can be concluded from previous reviewed studies that people strongly believe, and research generally supports, that daylight is a better and healthier workplace light source than electric light. Research favours daylight primarily as a psychological asset that raises comfort and reduces stress. Windowless and daylightless workplaces induce stress, and that has a negative impact on productivity.

4.8 Summary and Conclusions

This chapter reports on an investigation into the influence of the indoor physical environment on office worker comfort, health and performance. It is particularly concerned with the potential contributions of windows and daylight to improved working conditions and performance by office workers.

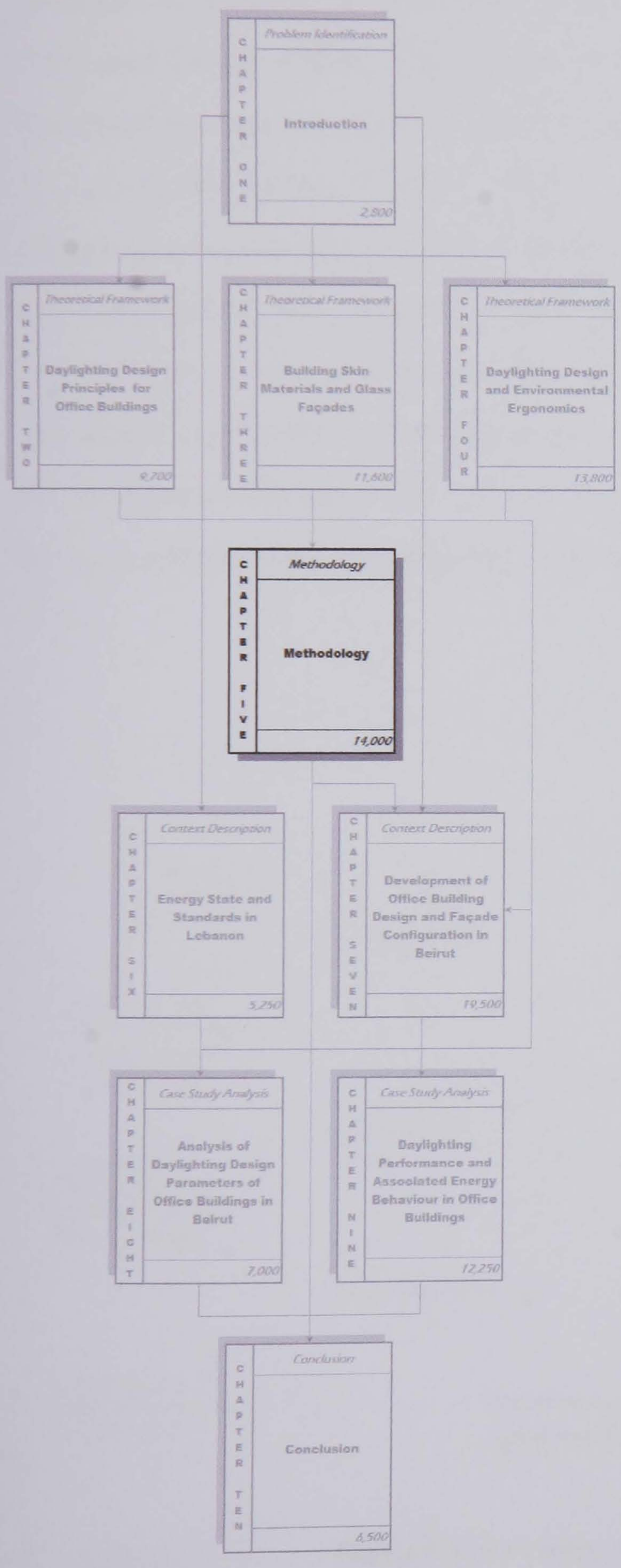
There is no doubt that good lighting quality can be created by daylight, electric light or a combination. The user must decide if 'it is good' in the end. The user is thus the ultimate target, and also the obstacle. He / she must experience the technology as meaningful and positive to the environment; if not, the building will be not accepted. Consequently, a study of the technical possibilities for saving energy by using daylight in combination with electric light is not really meaningful if the user's reaction is negative, even though the energy use parameters might be appropriate.

Workers and researchers alike confirm daylight as the preferred source of light in the workplace. This predisposition for daylighting does not appear to be derived from people's perceptions of research findings concerning its potential to increase performance and productivity; rather it derives from daylight's capability to create psychological comfort and an environment that is more supportive to worker health and overall productivity.

Thus while energy efficiency is important, it is always less important than the primary purposes of the building which can be affected by the occupants' health and comfort. This is particularly important in temperate climate, such as East Mediteranean, where temperature remains within the comfort zone all year around. The impact of indoor environment factors in general, and the existence or absence of window with associated light and view in particular, proved to be significant to workers' preferences, moods, satisfaction, stress, disorientation in time and space, depression etc.

METHODOLOGY

5



Chapter Five

5. Methodology

5.1 Introduction

This chapter aims to identify the approaches to the conducted research; research being a 'systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge' (Ernest, 1994; Tulloch, 1997 and Burns, 2000). The system in 'systematic' means that research should use an organised process of enquiry, linked to existing methodology, and provide a justification for knowledge claims (Ernest, 1994). Figure 5.1 illustrates the seven main stages of an organised research process, the paradigm of a scientific enquiry, and how this process has been applied in this research. Defining the research problem, formulating hypotheses, designing the study, data collection, context description, data analysis and generalization are all affected by the general theories, and in turn should affect them as well. According to Frankfort-Nachmias *et al.* (1996), the scientific research process is characterised by its cyclical nature: the generalization ending one cycle is the beginning of the next (Figure 5.1).

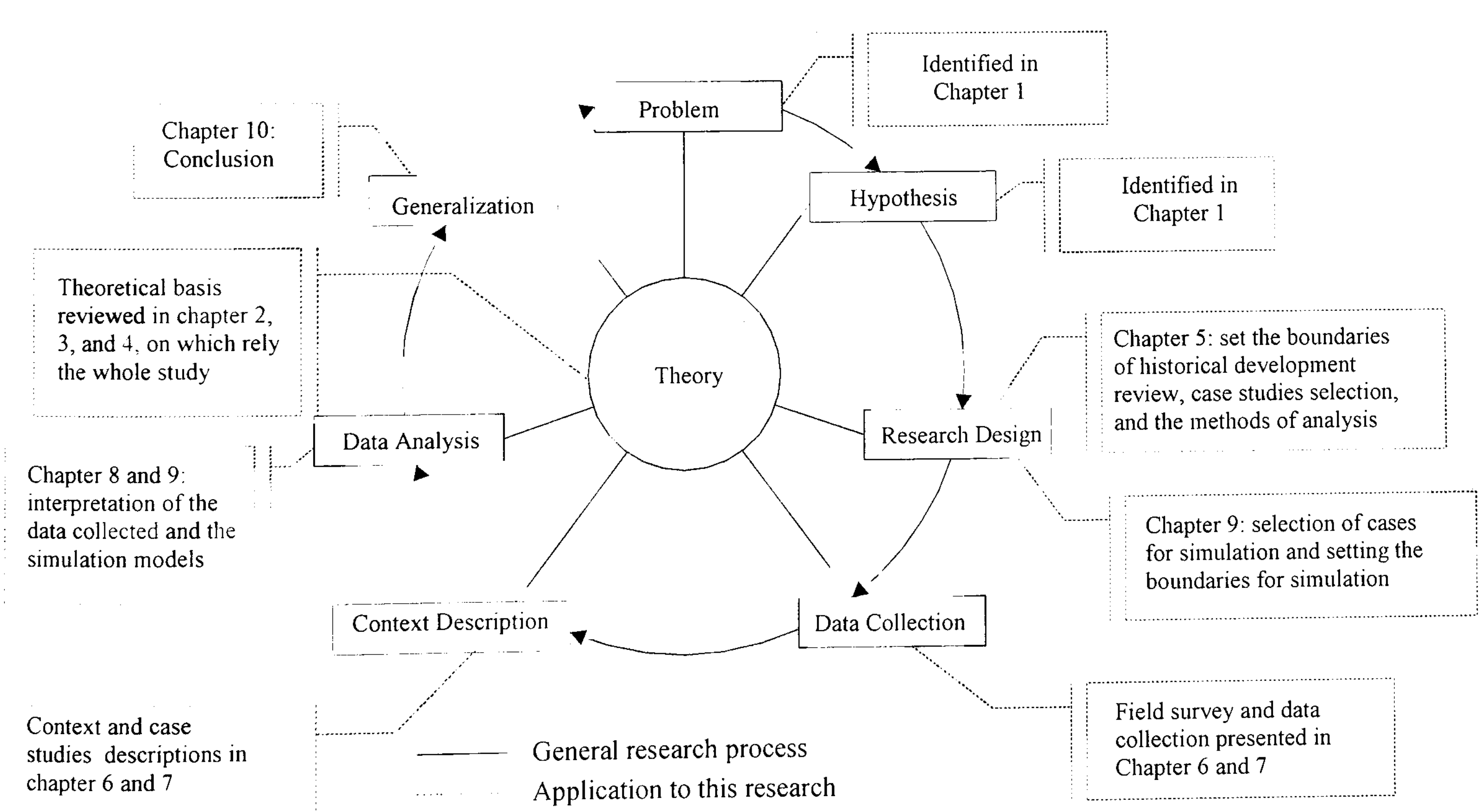


Figure 5.1. The main stages of the research process

Logical validity and empirical validation are the two criteria employed to evaluate claims for any scientific knowledge (Frankfort-Nachmias *et al.*, 1996). These two criteria are translated into research activities through the research process.

The research problem and objectives have been outlined in Chapter One. In the light of output from previous chapters, the following discussion has four main sections:

- Introduction, in which the philosophy and methodological approaches of this research are discussed in relation to general research theories.
- Research methods used in office building development and daylighting studies.
- Research methods for daylighting assessment in office buildings.
- Selection of the appropriate tools to assess daylighting in office buildings.

5.1.1 Research Philosophy

A research philosophy is a belief about the way in which data about a phenomenon should be gathered, analysed and used (Galliers, 1992). A brief discussion of research philosophy starts with the simple distinction between epistemology and methodology. The term epistemology, originally the Greek word 'epistêmê', refers to the different philosophical views about how or whether it is possible to obtain certain or objective knowledge about the world (Travers, 2001). In simple terms, it is the philosophy of knowledge, or of how to know. Methodology is also concerned with how to know, but is much more practical in nature. Methodology is focused on the specific ways or the methods that can be used to try to understand the world better. Epistemology and methodology are intimately related: the former involves the philosophy of how to know the world, and the latter involves the practice (Trochim, 2000).

In recent years, there has been considerable interest in the role of philosophical assumptions and paradigms when doing research. During the 1970's and 80's, serious concerns were raised about the limits of quantitative data and methods often associated with positivism, the prevailing epistemological paradigm (Gephart, 1999). The dominance of positivism has been increasingly challenged by critics from two alternative traditions, interpretive constructionism, and critical postmodernism. Constructionism and critical postmodernism raise fundamental philosophical challenges for positivism, and offer alternative theoretical, methodological and practical approaches to research.

Positivistic concerns to uncover truths and facts using experimental or survey methods have been challenged by interpretivists, who assert that these methods impose a view of the world on subjects rather than capturing, describing and understanding these paradigms. Critical postmodernists also argue that these imposed views or measures implicitly support forms of scientific knowledge that explicitly reproduce capitalist structures, and associated hierarchies of inequality. In order to identify the research philosophy that is the most descriptive of this study, Table 5.1 has been developed from the reviewed literature. Table 5.1 seeks to summarize the key features of each paradigm, the nature of knowledge pursued, and the different means by which knowledge is produced and assessed within each paradigm.

	POSITIVISM	INTERPRETIVISM	CRITICAL THEORY/ POSTMODERNISM
Assumptions	Objective world which science can 'mirror' with privileged knowledge	Inter-subjective world which science can represent with concepts of actors; social construction of reality	Material world of structured contradictions and/or exploitation which can be objectively known only by removing tacit ideological biases
Key Focus or Ideas	Search for contextual and organizational variables which cause organizational actions	Search for patterns of meaning	Search for disguised contradictions hidden by ideology; open spaces for previously silenced voices
Goal of Paradigm	Uncover truth and facts as quantitatively specified relations among variables	Describe meanings, understand members' definitions of the situation, examine how objective realities are produced	Uncover hidden interests; expose contractions; enable more informed consciousness; displace ideology with scientific insights; change
Nature of Knowledge or Form of Theory	Verified hypotheses involving valid, reliable and precisely measured variables	Abstract descriptions of meanings and members = definitions of situations produced in natural contexts	Structural or historical insights revealing contradictions
Criteria for Assessing Research	Prediction = Explanation Rigour; internal and external validity, reliability	Trustworthiness Authenticity	Theoretical consistency Historical insights Transcendent interpretations Basis for action, change potential and mobilization
Unit of Analysis	The variable	Meaning; symbolic act	Contradictions, incidents of exploitation
Research methods and Type(s) of Analysis	Experiments; questionnaires; secondary data analysis; quantitatively coded documents ***Quantitative***: regression; Likert scaling; structural equation modelling ***Qualitative***: grounded theory testing	Ethnography; participant observation; interviews; conversational analysis; grounded theory development Case studies; conversational and textual analysis; expansion analysis	Field research, historical analysis, dialectical analysis PM: deconstruction, textual analysis

Table 5.1. Key features of research paradigm.

The key focus of this research is to search for contextual and organizational variables that examine the impact of façade design development of office buildings in Beirut, on daylighting performance and energy consumption. It can be concluded that this thesis doesn't strictelly follow any particular paradigm represented in Table 5.1. This study mix a positivist analysis with the interpretivism as it crosses boundaries between enginnering and architecture.

As defined at the beginning of this section, methodology is the practical way to reach knowledge. Consequently, the following section will review the methodological approaches to assess daylighting performance in office buildings and associated energy behaviour, and relate it to the appropriate epistemological paradigm in order to justify the research strategies used in this study.

5.1.2 Research Methodological Approaches

Research methods are generally divided into being either quantitative or qualitative. Quantitative methods are traditionally associated with positivism, scientific, objectivity, and statistics. In contrast, qualitative methods have generally been associated with interpretivism, non-scientific and subjectivity. Qualitative methods attempt to capture and understand individual definitions, descriptions, and meanings of events. Quantitative methods, on the other hand, count and measure occurrences (Burns, 2000). From the reviewed literature regarding quantitative and qualitative research in social research, Table 5.2 has been developed to summarise the differences between the two methods of research. Table 5.3 also illustrates the distinct research methodologies, indicating whether they conform typically to positivist (quantitative) or interpretivist (qualitative) paradigms.

Before introducing the methodologies used in this research, the important features of the key methodologies are summarized in Table 5.3, identifying their respective strengths and weaknesses. It can be concluded from this table that this research can be described as historical and developmental, as it includes a study of multiple cases. Survey techniques are used to collect data, and correlational, modelling and simulation techniques are used for analysis. In the following sections, the choice of qualitative and quantitative approaches is justified; quantitative methods encompass the study of the impact of office buildings façade features on the different indoor lighting energy measures, and qualitative approaches are used to investigate the development of façade configuration and plan morphology of office buildings in Beirut.

	Qualitative	Applicability to the conducted research			Quantitative	Applicability to the conducted research		
		Yes	No	Notes		Yes	No	Notes
Assumptions	Reality socially constructed	✓		the development of the built environment is linked the development of the constructed society	Facts and data have an objective reality	✓		The development of façade configuration is linked to the improvement in façade and glass technologies
	Variables complex and interwoven; difficult to measure	✓		variables related to occupant comfort and satisfaction in their work environment	Variables can be measured and identified	✓		Identified and measurable façade variables that can evaluate daylighting performance
	Events viewed from informant's perspective		×		Events viewed from outsider's perspective	✓		Development of office buildings is related to literature, and local architects perspective
	Dynamic quality of life	✓		continuous development of the office buildings due to the urban development and social needs	Static reality to life		×	
Purpose	Interpretation	✓		Interpretation of	Prediction	✓		Prediction of daylighting performance (by a developed tool) and potential energy savings due to the daylight / electric light integration (by simulation)
	Contextualisation	✓		Relate the development of façade configuration and daylighting performance to the studied context	Generalisation	✓		Generalisation of daylighting performance analysis outputs
	Understanding the perspective of others		×		Causal explanation	✓		
Method	Data collection using participant observation, unstructured interviews	✓		Use of unstructured interviews with local architects	Testing and measuring		×	
	Concludes with hypothesis and grounded theory		×		Commence with hypothesis and theory	✓		hypotheses are set in the first chapter and analysis and linked to the reviewed theories
	Emergence and portrayal		×		Manipulation and control	✓		
	Inductive and naturalistic		×		Deductive and experimental	✓		
	Data analysis by themes from informants' descriptions		×		Statistical analysis	✓		
	Data reported in language of informant	✓			Statistical reporting	✓		
	Descriptive write-up	✓		Study of office buildings development by describing façade configuration, plan morphologies, material used etc.	Abstract impersonal write-up	✓		
Role of researcher	Researcher as instrument		×		Researcher applies formal instruments	✓		
Personal involvement	Empathic understanding		×		Objective	✓		

Table 5.2. Comparison of qualitative and quantitative methods.

Table 5.3. Taxonomy of research methodologies (continued on the following two pages)

Scientific / Positivist / Quantitative	Features		Interpretivist / Anti-positivist / Qualitative	Features	
Historical research	- Systematic search for facts relating to questions about the past and the interpretation of those facts (Borg *et al.*, 1996). - Involves specific definition of the period addressed within the research. - Encompasses use of primary (e.g. interviews) and secondary sources (literature materials). - Must be able to withstand criticism	✓ ✓ ✓ ✓	**Historical research**	- 'Is a systematic analysis and synthesis of evidence concerning human achievement. It is an integrated account of the relationship between the subject studied, people, events, times, and places (Burns, 2000) - Involves a wide range of studies from documents, interviews, biographies and events, and their interpretation. - Evokes both qualitative and quantitative methods and data.	✓ ✓ ✓
Case and field studies research	- Is the study of single or multiple case studies - Involves assessment, but not manipulation of a variety of variables that contribute to the case's current situation.	✓ ✗	**Case Studies research**	- Is chosen when a descriptive real life holistic account is required (Burns, 2000). - Sampling is usually non-probability, with the case chosen based on some relevant criteria. - Data analysis involves a coding system that permits higher order categories and conceptual analysis to develop. - Types: <u>historical</u>, observational, oral history, <u>situational analysis</u>, clinical, multi-case studies.	✓ ✓ ✓ ✓
Survey research	- Collection of data to determine the current status of the 'case-study' with respect to one or more variables. - Often is a precursor to other types of research, most commonly correlational and experimental research. - Includes the use of questionnaires, surveys, observations, and interviews.	✓ ✓ ✓	**Grounded theory**	- Using analytic induction, theories are generated from collected data (Frankfort-Nachmias and Nachmias, 1996). - Grounded theory is useful in situations where little is known about a topic or problem area. - Data collection is directed by theoretical sampling, which means that the sampling is based on theoretically relevant constructs.	✗ ✗ ✗

Scientific / Positivist / Quantitative (Con't)	Features (Con't)		Interpretivist / Anti-positivist / Qualitative (Con't)	Features (Con't)	
Developmental research	- Is the study of one or more variables over a relatively long period. - Is usually considered synonymous with the term longitudinal research. - Includes trend studies (trend sampling case studies), cohort studies (specifically-defined case studies) and panel studies (case studies assessed periodically)	✓ ✗ ✓	**Ethnographic research**	- 'Ethnography' literally means 'writing about people'. Ethnographic research encompasses any study of a group of people for the purpose of describing their socio-cultural activities and pattern; it is the science of cultural description (Burns, 2000). - Involves descriptive data collection as the basis for interpretation (observation and interviewing). - Generalization is not feasible, as statistical sampling is not involved. Triangulation is the principal way in which validity can be assessed (Burns, 2000).	✗ ✗ ✗
Causal Comparative research	- An attempt to attribute causation without experimental manipulation of a variable (Wilkinson *et al.*, 1996). - Based on the premise that both the effect and the alleged cause exist at the time the research is conducted.	✗ ✗			
Correlational research	- Includes studies having as the purpose to determine the relationships between or among variables using correctional statistics (Wilkinson *et al.*, 1996). - Has the advantage of allowing study of many variables simultaneously.	✓ ✓			
True-Experimental research	- Means that (theoretically) the researcher has control over all the relevant variables. - It permits the researcher to identify precise relationships between a small number of variables that are studied intensively via a designed laboratory, using quantitative analytical techniques with a view to making generalized statements applicable to real-life situations (Frankfort-Nachmias *et al.*, 1996).	✗ ✗			

Scientific / Positivist / Quantitative (Con't)	Features (Con't)		Interpretivist / Anti-positivist / Qualitative (Con't)	Features (Con't)	
Quasi-Experimental research	- Approximates true experimental research, except that complete control of all relevant variables is not possible (Burns, 2000). - Is usually differentiated from true experimental research by the inability to assign subjects to groups randomly, or lack of a control group (Mitchell *et al*, 1988).	✗ ✗			
Single-Subject Experimental research	- Involves studying an individual in both treatment and non-treatment conditions, and evaluating performance on the dependent variable in both conditions (McMillan *et al.*, 1997). - Should not be confused with a case-study; in single-subject research considerable effort is given to 'controlling' extraneous variables.	✗ ✗			
Action research	- Is an attempt to solve a specific, immediate, and concrete problem in a local setting (Moore, 1983). - Is not concerned with generalization to any significant degree - Often is used to test the effectiveness of new skills or methods of doing something. - Lacks credibility because of vague definitions and practices.	✗ ✗ ✗ ✗	**Action research**	- Is the application of fact finding to solving practical problems, with a view to improving the quality of action within it (Burns, 2000). - Is situational, collaborative and participatory. - Is a total process in which a 'problem situation is diagnosed, remedial action planned and implemented, and its effects monitored if improvements are to get underway'. (Burns, 2000) - The personal ethics of the researcher are critical, since the opportunity for direct researcher intervention is always present.	✗ ✗ ✗ ✗
Simulation and Modelling research	- Involves copying the behaviour of a system (Groat *et al.*, 2002) - Is used in situations where it would normally be difficult to solve problems analytically. - Involves the introduction of random variables. - As with experimental forms of research, it is difficult to make a simulation sufficiently realistic so that it resembles real world events.	✓ ✓ ✓ ✓			

5.2 Historical Research Methods in Daylighting and Office Building Development

Generally, 'historical research intends to help understand, explain or predict, through the systematic collection and objective evaluation of data relating to past occurrences in order to explore research questions, or test hypotheses concerning causes, effects or trends that may help to explain the present or anticipate future events' (Burns, 2000). This section reviews the research methods used in architecture and building development studies, with some emphasis on written work about daylighting. The following section reviews the methods of analysis used in previous studies on architectural developments in Lebanon.

5.2.1 Historical Research Methods in Architecture and Building Development Studies

Studies of architecture and buildings can usually be classified into one, or a combination, of the three types of research below (Routio, 2004):

- **Descriptive** studies aim at reporting the present (or past) state of the object, which in architectural studies can be either one building or any defined class or series of buildings, as well as the people related to these buildings. Monographs of buildings often belong to this category, as well as a large proportion of the histories of architecture.
- **Explanatory** studies try to find out why each building has taken the shape that it has. The reasons can be taken either from the past (causal explanation), from the concurrent context, or alternatively from the future (i.e. from the intentions of the builders).
- **Normative** studies attempt to point out in which respects the object of study could be improved, and the methods of doing that. When the outcome of normative studies is generalizable to later similar objects, it could be called a theory of design.

In this study, a combination of the three above approaches is adopted; the development of office building architecture in Beirut is described. Causal explanations from the past are used to understand the configuration of façade development. This study attempts to point out the best use of daylighting in Beirut during the last century, in order to guide local architects to design efficient daylit office buildings for the future.

The list of determinants of the evolution study of office buildings is quoted from Banister Fletcher's *History of Architecture* (1987):

- geographical influences
- geological influences
- climate
- religious influences
- social influences
- events in political history.

Louw (2002: 2) stated that "*the intellectual life of much of the 20th century was dominated by what has been termed 'hard technological determinism', an ideology that saw inputted agency, or 'the power to affect change', to technology as its most compelling intrinsic attribute*". Accordingly, in addition to the above list of determinants, technological dimension is another determinant that must also be considered while writing about architectural history. Collard and DeHerde (2001) reviewed the history of office building architecture in Europe, and adopted the following design features to describe the development of workspaces:

- architectural style
- scale and circulation morphology
- building depth, which impacts upon the access of daylight to the core of the building
- distance, separating office occupant from window
- flexibility in design, and the adoption of cellular / open plan concepts
- structural system, which affects the space span and the wall to aperture ratio
- services, such as air-conditioning, lifts etc.

In the study of office building development in Beirut, most of the previous features are described. Only circulation morphology and services are not considered, as they do not have influence on the daylighting performance of the building. Other façade design features reviewed in previous chapters are also examined.

5.2.2 Research Methods in the History of Architecture and Daylighting

Fletcher (1987), Moore (1991), Baker *et al.* (1993), and Baker *et al.* (2002) found that light has always played a role in humane architecture, in all cultures and religions. The above-mentioned authors divided architectural history into three major periods: pre-industrial, industrial, and post-industrial architecture. It was with the industrial revolution in the West, that the development of new materials and technologies brought rapid changes in both the requirements and the solutions for daylighting. This descriptive review was always related to past occurrences, and mainly focused on the role of structural systems, environmental features, and the window as an aesthetic feature in shaping the façade and affecting daylighting performance.

Baker *et al.* (2002: 4) interpreted the role of daylighting in architecture history from two basic perspectives: "that of art and science, emotion and quantity, or heavenly or earthly". According to the authors, historically these roles have been intertwined, but since the Age of Enlightenment they have begun to separate and become distinct. In that separation, the role of light lost the holistic understanding, but knowledge was gained about the science of light. It is through the application of this knowledge to scrutinising the qualities of architectural masterpieces, that artistry in lighting design is acquired. The purpose of this endeavour is to fulfil both the personal emotional needs of well-being, comfort and health, and the practical communal needs of illumination level and energy conservation. Thus, light in architecture is an integrated web of interdependent aesthetic and functional criteria. In other words, the integration and complementarity of daylight quality and quantity gives the potential to achieve sustainable and beautiful architecture. According to Baker *et al.* (2002), Vitruvius was perhaps the first architectural author who studied daylight both qualitatively and quantitatively. He proposed the following explicit rule to assess whether an interior is well daylit (Baker *et al.*, 2002: 11):

"We must take care that all the buildings are well lighted... hence we must apply the following test in this matter. On one side from which the light should be obtained, let a line be stretched from the top of the wall that seems to obstruct the light to the point at which it ought to be introduced, and if a considerable open

space can be seen when we look up above that line, there will be no obstruction to light in that situation."

Alberti, the archetypal Renaissance man, saw architecture as an intellectual discipline and a social art necessitating both artistic and mathematical skills (Baker *et al.*, 2002).

The romantic and empirical descriptions of light in nature and architecture were followed in the late Italian Renaissance by a more mathematical rule to size openings. This was an issue addressed by Andreas Palladio. His texts expressed the need to strike the balance between "clarity of light" while not allowing in too much heat. Palladio proposed that (Watkin, 1986: 155):

"... the windows ought not to be wider than the fourth part of the breadth of the rooms, or narrower than the fifth, and to be made squares and a sixth part of their breadth more in height."

Despite such formulaic approaches in architectural treatment, the science of light was subordinate to the aesthetic effects of proportional systems.

This study focuses more on the empirical description of daylighting and office building architecture in Lebanon. The literature review in Chapter 2 identified some mathematical rules to size the building, openings, and office and shading devices. This study is believed to be the first of its kind in Lebanon, where most of the studies in architectural history of the country may be considered 'romantic', aesthetic descriptions of the architecture in Beirut with no focus on daylighting or any other climatic-related feature (Interview with Robert Saliba on April 4, 2003). This statement is clarified by the review of previous historical research in Lebanon, presented in the following section.

5.2.3 Research Methods in the Architectural History of Lebanon

Published work about Beirut, or the history of Lebanese architecture is mostly confined to short comprehensive overviews (Ghosn, 1970) or to epilogues in books dealing with regional architecture in Lebanon (Liger-Blair, 1966; Ragette, 1974). More focused researches were conducted during the 1980s and early 1990s by non-architects, mainly historians (Sehnawi, 1981; Davie *et al.*, 1987). Most of these studies concerned the domestic architecture of the 18^{th} and 19^{th} centuries. Tabet (1998) and Arbid (2002) reviewed modern architecture in Beirut during the period between 1946 and 1970. In their reviews, the authors investigated the modernity and identity of the building boom associated with the 1950s and 1960s. A more detailed review of Lebanese domestic architecture was conducted by Saliba (1998). The author limited his study to 1920-1940. His analytical framework was articulated around a set of variables related to the formal, functional, and contextual attributes of buildings, using both diachronic and synchronic perspectives. Those variables were subdivided into three major categories: external, internal and status indicators. The variables of each category are represented in Table 5.4.

Phase	External indicators	Internal indicators	Status indicators
- Early Transitional - Mid Transitional - Late Transitional - Early Modern	- Architectural style and façade typology - Building construction and height - Floor-space concentration and models of extension	- Plan morphology - Vertical circulation and domestic services	- Size-Type - Level of ornamentation - Design quality

Table 5.4. Investigation framework, illustrating the typological evolution of Beirut's pre-elevator apartment buildings (Saliba, 1998)

The latest publication concerning the history of architecture in Lebanon is a work by Gebran Yacoub, '*A dictionary of 20th century architecture in Lebanon*', published in October 2003. This 'dictionary' lists many architectural features of the last century, such as buildings, distinguished architects, events, competitions etc. The author's aim was to create a reliable reference book of architectural data, and this prevented his work from including any critical analysis.

From the literature review, it can be concluded that the domestic architecture of the 18th and 19th century has been extensively studied. Some research studies were conducted on the emergence of a transitional style, generally referred to as 'colonial', during the French mandate period (Saliba, 1998). The post-World War II period, during which most of the present urban environment in Lebanon was built, is barely explored and subject to prejudiced interpretations (Ghosn, 1970). This was the case until the studies by Tabet (1998) and Arbid (2002), in which the authors tried to interpret the identity of the architecture of this period through the description of some "local pioneers' " architectural works. Therefore, the architecture of the pre-World War I (1900- 1920), the civil war (1975-1990) and the post-civil war (1990-now) remains mostly unexplored. In addition, the architecture of office buildings and related daylight studies has been generally neglected. Moreover, all the existing studies are qualitative and interpretive. Of necessity, other research tools have been used to make up for the shortage of relevant literature. These methods are discussed in the following sections.

5.2.3.1 *Sources of Data*

Historical research differs greatly from many of the other research methods discussed in this chapter. However, it shares a great deal with qualitative methods and the use of documents, interviews, biographies and events, and their interpretation. It may also make use of and analyse quantitative data such as façade design variables, (window to wall ratio, fenestration factor, sill height, etc.) and plan morphologies (building compactness ratio, daylight buffer zone, etc.).

Generally, oral records, artefacts and quantitative records are the main data sources used in historical research (Burns, 2000). The available documents or published literature reviewing the historical development of office buildings in Beirut during the last century are very few. Accordingly, the sources of data used for this study are oral and quantitative records, collected through unstructured interviews and field survey, respectively.

5.2.3.1.1 Semi-structured interview method

Interviews are considered as a primary source of data in historical research (Burns, 2000). An interview is a verbal interchange (often face to face, though the telephone may be used) in which an interviewer tries to elicit information, beliefs or opinions from another person (Creswell, 2003). Books about research methods classify interviews in a variety of ways: formal, less formal and informal; structured, semi-structured and unstructured; focused or non-directive; informant interviews versus respondent interviews (Drever, 1995).

'Unstructured' or 'open-ended', 'semi-structured' and 'structured' are three forms of interview. Structured interviews are used predominantly in surveys and opinion polls, with consequent quantitative analysis. An unstructured interview takes the form of a conversation between informants and researcher, in an unstructured way, on the informants' perception of themselves, of their environment and of their experiences. There is no standardised list of questions. The major disadvantage of this type of interview is that the researcher is open to the vagaries of the informant's interpretation and presentation of reality, which creates a problem of validity. Rather than having a specific interview schedule, or none at all in a semi-structured interview, an interview guide may be developed. Without any fixed wording or fixed ordering of questions, a direction is given to the interview so that the content focuses on the crucial issues of the study. The person interviewed can answer at some length in his or her own words, and the interviewer responds using prompts, probes and follow-up questions, to get the interviewee to clarify and expand on the answers.

Most of the information on which the Tabet (1998) and Arbid (2002) studies of modern architecture in Lebanon were based was collected through direct interviews with distinguished local architects and / or their collaborators. The authors did not clarify which type of interviews they were using.

In this study, a semi-structured interview method has been used, to emphasize the basis of the office building development descriptive survey discussed in the following section. A general interview guide was developed, concerned with the following issues:

- The main phases of the history of architecture in Lebanon, and the factors or reasons that led to this chronological division.
- In the interviewee's opinion, what are the more distinguished office buildings in Beirut and why.
- Office buildings that are considered prototypes for each phase.
- Personal experience in practicing architecture, and designing office buildings.
- To what extent daylighting and climatic issues are considered in their designs.
- Awareness of different glazing materials used.
- How much the building regulations related to window opening size affect their designs.
- The main purpose of using a curtain wall in their design (if relevant).
- Application or awareness of 'energy-efficient building' concepts.

The people interviewed are local architects who have been practicing from the late 1950's until now, or have designed several office buildings; and authors who have produced publications about architecture in Lebanon.

Tape recording and supplementary notes were used to record the direct interviews. Not having to take full notes enabled the researcher to take part in the conversation in a more natural way.

5.2.3.1.2 Survey method

Ragette's (1974) and Saliba's (1998) studies of domestic architecture in Lebanon, during the 19th century and early 20th century respectively, were based upon a descriptive architectural survey of existing buildings. The data collected for their descriptive survey included architectural drawings of plans and façades, ornament details and pictures.

A sampling, descriptive survey of office buildings in Beirut was undertaken for this study. The aim of sampling is to save time and effort, but also to obtain consistent and unbiased estimates of office design development (Schofield, 1996). The approach to collecting the survey data from the large office building stock in Beirut was systematic; the development of each daylighting design parameter being observed in seven historical phases, identified in Chapter 7.

The type of empirical data collected included architectural drawings, pictures, and details of monthly electrical consumption. Additional information obtained through field survey was recorded on a data sheet designed by the researcher, and included all the necessary data for the following analysis (Figure 5.2).

Data of 58 office buildings with different construction dates were collected. However, the limitations of data access reduced the number of case studies on which this study is based to 35 office buildings. The sources of architectural drawings were architects' archives, Lebanese architectural journals and other books. Pictures of the buildings were taken by the researcher. Electrical empirical data were obtained from EDL (Electricite du Liban). These data were divided into three categories:

- Descriptive Data:
  - date of construction
  - photos
  - drawings: plans, elevations, sections, and details
  - published work (if any) on the architectural style or the design characteristics
  - interview with the building's architect(s)

- Post occupancy evaluation (discussed later in this chapter):
  - Number of questionnaires distributed
  - Number of Respondents
  - Constraints (Yes / No, reasons)
- Empirical energy data: monthly energy consumption

Data Collection Worksheet

Building ID	
Building Name	
Building Location	

Date of Construction	
Building Use	
Area (m^2)	

Building Shape and Orientation (Key plan for Photos)

Available data

		Yes	No			Yes	No
Architectural maps	Typical floor			Energy Data	Monthly electrical consumption		
	Sections				Yearly electrical consumption		
	North elevation				Additional notes:		
	South elevation						
	East Elevation						
	West Elevation						

Building Configuration

		Yes	No			
Basic Plan form	Deep plan			Façade properties	No. of Floors	
	Narrow				Building Height (floor no.)	
	courtyard				Percentage of Glazing area	
	Atrium				Glazing material	
					Building wall material	

Shading Devices

		Yes	No		
Active	Overhang			Passive	If yes, give details:
	Lightshelve				
	Fins				
	Baffle				
	Jalousie				
	Louvres				
	Brise-Soleil				
	Shutter				

Daylight Zone

Depth	
Room Height	
Room shape coefficient (Length / depth)	
Window to Wall ratio	
Fenestration Factor	

Aperture Configuration

Location	Unilateral		Shape	Vertical (2.0<CS)		Height	High	
	Bilateral			Intermediate (0.5<CS<2.0)			Intermediate	
	Multi-lateral			Horizontal (0.5>CS)			Low	
	Total glazed wall			Total glazed wall			Total glazed wall	

Figure 5.2. Data collection worksheet

5.3 Research Methods for Daylighting and Energy Assessment in Office Buildings

Daylighting design is both an art and a science. Qualitative information and visual feedback on a given daylighting concept are usually as important as the quantitative figures that reflect the engineering aspects of daylighting design.

Lighting recommendations reviewed in Chapter 4 showed that good natural lighting, and unobstructed views out of a building are minimum standards required by the guidelines for workplaces in many countries. Some of these conditions can be broken down into criteria quantifying the performance of a design solution with a particular design system, such as daylight factor, glare index, illumination, etc. These factors are numerical performance criteria derived from specific formulas. Quantitative recommendations are often made to predict and analyse qualitative aspirations, such as safety, good visibility, visual comfort and thermal comfort (Osterhaus, 1993). In all daylighting design measures, attention should not focus only on adequate levels of lighting in a room. Attention should also be given to enhancing the quality of lighting, ensuring an even and intense standard of illumination in all areas. Although investigations focus on trends in quantitative recommendations, it is necessary to evaluate those trends in the context of qualitative needs and assumptions (view out, wellbeing, visual comfort and mood, etc.).

In accordance with the review of theories in Chapters 2, 3, and 4, the best use of daylighting is assessed along with the following associated qualitative and quantitative performance expectations:

- architectural: the impact of façade configuration and plan morphology in collecting or rejecting the daylight needed to illuminate indoor spaces and enhance the environmental conditions of the workplace.
- lighting energy savings: the replacement of indoor electric illumination needs by daylight, resulting in reduced annual energy consumption for lighting.

This section presents the methods and approaches used to assess daylighting performance in office buildings. The daylighting performance addressed also includes the contribution made by daylight to indoor lighting, e.g. energy savings from displaced electrical lighting consumption.

Sections 5.3.1, 5.3.2 and Section 5.3.3 review daylighting and thermal and energy assessment methods. User comfort, behaviour, and productivity evaluation methods in relation to daylighted environments are reviewed in Section 5.3.4.

5.3.1 Research Methods for Daylighting Assessment in Office Buildings

In the last decade, there has been a growing concern about the development tools used to provide assistance in daylighting design. Several surveys have been carried out during the last 10 years to identify the tools available to monitor the behaviour of daylighting in buildings (Baker *et al.*, 1993; McNicholl *et al.*, 1994; Kenney *et al.*, 1995; Aizelwood and *et al.*, 1996; Baker *et al.*, 2002). Table 5.5 gives the results of one such survey, conducted recently as part of the IEA Task 21 (de Bower *et al.*, 1998).

Although old tools such as empirical equations, tables and diagrams, based on practical experience or simple calculation, may reflect historical conditions now that computer technology is available. Nevertheless they could be useful in the design of a simple evaluation tool. The developed tool is intended to evaluate the daylighting performance of a façade design, and it could be used by architects to check their work. Based on the principle of the morphological box, Baker *et al.* (1993) used simple formulas, typologies and diagrams to develop a tool to describe and compare a small sample of daylit buildings in Europe. The same concept is used in this study, in order to develop a tool to evaluate the impact of façade configuration on daylighting performance in the office buildings of Beirut. This tool, described in the following section, includes simple empirical equations to measure daylighting design variables that are considered significant to the performance and availability of daylighting in indoor spaces.

Computer tools are also used in this study. A computer simulation tool is needed to predict electric lighting consumption, and the potential savings due to electric lighting control strategies. The criteria for the selection of the appropriate simulation software for this research are studied in Section 5.3.7. SPSS and Excel computer software are also used for the correlational, comparative and developmental analyses of daylighting performance and associated energy behaviour in the office buildings case studies.

Type	Daylight factor for sidelit rooms	Daylight factor for rooflit rooms	Window design	Rooflight design	Atria design	Energetic behaviour / Daylight autonomy	Shadow and reflection analysis / Sunshine duration	Visual Comfort
	Subject							
Formulas	✓	✓	✓	✓				
Tables	✓	✓	✓	✓				
Nomograms	✓	✓	✓	✓	✓			
Diagrams	✓	✓	✓	✓		✓	✓	✓
Protractors	✓	✓	✓	✓				
Computer tools	✓	✓	✓	✓		✓	✓	
Typology	✓	✓	✓	✓			✓	✓
Scale Modelling	✓	✓	✓	✓	✓		✓	✓

Table 5.5. Survey of daylight design tools carried out as part of the IEA Task 21 (de Boer *et al.*, 1998).

5.3.1.1 *Development of a Daylighting Design Evaluation Tool*

In order to study the development of office buildings in Beirut, a comparative analysis method is needed to evaluate the surveyed office buildings and map those buildings that are well daylit. Baker *et al.* (1993) used a morphological analysis approach, trying to draw a pattern that would permit comparison between daylit buildings in Europe. The morphological method was proposed by Zwicky *et al.* in 1967. Zwicky *et al.* outlined five basic steps in the development of morphological methods:

- Formulation and definition of problems.
- Identification and characterization of all parameters.
- Construction of a multi-dimensional matrix (morphological box) whose combinations will contain all possible solutions.

- Evaluation of the outcome, based on feasibility and achievement of desired goals.
- In-depth analysis of the best possibilities, considering available resources.

Baker *et al.* (1993) developed a morphological box consisting of 3 columns and 13 rows (Table 5.6). The first column represents the level of daylighting analysis; i.e. I is the room level, II is the building level and III is the urban space layout level. Daylighting parameters and possible variables are listed on the second and the third columns of the table (or box). Each row corresponds to one descriptive parameter, with all the possible variations of those parameters. These variations were given a numerical value that permitted the user to draw a morphological diagram. It seems that the authors could not draw any conclusions from their study. It is to be noted that the numbers given are codes and not scores.

MORPHOLOGICAL DIAGRAM											
LEVEL	PARAMETRS		VARIABLES								
I	A	room layout	1	2	3	4					
	B	colectors' position	1	2	3	4	5	6			
	C	collecting area	1	2	3	4	5	6	7		
	D	aperture shape	1	2	3	4	5	6	7		
II	E	glare control	1	2	3						
	F	plan layout	1	2	3	4	5	6	7		
	G	wall/aperture	1	2	3	4					
	H	aperture distribution	1	2	3	4					
	I	shading device	1	2	3	4					
	J	roof aperture	1	2	3	4	5	6			
III	K	urban layout	1	2	3	4	5	6	7	8	9
	L	façade reflectance	1	2	3	4					
	M	street top lighting	1	2	3	4					

Table 5.6. The morphological box (Baker *et al.*, 1993).

The same concept described above was used to develop a preliminary daylight evaluation tool for office buildings in Beirut, but with a different typological grammar. This grammar consists of a set of composition parameters, and a repertoire of architectural variables previously reviewed in Chapter 2 (Table 5.7).

Four levels of parametric analysis were considered:

1- **Building Shape:** describes the building's shape in 3 dimensions.

2- **Window / Façade**: depicts the relationship between apertures and opaque components of the building façade in general, and the office façade in particular.

3- **Window / Office**: draws the relationship between the side windows' properties and the office dimensions.

4- **Shading Devices**: describes the shading devices used.

Table 5.7 represents the variables of each parametric scale, and the associated evaluation value. Theses variables have been described in detail and discussed in previous chapters (Chapters 2 and 3). All these daylighting design variables were calculated for the 35 case studies and the 2 base cases of the Lebanese Energy Standards project, as described later in Chapter 6. The variables of 'Window / Façade', 'Window / Office' and "Shading Devices' parametric levels were calculated for each orientation separately (north, south, east / west). An average of each variable for the whole building was also considered. The calculated values of all the variables are illustrated in a designed building description worksheet, documented in Appendix I. All the variables are categorized in four ranges, to which a score from 1 to 4 is assigned to quantify daylight availability in office buildings in Beirut. A variable with an evaluation value equal to 1 would be regarded as a daylight-rejecting variable, while 4 would represent a highly daylight-collecting variable. The evaluation values are set out according to the range of each variable's findings, calculated for the 35 case study buildings. Therefore, these categories are particularly applicable to the studied context. This approach was chosen to anticipate the quantity of daylight available inside the building. This daylighting evaluation tool allows mapping of daylight-rejecting designs, or highly daylight-collecting designs in office buildings in Beirut.

Parametric Level of Analysis	Variables					Evaluation Value			
	Name	Code	Formula	Related Factors Definition	Findings Range	1	2	3	4
Building Shape	Compactness Ratio (CR)	A	$CR = P^2/4\pi A$	P = total building perimeter A =building floor area	1.29 - 4.32 (6.54 is considered as noise)	$0 \leq CR < 2.00$	$2.00 \leq CR < 2.75$	$2.75 \leq CR < 3.50$	$3.50 \leq CR < \infty$
	Shape Coefficient (C_f)	B	$C_f = V/Se$	V = total building inner volume S_e = total envelope surface area	2.41 - 9.32	$7.50 \leq C_f < \infty$	$5.75 \leq C_f < 7.50$	$4.00 \leq Cf < 5.75$	$2.55 \leq Cf < 4.00$
	Envelope to Floor Area Ratio (u)	C	$\hat{u} = S_e / A_T$	S_e = total envelope surface area A_T = total building floors area	0.35 - 1.59	$0 \leq \hat{u} < 0.60$	$0.60 \leq \hat{u} < 0.85$	$0.85 \leq \hat{u} < 1.10$	$1.10 \leq \hat{u} < \infty$
	Porosity Ratio (PR)	D	$R_p = V_v / V$	V_v = total volume of inner void V = total building inner volume	0.00 - 0.27	$0 \leq R_p < 0.05$	$0.05 \leq R_p < 0.10$	$0.10 \leq R_p < 0.15$	$0.15 \leq R_p < 1$
Window and Office Façade Relationship	Wall to Aperture Ratio (WAR)	$E_{N, S, E.W, Av}$	$WAR = S_a/S_f$	S_a = total apertures' surface area S_f = total façade surface area	0.00 - 0.89	0≤WAR<0.25	0.25≤WAR<0.4	0.4≤WAR<0.55	0.55≤WAR<1
	Aperture Location (AL)	$F_{N, S, E.W, Av}$			-	Unilateral	Bilateral	Multilateral	Complete Glazing
	Window Shape Coefficient (C_{ws})	$G_{N, S, E.W, Av}$	$C_{ws} = L_w/H_w$	L_w = window length H_w = window height	-	Horizontal ($2 \leq C_{ws} < 3.5$)	Intermediate ($0.5 \leq C_{ws} < 2$)	Vertical ($0 \leq C_{ws} < 0.5$)	Complete Glazing $3.50 \leq CR < \infty$
	Window Sill Height (H_{ws})	$H_{N, S, E.W, Av}$		H_{ws} is measured in meter	0.00 - 1.80	Low ($0 \leq H_{ws} < 0.75$)	Intermediate ($0.75 \leq H_{ws} < 1.60$)	High ($H_{ws} \geq 1.60$)	Complete Glazing
	Window to Wall Ratio (WWR)	$I_{N, S, E.W, Av}$	$WWR = A_g/A_w$	A_g = net glazing area A_w = gross exterior wall area	0.00 - 0.70 (values over 0.70 are considered as noise)	0≤WWR<0.25	0.25≤WWR<0.4	0.4≤WWR<0.55	0.55≤WWR<1
	Daylight Aperture Ratio (DAR)	$J_{N, S, E.W, Av}$	DAR = WWR x VT	WWR = window to wall ratio VT = glazing visible light transmittance	0.00 - 0.50 (values over 0.50 are considered as noise)	0≤DAR<0.20	0.20≤DAR<0.30	0.30≤DAR<0.40	0.40≤DAR<1
Window and Office Volume Relationship	Daylight Buffer Zone (DBZ)	$K_{N, S, E.W, Av}$		DBZ is measured in meter	3.00 - 9.00 (values over 9.00 are considered as noise)	$8.0 \leq DBZ < \infty$	$6.0 \leq DBZ < 8.0$	$4 \leq DBZ < 6$	$0 \leq DBZ < 4$
	Room Limiting Depth Rule (LD_r)	$L_{N, S, E.W, Av}$	$LD_r = (l/w) + (l/h)$	l = av. room depth ; w = av. room width h = height of window head above floor	1.63 - 4.76 (values over 4.76 are considered asa noise)	$4 \leq LD_r < \infty$	$3 \leq LD_r < 4$	$2 \leq LD_r < 3$	$0 \leq LD_r < 2$
	Office Average Area (A_r)	$M_{N, S, E.W, Av}$	$A_r = l * w$	l = typical office depth w= Typical office depth	9.60 - 140.00	Very Large $30m^2 \leq A_r < \infty$	Large $20m^2 \leq A_r < 30m^2$	Medium $10m^2 \leq A_r < 20m^2$	Small $0m^2 \leq A_r < 10m^2$
	Fenestration Factor (FF)	$N_{N, S, E.W, Av}$	$FF = A_g/A_r$	A_g = net glazing area A_r = typical office total area	0.10 - 0.40 (values over 0.40 are considered as noise)	$0.00 \leq FF < 0.15$	$0.15 \leq FF < 0.25$	$0.25 \leq FF < 0.35$	$0.35 \leq FF < 1.00$
	Glazing Ratio (GR)	$O_{N, S, E.W, Av}$	$GR = A_g * VT / A_r$	A_g = net glazing area VT = glazing visible light transmittance A_r = typical office total area	0.07 - 0.35 (values over 0.35 are considered as noise	$0.00 \leq GR < 0.14$	$0.14 \leq GR < 0.21$	$0.21 \leq GR < 0.28$	$0.28 \leq GR < 1.00$
Shading Devices	Projection Ratio (PR)	$P_{N, S, E.W, Av}$	$PR = w_{sd}/h_{sd}$	w_{sd} = width of the overhang or depth of the vertical fin. h_{sd} = height from window sill to the bottom of overhang or distance between side fins.	0.00 - 1.00	$0.45 \leq PR < 1.00$	$0.30 \leq PR < 0.45$	$0.15 \leq PR < 0.30$	$0.00 \leq PR < 0.15$
	Overhang Ratio (OVR)	$Q_{N, S, E/W, Av}$	$OVR = 1 + a * PR + b * PR^2$	PR = overhang projection factor a = -0.41 for north façade, -1.22 for south façade and -0.92 for east/west façade b = 0.2 for north façade, 0.66 for south façade and 0.35 for east/west façade	0.44 - 1.00	0.00≤OVR<0.55	0.55≤OVR<0.70	0.70≤OVR<0.80	0.80≤OVR<1.00
	Relative Solar Heat Gain (RSHG)	$R_{N, S, E.W, Av}$	$RSHG = OVR x SHGC_{win}$	OVR = Overhang ratio $SHGC_{win}$ = solar heat gain coefficient of the window	0.32 - 0.80	0.0≤RSHG<0.35	0.35≤RSHG<0.5	0.5≤RSHG<0.65	0.65≤RSHG<1.0

Table 5.7. List of variables used in the preliminary evaluation tool of daylighting performance.

5.3.1.1.1 Interpretation and analysis methods of the daylighting evaluation tool outputs

This evaluation tool permits the user to draw a descriptive diagram (or morphological diagram) by which the configuration of building façades can be visually described and compared with each other (Figure 5.3). An irregular diagram means that façades are treated differently, while a regular diagram indicates that façade and offices of different orientation have different configurations and consequent daylighting performance.

The use of the morphological diagram can also facilitate the comparison of buildings, with emphasis on the daylighting performance of their façade design and plan morphology. The comparison of the 35 case studies is done in accordance with the performance of the four identified parametric levels separately, and the total design performance; e.g. the sum of the four parametric levels' performance. This method is used to describe and compare the case studies in Chapter 7.

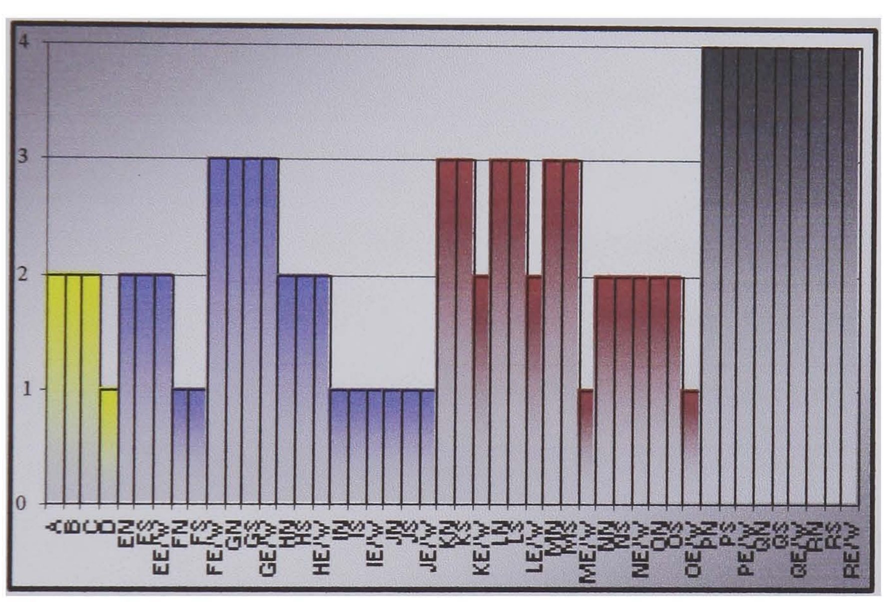


Figure 5.3. Example of a building descriptive diagram; the x axis stands for the design variables and the y axis for the evaluation score.

Using SPSS statistical software, correlational analysis is used to study the significance of each design variable for the daylighting performance evaluation of office buildings in Beirut. This method also permits identification of variables that have been considered or neglected in the studied context. This study is presented in Chapter 8 of this thesis.

Scatter plots and associated trendlines are used to study the development of the four daylighting design parametric levels in general, and each considered variable in particular. This method of analysis permits us to examine the architects' aspirations and design concepts at each period of time, as well as to map the period of the best use of daylighting in office buildings in Beirut.

5.3.1.2 *Daylighting Monitoring Methods*

According to Atif *et al.* (1997) there has been a lack of daylighting monitoring protocols and procedures for buildings, and this has greatly contributed to the small number of daylit buildings monitored worldwide. High electricity savings claimed to result from the use of daylighting were mostly driven from modelling, illuminance measurements from test cells or scale modelling, or just from high daylighting availability. As a result many international projects, mostly in Europe, North America, and Australia, have been established to identify efficient measures for monitoring daylighting performance in real buildings. These include Daylight Europe and IEA Task 21. Johnsen (1998) averred that the process of daylight performance monitoring in an occupied building could be extremely time consuming and expensive, due (among other reasons) to short-term and seasonal variations in the complex conditions that determine the daylight quantity and quality in different spaces of the building.

In 1997, after two years of work, a monitoring protocol was drawn up by the International Energy Agency Task 21 'Daylight in Buildings'. This was to be used as a basis for the appraisal of daylighting systems and daylight-responsive lighting control systems. The main objective of subtask D of IEA Task 21 was to demonstrate the viability of daylighting buildings in various climate zones of the world, providing potential energy savings in buildings while maintaining a satisfactory visual and thermal environment for the occupants and providing real validation data to computer models. The methods of monitoring have been arranged into three levels (Atif *et al.*, 1997):

- Measured performance.
- Measurements of performance control parameters.
- Predicted annual performance based on short-term measurements.

Measured performance provides detailed, hard-fact data on daylighting performance over a short-term period. The monitoring of performance control parameters such as occupancy, lighting control systems and glazing transmittance (visual light transmittance and solar heat transmittance) helps in explaining good or poor daylighting performance. The predicted performance is important to reflect the annual performance that cannot otherwise be achieved with short-term monitoring. Figure 5.4 shows a schematic description of these assessment levels.

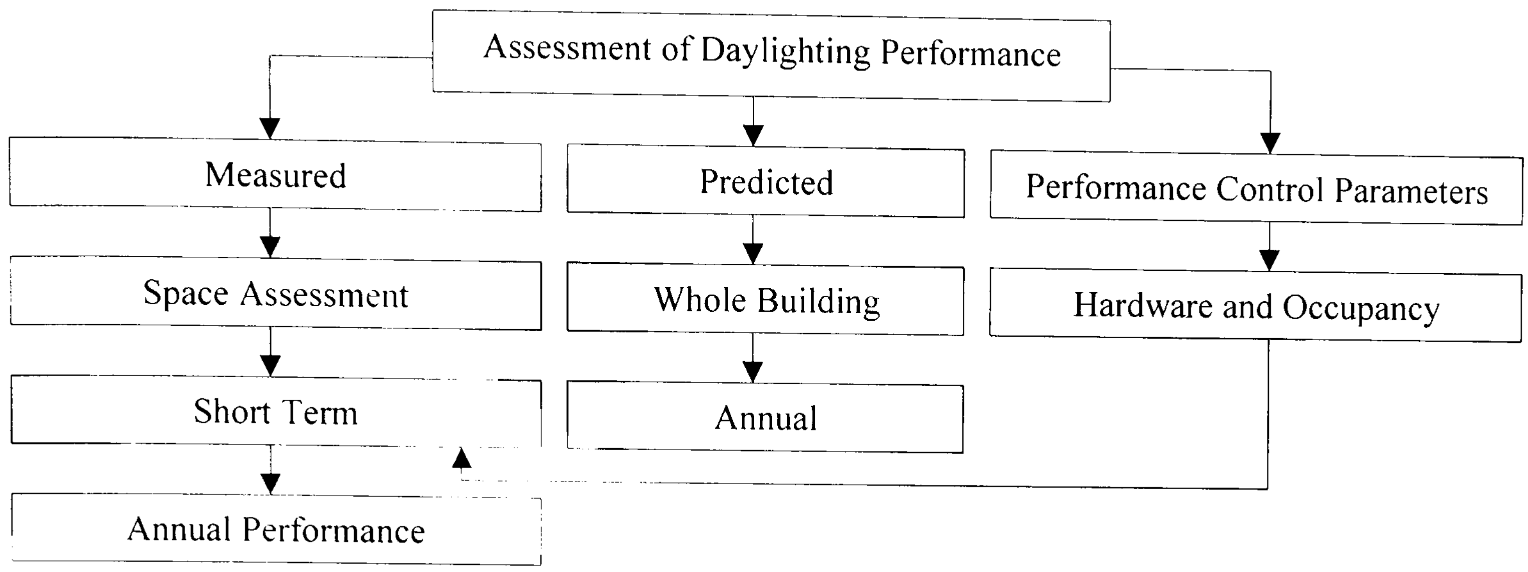


Figure 5.4: Schematic description of daylighting performance assessment methods (Atif *et al.*, 1997).

5.3.1.2.1 Measured performance

Field measurement of indoor illuminance in real buildings is a method that has been adopted in many studies (Baker *et al.*, 1993; Fontoynont, 1999; Li *et al.*, 2000 and Li *et al.*, 2001). The measurement of indoor illuminance is a common approach, but is not the only parameter to assess the daylighting performance in buildings. Post-occupancy evaluation and reported occupants' responses act as support elements to help assess occupants' level of satisfaction.

Monitoring the daylighting performance of entire buildings is impractical, and expensive if the building is large. A selected space assessment over a short-term period can be an alternative solution (Fontoynont, 1999). The contribution made by daylighting to indoor illuminance can then be limited to selected test measurements. An increase in the sample number increases the accuracy of the measurements of daylighting's contribution to indoor illuminance.

Measured parameters should reflect the daylighting contribution to indoor illuminance, and the electrical lighting displaced by daylighting. Figure 5.5 shows a schematic description of the daylighting monitoring process (Atif *et al.*, 1997).

According to Muller (2002), the criteria for daylight monitoring in existing buildings should include:

- One-week measurement of horizontal illuminance in the selected space for a typical summer and winter solstice as well as equinox, either spring or autumn (around June / December 21, and September / March 21).

- One-week measurement of external horizontal illuminance; this should be recorded simultaneously with the indoor illuminance measurements. It has also to be measured to reflect the availability of daylight just before daylight enters the building.

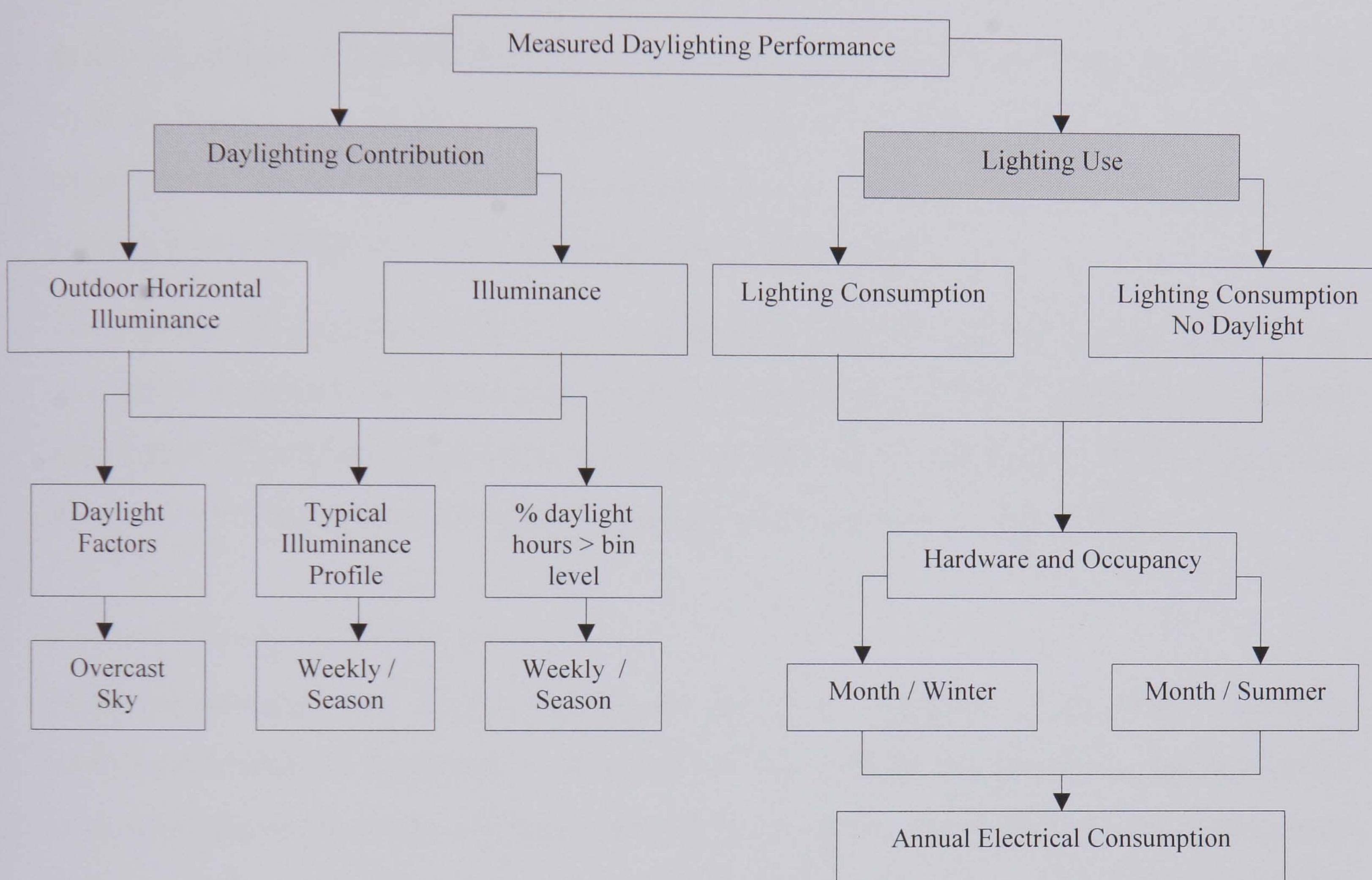


Figure 5.5: Schematic description of the daylighting monitoring process (Atif *et al.*, 1997).

5.3.1.2.1.1 Output of the measured performance level

The outputs and performance indicators of the measured performance levels pointed out in the previous section, and which contribute to indoor illumination are:

- Typical weekly (and daily) profile per season of the indoor illuminance.
- Percentage of daylight-hours where the indoor illuminance exceeds the required indoor horizontal illuminance.
- Typical daylight resulting from measurements taken during overcast sky conditions.

5.3.1.2.1.2 Selection of test points and daylighted zones

Daylighted zones in the selected space should be defined before selection of the measurement points. These zones should be defined based on their distance from the window, and based on the activity in the zone. Measurement points should represent typical illuminance in each daylighted zone. The number of daylighted zones and test points depends on the dimensions of the space, and on the activity.

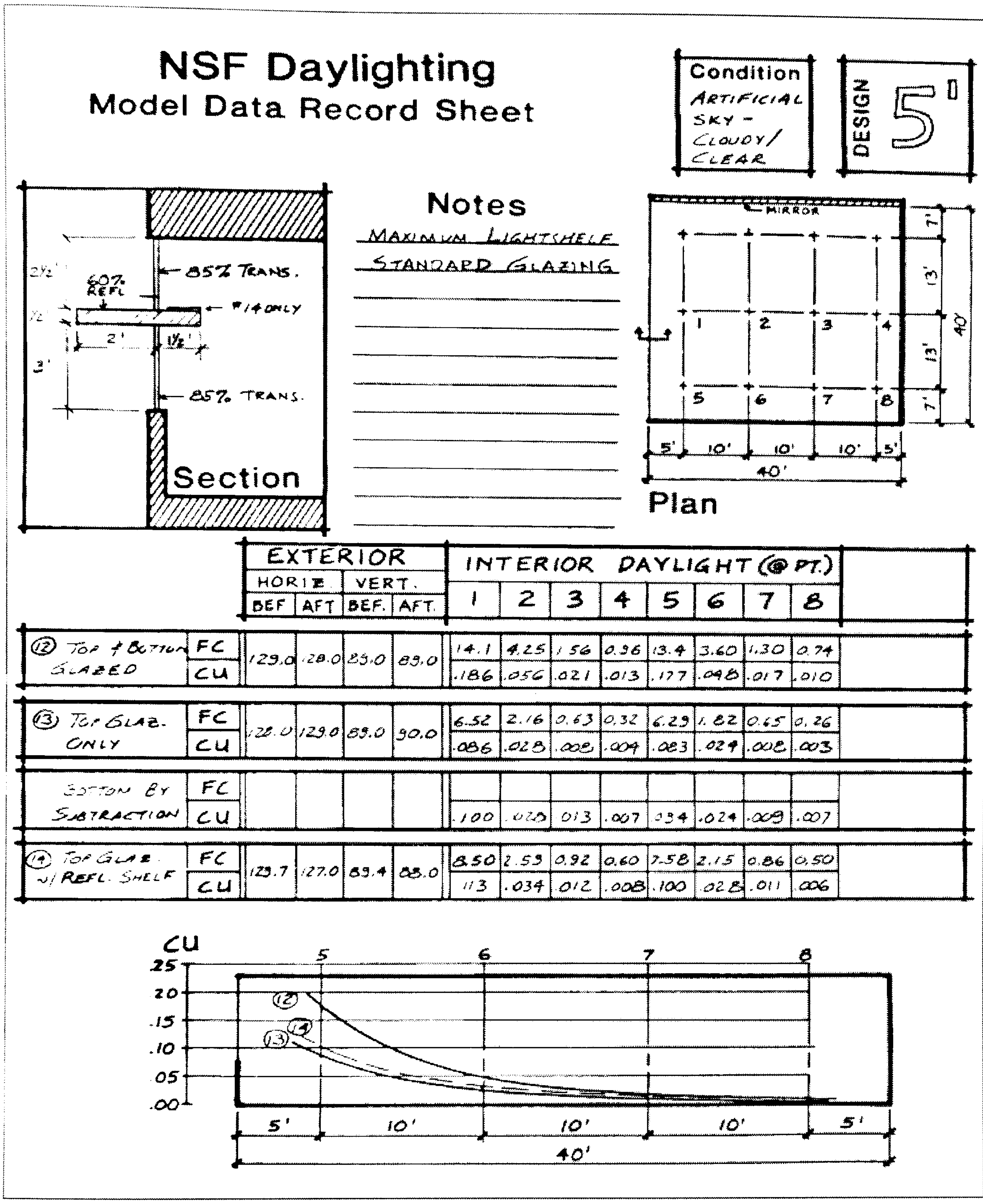
A private office with a sidelit window should not have more than 2 test points, one for each daylighted zone, one of which has to represent a dark area (Atif et. al., 1997). On the other hand, for a daylighting illuminance levels distribution study Mueller (2002) recommended a minimum of seven test points in each room.

The number of daylighted zones in an open plan office should be at least equal to the number of workstations in the selected space. A minimum of one test point at the working plane level (75 cm above the floor) should represent each workstation. The test point can be at centre of the zone or represent a critical location of activity, e.g. a desk.

5.3.1.2.1.3 Recording illuminance

Field measurements of illuminance levels are most commonly made with a portable instrument called the lightmeter or luxmeter, or illumination photometers. The instrument is simply held in the plane of measurement (75 cm above the floor), and the illuminance in lux is read on the scale. Instruments of this kind commonly read from 1 lux to 20000 lux, although more sensitive types are available for reading much lower levels as in emergency lighting. Small handheld units are easy to use, but more accurate, stationary units provide more complete and reliable data. In most cases, fixed photocells are impractical if the building is occupied. If the photocell is mounted on a desk, occupants and papers can affect the illuminance recorded by the detectors.

It is important to record every illuminance measurement on a properly designed worksheet, to assure the consistency and accuracy of the field survey. Figure 5.6 shows an example of a 'daylighting model data record sheet' designed by Schiler *et al.* (2000). This includes a log sheet showing the plan of the building, together with the points at which measurements are to be made. The date, time and sky conditions should also be recorded on this sheet. It is also necessary to record any luminaires that are on while taking the measurement.



		EXTERIOR				INTERIOR DAYLIGHT (@ PT.)							
		HORIZ.		VERT.									
		BEF	AFT	BEF.	AFT.	1	2	3	4	5	6	7	8
(12) TOP + BOTTOM GLAZED	FC	129.0	128.0	83.0	83.0	14.1	4.25	1.56	0.36	13.4	3.60	1.30	0.74
	CU					.186	.056	.021	.013	.177	.048	.017	.010
(13) TOP GLAZ. ONLY	FC	122.0	129.0	83.0	90.0	6.52	2.16	0.63	0.32	6.29	1.82	0.65	0.26
	CU					.086	.028	.008	.004	.083	.024	.008	.003
BOTTOM BY SUBTRACTION	FC												
	CU					.100	.028	.013	.007	.034	.024	.009	.007
(14) TOP GLAZ. W/ REFL. SHELF	FC	123.7	127.0	83.4	83.0	8.50	2.53	0.92	0.60	7.58	2.15	0.86	0.50
	CU					.113	.034	.012	.008	.100	.028	.011	.006

Figure 5.6. Example of data record sheet (Schiler and Japee, 2000).

5.3.1.2.1.4 Constraints of daylighting field measurement methods

It was noted in the previous review that monitoring daylight in real buildings has been done as part of certain international projects (e.g. IEA Task 21 and Daylight Europe) but this process is extremely time consuming and expensive. The possibility of conducting field measurements of daylighting in the 35 case studies included in this study would therefore be impractical and inaccurate. Research potential, time limitations and the complex conditions determined by continuous variation in daylight quantity and quality are the main reasons for not performing daylighting field measurement in this study.

A pilot study of daylighting field measurement was done in one of the office buildings in Beirut (Saridar *et al.*, 2001). Illuminance measurement in some office buildings was not acceptable to some office owners (e,g, companies, bank headquarters, other organisations) and occupants, as they considered it distracting from their work. In some buildings, permission of measuring illuminance was limited to only one time and only in restricted areas, which would not necessarily fulfil the criteria of area selection to be monitored. Therefore, the measurement of daylighting illuminance at different seasons and time seemed to be impractical and accordingly the monitoring results would have been inaccurate.

However, as the practice of architecture and lighting design has become increasingly computerised, daylighting field measurement has been used to validate the results of simulation tools (Athienitis *et al.*, 2002; Galasiu *et al.*, 2002 and Ng, 2001). Therefore, in this study, illuminance profiles of the case studies were only predicted using a simulation tool; the selection of the appropriate simulation tool and validation of its results are discussed later, in 5.3.7. Setting the boundaries for daylighting simulation will also be extensively described in Chapter 9.

The contribution of daylighting to overall electricity use for lighting is also predicted. The predicted results are evaluated using real monthly electrical consumption. It was intended that this information should be obtained for 3 years (2000-2002) for each case study. 2000, 2001 and 2002 were considered to give a more precise description of electricity consumption in the case studies than the years before, for two reasons:

- Electricity was not available in buildings for a continuous 24 hours per day
- Illegal tapping of the distribution lines was practiced by a large number of people, while the state was unable to take corrective measures.

However, the acquisition of the required data was not always easy and ultimately proved unsuccessful. These limitations are discussed later, in Section 9.4.3 of Chapter 9.

5.3.1.2.2 Predicted performance level: short-term and annual

In most of the reviewed daylighting studies, computer simulation tools are used to estimate lighting flow patterns in buildings, daylighting contribution in the space, electrical lighting consumption and /or the impact of daylighting on thermal loads. The advantages and disadvantages of available daylighting/lighting simulation packages are reviewed in Section 5.3.5. This review aims to select the appropriate simulation tools for this study.

The objectives of the predicted performance level are:

- To overcome the shortcomings of daylight monitoring.
- To examine the potential savings due to daylight / electric light integration.

The simulation boundaries of this study are explained later, in Section 9.3 of Chapter 9.

5.3.1.2.3 Performance control parameters

Performance control parameters refer to daylighting hardware and occupancy that improve or worsen daylighting performance. The characteristics of these parameters help in explaining the daylighting performance.

5.3.2 Research Methods for Daylighting and Associated Energy-Saving Assessment

A great number of studies have been done dealing with the reduction of energy consumption in buildings, over a period of many years. However, impressive progress in the electronic field (e.g. computers, measuring instruments) in the last few years has opened new prospects in the field of lighting energy savings, particularly in office buildings. Daylighting can lead not only to reductions in artificial lighting consumption, but also to a reduction in lighting internal loads and thus in cooling loads. However, the admission of too much daylight can increase cooling loads. If a model only considers the energy used for lighting, it would give the false impression that the optimum solution is 100% glazing. An integrated approach, combining daylighting and thermal aspects is required; this should take account of energy used for lighting while at the same time considering heat gains and losses from windows and luminaires. The method must provide a breakdown of heating, cooling and lighting energy use, to allow the full effect of energy overall demand to be assessed.

The literature shows that it is particularly difficult to measure the energy efficiency of appropriate use of daylighting with non-standard windows. For example, Szerman (1993) simulated an office building with classical windows, i.e. no specific daylighting system. The results showed 77% of lighting energy savings, and 14% of total electricity consumption savings. Zeguers (1993) speaks about 20% lighting energy saving. Embrechts *et al.* (1997) estimated that an individual lighting dimming system could offer 20–40% of electric lighting consumption savings. Opdal *et al.* (1995) compared measurements and calculation results, and obtained 40% of lighting savings (simulations) and 30% of lighting energy saving (measurements). In their case, they did not find any difference in heating and cooling consumption.

The above range of expectations and results demonstrates the difficulties facing the use of simulation techniques in daylighting, to predict accurate energy savings. The difference in values can be explained by the fact that many parameters play a role in the results, and only one change in these parameters can change the results significantly. The values presented here are difficult to compare because they are related to a particular climate, building, and daylighting system. However, all the authors agree that artificial lighting management according to daylighting availability can reduce electrical lighting consumption, but this management cannot be done without taking visual comfort into account. Another important fact is that any lighting management system has to be accepted by the employees. If this is not the case, energy savings can fall to zero (Embrechts *et al.*, 1997).

5.3.2.1 *Performance Control Parameters*

In order to calculate the energy contribution from daylighting, Attenborough *et al.*, (1996): considered the following steps ideal for a daylighting / energy performance assessment:

- Determine the interior illuminance levels at a chosen location, based on the geometry of the room; its glazing and shading characteristics; internal and external obstructions, and the assumed external illuminance of the sky (based on either CIE standard overcast sky; average sky data or real or measured sky data). This has been extensively studied in Section 5.3.1.2.

- Describe the switching criteria for the lighting in the chosen location, for example manual switching, continuous dimming linked to a photosensor, stepped switch off in response to a photosensor, etc. A description of control strategies will be found in Section 9.3.1.3.4.
- Set the target illuminance for the chosen location, for example 300 lux in the working plane, or at a photoelectric control sensor (see Section 9.3.1.3.1)
- Describe the characteristics of the proposed artificial lighting system, for example the installed circuit load (W/m^2), the lamp efficacy (lumens/W), task or uniform lighting, etc. (see Section 9.3.1.3.2)
- Use this information to decide for a given time period whether the light will be on, off or dimmed, calculate the lighting power consumption over the time, and the heat gains to the space.
- Calculate the overall energy demand for the lighting circuit, heating and cooling.

This study has only focused on the energy required for electric lighting, as the selected software does not support simulation of heating and cooling loads. However, the simulation outputs could be used in thermal simulation tools such as DOE2, TRNSYS, etc.

5.3.2.1.1 Assessment of switching strategies

However accurate the prediction of internal illuminance may be, the greatest factor affecting predicted energy contribution is the assumptions made regarding switching. Having determined the internal illuminance level at a given step time, a method is required to determine whether the lights are likely to be switched on, off, or dimmed in response to the daylight available, and to determine what effect this has on the power consumed by the lighting circuit. A number of papers have been published about this subject (Hunt, 1980; Knight, 1999; Athienitis *et al.*, 2000; Li *et al.*, 2001 and Athienitis *et al.*, 2002).

Most of the methods allow the following switching arrangements to be modelled:

- Preset manual switching schedules based on hours of occupancy. These take no account of daylight.

- Manual switching methods linked to the probability of the lights being switched on or off for a given daylight level.
- Ideal dimming systems where the lights are automatically dimmed directly in proportion to the illuminance level measured at a sensor (either internal or external).
- Stepped dimming systems, where a proportion of the lights are switched off when daylight levels exceed a preset level or are switched on when they drop below a separately defined level. The illuminance levels must be determined at the position of the photosensor control.

The power savings related to dimming switching assumptions are relatively simple to calculate, however a correlation needs to be made between the degree of dimming and its effect on the circuit load. For example, dimming the light output of a fluorescent tube by 30% might only result in a power saving of 20%, and algorithms are required to consider this.

The greatest difficulty arises where the assumption must be made in relation to the occupants' use of manual switching. Adeline, APACHE, ESP, and SERI-RES all use assumptions based on Hunt's method. Field studies of switching patterns undertaken by Hunt (1980) resulted in three conclusions:

- In each room usually all or none of the lighting was in use.
- On entering an empty room, people would decide whether to switch the light on. Once on, the lights were rarely switched off until the room became completely empty again.
- The probability of people switching the lights on was most closely related to the minimum daylight illuminance on the working plane.

Hunt (1980) derived a series of curves that relate the minimum illuminance level in the room to the probability of someone switching on the lights at the start of occupancy period. These probability assumptions can be used to determine whether the lights will be on or off at each time step in dynamic daylight analysis.

All these lighting control strategies are included within the selected simulation software Adeline, and are used in this study. These strategies are discussed in more detail in Chapter 9.

5.3.2.1.2 Output of lighting energy savings assessment

The simulation outputs that might contribute to the assessment of energy savings due to daylighting and electric lighting control strategies are:

- Monthly electrical lighting consumption with no daylighting (kWh/m²/month).
- Monthly electrical lighting consumption with daylighting / electric lighting integration controlled by on/off lightswitch and dimming strategies (kWh/m²/month).
- Percentage of electrical lighting savings per month.
- Predicted annual electrical lighting consumption (kWh/m²/year).
- Estimated annual electrical lighting savings (kWh/m²/year).

The possibility of acquiring such outputs, using the selected simulation software Adeline is discussed in Section 9.3.2 of Chapter 9.

5.3.2.2 *Energy Outputs Aanalysis Methods*

A simple approach is to use empirical data to relate energy use to a number of key parameters, such as glazing area, room depth, daylight factor, the effectiveness of controls, and installed power load. This is the approach adopted by ESICHECK, the CIBSE Energy Code Part 2c, and the Dutch method NPR 2917.

An earlier review of energy targeting methodologies undertaken by ECD for BRE revealed two main approaches for setting targets against which a building's overall energy performance can be compared (Attenborough *et al.*, 1996):

- Comparison against a benchmark.
- Comparison against a reference building.

The BREEAM scheme in the UK, and a number of proposed methodologies for predicting overall energy consumption in European countries, use a benchmarking approach (Baldwin *et al.*, 1998). The building's energy is calculated using a standard procedure or computer model, and compared against a published benchmark figure or target. For example, the Netherlands building regulations are based on numerical energy performance coefficients that determine the total primary energy use for heating, fans, pumps, lighting, comfort cooling, humidification, and the production of domestic hot water.

Using a benchmark method, where the method of calculation is the same in all cases, allows meaningful comparison between one building and another (Attenborough *et al.*, 1996).

On the other hand, where a benchmark is used for energy targeting a standard set of assumptions must be agreed, to cover occupancy factors such as equipment loads, hours of use, occupancy density etc. In addition, difficulties may arise in dealing with deferred daylight availability in different parts of the world.

As for the comparison against a reference building, the ASHRAE 90.1 standard (1989), for example, sets out a Building Energy Cost Budget Method where energy-running costs for the building design are compared to a prototype reference building. The prototype is essentially a building of similar size to the design building, that complies with the prescriptive and sub-system performance standards set out elsewhere in the ASHRAE 90.1 code. The sub-system performance standards cover heat loss, lighting energy use, HVAC systems and hot water.

In this study, the energy outputs (discussed in Section 5.3.2.2) of simulated case studies are mainly compared to each other. A correlational relation will be drawn between the energy outputs and daylighting variables considered in the developed evaluation tool. A UNDP project that aims to develop a new energy code in Lebanon is taking place at the time of writing. Simulation modelling is being developed for two office building prototypes in the coastal climatic zone of Lebanon, using the DOE.2 package. However the results of this project are not yet published, which limits the possibility of comparing the energy outputs of the simulated case studies with any published benchmark figures.

5.3.3 Research Methods for Daylighting and Associated Thermal Load Analysis

In general, heat within a building originates in three ways: external, internal and ventilation. The external heat gains consist of solar radiation conducted through opaque building materials and transparent openings. Internal heat loads are caused by the occupants, mechanical and electrical equipment, and artificial lighting. Outdoor air which infiltrates through cracks and openings also contributes to the heat in the interior space, and increases the cooling and dehumidifying loads.

For a given window of a specific glazing type, the critical variable determining the solar heat gains and the amount of daylight entering a building is the glazing area. A large window area will result in more cooling requirements, due to an increase in solar radiation. It will however also admit more daylight, and may reduce electric lighting consumption. Because daylight has high luminous efficacy, less heat is dissipated for the same artificial lighting requirement. Hence internal heat due to artificial lighting tends to decrease. It is therefore important to assess the trade-off between beneficial natural daylight and unwanted solar heat gain.

There have been many empirical and theoretical studies dealing with the complex interactions involved in the analysis of daylighting, and associated thermal performance in office buildings (Lam *et al.*, 1996). Computer simulations programs such as Adeline, DOE-2 and Seri-RES are used to conduct hour-by hour computation of the thermal loads associated with daylighting schemes, and assess the relative benefits and penalties of natural daylight and the corresponding lighting internal heat gains and solar heat gains, respectively.

The climatic conditions in Beirut falls in the comfort zone all year around which enables users to open windows. With proper natural ventilation techniques, heat gain can be dramatically reduced. This is a characteristic in the East Mediteranean that hasn't been properly considered.

5.3.4 Assessment and Measurement Techniques of Human Comfort in Daylit Office Spaces

Results from modelling and measurement of building daylighting systems may show electricity savings, but any daylighting system is only successful if the building's occupants are satisfied with the indoor environment and operation of the system. (Bordass *et al.*, 1995; Hygge *et al.*, 1997 and Jahnkassim, 2002). The literature reviewed in Chapter 4 showed that daylighting, or more generally the indoor environment, may affect occupant health, behaviour and productivity in office spaces.

One task of most international daylighting projects, for example IEA Task 21 and Daylight Europe, conducted during recent decades was to study and evaluate the quality of daylight design and user acceptance. According to Hygge *et al.* (1997), there are only two ways to get a user's reactions: measure their performance in some way, or their attitude to the environment. The latter is generally done in a so-called post-occupancy evaluation POE. Preiser *et al.* (1988: 3) defined POE as '*the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time. By analogy, the actual performance of the building is compared with explicitly stated performance criteria; the difference between the two constitutes the evaluation*' (Figure 5.7).

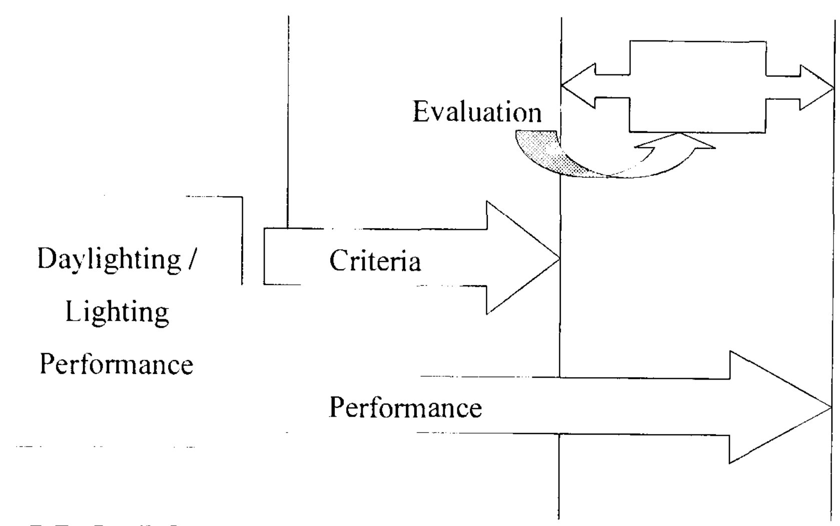


Figure 5.7. In POE, the evaluation is the difference between the performance criteria and the actual building (Preiser *et al.*,1988).

The tools used in POE may be interviews with the building's users, questionnaires and controlled environment measurements. The latter method was difficult for use in this study, due to limitations on controlling the environmental conditions in the studied cases. On the other hand, the main disadvantage of interviews is that they are more time consuming than questionnaires. An 'interviewer effect' may result from interaction between the interviewer and respondent. Variations in the use of interview techniques, including tone of voice and the inconsistent use of probes, also reduce standardization. Validity and reliability are seriously affected by these disadvantages (Burns, 2000). Therefore, a POE questionnaire was the method selected for this research to measure occupants' comfort and attitudes in office buildings in Beirut.

The aim of the POE questionnaire is to give an indication of what the users think of the building as a whole, of their daylit (or non-daylit) interior work environment, including noise and thermal conditions. It should also give an indication of how the lit environment is experienced, and to what extent the users think that lighting and daylighting influence their productivity.

The indoor environment varies over time, especially daylight, and problems might arise only under specific conditions; equally the questionnaire should be designed to collect the users' experiences over time.

Since individuals differ in their attitudes and demands, there is always a spread in responses. To account for that, the questionnaire must be distributed to a number of users in the building. As a rule of thumb, 30 persons or more are needed in each group or case study (Hygge *et al.*, 1997).

5.3.4.1 *Review of Questionnaires in Earlier Post Occupancy Evaluation Studies*

Researchers have used several POE questionnaires over the years. Many have been constructed for a specific project, and used only once (Elder *et al.*, 1979; Collins *et. al.*, 1989; Energy Edge, 1991; Fontoynont 1999). Therefore, few POEs have been seriously evaluated. Internationally, some efforts have been made to design questionnaires in order to get a 'standard' POE questionnaire (or method), but so far those efforts have not shown any success (Hygge *et al.*, 1999). No questionnaire can be used as it is, with known merits and weaknesses.

There are very few POEs specifically focused on the lighting of a building. Recently, a POE questionnaire was designed for the IEA Task 21/ ECBCS Annex 29. This questionnaire is described in the Joule II project Daylight Europe, and in turn was based on questions used in former POE studies (Fontoynont, 1999). Another POE questionnaire was designed by the Building Use Studies (BUS). Since 1985, BUS has improved a Probe questionnaire format that aims to evaluate all-round building performance with an equal emphasis on building services, facilities management and architectural aspects. Two proposed questionnaires are described in the following sections.

5.3.4.1.1 Post occupancy evaluation questionnaire used in JOULE II / Daylight Europe and IEA Task 21

The questionnaire consists of 37 questions that cover attitudes to the building as a whole, the work station, lighting and other environmental factors such as thermal and acoustical conditions, privacy, view etc. The major part is about lighting, both daylight and artificial light.

There are also questions about how the workplace is lit, if the windows create problems, the attitude to windows with their advantages and disadvantages. The worker's position in relation to the nearest window is recorded and the orientation of the window can be found from the drawings. Finally, data concerning age, sex, etc. of the respondent and about how long he or she has been working in the building are also collected.

The user is asked to give an opinion on how the conditions are experienced over time and to try to tell when problems arise, if they do.

This questionnaire uses the nominal scale method to measure the respondent's attitude to his / her workspace. By definition, nominal means 'name'; a nominal scale does not actually measure, but rather names (Burns, 2000).

5.3.4.1.2 BUS Probe questionnaire

This questionnaire is divided into 12 different sections. The first section is concerned with respondents' age, sex, and information about their location in the building, and the type of work they do. In sections two through five, the questions are more concerned with the architectural design aspects of the building and the work area. The respondent is asked to evaluate the design according to his/her work requirements. Parts six, seven and eight are intended to evaluate thermal, acoustical and lighting conditions, respectively. The last four sections are about user comfort, health and productivity, in accordance to indoor environmental conditions. The last section seeks to obtain information about user control over their environment.

The BUS questionnaire does not focus on daylighting / lighting user evaluation like the previous questionnaire, but it includes some evaluation of work productivity and health.

In this questionnaire the Likert scale method is used to measure the respondent's attitude to his / her workspace. The advantage of this method is that it is based entirely on empirical data from the subjects' responses, rather than the subjective opinions of judges. This method produces more homogeneous scales and increases the probability that a unitary attitude is being measured, and therefore that validity and reliability are reasonably high (Burns, 2000).

5.3.4.2 *Questionnaire Design*

The design of the questionnaire used in this study is based on the reviewed POE questionnaires. The designed questionnaire (documented in Appendix VI) consists of six different sections, described in the following subsections. The questionnaire starts with a brief introduction about the aim of the conducted survey and the confidentiality of information collected. It has also been translated into Arabic and French, these being languages commonly used in Beirut.

5.3.4.2.1 User's general background

In general, with POEs it is not important to be able to identify the person who is completing in the questionnaire. The most important thing is to identify workspaces, to facilitate the analysis of data on a locational basis. Furthermore, in POE about daylighting and lighting conditions it is useful to involve an equal number of female and male occupants, if possible, and to divide them depending on their eyesight and age (Baker, 2002). The user's age might affect their optimum daylight illuminance requirements, and the use of additional or reduced electric lighting. In addition, it is necessary to make a correlation between users' age, visual and general health complaints caused by inappropriate environmental conditions.

Questions 3 to 8 are general, descriptive questions about the type of work conducted in the building and the occupancy profile of the building.

5.3.4.2.2 Desk and work area description

In this section of the questionnaire, the user describes his work area and the number of persons sharing the same room.

The data collected from this section is to investigate the development of interior space during the 20th century in Beirut.

5.3.4.2.3 Physical environment

The aim of this section is to collect data that responds to the following questions:

- What the occupants want from their indoor office environment.

  The replies to these questions are indicators of what the occupants want and not what they have.

- How the occupants rate their indoor office environment.

  The replies to these questions are indicators of the performance of the façade and space design.

5.3.4.2.4 Health and productivity

The questions in this section are intended to produce a self-user estimate of their health and productivity. They seek to find a relationship between health problems occurring in the building and the distance of the user from a window. The best way of finding out is to look at the frequency of complaints, or symptoms of illness caused by the building. The frequency of sick building syndrome is correlated with the distance of occupants (working with VDUs or doing conventional office work) from the nearest window.

5.3.4.2.5 Daylight and relation to window

The first question in this section (question 19) examines the users' preferences regarding windows in their workspace. Questions 20 to 22 aim to describe the position of the office occupants relative to the nearest window. In the following questions occupants are asked to rate the size and visual / thermal performance of their office window.

5.3.4.2.6 Light conditions and electric light usage

In this section, users should describe and evaluate the daylighting / electric lighting performance in their workspaces. The causes of visual discomfort are identified; whether it is because of inappropriate artificial lighting or daylight / sunlight coming through windows.

5.3.4.3 *Constraints of Post Occupancy Evaluation Studies in Office Buildings in Beirut*

The designed questionnaire described in the previous section was used in a pilot study of POE of office buildings in Beirut. Table 5.8 shows the number of questionnaires distributed among 8 office buildings, and the number of questionnaires collected. It is quite clear from that table that the number of respondents was very small, and would not satisfy the rule of thumb that requires 30 persons or more in each case study to obtain valid, accurate, and significant results (Hygge *et al.*, 1997). In addition, the researcher was not allowed to distribute the POE questionnaire in several buildings, namely the ESCWA building (B32), BLOM Headquarters (B31 and B34) and the Starco Buildings (B12 and B13). The managers of these buildings, occupied by the international organization ESCWA, a bank and the Ministry of Higher Education respectively, considered that the distribution of the questionnaire would be a distraction for the employees and would affect the security of the building. Another constraint was the vacancy of some case studies, making POE survey impossible (e.g. B04, B04, B09, B17, B33, B35).

However, a total of 72 responses from the 8 buildings surveyed were used to obtain general information, such as occupants' preferences regarding daylight, and the relation between the occupant's distance from a window and health syndromes. These analyses were studied in Chapter 4.

	Building ID - Building Name	No. of distributed questionnaires	No. of collected questionnaires
1	B03 - Beirut Municaplity	27	17
2	B16 - Horseshoe Building	10	0
3	B23 - Arab Bank Building (BCD)	30	17
4	B24 - Verdun Centre	40	6
5	B28 - Unesco Centre	10	5
6	B29 - El-Ghazal Tower	50	9
7	B30 - Intercontinental Bank Headquarter	40	15
8	Deputies Office Building	100	3
	Total	**307**	**72**

Table 5.8. The number of questionnaires distributed and collected in a pilot study for a POE survey conducted in eight office buildings in Beirut.

5.3.5 Potentials of the Recommended Simulation Tool

There is a wide range of existing packages that, to a greater or lesser extent, offer the ability to model performance of daylight in buildings. To select the appropriate tool, selection criteria are needed. The criteria are based on previous studies reviewed below.

An earlier survey of the use of daylight prediction methods undertaken by BRE for ETSU (Attenborough *et al.,* 1996), asked respondents to list features they felt were important to include in daylighting prediction methods. These included the following technical abilities:

- Ability to model complex, non-rectangular rooms
- Ability to model sunlight or real sky conditions in addition to overcast skies
- Ability to model complex obstructions (both internal and external)
- Ability to model complex systems such as light shelves
- Plots of illuminance values and 3D isolux diagrams
- Visualization of interiors

The BRE survey (Attenborough *et al.*, 1996), and the review undertaken by Roy (2000), listed ease of use as being an important factor for the selection of a simulation tool. The main factor affecting ease of use is the 'front end', or user 'interface'. Windows systems with pull down menus are increasingly popular, and help to improve ease of data input. Another aspect of ease of use is the form in which the output is presented. It is helpful to be able to plot graphs and tables of key information, rather than simply being presented with a long list of numbers.

Roy (2000) listed the problems associated with ease of use, i.e. the time taken to prepare and edit the data describing the geometry and optical properties of the scene, and the time needed to run the simulations. These two problems are linked by the fact that the more accurately the scene is constructed, the more effort is required to prepare the data.

Credibility or validity is another criterion when choosing a daylighting (or energy) simulation tool. Credibility can be defined by how closely the simulation results gained by any adopted program correspond to reality.

Before reviewing the existing packages and possible applicability to this research (Section 5.3.6 and Section 5.3.7), it is important to review the main techniques used to predict daylighting and lighting levels in indoor spaces. All existing daylighting simulation tools are based on two calculation methods: the radiosity technique and the ray-tracing technique.

5.3.5.1 *Radiosity Method*

The radiosity method was probably one of the first lighting calculation techniques applicable to the evaluation of the interchange of light among all the surfaces defining an architectural space. This method has a significant advantage over former analytical techniques, because it allows for light inter-reflections between surface walls.

Originally developed for energy calculations, the radiosity method was used to determine the energy balance of a set of surfaces exchanging radiant energy. Some of its basic hypotheses and limitations are that:

- wall surfaces must be subdivided into small finite elements (generally triangles) characterised by homogeneous photometric properties (e.g., reflection coefficient);

- all elements must be perfect diffusers (Lambert's law);
- similar hypotheses must be applied to all the external obstructions situated in front of windows and openings.

The radiosity method is used to determine the illuminance and luminance of a set of points located at the centres of different surface elements. This approach offers the distinct advantage that light computation is independent of viewpoint, hence several views can be efficiently constructed after the main set of computations have been completed

The SUPERLITE programme was one of the first widely available daylighting computer tools based on the radiosity method. The current version can handle daylighting and electric lighting, as well as rather complex room geometries (e.g., L-shaped rooms). Only perfectly diffusing surfaces can be considered; glazing can be transparent or diffusing, and windows can have shades.

5.3.5.2 *The Ray-Rracing Technique*

Ray tracing works on the principle of tracing all the light paths, including reflections and refractions through the scene. The ray-tracing technique determines the visibility of surfaces by tracing imaginary rays of light from a viewer's eye to the objects of a rendered scene. This is called backward tracing, as it traces rays in reverse, i.e. from their destination to their source. Each ray must be traced through the 3D scene to a light source (or reflecting surface), and beyond if the surface is reflecting light.

Most daylighting and electric lighting programmes currently use the backward ray-tracing technique. A slightly different technique is used by some software to improve daylighting calculations, especially for clear sky conditions. Originally developed for imaging purposes, some ray-tracing programmes (e.g. RADIANCE, GENELUX and PASSPORT) were adapted and optimised for calculation of daylighting within building spaces (Ward *et al.*, 1988). In this case, light rays are traced until they reach the main daylight source, which is usually the sun position (clear and intermediate skies) or the sky vault (cloudy skies). Several validations of ray tracing programmes have demonstrated their reliability in daylighting performance assessment and advanced systems design (Compagno, 1993 and Fontoynont, 1999).

5.3.6 Existing Packages

In 1996, ETSU undertook a review of the energy prediction methods of daylight calculation currently in use in the UK (Attenborough *et al.*, 1996). This was based on a literature review and discussions with large engineering practices and academics involved in the areas of daylighting and energy simulation research. The aim of this review was to identify manual methods or computer programs that were capable of determining energy use in non-domestic buildings, and of taking into account the energy savings resulting from daylighting. The review identified a range of methods that are capable of predicting overall energy use while accounting for daylight. These vary in complexity, from empirical methods such as the CIBSE Energy Code to the dynamic energy simulation models such as DOE2 and ESP.

This section gives an overview of existing daylighting and energy simulation tools. The software listed in Table 5.9 are the common tools surveyed by Attenborough *et al.* (1996), *Fontoynont et al.* (1999), Roy (2000) and the US Department of Energy (2001). In Table 5.9, the potential abilities identified in section 5.3.5 are used and their significance for this study is evaluated. The aim of this review is to identify computer programs that are capable of determining the energy potentials of daylighting in office buildings in Beirut.

Simulation tools	Analytical Methodology: Radiosity	Analytical Methodology: Ray-Tracing	Operating System: MS Windows	Operating System: MS DOS	Operating System: Unix	Operating System: Web-Based	Operating System: CAD Interface	General application: Daylighting	General application: Lighting	General application: Lighting Heat Gain Analysis	General application: Lighting Energy Analysis	General application: Visual Comfort Analysis (Glare)
Adeline (v. 3)	✓	✓	✓				✓	✓	✓	✓	✓	✓
RadioRay		✓	✓				✓	✓	✓			
Lightscape (v. 3.2)		✓	✓					✓	✓			
Radiance (v. 2.4)	✓	✓			✓		✓	✓	✓			✓
Genelux		✓	✓			✓	✓	✓	✓			✓
Leso-Dial	✓		✓					✓				
Rayfront (v. 1.0.3)		✓	✓				✓	✓	✓			
FLUCS/APACHE	✓		✓					✓	✓	✓	✓	
Superlite (v. 2.4)	✓			✓				✓	✓			✓
LumenMicro 2000	✓	✓	✓				✓	✓	✓			✓
BSim2000	✓		✓					✓		✓	✓	
DOE-2			✓	✓	✓			✓	✓	✓	✓	
Energy-10			✓					✓	✓	✓	✓	
TRNSYS			✓							✓	✓	
Ener-Win			✓					✓		✓	✓	

Simulation tools	Type of Analysis: Horizontal Point-by-Point Illumination	Vertical Point-by-Point Illumination	Room Surface Luminance	Average indoor illuminance	Average Outdoor Illuminance	Visual Comfort Probability	Unit Power Densisty	Electric Lighting Consumption	Solar Heat Gain Calculation	Cooling and Heating Load	Economic Analysis
Adeline (v. 3)	✓	✓	✓	✓		✓	✓	✓	✓		
RadioRay	✓	✓									
Lightscape (v. 3.2)	✓	✓	✓	✓							
Radiance (v. 2.4)	✓	✓	✓			✓					
Genelux	✓		✓	✓	✓		✓	✓	✓		
Leso-Dial	✓			✓							
Rayfront (v. 1.0.3)											
FLUCS/APACHE	✓		✓	✓			✓	✓	✓	✓	✓
Superlite (v. 2.4)	✓	✓	✓	✓		✓	✓	✓			
LumenMicro 2000	✓	✓	✓	✓	✓	✓					
BSim2000				✓				✓	✓	✓	
DOE-2	✓	✓	✓	✓			✓	✓	✓	✓	✓
Energy-10	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
TRNSYS									✓	✓	
Ener-Win							✓	✓	✓	✓	✓

Simulation tools	Modelling Capabilities: Rectangular Room shape	Complicated Room Shape	Multiple Windows	Additional Daylighting Systems	Skylights	Light Shelves	Interior Glazed Partitions	Window Shading Devices	External Sky / Ground Obstructions	Light Guides . Tubes	Atria	Furniture Database
Adeline (v. 3)	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
RadioRay	✓	✓	✓		✓		✓					
Lightscape (v. 3.2)	✓	✓	✓		✓							
Radiance (v. 2.4)	✓	✓	✓		✓		✓	✓			✓	
Genelux	✓	✓	✓		✓		✓				✓	
Leso-Dial	✓	✓	✓		✓						✓	
Rayfront (v. 1.0.3)	✓	✓	✓		✓		✓				✓	
FLUCS/APACHE	✓		✓		✓		✓					
Superlite (v. 2.4)	✓	✓	✓	✓	✓		✓	✓			✓	
LumenMicro 2000	✓	✓	✓		✓		✓				✓	
BSim2000	✓	✓	✓		✓		✓				✓	
DOE-2	✓	✓	✓		✓		✓				✓	
Energy-10	✓	✓	✓		✓		✓		✓		✓	
TRNSYS												
Ener-Win	✓		✓									

Simulation tools	Data Input: Space Geometry	Surface characteristics	Luminaires Photometry	Geographic Location / Climatic Data	Materials Photometry	Lighting-Control Strategy	Desired Workplane Illuminance	User-Defined Worktime Schedule	Hourly Sunshine Probability
Adeline (v. 3)	✓	✓	✓	✓	✓	✓	✓	✓	✓
RadioRay	✓		✓	✓	✓				
Lightscape (v. 3.2)	✓	✓	✓	✓	✓				
Radiance (v. 2.4)	✓	✓	✓	✓	✓				
Genelux	✓	✓	✓	✓	✓				
Leso-Dial	✓	✓			✓				
Rayfront (v. 1.0.3)	✓	✓	✓						
FLUCS/APACHE	✓	✓	✓	✓	✓	✓	✓	✓	
Superlite (v. 2.4)	✓	✓	✓	✓	✓	✓	✓	✓	✓
LumenMicro 2000	✓	✓	✓	✓	✓				
BSim2000	✓	✓		✓	✓				
DOE-2	✓	✓	✓	✓	✓	✓	✓	✓	✓
Energy-10	✓	✓	✓	✓	✓	✓	✓		
TRNSYS									
Ener-Win	✓	✓	✓	✓	✓				

Simulation tools	Type of Outputs: Daylight Factor	Point-by-Point Illuminance	Average Indoor Illuminance	Isolux Contours	3D Model View	Numerical (Tables)	Graphic Images	Sky Conditions: Uniform Sky	Overcast Sky	Clear Sky	Sunlight Only
Adeline (v. 3)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
RadioRay					✓		✓				
Lightscape (v. 3.2)					✓		✓				
Radiance (v. 2.4)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Genelux	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Leso-Dial	✓	✓	✓	✓	✓	✓	✓		✓		
Rayfront (v. 1.0.3)					✓		✓				
FLUCS/APACHE	✓	✓	✓	✓	✓	✓			✓		
Superlite (v. 2.4)	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
LumenMicro 2000	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
BSim2000					✓	✓	✓	✓	✓	✓	
DOE-2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Energy-10	✓	✓	✓			✓		✓	✓	✓	
TRNSYS						✓					
Ener-Win						✓					

Table Key: Very Important — Important — Less Important — Not Important

Table 5.9. Survey of daylighting / energy simulation tools in accordance to their potentials and applicability to the research.

5.3.7 Simulation Tool Selection

Several attempts and pilot studies were made to identify a suitable simulation tool for this study. Adeline (Advanced Daylighting and Electric Lighting Integrated New Environment) was found to be the most appropriate software. Adeline has most of the 'very important' and 'important' features necessary for this study (Table 5.9). The main reason for choosing this software is that Adeline has the ability to calculate the energy potentials of daylighting in accordance to the sky condition of the studied context, and not according to standard sky. This is because Adeline is able to calculate the 'hourly sunshine probability' in the considered geographic location by assigning hourly direct normal radiation data. The 'hourly sunshine probability' file is therefore used to simulate daylighting illumination in the studied model.

Another reason for choosing Adeline is that this computer tool works under MS Windows, which is a user-friendly and easy to use operating system (at least for this researcher). The possibility of CAD interface is another feature that makes the software more attractive, being faster in modelling the case studies.

Superlite and Radiance can both be run under Adeline, for simplified and detailed analysis respectively. Therefore Adeline, using both radiosity and ray-tracing methodologies, is capable of giving detailed and accurate numerical and graphical analysis of daylighting and electric lighting behaviour in indoor spaces. Adeline is described in detail in Section 9.3 of Chapter 9, where the simulation boundaries are also explained.

The other package that could be used is Genelux, which was developed within Daylight Europe Project. The disadvantage of using Genelux for this research is that it operates under Unix or through the Web. Genelux - Web was produced for building designers to accurately evaluate the daylighting performance of their projects (Light and Radiation Group, 1998). It is therefore considered more useful for consultancy work than research analysis.

Both Genelux and Adeline simulate the energetic and thermal loads resulting from lighting and daylighting only. The outcome of the calculations can therefore be used to perform hourly thermal simulations with dynamic building simulation programs such as

DOE2 or TRNSYS (Laforgue *et al.*, 1997; Bodart *et al.*, 2002). This study focuses only on lighting and the energetic behaviour of daylighting. The outputs from Adeline (listed in Table 5.9 are sufficient for the research analyses.

It is important to notify that in the early stages of this study, Apache /FLUCS software tools were used to analyse one of the case studies. The problem with FLUCS is that it performs daylighting calculations in accordance with the BRS Split-Flux method and assumes that the sky luminance is that of the CIE standard overcast sky only, which is not the case in Beirut. Nor is it ideal for non-rectangular rooms (US Department of Energy, 2000). Given the study context, the results obtained could not be considered accurate enough for measuring the potentials of daylighting / energy in office buildings in Beirut.

5.4 Conclusion

This chapter sets out the methodological approaches adopted in this research. Different research methods for assessing daylighting, human comfort and energy-related factors in buildings are reviewed. This chapter reviews the approaches of historical studies of architectural development and daylighting. Data sources and data collection techniques are identified. A detailed discussion of daylighting / energy studies identifies the main outputs that contribute to the assessment of daylighting and associated energy in office buildings.

Based on the 'morphological box' method adopted by Baker *et al.* in 1993, a daylighting evaluation tool has been developed to quantify daylight availability in office buildings in Beirut. This tool includes 18 variables. Each variable is divided into 4 ranges of values associated with the studied context, and these ranges are given a score between 1 and 4. This method permits the user to draw a diagram that describes the impact of façade configuration and plan morphology on daylighting performance in the studied buildings. The evaluation tool was developed to assist the comparative and developmental analyses of 35 office buildings in Beirut during the 20th century.

Simulation technique is used to assess the energy behaviour of daylit office buildings in Beirut. Using Adeline, lighting consumption and potential savings due to daylighting / electric lighting integration are simulated. The simulation outputs are correlated to the considered variables in the developed evaluation tool, to identify the significant design variables that should be considered in designing a well-daylit and energy efficient office building in Beirut. Correlational and comparative analyses are validated by empirical data and a POE pilot study. Following these methodological approaches, this study will set recommendations for the best use of daylighting in office buildings in Beirut (Figure 5.8).

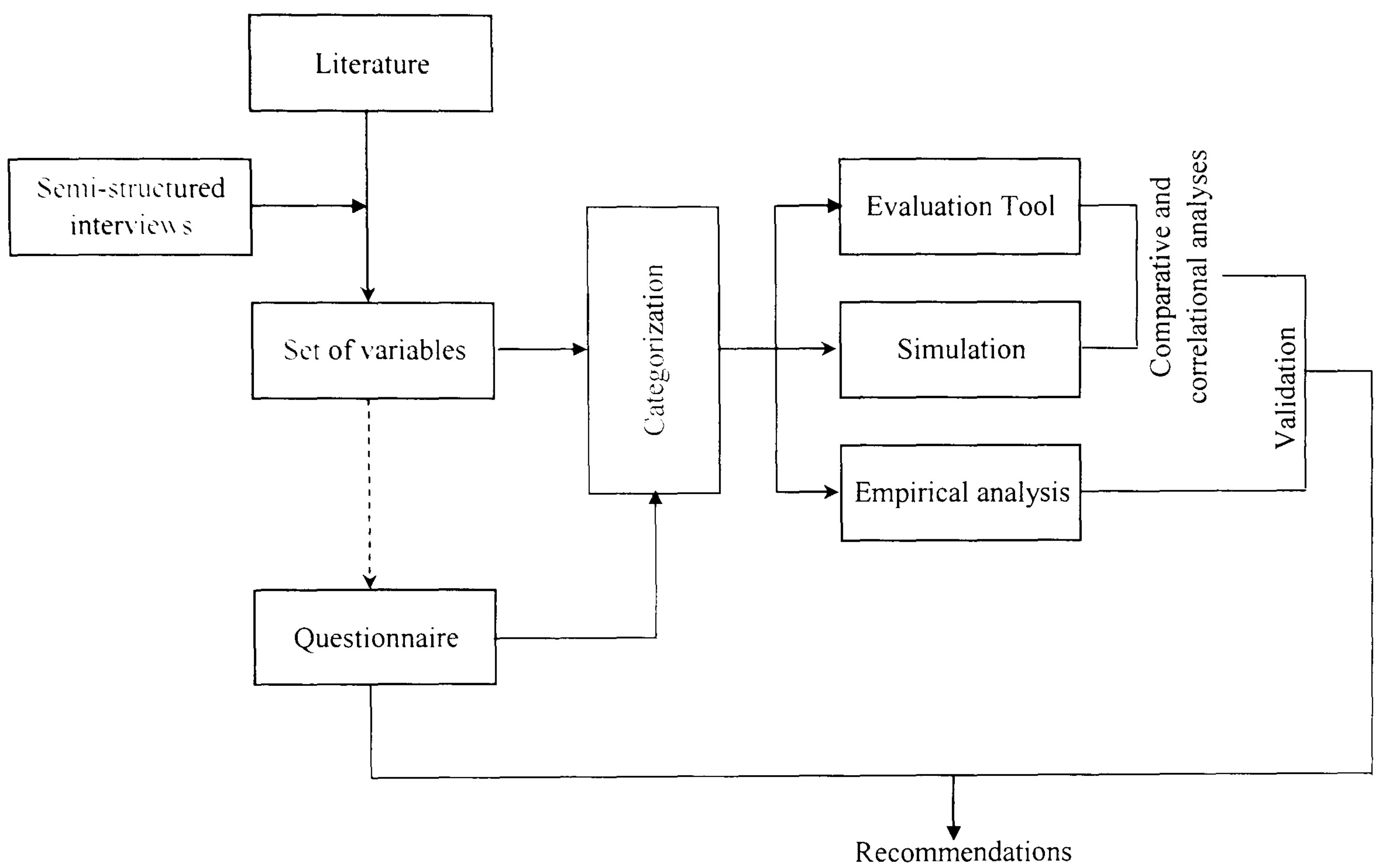
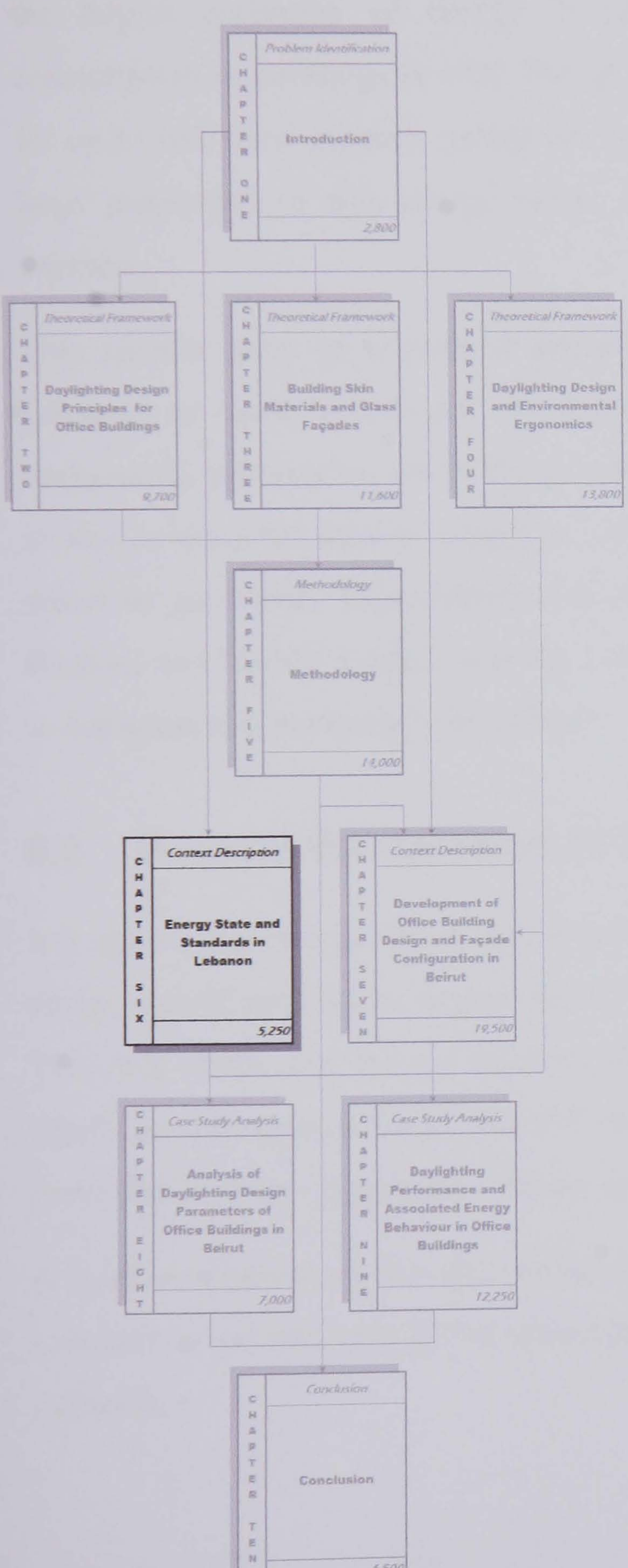


Figure 5.8. The methodological diagram of the thesis.

ENERGY STATE AND STANDARDS IN LEBANON

6



Chapter Six

6. Energy State and Standards in Lebanon

6.1 Introduction

Following the local problems that started in Lebanon in 1975, the electricity sector suffered serious damages and continuous energy shortage. The building sector remains the largest consumer of energy in Lebanon, and the need to rationalise energy consumption in buildings is vital. Energy use for artificial lighting in offices can account for up to half their primary energy use (Burton, 2001). Using daylight could eliminate a large proportion of this energy usage, since office working hours are mostly during daytime.

This chapter aims to provide a general background to the context of this research, Lebanon or more specifically its capital Beirut. The chapter is prefaced by some background information about the geography and climate of the country. The following section reviews the state of energy in Lebanon in general, and in Beirut and the building sector in particular. This chapter also discusses energy conservation awareness in the Western and Middle Eastern regions, and the energy standards that have been developed or implemented, particularly in Lebanon.

6.2 General Background of Lebanon

It is agreed that daylighting design should be bioregionally approached. This means that a design should respond to, engage in, and benefit from the life forces of a specific region. The track of the sun, the condition of the sky, the climate and the nature of the site are significant bioregional forces that influence daylighting. These forces are functions of the particular geology, geography, latitude and longitude of the context.

A brief description of the above-mentioned bioregional forces and climatic features of Lebanon in general, and Beirut specifically, follows an introduction to the geography of Lebanon.

6.2.1 The Geography of Lebanon

Located on the eastern shore on the Mediterranean Sea between northern latitudes 33°03′38″and 34°41′35″ and eastern longitudes 35°06′22″ and 36°37′22″, Lebanon covers an area of 10,452 km^2 with a population of around 4 million (Figure 6.1). Even at its widest point it is only 85 km from east to west. The country consists of a narrow coastal strip 212 km long. It is bounded to the north and east by Syria and to the south by the occupied territory of Palestine, otherwise called Israel (Figure 6.2). Its capital Beirut, which is the focus of this study, is the largest Lebanese coastal city located at latitude 33°49′ north, and longitude 35°29′ east. The area of Beirut is only 20 km^2, equivalent to 0.2% of the country's total area. The Central Administration of Statistics (CAS) estimated Beirut's population at 403,337 in 1997. The population of Beirut constitutes 10% of the total population, with a density of 20,162 people/km^2 (Table 6.1, Ministry of Environment / LEDO, 2001).

Figure 6.1. The location of Lebanon on the world map.

Area (Mohafaza)	Population	Percentage of Total Population	Surface Area (km^2)	Population Density (person / km^2)
Beirut	403,337	10%	20	20,167
Beirut Suburbs	899,792	22%	233	3,862
Rest of Mount Lebanon	607,767	15%	1735	350
North	807,204	20%	2025	399
Bekaa	539,448	13%	4161	130
Nabatieh	275,372	7%	1098	251
South	472,105	12%	930	508
Total	**4,005,025**	**100%**	**10202**	**393**

Table 6.1. Distribution of Population by Mohafaza (1997).

Lebanon is a mountainous country. Approximately half of the country lies at an altitude of over 900m, the highest point being 3,090 metres at Qornat Essauda. Most of the cities in Lebanon are on the coastal plain (Tripoli on the north coast, Beirut in the centre, and Sidon and Tyre on the south coast), sandwiched between the mountains and the Mediterranean. The main mountain ranges are the Lebanon Mountain chain, which runs north-south through the centre of the country overlooking the coast, and the Anti-Lebanon chain which runs north-south along the eastern border, overlooking a fertile plain known as the Bekaa valley (Figure 6.2). These geographic features divide Lebanon into four zones: the coastal plain, the coastal mountain, the central plateau and the eastern mountain.

Figure 6.2. A detailed map of Lebanon

6.2.2 The Climate in Lebanon

The climate in Lebanon is inextricably related to the four geographical zones mentioned above. The ongoing project for Lebanese Energy Standards, carried out by the General Directorate of Urban Planning in Lebanon and the United Nations Development Programme (UNDP), identified three climatic zones (Figure 6.3):

- Climatic zone A, divided into 2 sub-zones A1 and A2: this includes the coastal plain (A1 < 500m altitude) and the coastal chain (A2 > 500m). As illustrated in Figure 6.3, Beirut is situated within climatic zone A1. The climate in this zone is typically Mediterranean with hot and humid summer months, and a warm, mild winter. The climate in this zone is hot and humid in summer and mild in winter. The temperature in January, the coldest month, varies between 9.3°C and 16.1°C and in August, the hottest month, between 22.5°C and 30.7°C. The climatic conditions in this zone, specifically Beirut, are reviewed in the following section.
- Climatic zone B, divided into 2 sub-zones B1 and B2: this includes the occidental versant of the coastal chain reaching out to the north, centre and south, where the regulator is the sea. Within zone B, sub-zone B1 comprises the regions of 900 to 1500m altitude. B2 includes regions that have an altitude above 1500m. The climate in this zone is mild in summer and cold in winter. The temperature in January, the coldest month, varies between -2.9°C and 10.5°C and in August, the hottest month, between 12.7°C and 30.5°C.
- Climatic zone C: this extends from the summits of the coastal chain to the frontier, and includes only the regions between 900 and 1500m. The summers of this zone are hot and dry and the winters are cold. The temperature in the coldest month, January, varies from 0.2°C and 11.2°C and the hottest month, August, between 14.5°C and 34.4°C.

This research is concerned only with the study of office buildings in Beirut, which is located in coastal zone A1. The differences in climatic conditions across Lebanon, as explained in the climatic zones described above, limited the application of this study to the coastal zone.

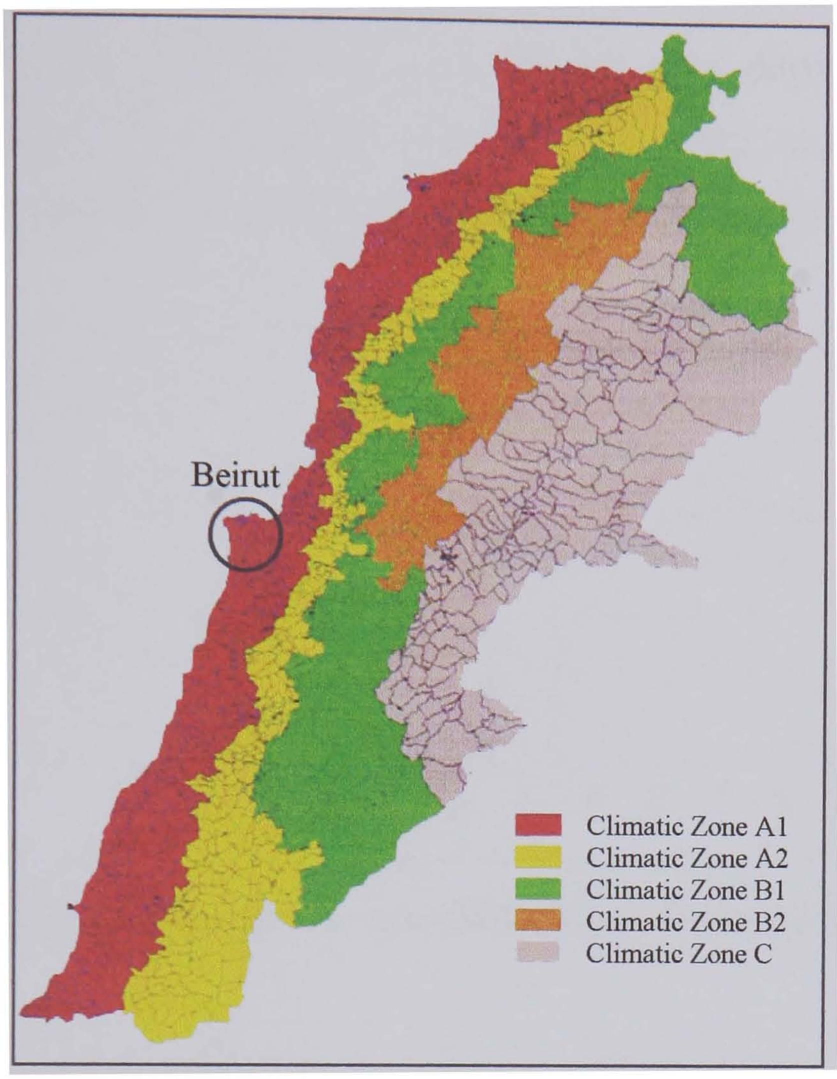


Figure 6.3. Climatic zones of Lebanon (AETS - APAVE SUD, 2003)

6.2.3 Climatic Conditions in Beirut

As mentioned in the previous section, Beirut is located in Lebanese climatic zone A1 (the coastal strip) and has a typical Mediterranean climate. The following sections describe the climatic features of Beirut.

6.2.3.1 *Daylight Availability in Lebanon*

Daylighting can be a good contributor to energy efficiency in the buildings of Beirut, where the climate is typically Mediterranean and the average daylight duration varies from 10 hours in winter to 14 hours in summer (Figure 6.4). The sky in Beirut is clear during 6 months of the year (from May to October) and partly cloudy for the rest of the year, except for January when cloudy skies are most frequent (Figure 6.5). There are no recorded data concerning global horizontal illuminance in Beirut, but the nearest location where daylight has been measured may be considered as a reference point for daylight availability. In the eastern Mediterranean, daylight data were collected by the Israeli meteorological service at Bet Dagan, which is located at latitude 32° North and longitude 34.49° East, as part of the International Daylighting Measurement Programme. The global horizontal illuminance (in lux) was measured in Tel Aviv during the normal office working hours, 8:00 to 18:00. Most of the time the illuminance level is over the value of 10 000 lux, including most of the working hours throughout the year (Capeluto, 2003).

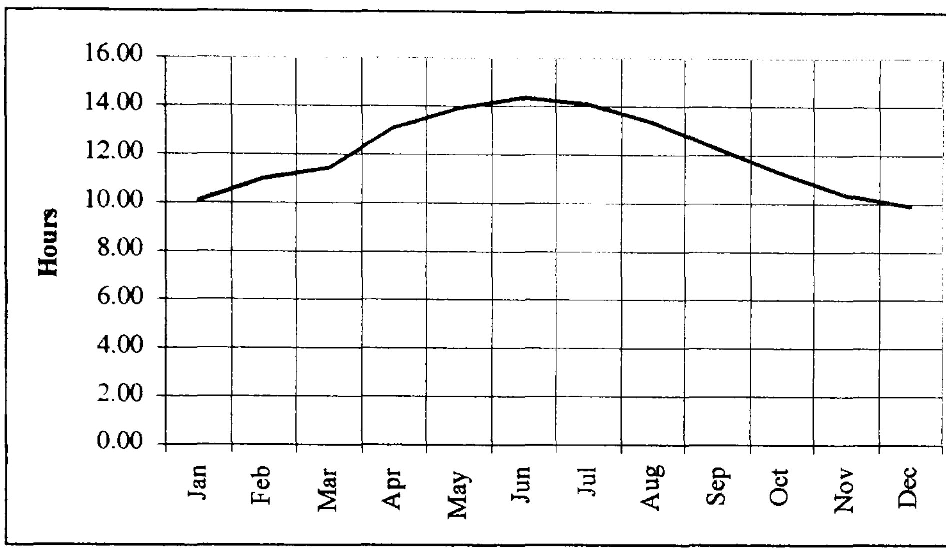


Figure 6.4. The monthly mean daylight duration in Beirut.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5/8	4/8	4/8	3/8	2/8	1/8	1/8	1/8	2/8	2/8	3/8	4/8

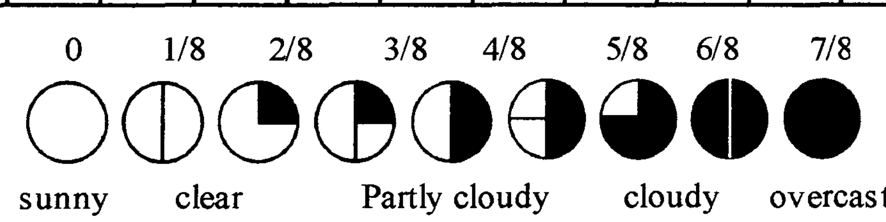


Figure 6.5. The monthly average cloud cover in Beirut expressed in eighths.

6.2.3.2 *Sunshine and Solar Radiation*

Figure 6.6 shows that the maximum sunshine duration in Beirut is between 9 and 13 hrs/day, while the minimum duration is between 2 and 11 hrs/day. The average sunshine duration is lowest in December and January (6 hrs/day), and peaks in June with 12 hrs/day. The annual average sunshine duration is 9.5 hrs/day. Figure 6.7 shows that the daily average direct normal, and total horizontal solar radiation peak between April and August. Their lowest values occur between October and February.

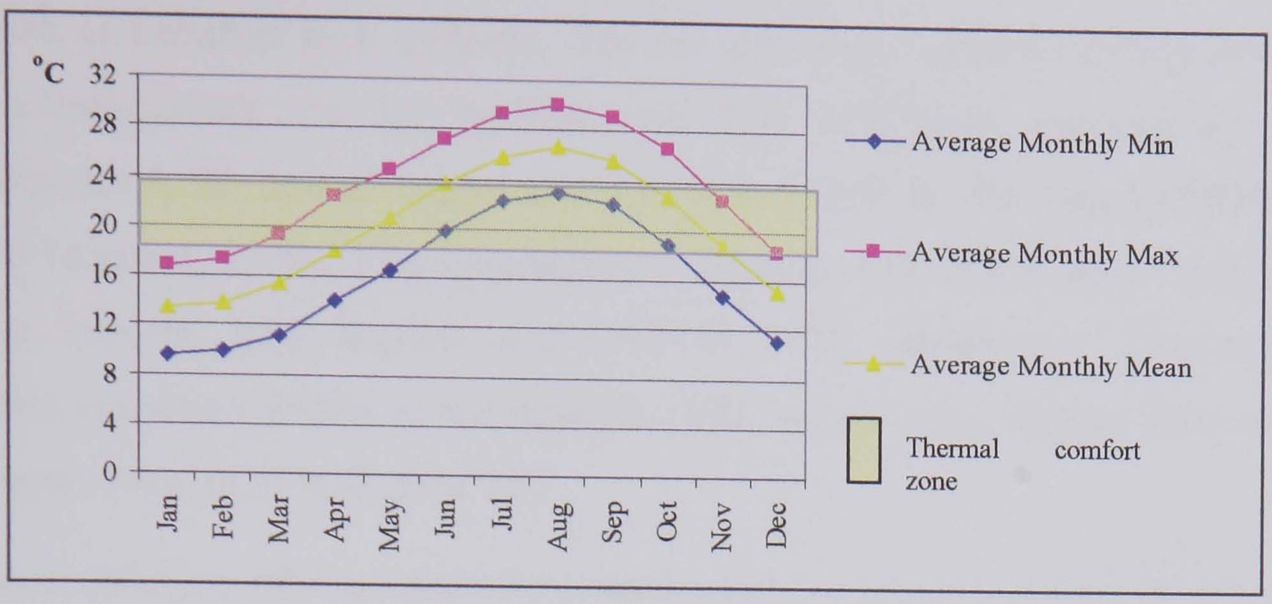


Figure 6.8. Temperature data of Beirut.

6.3 Energy State in Lebanon

This section analyses the current state of the energy sector in Lebanon, looking first at the impact of the energy sector on the economy, next at power generation, and finally the demand in Lebanon in general. It also considers Beirut, and the building sector in particular. Apart from the environmental contribution of energy efficient measures, the aim of this section is to justify how important it is to rationalise the use of electricity in the building sector, to reduce energy imports and to contribute positively to the adverse economic situation in Lebanon.

6.3.1 The Impact of the Energy Sector on the Economy in Lebanon

The purpose of this section is to overview the interrelationship between energy and economy, and to illustrate the heavy burden of the energy sector on the Lebanese economy.

In Lebanon, electricity and petroleum products are the predominant energy carriers. Although the consumption of electricity in Lebanon is relatively low compared with most industrialized countries, it is high compared with many developing countries in similar circumstances (Chedid *et al.*, 2004). In 1999 the primary energy consumption was 4963 mtoe, and electric energy consumption reached 8421 GWh (EIA, 2004). Referring to a survey of Economic and Social Developments in the ESCWA Region in 2000, Chedid *et al.* (2004) stated that the GDP in 1999 was US$13,965 million. The primary energy and electric energy densities were 0.35 koe/US$ and 0.60 kWh/US$ respectively. As the

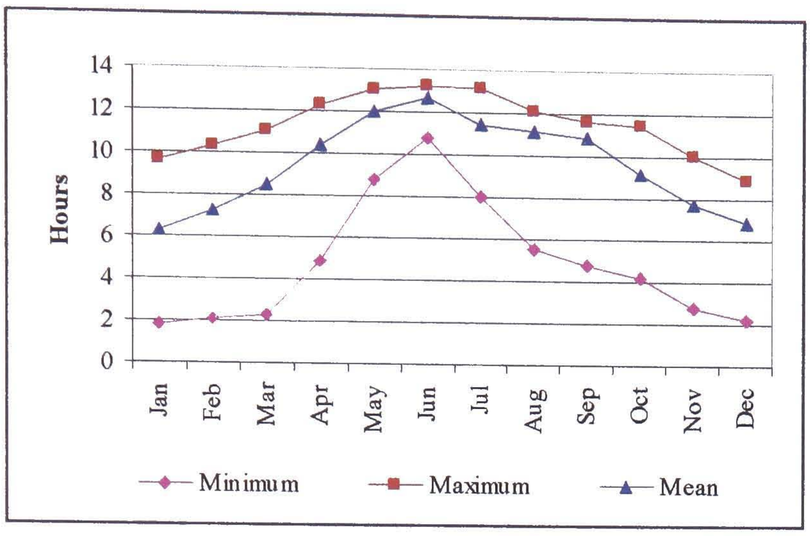


Figure 6.6. The monthly minimum, maximum and average insolation duration in Beirut.

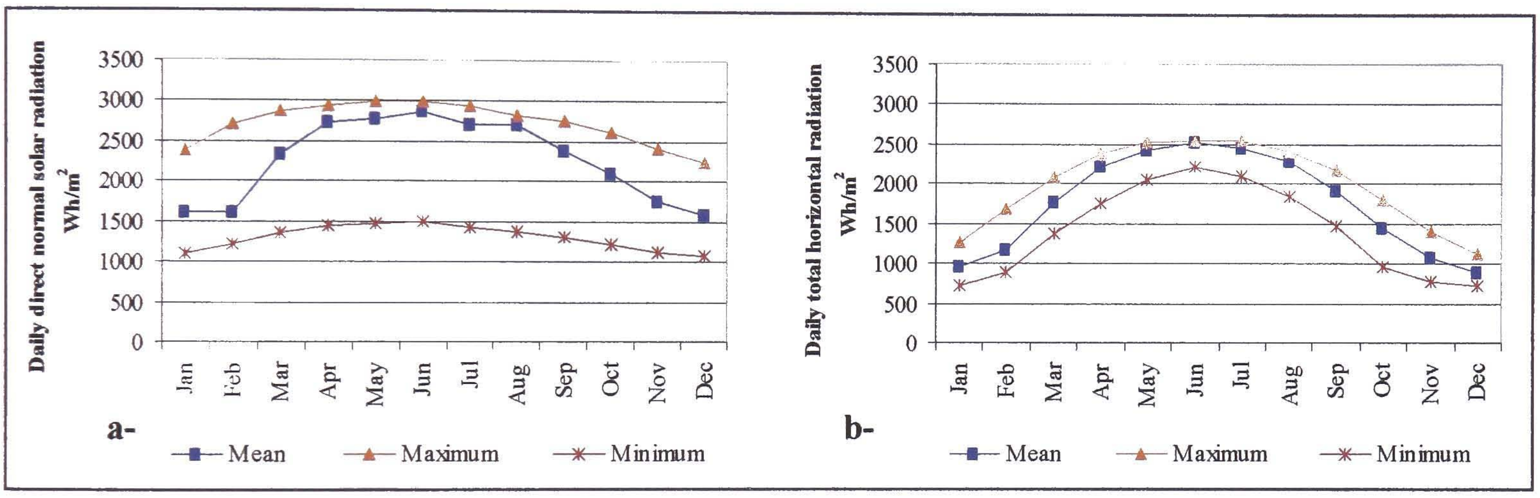


Figure 6.7. Solar radiation in Beirut: a- daily direct normal solar radiation; b- daily total horizontal solar radiation

6.2.3.3 *Temperature*

Figure 6.8 shows that the average monthly maximum temperature in Beirut varies between 16°C in January and 30°C in August. Figure 6.8 also shows that the temperature rises above 24°C in the summer months, July until September. The maximal temperature exceeds the comfort zone starting from May till October. The minimal temperature varies between 9°C in January and 24°C in August.

Daylight availability, clear sky conditions and moderate temperature levels provide excellent reasons for taking advantage of this free energy, to improve the energy performance of buildings and to improve working conditions in offices.

population in Lebanon is 4 millions, thus the per capita primary energy and electric energy consumptions are 1.4 toe/year and 2.41 MWh/year, respectively. On the operational level, the cost of imported energy (fossil fuel) in 1999 was US$805 millions (Bank of Lebanon, 1999). This expenditure represents 93%, 13% and 5.7% of the total Lebanese exports, total imports and GDP of 1999, respectively. Electrical power production consumes 29.5% of the imported fuel, which is the highest percentage after the transport share of 36% (Figure 6.9).

The above statistics indicate that the consumption of primary and electrical energy is relatively high for Lebanon. There is a need to rationalise energy use in Lebanon in general, and the building sector in particular since that has contributed most to the increase in energy demand. This statement is confirmed in the following sections, which review electrical power production and consumption in Lebanon, and in Beirut and the building sector in particular.

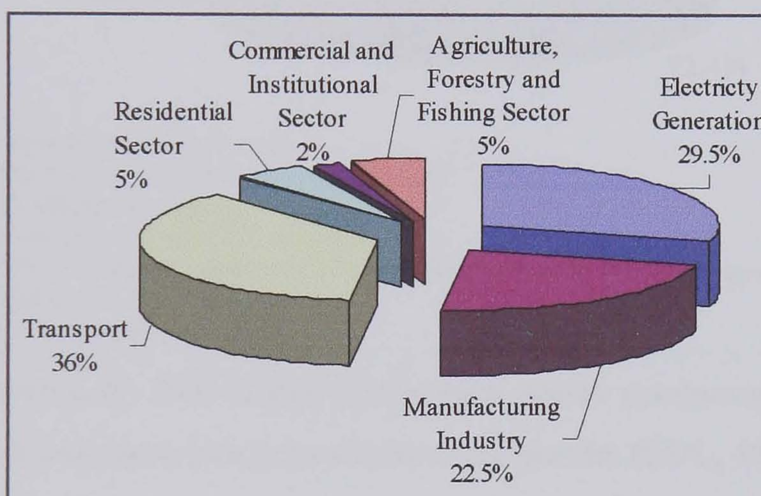


Figure 6.9. The consumption of the imported fuel in Lebanon per sector (Jeffreys, 1999).

6.3.2 Power Generation in Lebanon

Eight different companies collaborate to produce electrical power in Lebanon. These companies own 21 factories. 15 are hydraulic, operating with water pressure, and the rest are thermal, operating with fuel oil or gas oil. "L'Electricité du Liban (EDL)", an autonomous government office with its own budget, produces 72.4 % of the electrical power production of Lebanon and buys the production of five other companies (Figure 6.10). The national department of Litani River produces electricity to supply power requirements in Zahleh and the Bekaa. The Lebanese Cement Company generates electrical power for its own consumption, but not enough. EDL cooperates to cover the energy shortage in the last two companies. EDL supplies 85.7% of the total electricity requirements in Lebanon. In addition, electricity is imported from Syria via a shared grid system. Electricity imports began in 1995, at 292 KWh and have since almost tripled, reaching 846 KWh in 1999 (Ministry of Environment, 2001).

Figure 6.11 shows that in the last 10 years the thermal generation of electrical power has been increasing, and constituted 91.3% of the total power generated by EDL in 1998. In 1996, this growth in thermal production resulted in 29% national increase in petroleum imports. Thermal power production is the second-largest contributor to energy-related GHG emissions (26.3%), while transport represents about 43.4% (Fadel *et al.*, 2002).

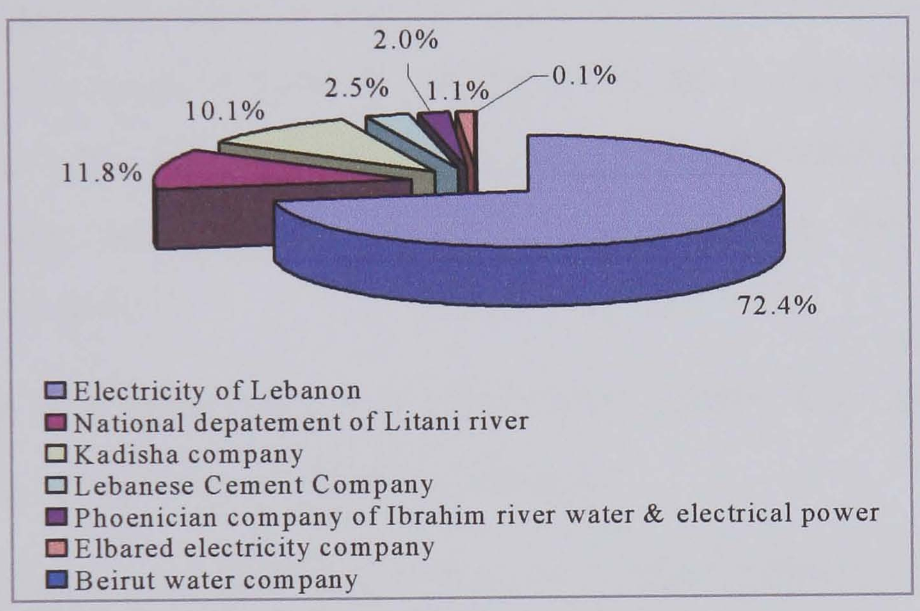


Figure 6.10. Percentage of electrical power production per each Lebanese power production companies (EDL, 1994).

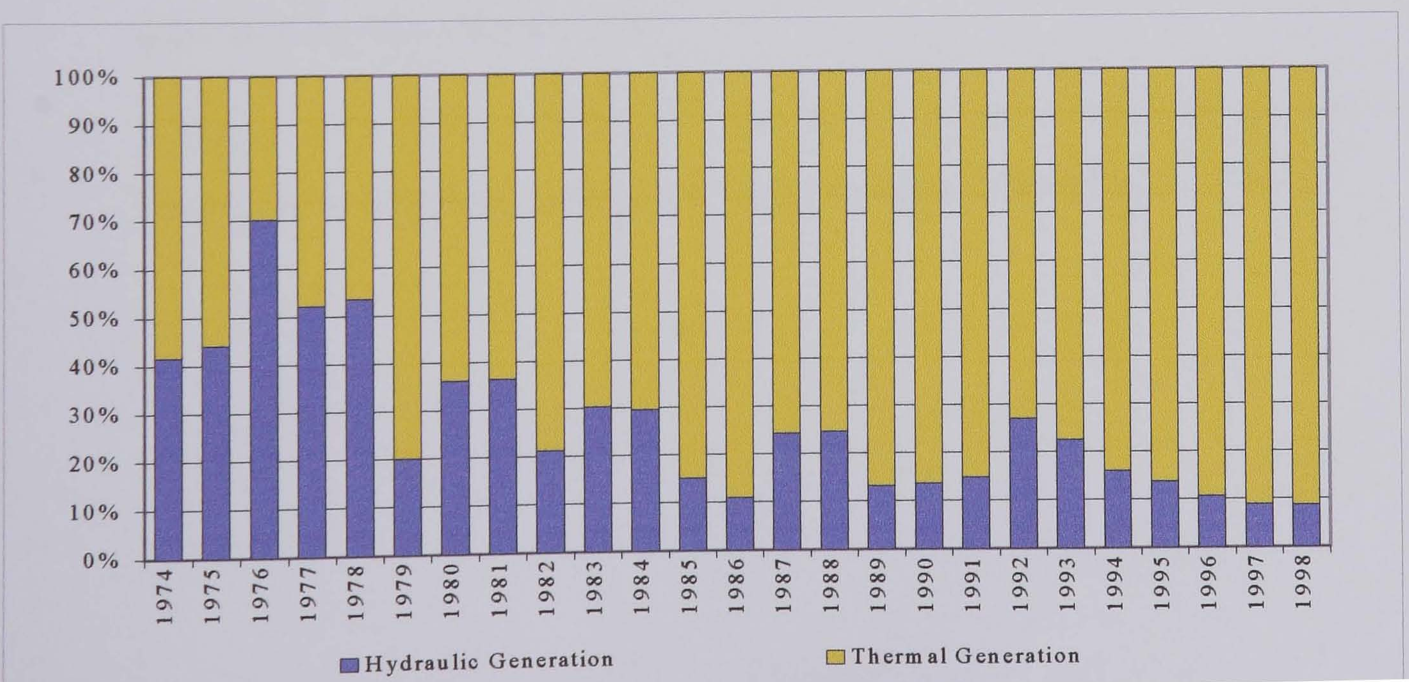


Figure 6.11. Percentage of thermal and hydraulic power generation in Lebanon during the last three decades (Jeffreys, 1999).

6.3.3 Generation versus Demand: Electricity Shortage in Lebanon

Figure 6.12 shows that between 1980 and 2002 electricity production rose by 15% annually, reaching 8065 GWh in 2002. Despite the increase in electricity production, the demand for power has also continued to grow; by 14% annually, reaching 8591 GWh in 2002. By 2002 the electricity shortage was 525GWh. Figure 6.12 also shows that this shortage has existed in Lebanon since 1980. With the start of the local problems in Lebanon in 1975, reserve power dwindled until it disappeared entirely in 1979. In spite of those troubles (1975 - 1990), EDL was able to generate the minimum level of required power, but often had to resort to rationing or rotation of distribution because of major system stoppages. With the end of the war in 1990, the energy shortage reached a peak of 20%. The sudden reduction in shortage after the war can be explained by the strict rationing in power supply distribution. Since 1995, the energy shortage has increased to reach a peak of 12% in 2000 (651GWh). Apart from increased power demand, EDL is still facing many difficulties in trying to overcome this shortage. Some of these difficulties are as follows:

- Refusal of a large portion of subscribers to settle their electricity bills, and the inability of EDL to cut off their electricity.
- Illegal tapping of distribution lines by a large number of people, with the state being unable to take corrective measures.
- Continuous increase in fuel-oil prices at a time when 91.3% of the power generated by EDL depends on it.
- Today a kWh costs USD$0.07. The tariff is kept below the actual cost of the electricity production, mainly for social reasons (Chedid *et al.*, 2004).

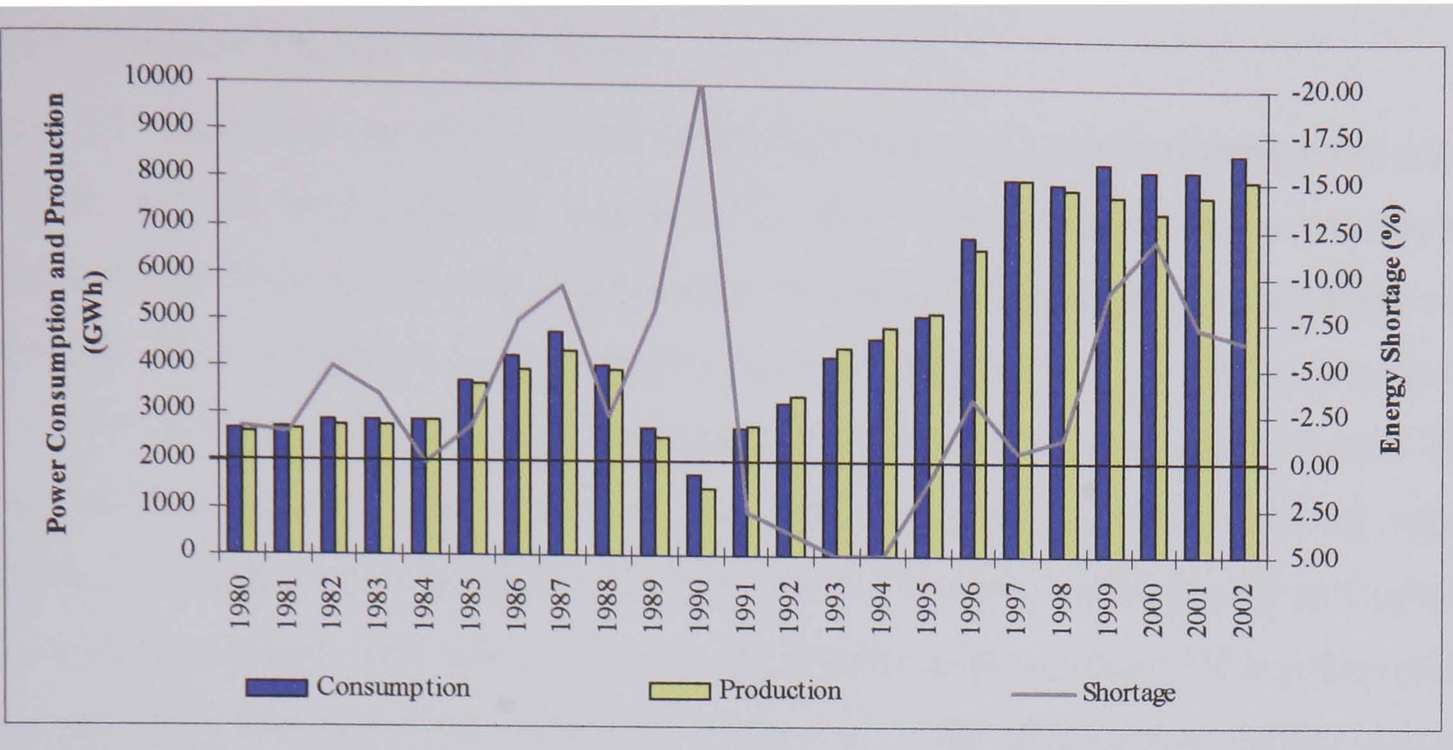


Figure 6.12. The amount of electricity production and consumption in Lebanon from 1980 to 2000, showing a continuous power shortage (EIA, 2004).

6.3.4 Energy State of Beirut

As Beirut is the capital of Lebanon and contains the main central business and services, the city has been consuming most of the electrical power produced by EDL. In 1974, Beirut and its suburbs consumed 67% of the electrical production capacity of Lebanon (Figure 6.13a). This percentage has decreased to attain 50% in 1993 and the consumption of other Lebanese regions has increased (Figure 6.13b). This augmentation denotes that Beirut is still the main urban area, but new regions have been developed. In 1999, statistical studies indicated that 32% of the population lives in Beirut and its suburbs, and consumes 60% of Lebanon's electricity (Jeffreys, 1999).

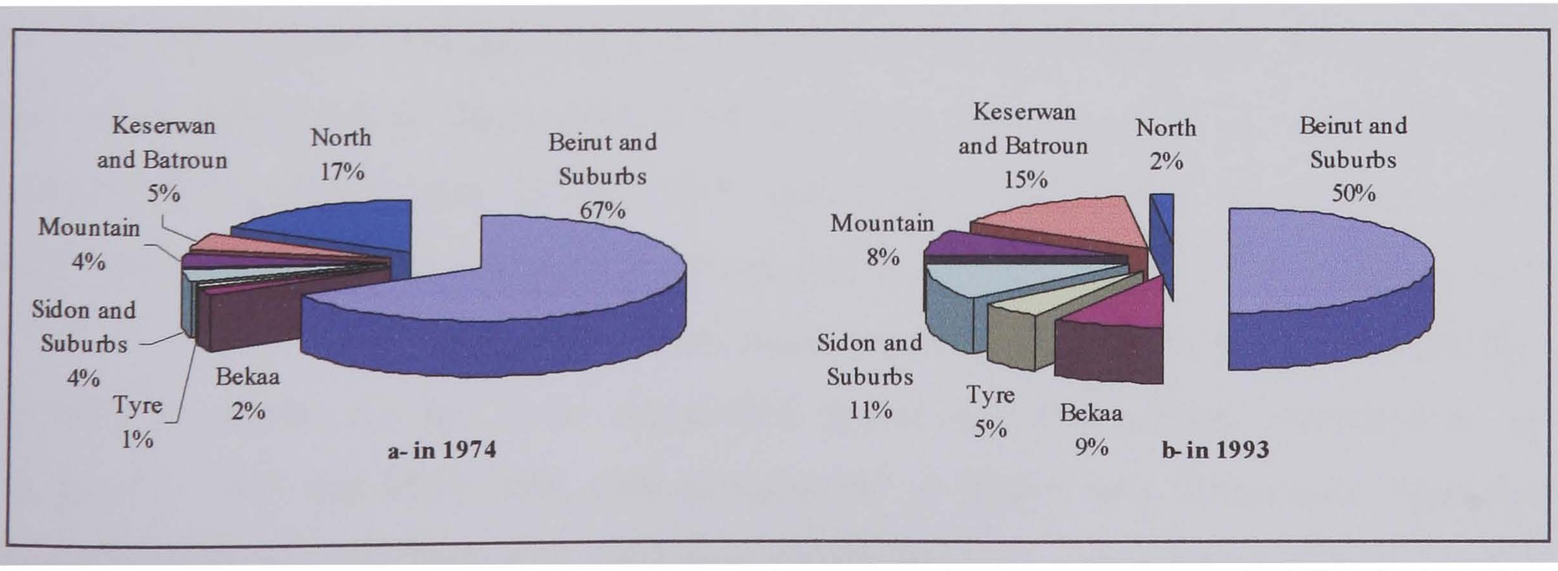


Figure 6.13. Distribution of Electricity consumption per region in Lebanon: a- in 1974; b- in 1993 (EDL, 1994).

6.3.4.1 *Electrical Energy Use per Sector*

Figure 6.14 illustrates the development of the distribution of electrical energy per sector in Beirut in 1974, before the war, and in 1993, after the war. It should be noted that the building sector in Beirut has always consumed the highest percentage of total energy used in the city. This percentage has grown 23% during nineteen years, an annual increase of 1.2%. The building sector in Beirut, the central business and service city, consumed 70% of the supplied energy. The reason for this high percentage is that Beirut no longer depends on industry as it did before. (25% in 1974). This city relies mainly on business and service provision. The other reason is the growth in population (32% of the total), which naturally has increased residential energy use. This consumption pattern has not changed greatly during the last 10 years (Chedid *et al.*, 2004).

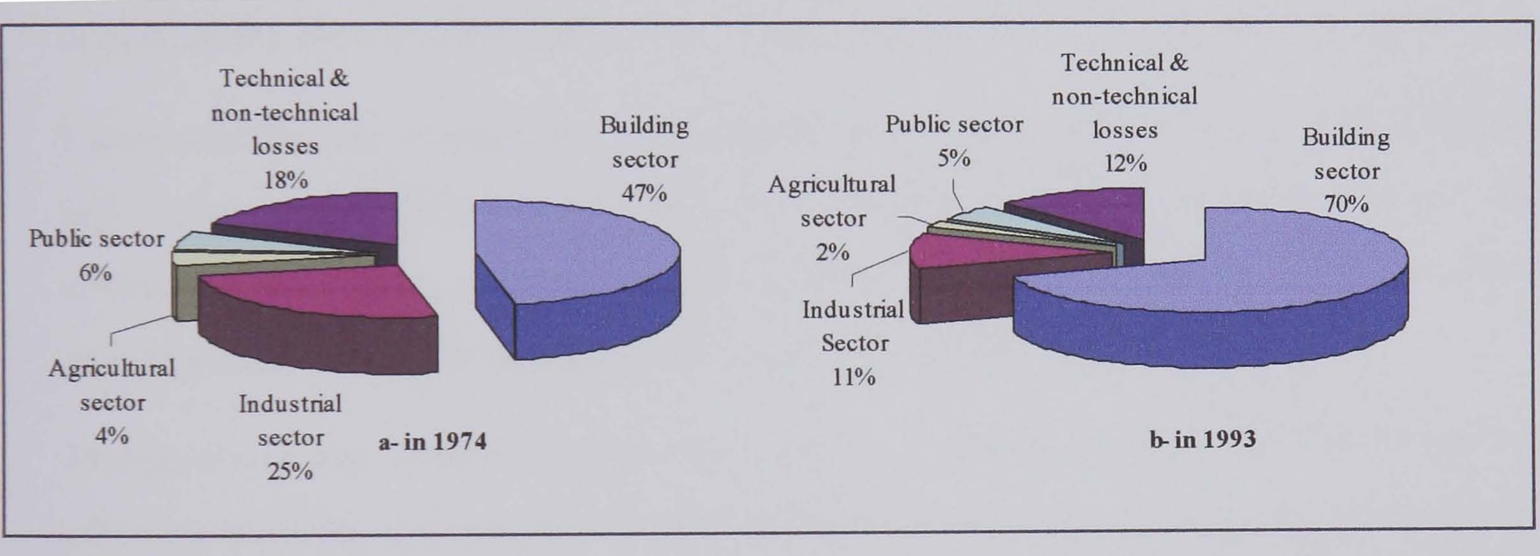


Figure 6.14. Distribution of Electricity consumption per sector in Beirut: a- in 1974; b- in 1993 (EDL, 1994).

6.3.4.2 *Consumption of Office Buildings in Beirut.*

In 1996, The Central Administration of Statistics surveyed all buildings of Beirut. From their data published in September 1996, the total area occupied by establishments considered as offices was 736,923 m^2. According to the Order of Architects and Engineers (2004) the area occupied by offices has increased by 30% (office buildings area = 958,000 m^2) in Beirut during the last ten years, because of the high level of commercial investments there. As has been mentioned previously, the annual consumption in Lebanon in 2002 was 8591GWh, with consumption in Beirut 40% of the total. Thus the annual consumption of Beirut in 2002 was 3310GWh. The collected empirical data for office buildings in Beirut showed that the consumption of an office is 180 $kWh/m^2/year$.

Therefore office buildings in Beirut took 7.5% of Beirut's energy consumption, and 1.6% of the national consumption. It is of note that in 1995, 50.1% of the residential units in Beirut were multi-use, i.e. providing both residential and office space (Central Administration of Statistics, 1996). Empirical data on office buildings consumption show that 20-25% of that energy use is for electric lighting.

6.4 Building Energy Codes and Standards

6.4.1 Building Energy Codes and Standards

Energy-efficient buildings offer energy, economic and environmental benefits. They reduce energy expenditure and environmental pollution. They also create economic opportunities for business and industry, by promoting new energy-efficient technologies.

Unfortunately, the marketplace in Lebanon does not guarantee energy-efficient design and construction. Owners of commercial buildings generally pass on energy costs to consumers or tenants, eliminating any incentive for such efficiency. Office buyers often are generally concerned with up-front costs than operating costs.

Energy codes and standards play a vital role in overcoming the market barriers to energy efficient building designs, by setting minimum requirements for energy-efficient design and construction. They also help to raise awareness and concern about building energy conservation in society, and encourage the development of energy efficient building products. They outline standard requirements for new buildings, as well as additions and renovations.

Bartlett *et al.* (2003) identified the differences between energy codes, energy standards and model energy code. **Energy codes** aim to specify how buildings must be constructed or perform, and are usually written in mandatory, enforceable language. States or local governments adopt and enforce energy codes for their jurisdictions. **Energy standards** describe how buildings should be constructed to save energy cost-effectively. They are published by national organizations such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). They are not mandatory but serve as national recommendations, with some variations for regional climate. States and local governments frequently use energy standards as the technical basis for developing their energy codes. Some energy standards are written in mandatory, enforceable language, making it easy for jurisdictions to incorporate the provisions of the energy standards directly into their laws or regulations. **A model energy code** makes allowances for different climate zones. It is written in mandatory, enforceable language. Regions having the same climatic zone can easily adopt the model as their energy code by making some changes to accommodate regional building practices.

The following section offers a review of building energy standards and codes in the major countries of the World. Section 6.4.3 describes the ongoing project of the 'Lebanese Energy Standards for Buildings'. 6.4.4 reviews the daylighting measures that are included in building regulations and energy standards around the world, and in Lebanon.

6.4.2 International and Regional Energy Standards

In recent years, there has been strong interest around the world in developing or revising building energy standards using a performance-based approach. Figure 6.15 shows the status of efficiency standards around the globe in 1999. Janda *et al.* (1994) predicted that by 1999 twenty-two countries would have mandatory standards, three would have voluntary standards, and many others would have proposed or be considering standards. Today, there are at least 46 countries with some kind of standards for energy use in buildings. (Thibon, 2003).

Figure 6.15. Predicted status of efficiency standards around the globe in year 1999 (Janda *et al.*, 1994).

The ASHRAE Standard 90 series is by far the most widely accepted reference model for designing building energy codes in North America and elsewhere around the world. An energy cost budget method is used to evaluate the energy performance of a whole building. In Canada a similar approach, called the building energy performance method, is being used as an alternative to the prescriptive path for the major building elements.

In the ASEAN countries (Indonesia, Malaysia, Philippines, Singapore and Thailand), the Overall Thermal Transfer Value (OTTV) method originated from ASHRAE has been adopted for legislative control of the building envelope. OTTV is basically a measure of the amount of heat gain through the building envelope into the building; the larger the OTTV, the more the heat gain. South Korea implemented mandatory building energy standards (the Korean Building Energy Performance Standards) in 2001, using ASHRAE 90.1 and the Japanese building energy standards as references.

In Eastern Europe, apart from some prescriptive thermal insulation requirements no formal standards exist for the construction of buildings with regard to energy efficiency. In 2001, the "Energy Efficiency of Buildings Energy Consumption and Thermal Protection Standards" was approved in 13 regions of Russia (Thibon, 2003). In Western Europe, countries like the UK, Austria, France and Germany have a longer history with thermal standards for buildings. In Southern Europe, Spain has developed the "NBE-CT-79 Spanish Thermal Requirements for Buildings". A maximum thermal transmission factor similar to the OTTV concept is used to specify building envelope performance. However, a series of standard calculation methods for the design and evaluation of the performance of buildings and building components is being developed by the European Committee for Standardisation (CEN).

South Africa prepared a 'Manual for Energy Auditing' in 1988, for the promotion of energy efficiency through building. Ivory Coast developed a building energy standard in 1993. Morocco, Algeria and Tunisia started the process of establishing of a building energy standard 'Réglementation Thermique Maghrébine' in 1996.

In New Zealand, the energy efficiency requirements for buildings are contained in the New Zealand Building Code (NZBC), which is a statutory requirement because it is part of the Building Regulations 1992. Performance requirements are provided for both housing and other buildings. A mandatory guideline provides the mechanism for demonstrating compliance with the performance stated in the code.

In Australia, Building Code BCA96 was adopted nationally in 1997. BCA96 is a performance-based code, incorporating performance requirements and Deemed-to Satisfy (DTS) provision and verification methods.

Only a few countries in the Middle-East have indicated that they have some form of building energy standards for promoting building energy conservation. In 1989 Kuwait developed a code of practice for energy conservation in buildings, using American technology and the DOE-2 program. Israel and Jordan have some thermal insulation standards for schools and residential buildings. The Egyptian Standards for thermal insulation efficiency of buildings, which incorporate energy conservation requirements as part of the building byelaws, were published in 1998. More recently a residential energy code has been developed in Egypt. It is very innovative as it specifies minimum building requirements to improve both thermal and visual comfort in buildings with no A/C, as well as minimum energy efficiency requirements in air-conditioned buildings. (Hanna *et al.*, 2003). This code gives minimum performance standards for windows and openings, natural ventilation and thermal comfort, ventilating and air conditioning equipment, natural and artificial lighting and electric power.

Today, Lebanon and Palestine are in the process of developing new energy standards for residential and non-residential buildings. The following section will describe the objectives, methodology and goals of the Lebanese Energy Standards for Buildings. These efforts are mainly concerned with thermal performance. No attention has been given to the significance of adequate provision for daylighting.

6.4.3 The Lebanese Energy Standards for Buildings

The 'Lebanese Energy Standards for Buildings' project (Leb/99/G35) was launched in February 2002 under the management of the United Nations Development Programmes (UNDP). This project is being executed by the General Directorate of Urban Planning in Lebanon, and is based on the Lebanese Standards Institution's (Libnor) "Guide to thermal insulation for buildings in Lebanon". This project is not completed yet. Only first draft reports have been presented at stakeholders' conferences and seminars.

According to the General Directorate of Urban Planning (2003) the purposes of this standard are to:

- Set minimum requirements for the energy performance design of new buildings, so that they may be constructed in a manner that minimizes the use of energy for heating and cooling without constraining the building's functions nor the comfort or productivity of the occupants.
- Provide criteria for energy efficient design of the building envelope, and methods for determining compliance with these criteria.

The scope of this project is to set energy requirements for newly constructed non-residential buildings, high-rise and low-rise residential buildings. Accordingly, for each climatic zone and sub-zone, previously described in section 6.2.2, 18 base cases were developed in total. Table 6.2 gives the ID numbers of these base case buildings. In each case, 10 design parameters with alternative scenarios were simulated using DOE 3.0 to identify their contribution to the overall energy performance of the building. These parameters and associated scenarios are illustrated in Table 6.3.

It is noted from the previous description that only thermal parameters are considered. The visible light transmittance (VLT) of the glazing is not considered an alternative in the built scenarios. In A1-O and A1-OL, the office base cases in zone A1 and which are the concern of this study, the glazing type used is 6mm single bronze with 50% VLT. This assumption may increase the energy consumption of the building, due to increased lighting usage and associated heat gain. The emphasis on thermal performance may actually lead to an increase in energy consumption, as the limited benefit from heat gain can be at the cost of significant reduction in daylighting availability, and hence more use of artificial lighting. At the same time, the low transmittance and colour of the glazing might negatively affect office users and reduce their productivity. A result such as this would contradict the main purpose of 'Lebanese Energy Standards for Buildings' project. On the other hand, lighting control strategies were also disregarded in the conducted simulations. This is another reason to prove that the role of daylighting in saving energy has been completely disregarded in the mentioned national project.

The description of the 'Lebanese Energy Standards for Buildings' project and its aims show that the ongoing project should not be considered as an energy standard but a thermal standard, because only heating and cooling loads are considered. This conclusion will be justified further in the following chapters, when the base cases A1-O and A1-OL are analysed and compared with the existing building stock.

Climatic Zone	Residential large with A/C	Residential large without A/C	Office large with A/C	Office small with A/C	Hotels	Schools
A1 0<H<500	A1-RL	A1-R	A1-OL	A1-O	A1-H	A1-S
A2 500<H<900	A2-RL	A2-R	-	A2-O	A2-H	A2-S
B1 900<H<1500	-	B1-R	-	-	-	B1-S
B2 1500<H	-	B2-R	-	-	-	-
C Inland	-	C-R	-	C-O	C-H	C-S

Table 6.2. Identification numbers of base case buildings per climatic zone developed with the 'Lebanese Energy Standards for Buildings'

	Parameter	Base Case	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	Orientation	North / South	East / West	South West / North East	South East / North West	
2	Roof Insulation (ETP cm)	0	2	4	6	8
3	Roof Colour	M	C	D		
4	Wall Insulation (ETP cm)	0	2	4	6	8
5	Roof Colour	M	C	D		
6	Window to Wall Ratio (%)	28	34	41	75	
7	Glazing U-value (W/m^2.K)	5.8	4	3.3	2.6	2.2
8	SC factor	0.71	0.95	0.6	0.5	0.3
9	Glazing Overhang (%)	66	10	30	50	100
10	Glazing Fins (%)	0	10	30	50	100

Table 6.3. The parameters and associated simulation scenarios developed within the 'Lebanese Energy Standards for Buildings' project.

6.4.4 Energy Standards, Building Regulations and Daylighting

Regulations governing daylighting in buildings are commonplace worldwide. However it is clear that their main aim is to protect occupants health and provide amenity, particularly in housing, offices and schools. Few examples have yet been found where energy conservation is the sole aim of a daylighting measure. Love (1995) reviewed this issue worldwide, but only in housing. The most common measure is to require the glazing area to be a particular fraction of the floor area. This fraction (i.e. the fenestration factor) is usually chosen to be 10%, and this is also the case in Lebanon. Canada allows openings to be as small as 5% for bedrooms in houses. Austria operates a sliding scale, increasing the required percentage as room depth increases. 10% is very low, well below the recommendations of the UK British Standard Code of Practice, for example BSI (1992). According to Littlefair, (1999) an area of 10% will give a very basic provision of daylighting for health and safety purposes.

Dutch housing regulations have an additional requirement; the glass transmittance should be at least 0.65, otherwise the glazing does not count towards the required window area (Love, 1995). In France, the window area is corrected by multiplying by the diffuse visible transmittance. This corrected area must be at least 10% of the floor area. There is also a requirement for a particular point daylight factor, as there is in Germany and Sweden (Littlefair, 1999).

The Scottish building regulations contained a requirement for daylight in housing, which was in force from 1963 (Pickering *et al.*, 1993). One problem with it was the complexity of calculation. However it did use the point daylight factor, which is harder to calculate than the average daylight factor currently recommended in the UK British Standard (1992). It was replaced by a simpler glazing area ratio, and then abandoned altogether in 1980.

The only mandatory standard for daylighting is contained in the *Workplace: Health, Safety and Welfare* Regulations, which apply to all EU countries including the UK. (Health and Safety Commission, 1992). This stipulates that 'every workplace shall have suitable and sufficient lighting' and that this lighting 'shall, so far as is reasonably practicable, be by natural light'. In addition, staff must not be located further than six metres from a window (Ander, 2003). These regulations do not set numerical guidelines for the amount of natural light.

Non-mandatory advice and guidance on interior daylight in the UK is contained in BS 8206 Part 2 (BSI, 1992) and the CIBSE applications manual on window design (CIBSE, 1999). Both documents set out three main criteria, all of which need to be satisfied if a room is to look adequately daylit. The overall amount of daylight in a room is quantified by the average daylight factor. If a predominantly daylit appearance is required, then the average daylight factor should be 5% or more if there is no supplementary electric lighting, or 2% or more if supplementary electric lighting is provided. This rule cannot be applied in Lebanon, where the sky conditions are not the same as in the UK. The two other criteria relate to the distribution of daylight in a room. One is a maximum depth criterion for side lit rooms; i.e. the limiting depth rule adopted in this research as a variable of the developed evaluation tool. The other states that supplementary electric lighting will be needed if a significant part of the working plane lies beyond the 'no skyline' (i.e., it receives no direct skylight). As well as these daylight recommendations the BS code also gives numerical guidance about sunlighting, and window areas for adequate view out (BSI, 1992).

In 2002 the Public Works and Government Services in Canada developed a daylighting guide for Canadian commercial buildings. Initial-stage planning parameters are outlined in it, and specific functional objectives of the daylighting strategies are established. Basic decisions about building form and window size are followed by approaches for daylighting the building's perimeter and core. Design considerations for glazing selection, shading strategies and occupant visual comfort are also discussed.

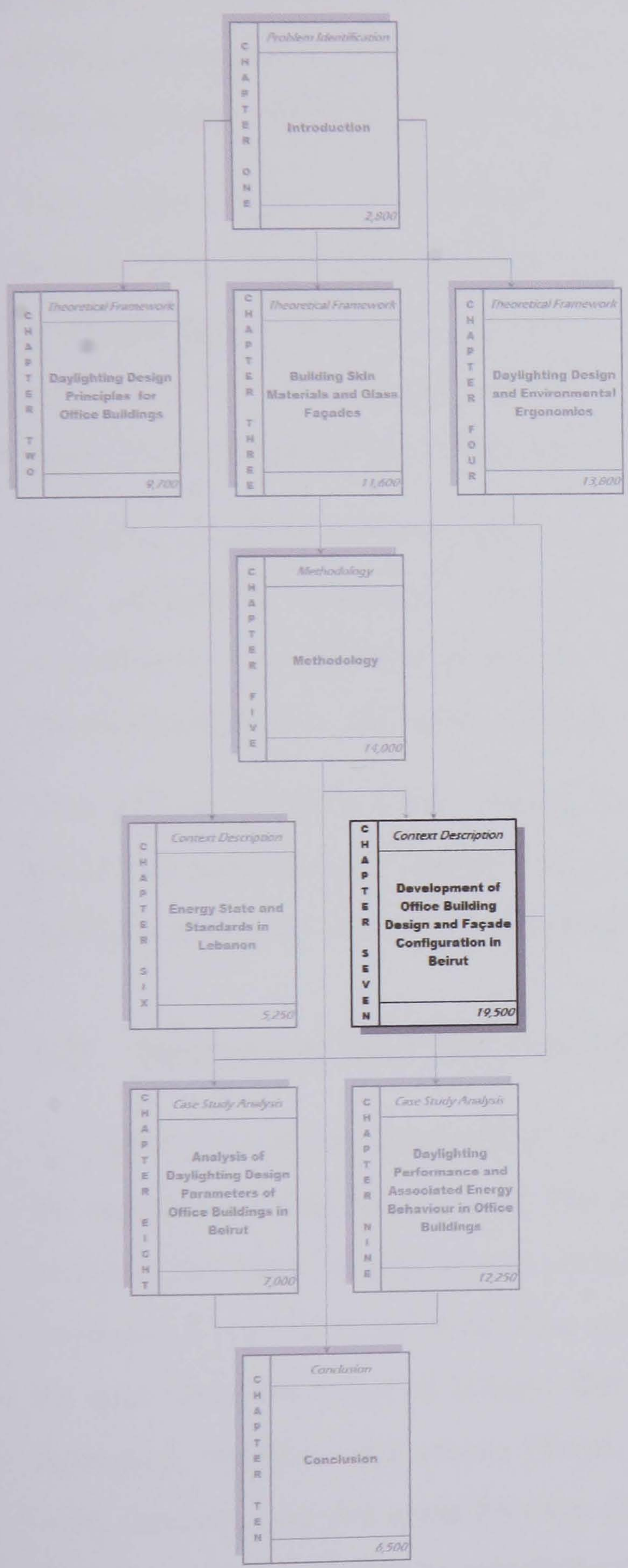
To conclude, the previous review showed that daylighting design recommendations have been marginalised in the international energy codes and standards. Some building regulations have emphasised certain design issues regarding the provision of optimum daylight in the indoor space. Most of these regulations are to do with health and safety, and have no energy-related aims. Non-mandatory guidance and advice on interior daylight have been developed in some countries. Lebanon is lagging behind, as daylighting in buildings has not been considered in any study. The Lebanese building regulations include very general rules addressing window sizing and room depth; these basic and outdated rules have been reviewed in Chapter 2. In addition, architects and building professionals in Lebanon lack any guidance that might help them to design well-daylit buildings. Given the lack of guidance about daylighting design in the 'Lebanese Energy Standards for Buildings', even the potential savings from daylighting are neglected. The analysis of the office building base cases used by the Lebanese energy standards will support this conclusion. All these facts increase the significance of this study, which may be considered as a basis for developing a daylighting guide for office buildings in Beirut.

6.5 Conclusion

This chapter began with some general background information about Lebanon and Beirut. The climatic conditions of Beirut were reviewed. The chapter also reviewed the state of energy in Lebanon in general, and in Beirut and the building sector in particular. It also discussed energy conservation awareness in the Western and Middle-Eastern regions. The ongoing project of the 'Lebanese Energy Standards for Buildings' was discussed. This study of the state of energy highlighted the dramatic growth in electricity use equal to 15% per annum. This growth was associated with by a continuous shortage of reserve power that peaked in 1990 with a 21% of the total power production. Beirut consumes 40% of electrical production, of which 70% is consumed by the building sector. 7.5% of the building sector requirement in Beirut is consumed by commercial buildings, which in turn use 20-25% of their supplied energy for electric lighting. With the acute shortage of energy supplies in Lebanon, this study has highlighted the immediate need to rationalise consumption in the building sector. An investigation of the ongoing project entitled 'The Lebanese Energy Standards for Buildings' showed that it places more emphasis on the thermal performance of office buildings, and marginalises the role of daylighting in saving energy. The role of daylighting is also largely ignored in the Lebanese building regulations.

DEVELOPMENT OF OFFICE BUILDING DESIGN AND FAÇADE CONFIGURATION IN BEIRUT

7



Chapter Seven

7. Development of Office Building Design and Façade Configuration in Beirut

7.1 Introduction

Chapter 7 reviews the emergence and development of office buildings in Beirut. The aim of this chapter is to study the alteration of façade typology and urban morphology of those buildings, and their impact on daylighting performance within office spaces.

This chapter begins by reviewing the historical and social background of Beirut as a city. Section 7.2 traces the first real signs of urbanization, that began in prehistory and resulted in the emergence of commercial and / or office use structures. Consequently, the major political, social, economic and cultural events are reviewed in order to frame the period of study. The different phases of development are identified in section 7.2.2.

Examples of office buildings from each identified phase are described and analysed for their daylighting efficiency. The daylight potentials of each example are evaluated according to four different parametric levels, which are 'Building Shape', 'Window / Façade' relationship, 'Window / Office' relationship, and 'Shading Devices' used.

Note that in the first three phases, some emphasis is given to the development of residential building architecture. The reason for this is that during certain periods office buildings were very few, while residential buildings had multiple functions.

7.2 Historical and Spatial Background of Office Development

As a starting point, the geographical context needs to be examined in order to understand the emergence of Beirut as a city. The Beirut peninsula occupies a complex site wedged between the base of the Mount Lebanon range and the Mediterranean Sea, which surrounds it on two of its three sides and has had a most important role in the history of the city. From the dawn of history, Beirut has been a sea-port and the natural place for fishermen, seafarers and traders (Serof, 1983). This triangular shaped area is far from being uniform, and flat areas for easy expansion are very limited. The topography of the historical centre includes an 'amphitheatre-like' shape sloping down to the natural cove below. Two hills (named the Ashrafieh and Ras Bayrut) occupy the northern part of the peninsula. The Ras Bayrut hill falls steeply into the sea at the Rawsheh cliffs, while the eastern edge of Ashrafieh has been cut by the Beirut River forming an escarpment at Siufe and Karm Zaytun. These two hills overlook low-lying areas to the North and South (Figure 7.1).

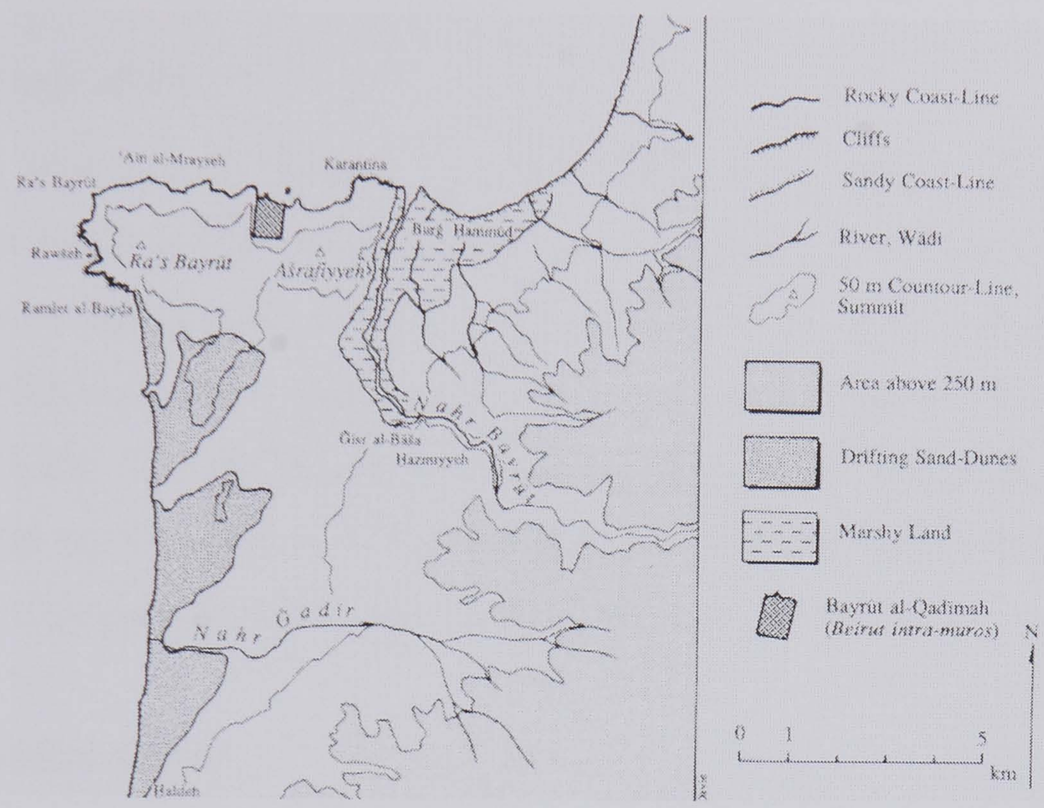


Figure 7.1. Geographical context of Beirut Peninsula (Davie, 1987).

One of the most prominent features of Beirut's growth as a dominant urban centre is its poly-nuclear character, with various distinct communities developing around its traditional core – the fortified medieval city. To a substantial extent, the history of Beirut is the history of various groups who either subjugated the city or sought refuge in one of its communities. In this sense, the urban development of Beirut is intimately dependent on exceptional circumstances of varying intensity and exogenous forces which shaped its physical structure and its importance as a commercial and cultural centre. Accordingly, one cannot adequately understand the emergence of one particular issue without placing it in its proper historical framework. A brief historical sketch of Beirut, therefore, will enable us to view the emergence and development of office building architecture within its broader historical context.

7.2.1 A Brief Historical Sketch of Beirut

This Section will provide a brief overview of some historical landmarks as a backdrop for reviewing the more recent determinants of Beirut's urbanization, and its associated office-use architecture.

7.2.1.1 *Prehistoric Beirut*

Beirut, along with Tripoli, Byblos, Tyre, and Sidon, is one of the oldest cities on the Mediterranean coast. In fact, Beirut provides a focal point in an area often depicted by archaeologists as the 'nursery of homo sapiens'. Archaeological findings in prehistoric Beirut repeatedly show the Lebanese coast to be one of the oldest settlements of man, as evidenced by relics from prehistoric communities. Some of the implements (mainly stone artefacts) found on the seashore of the Beirut coast belong to the Lower Palaeolithic era, being roughly 2 or even 3 million years old (Khalaf *et al.*, 1973).

7.2.1.2 *Phoenician Beirut*

Beirut grew from a small Phoenician port of little commercial or strategic importance, taking its name from the multitude of water wells in the area (*beryte*, the Canaanite world for well, is the original name for Beirut). Beirut, like the rest of Phoenicia, had been under Egyptian rule since the XIIth dynasty (1580 B.C. onwards) and tablets discovered in Egypt in 1887 reveal the correspondence between the Egyptian pharaohs and Ammunira, who ruled Beirut as a fortified and organized city. According to Serof (1983), some deity related to good life and generous nature was venerated on the western hill, later turned into an acropolis.

7.2.1.3 *The Roman City*

In the Hellenistic period, Beirut grew into a medium sized town still of no great importance, but it was to become a leading city of Roman Civilization. Marcus Agripa, admiral of Augustus, captured the city in 15 B.C. and Beirut was granted the status of a Roman colony with the honorific title of "Colonia Julia Augusta Felix Berytus" (Serof, 1983). It became virtually a garrison town with a castle, a fortified wall and impressive evidence of rational planning and urban zones. The reasons behind this sudden growth in significance are not very clear. Excavations in the centre of the town of 1941 and 1946-

1947 reveal aspects of Roman planning and urban zones. According to Khalaf *et al.* (1973), the kings of the Herodian dynasty in Palestine embellished Beirut with public buildings, hippodromes, amphitheatres, baths and porticoes, to please the Roman emperor. However the real role of Beirut under the Romans was cultural in nature. The law school founded there, which flourished between the 3rd and 6th centuries gave the town a cultural significance and an area of specialty that were envied by important Mediterranean towns such as Antioch and Alexandria. This strong regional role for Beirut was only lost when the whole town was left in complete ruin by a series of earthquakes that occurred between 551-560, accompanied by a huge tidal wave and an overwhelming fire. The school of Law was transferred to Sidon, and Beirut's silk industry and commerce moved to Greece and Sicily. Beirut would not recapture its past splendour until the 19th century (Serof, 1983).

7.2.1.4 *Beirut in the Middle Ages*

For over twelve centuries following the destruction of the Roman city, and all through the Arab, Crusader and Ottoman rules, Beirut was a relatively insignificant town. The concern during these restless and ruthless times was for the fortification of the city. The city walls and gates, the "Sea Castle", the harbour towers, the "Bourj" observation tower were all erected during this period. The exquisite Crusader churches, later to be turned into mosques, were also constructed then. Many broken columns from the old Roman city went into the construction of the walls; others were left scattered about the city (Serof, 1983).

It was only as the nineteenth century approached that Beirut became a Turkish *Vilayet*, due to restructuring of the political system in Lebanon.

7.2.1.5 *The Ottoman Period until 1919*

Prior to 1840, despite its eventful past and commanding geographic site as an entrepot and gateway between East and West, *Beirut intra muros* was no more than a small fortified medieval town with six main gates and about 0.65 square kilometres surrounded by gardens (Figure 7.2). Mosques, castles and fortification towers marked the medieval silhouette of Beirut (Davie, 1987).

In 1832, Beirut was established as the capital of *vilayet* Sidon under Egyptian occupation. Urban improvements included the enlargement and cleaning of Beirut port, and the establishment of a quarantine area to the east of the port. The first physical manifestation of Ottoman reassertion of power over Beirut can be dated to the 1850s following Egypt's withdrawal in 1841, after a confrontation with the British fleet. The Ottomans built new military barracks and an administration building, the *kushlak,* which later became known as the Grand Serail (Figure 7.3). Completed in 1853, this construction was the architectural expression of the new Ottoman military organization. Both in terms of its elevated location and ascetic façade, it was in fact a smaller version of the *Selimiyye* Barracks in Istanbul. The two floors stretched over eighty metres on the elongated side, easily making it Beirut's largest building in living memory. Its arcaded portico, protruding on the eastern façade was framed by two symmetrical wings, regularly structured with three rows of sixteen small, identical windows (Davie, 1987).

Figure 7.2. Beirut intra Muros, 1841 (Davie, 1987).

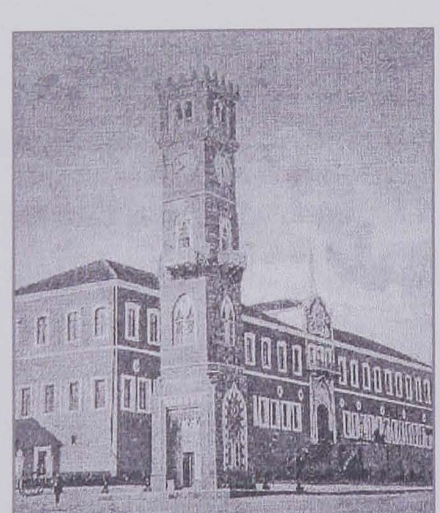


Figure 7.3. The Grand Serail

However, it is between 1840 and 1864 that Beirut underwent the most important changes. They constituted a turning point in its modern history (Saliba, 1998). In 1856, the Ottomans introduced recentralisation reforms and created centralized institutions such as the Ottoman Bank, to supervise the affairs of the empire (Sarkis *et al.*, 1993). The French controlled Ottoman Bank acted as the key negotiator, giving French investors priority in development projects. In addition, low import duties and the building of shipping wharves attracted foreign entrepreneurs and investors. Foreign investments were made in silk spinning factories, banks, insurance companies and foreign merchant houses, currency, commodities, real estate speculation and the hotel business. These business developments were followed by trading firms and consular representatives.

It was at this time that the extramural expansion began, and army barracks, government buildings (Petit Serail, 1883), educational buildings (the Syrian Protestant College now known as the American University of Beirut, 1866; Saint Joseph Institute for higher Education, 1884), and private residences were all built outside the medieval city walls.

Finally the construction of the Beirut – Damascus mountain road, completed in 1863 by a French company, opened Beirut to the Syrian/Arabian interior and made it the principal entrepot of the region.

This urbanisation was accompanied by rapid population growth. By the time of Egypt's withdrawal in 1841, the city's population was 15,000 and reached 100,000 in 1885 (Sarkis *et al.*, 1993). By 1920, with the declaration of Beirut as the Capital of Greater Lebanon under the French Mandate, and after the withdrawal of Ottoman troops from the Levant in 1918, the population of Beirut had reached 130,000 to become 160,000 in 1932 (Saliba, 1998).

To conclude, this brief review should be sufficient to demonstrate that Beirut's prehistoric eminence and apparent momentous history is somewhat misleading. Beirut is fundamentally a city of the 19th century, and one need not to go too far back into its past to discover the establishment of governmental or office-use buildings. In fact, it was not until late in the 19th and early 20th centuries that the first true signs of urbanization began to appear (Figure 7.4). For this reason, the architectural development of office-use buildings is investigated within the period falling between the late 19th and 20th centuries.

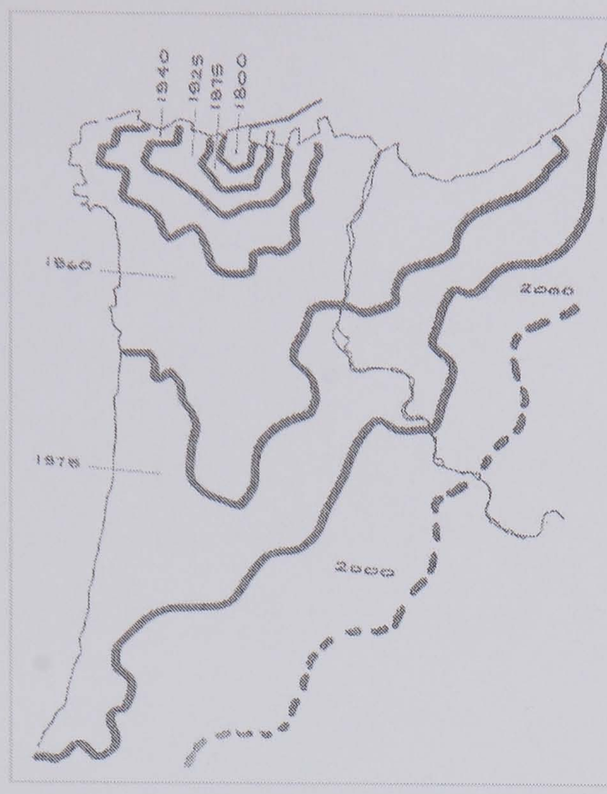


Figure 7.4. Expansion of Beirut City from the old town to the surrounding suburbs (Serof, 1983)

7.2.2 Framing Historical Phases of Beirut Architectural Development

Sarkis *et al.* (1993), Salam (1998), Saliba (1998) and Arbid (2002) set out a chronology of events that affected the modern urban and architectural history of Beirut. The chronology presented by Sarkis *et al.* (1993) is not an attempt to review the historical development of architecture. It is simply a listing of major political and cultural interventions in the urban environment, and their documentation in the form of a chronology permits association with the political history of the city.

Salam (1998), Saliba (1998), and Arbid (2002), use dates of important political (mainly), social, economic and cultural events in the history of the city to frame the historical phases of urban and architectural development. Some of these dates are listed below:

1920 Lebanon allotted to France as a mandated territory

Declaration of the State of Greater Lebanon with Beirut as its capital

1922 Reinforced concrete industry becomes commercially available

Improvement of electrical infrastructure

1930 The building of la Place de L'Etoile in Beirut

1932 Master plan for Beirut by the French planning consultant Danger

New building laws enacted regulating procedures for building permits and construction

1933 Building regulations introduced specifying set backs, technical specifications and sanitary and ventilation requirements

1940 Enactment of a new building code (decree No 61/LE) regulating building permit procedures, building height, protrusion and set backs with ancillary provisions for 'passive defence' measures, such as fire protection and underground shelter specifications

1943 Independence of Lebanon

1944 Beirut Master Plan produced by a French architect, Michel Ecochard

1946 French troops completely evacuated from Lebanon

1948 Creation of the State of Israel and influx of Palestinian refugees that produced population pressures, flow of capital and an increase in building activity, hence number of land transactions

1950 Egli planning report presented, recommending the adoption of the Ecochard Plan but never approved.

1954 Suppression of the 21m-height limit for the building code

1956 Suez Canal crisis which compelled aviation companies, banks and oil companies to relocate their overseas offices in Beirut

1958 Start of Fouad Shihab Regime, with strong planning policies enforced against laissez-faire urbanism for the first time since independence. In general the Shihabist period (1958-1964) is remembered mainly for administrative reforms, which continued in the following regime (1964-1970)

1970 "Loi des Grands Ensembles" was inaugurated to increase the building height limit from 24 metres to 40 metres

1973 Livre Blanc (the White Book), a new proposal for a master plan, advanced policies for decentralization. Ministries sought office space in the immediate suburbs outside the city

1975 Start of the civil war

1990 End of the civil war.

Using these dates, the Saliba study in 1998 focused on the period between the start of the French mandate in 1920 and 1940, a few years before independence. He subdivided the first 4 decades of the 20th century into 3 phases:

- Before 1920: Early Transitional phase or Traditional and Neo-Traditional phase
- Between 1920 and 1930: Mid Transitional phase
- 1930 – 1940: Late Transitional and Early Modern phase.

On the other hand, Salam (1998) viewed the urban planning development of Beirut city as passing through 5 identified stages:

- 1922 - 1946: The French Mandate Phase
- 1946 – 1958: The Early Years of Independence Phase
- 1958 – 1975: The Shihabist and Post Shihabist Period
- 1975 – 1990: The Civil War Period
- 1990 to present: The Post-War Reconstruction Period.

The division into historical phases by Salam is framed by political events. The first phase is the period between the beginnings of Great Lebanon under French mandate until independence, which some identify as 1946 when the last French soldier was evacuated from Lebanon. The Shihabist Regime was a challenging period for the development of the city (Interview with Assem Salam on April 4, 2003). The second phase was from the early years of independence until the start of the Shihab's regime. The third phase includes the Shihabist regime and those following, before the beginning of the civil war in Lebanon in 1975 which continued until 1990. The war had major effects on construction in the whole country. The last phase is considered to be the post-war reconstruction period.

Arbid (2002) considered the period between 1946 and 1970 as a period of architectural modernism in Beirut. The same considerations were taken by that author for choosing the period of his study, except that the year 1970 was considered more precise than 1975 to frame the historical period of architectural modernism in Beirut. Arbid (2002) justified his selection by saying that 'symptoms of political malaise were already showing in the last days of President Helou's regime (1964 – 1970). However, within the profession of architecture and building, major events happened beginning in 1946, and later around the end of the 1960s, that helped to shape the period.'

To validate the literature reviewed previously, interviews were conducted by the researcher with Assem Salam, Robert Saliba, Georges Arbid and Pierre Nehmeh, architects and specialists in regional architecture and planning, asking whether such phase division could correctly be adopted for a historical review of architecture. The following seven stages were found to be appropriate to describe the office-use architecture of Beirut, which has changed from being a mediaeval city into a bourgeois Mediterranean city during the last 150 years.

1. Traditional and neo-traditional phase (before 1920)
2. Transitional phase (1920 - 1930)
3. Late transitional and early modern phase (1930- 1946)
4. The early years of independence phase (1946 - 1958)
5. The Shihabist and Post-Shihabist phase (1958 – 1975)
6. The civil war phase (1975 – 1990)
7. The post–war reconstruction phase (1990 – present).

The first phase is framed by two main events: the end of the Ottoman occupation, and the introduction of concrete as a new construction and structural material. The name of this phase is adopted from Saliba (1998). Saliba's analysis of architecture before 1920 is divided into 2 sub-stages: the traditional architecture of the old city of Beirut, and the neo-traditional architecture of early urbanization in the late 19th and early 20th century.

The framing of the second phase is also taken from Saliba (1998). It is identified as transitional because it was a phase in which architecture was changing from traditional to modern, mostly because of the increasing use of concrete as a new material (local cement production started in 1931) but with the same design techniques, imitating traditional architecture.

The end of the third phase is adopted from Salam (1998) and Arbid (2002). 1946 was the end of French troops' presence in Lebanon and the real launch of the Lebanese Republic, having gained its independence in 1943.

The last four phases, adopted from Salam (1998), are mostly bounded by political events which had major effects on architecture in Lebanon: the Shihabist regime which is considered significant by most of the architects interviewed, and according to Arbid (2002), a challenging period when many buildings, especially governmental, were constructed in response to the economic growth of this period. The Civil War, which started in 1975 and ended in 1990, established other major dates that affected the construction sector.

The following section will, therefore, describe the modern history of architecture, mainly office building architecture, through these seven stages. This description will mark the differences that occurred in plan morphology and façade configuration.

7.3 Modern History of Office Building Development in Beirut

In this section, examples of office-use buildings in each phase will be described. The buildings presented are the results of a deliberate survey by the researcher. According to interviews with local architects, most of whom have been practising architecture for more than 25 years, some of these buildings are considered good examples or representatives of the phase in which they were built. On the other hand, buildings constructed in the first 3 phases have been selected according to the data available about non-residential architecture, preserved in the old Ottoman archives and those from the early French mandate. The following section will compare these buildings through the analysis of diagrammatic presentation of empirical data, which evaluate daylight design factors presented in the previous chapter.

7.3.1 The Traditional and Neo-Traditional Phase (before 1920)

The centralisation of commercial and administration areas increased between 1860 and 1880. During this period the previous garden suburbs became an urbanised periphery, having been transformed into an urbanised district in the preceding forty years.

With the continuing urban growth, suburban residential types underwent a process of change to adapt to their new functions. Therefore, it is important to discuss the development of the residential building, which at certain periods has had a multi-use function. Non-residential buildings of this period will also be described and analysed.

7.3.1.1 *Development of the Residential Building*

The suburban house usually opened onto a garden, with a fountain in the middle and aligned with the central bay. Its construction material was local sandstone, plastered and painted for weathering (Figure 7.5).

By the first decade of the 20th century urban facades were aligned with streets, or built freestanding in the middle of medium to large size lots separated from the street by an elaborate fence. Common integrated vertical circulation, ground entrance and roof design characterised the urban houses of the neo-traditional phase (Figure 7.6). Mainstream residential buildings of the early 1900s underwent a fundamental change of function; the street-aligned ground floor was allocated for commercial activities (Figure 7.6b, c, d and e), clearly expressing the new vocation of the urban apartment building as a speculative structure. The vertical extension of these buildings aimed at being three floors above street level. Low cost structures sometimes reached four floors in height.

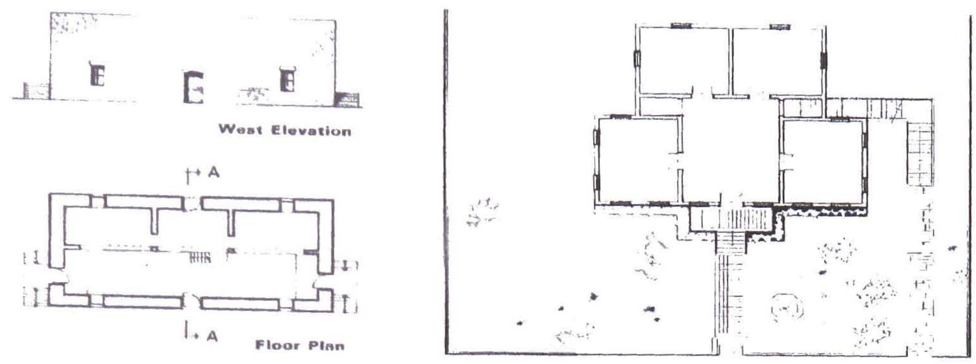


Figure 7.5. Example of a traditional suburban house, with load-bearing walls and small openings (Ragette, 1974).

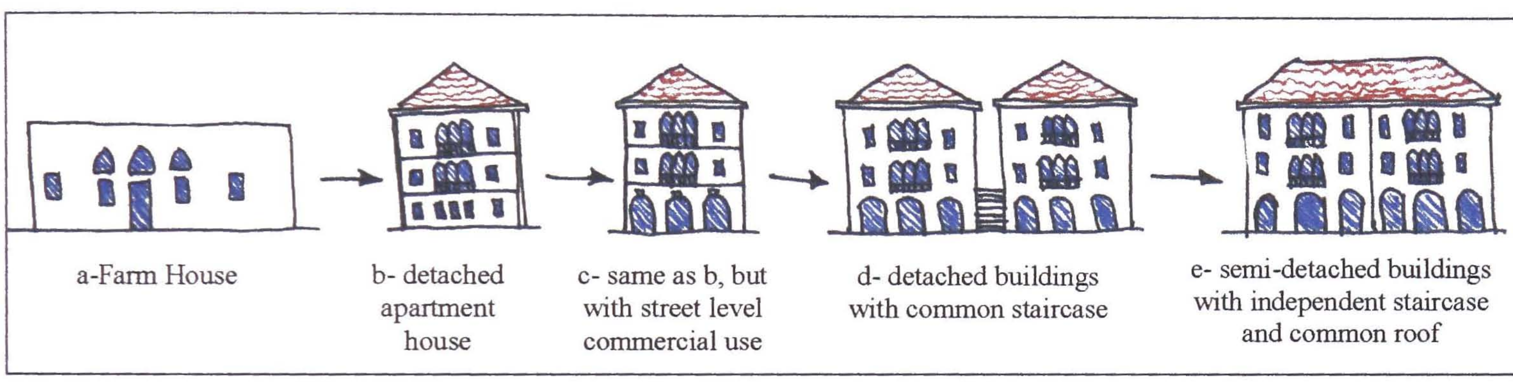


Figure 7.6. Urban façade typology development in the traditional and neo-traditional phase.

The attachment of buildings reduced daylight penetration from four sides (suburban houses and detached apartment buildings) to three (detached buildings with a common staircase, with restricted neighbour setbacks) or even two sides (semi-detached buildings with a common roof or attached buildings). Traditional houses were therefore developed to bear a resemblance to terrace houses. Consequently, rooms become unilaterally lit by daylight after they had been daylit multi-laterally (Figure 7.7).

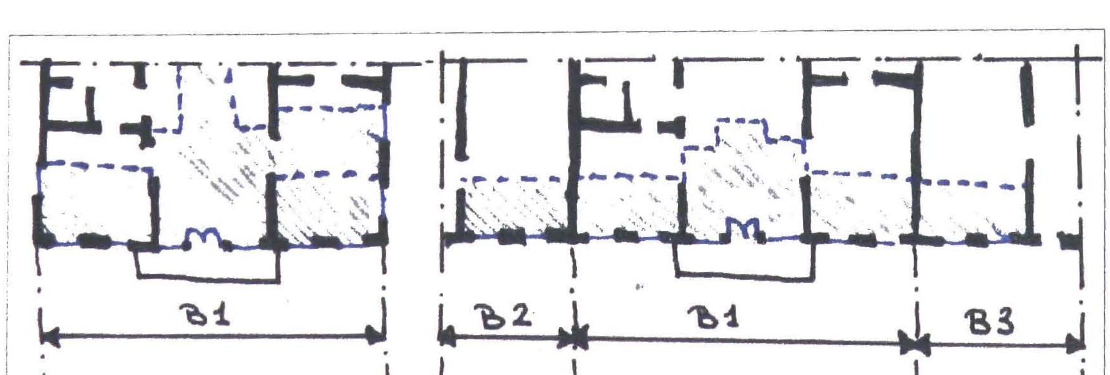


Figure 7.7. Daylight penetration in rooms of attached and detached buildings (referring to a rule of thumb: daylight penetrates about 2.5x the aperture height. Robbins, 1986).

The triple arch central bay was the dominant feature of residential building facade at this period. It is a combination of three generic elements: the window, the door and the arch. These elements had different forms, which were adaptable to the width and the height restrictions. Its main components can be identified as follows (Figure 7.8):

- The upper section or arched head, usually having decorative tracery and coloured glazing (Figure 7.8(a)).
- The intermediate section in the shape of a rectangular horizontal bay, with equivalent tracery at the arched head (Figure 7.8(b)).
- The lower section formed by door and window lights (Figure 7.8(c)).
- The vertical supports consisting of marble columns (Figure 7.8(d)).

During the second decade of the 20th century, the use of ashlar declined in high and mainstream buildings. Instead, poor quality sandstone with external plastering was used. A new trend emerged, consisting of reproducing stone courses and surface ornamentation with incised and painted stucco (Figure 7.9).

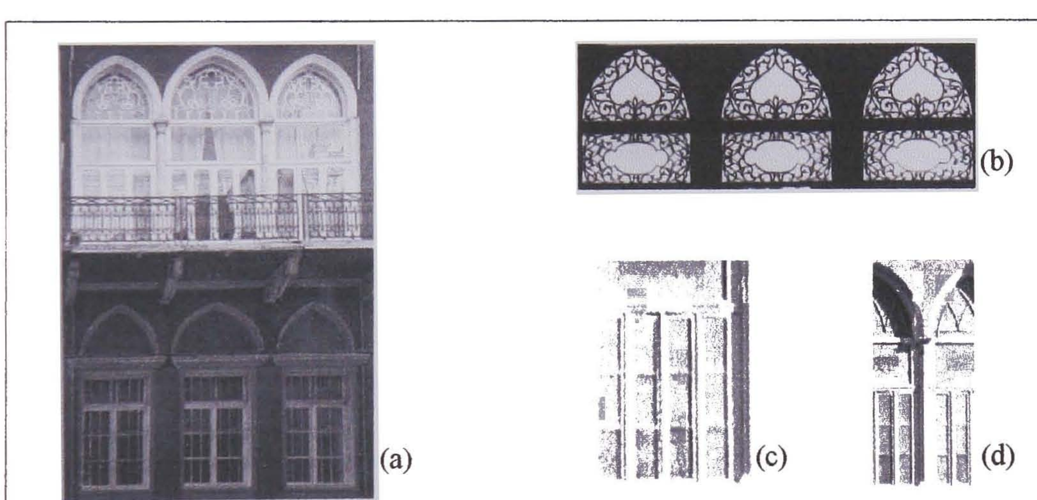


Figure 7.8. a- The triple arch central bay. b- arched head and intermediate section. c- lower section (door or window). d- vertical supports (Saliba, 1998).

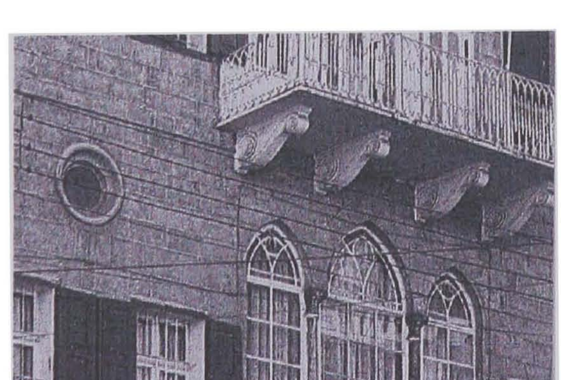


Figure 7.9. Building constructed with poor quality sandstone and stucco finishing, imitating stone courses (Saliba, 1998).

7.3.1.2 *Non-Residential Building Development*

In the 19th and early 20th century this urbanized district was subdivided into two parts by 'Weygand' street, the lower and the upper parts. The part below Weygand Street related to the port of Beirut, which was originally the old city, and the part above related to the city centre.

In the lower part of the city were the 'khans'. Saliba (2003) states that the 'early forms of office used in traditional Islamic cities were khans'. They included shops, storage space, workshops and lodgings, and, in some cases accommodated financial institutions and consular offices. The last khans were built in the 19th century, and no longer exist. Khans were originally inward looking structures, built around an open courtyard and accessed from the narrow streets of the intramural city (Figure 7.10). They lacked formal elevations, other than a decorated portal indicating their entrance to the passer-by. In the second half of the 19th century, when new street patterns appeared with the city's modernization, khans began to change into more extrovert structures. Khan Antoun Bey, for example, revealed an imposing symmetrical elevation, with a variety of window shapes and upper floor colonnaded balconies (Figure 7.11). The street façade configuration of Khan Fakhry Bey is a repetition of the same window unit over the full width, which prefigured the modular elevation of modern office buildings described later in this chapter.

Figure 7.10. The inward-looking khan in the foreground (Saliba, 2004).

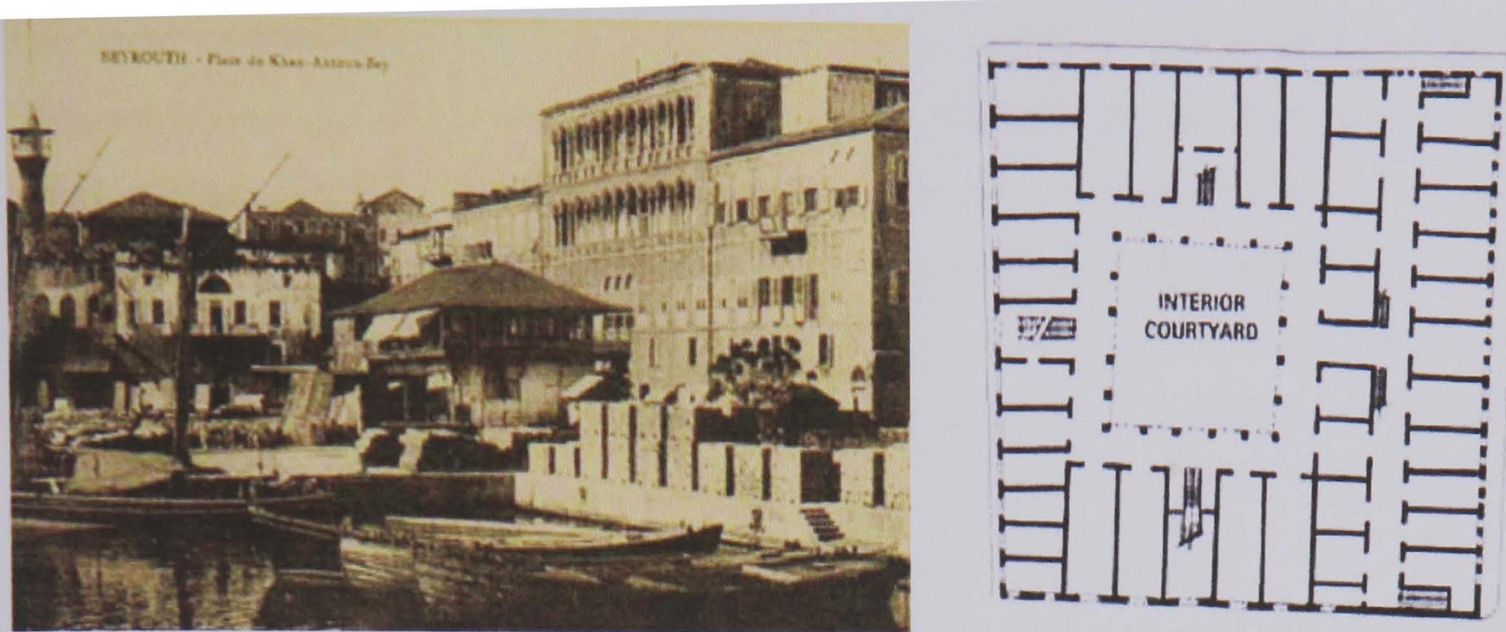


Figure 7.11. The outward-looking khan (khan Antoun Bey; Saliba, 2004).

At the turns of the twentieth century, khans developed into two other types of commercial or office buildings: the exclusive corporate headquarters or branch office, and rental or speculative buildings (Saliba, 2004). The former was usually designed as a sophisticated structure aimed at promoting the image of a commercial or financial institution. The Imperial Ottoman Bank belonged to this category (Figure 7.13c). Speculative buildings formed the majority of commercial constructions during this period. The earlier ones adopted the building type with a prevalent central hall, having a red-tiled pitched roof, triple arch and corbelled balconies (Figure 7.12) This type of building would accommodate shops or storage at the lower or street level, while the upper levels were rented offices, or could equally have been rented apartments. Buildings of this type were discussed in the previous section.

Figure 7.12. 'Avenue des Francais' with central hall buildings and red-tiled pitched roof (Saliba, 2004).

The most important governmental and institutional buildings constructed during the Ottoman period are the 'Grand Serail', the military hospital, the clock tower, the 'Petit Serail' (Figure 7.13a), The Orosdi Back Department Store (Figure 7.13b), the Imperial Ottoman Bank (Figure 7.13c), and many other educational establishments of foreign origin. Of these buildings the Grand Serail, which is described in Section 7.2.1.5, was initially designed as a barracks. The Orosdi Back, constructed in 1900 as a department store, is considered to represent turn of the century eclectism. The term 'eclectism' was used for the first time by the French philosopher Victor Cousin in the 1840s. It referred originally to an intellectual approach encompassing a variety of views borrowed from different systems of thought. Only the Petit Serail (B01; B stands for building and 01 for building ID number) and the Imperial Ottoman Bank (B02) are the archived buildings which had an office use function. Sheets 1 and 2 of Appendix I describe both buildings from the point of view of daylighting design.

Figure 7.13. Turn of the century urban eclectism: a- the Petit Serail (B01, D.O.C. 1884), b- Orosdi Back Department Store (D.O.C. 1900), c- The Imperial Ottoman Bank (B02, D.O.C. 1906) (The Levant, 1994).

The Petit Serail was given an eclectic outer appearance. It demonstrated early attempts to incorporate classical touches in a traditional form. The building consisted of two floors above a semi-basement, erected on a rectangular ground plan with a central courtyard. The two floors were lined with tall windows set off by Neo-Baroque marble frames producing a marked contrast to the dark Beiruti sandstone façade. The monumental white marble portal stretched over the basement and first floor, recalling the entrance to a palazzo of the Italian renaissance. The western-inspired treatment of window surrounds with light stone, segmental lintels, curved cornices and moulded sills, would be depicted in traditional and neo-traditional apartment houses one to two decades later. This affinity between public and residential buildings, before the introduction of Western building types, may be attributed to the use of the same construction material and architectural vocabulary, from fenestration to detailing to overall massing. It is interesting to note that a single window type is depicted in the Grand Serail, Petit Serail and suburban villas of the same period; only the window's ornamental treatment changes according to use, taste and budget.

By the end of the century, it was no longer clear if *vilayet* Beirut was a European colony or an Ottoman province. This is quite apparent in the Imperial Ottoman Bank, which was a piece of Second Empire architecture. Designed by a French architect, the building was topped with mansard roofing belonging more to Paris than to the Beirut seafront. This is due to the early westernisation which was shaped by the overlapping influences of European colonial interests and an accommodating Ottoman administration, pressured to loosen its grip on its Arab provincial possessions. The Ottoman Bank consisted of two floors, built on a narrow rectangular ground plan. The ground floor was for use by commercial stores, and the first floor was lined with tall windows.

Figure 7.15 and Figure 7.14 illustrate the diagrammatic description of the daylighting design features of these two buildings. In the two diagrams, the continuous lines measuring each variable show that façades of different orientations were more or less similar, and the percentages of area under curves are approximately equivalent (69% for B01 and 63% for B02). It can be concluded that the configuration of the two buildings leads to similar daylighting performance. The two buildings can be considered to have moderate daylighting levels, since the percentages of area under curve are above the average. The percentages of performance of 'Building Shape', 'Window / Façade', 'Window / Office' and 'Shading Devices' design variables of B01 are 100%, 33%, 70% and 100% respectively. Having high percentage of performance, the 'Building Shape', 'Window / Office', and 'Shading Devices' variables contribute more to daylighting performance and offer sufficient natural lighting. 'Window / Façade' variables have less impact on daylighting performance. As for building B02, the percentages of area under curve of the four main design aspects are 63%, 38%, 70% and 100%. Comparing the two buildings, it can be concluded that the main aspects that affect daylighting performance are the same in buildings B01 and B02, i.e. 'Building Shape', 'Window / Office' variables. This can be explained by the fact that during this period windows were narrow because of the construction system, while glass technology was limited to clear glazing. In addition, the lack of shading devices increased daylighting levels, with uncontrolled sunlight in interior spaces. However, the narrow tall openings were enough to illuminate small rooms of small daylight buffer zone depth (3 – 4.50 m). Also buildings were narrow in shape or opened onto a courtyard, such as that used in residential houses and khans.

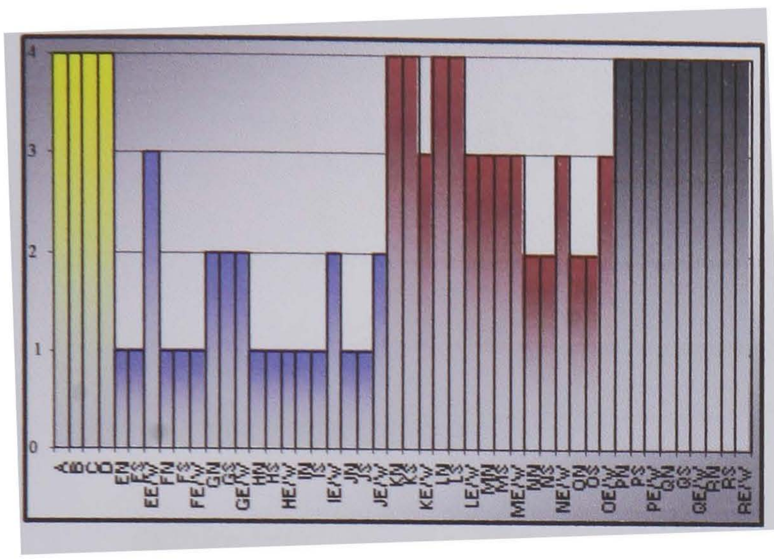


Figure 7.15. Diagrammatic description of the 'Petit Serail' (B01), D.O.C. 1884.

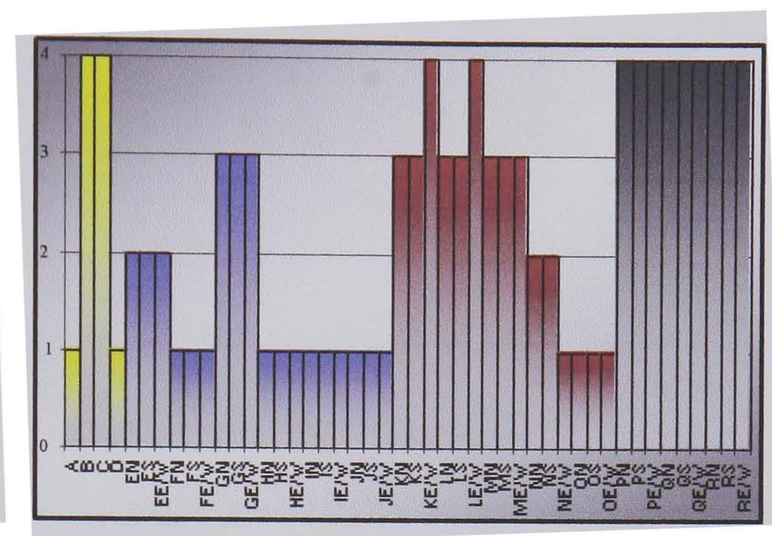


Figure 7.14. Diagrammatic description of the 'Imperial Ottoman Bank' (B02), D.O.C. 1906.

7.3.2 Transitional Phase (1920 - 1930)

With the beginning of the French mandate, cement was gradually integrated into construction. Following the arrival of the material in Lebanon, the use of imported cement increased about five times between 1920 and 1930 or '31 (Figure 7.16). Concrete consumption was driven by residential growth during that period. Builders and the public at large perceived this new material as 'artificial cast stone'. The resulting changes that occurred in massing and façade treatment may be summarised as follows:

- The decline of red brick roofing because of using flat roofs (Figure 7.19).
- Progressive replacement of the triple arch by alternative designs and shapes: the lower section of the central bay was least affected by successive changes; only the width of lights was modified, following the vertical subdivision of the arched head. In contrast the arched head was subject to extensive variations, ranging from horseshoe to elliptical arches and square heads. In the final stage the upper section disappeared, due to height restrictions and early modern influences (Figure 7.17).
- Disappearance of hood moulds and plastered bands outlining structural openings.

- The use of plain stucco finishes to external walls (Figure 7.18).

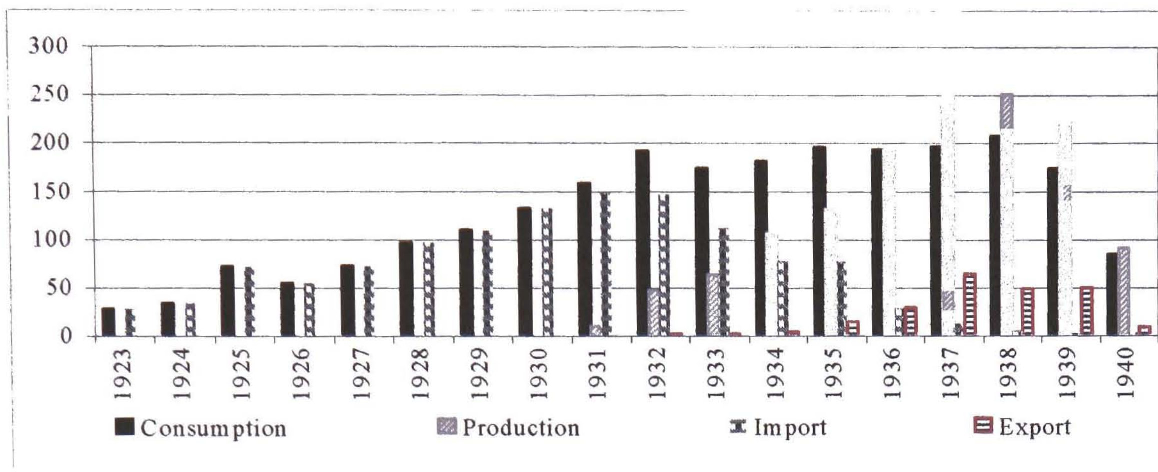


Figure 7.16. Consumption, production, import and export of cement (in thousands of tons) during the French mandate period (Saliba, 1998).

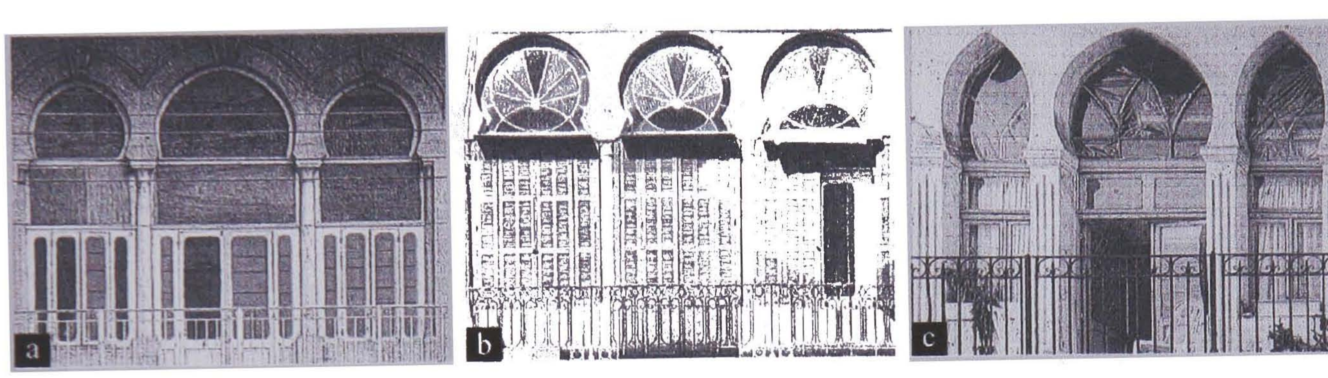


Figure 7.17. a- pointed arch with plastered bands outline, b-c- variation of horseshoe arch, with disappearance of upper section in b (Saliba, 1998).

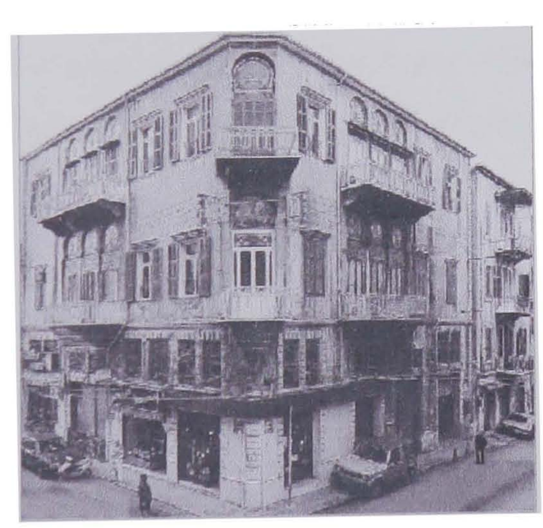


Figure 7.18. Barakat building (1923): the use of stucco finishing and horseshoe arch (Arbid, 2002).

In this section, the changes in façade design due to the use of cement in construction are investigated through the development of residential buildings. During this period many offices were still located in residential buildings. The Beirut municipality building, constructed between 1925 and 1928, is the only completed edifice from that period used solely for office purposes. Another example in Fosh Street, which is the first urban extension of the port area, will also be analysed. Fosh 128 Building, constructed in 1925, is considered a developed example of the speculative buildings described in the previous historical phase. This building has subsequently been renovated to become purely an office building.

7.3.2.1 *Development of Residential Buildings in Transitional Phase*

It is apparent from the analysis of buildings from the 1920s & 1930s (Saliba, 1998) that with the increase of cement use, residential buildings changed to become of central bay, veranda or bay window design. Figure 7.19 shows how the arch was subject to many changes, and red roofing declined gradually from the popularity it had enjoyed in the traditional and neo-traditional phases prior to 1920.

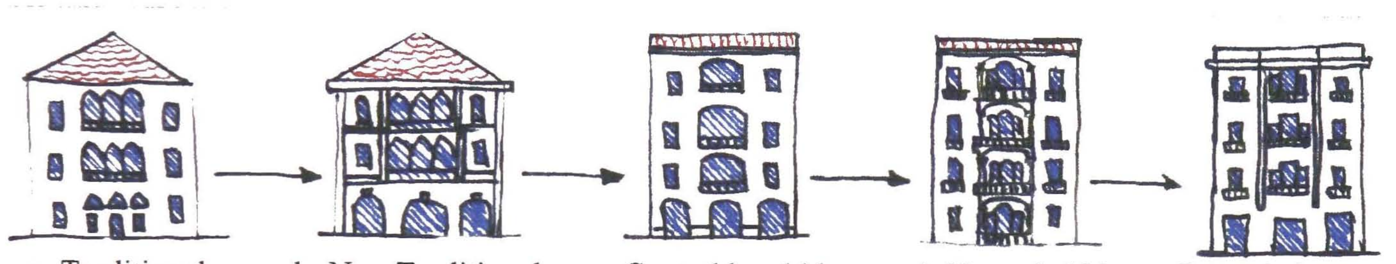


Figure 7.19. The typological evolution of the residential building façade: the triple arcade central bay to a simple rectangular box, and the gradual disappearance of red roofing.

As in previous periods, narrow and oddly-shaped sites in key locations were usually packed tightly with buildings. In the absence of a detailed law stipulating the size and shape of substandard lots, the façades occupied the full width of the lot. The use of concrete skeleton structures increased the flexibility of vertical extension. Prevalent examples of four-storey buildings correspond to the maximum height of buildings in that period.

According to Saliba (1998), the floor to ceiling height decreased from an average of 4.50m in the early 1920s to an average of 4.10m, in the walk-up apartment buildings of the early 1930s. The floor to ceiling height was prescribed as a minimum of 3.40m at the end of the French mandate period, by decree 61/LE, 1940, Art. 20. Accordingly, the height of windows decreased. Analysis of the arch, which is the dominant image of the façade, shows how it was influenced by this reduction. The lower section underwent successive changes, and the width and depth of daylit area were modified following these vertical influences. Consequently the quantity of daylight penetrating from openings decreased.

Another new feature was the introduction of the French window (door-window) opening onto on a small balcony (Figure 7.20). In spite of the disappearance of an arched head to the central bay side openings, French windows permitted deeper narrow daylight penetration (rule of thumb).

Figure 7.20. The French window, consisting of a long and narrow door opening on a small veranda.

7.3.2.2 *Development of Non-Residential Buildings in Transitional Phase*

As mentioned in the previous section, the urbanized city of Beirut was firstly extended to General Fosh Street and Allenby Street, which are adjacent to the port area. Figure 7.21 shows a view of the two streets in 1948. Most of the buildings consisted of four floors, with the ground floor used for commercial purpose. As for the floors above, apartments were rented for residential and/or office use. Today some of these buildings are still there, and since the civil war they have been renovated by the Solidere company for use as office buildings. The use of French windows is quite clear in the elevations. The use of multiple forms of arches is also apparent in the aligned elevations, occupying the whole length of their sites. One building in each street has been extensively analysed: the 'Beirut Municipality' building B03 (Figure 7.22) and 'Fosh 128' building B04 (Figure 7.23), which are represented in Sheets 3 and 4 of Appendix I, respectively.

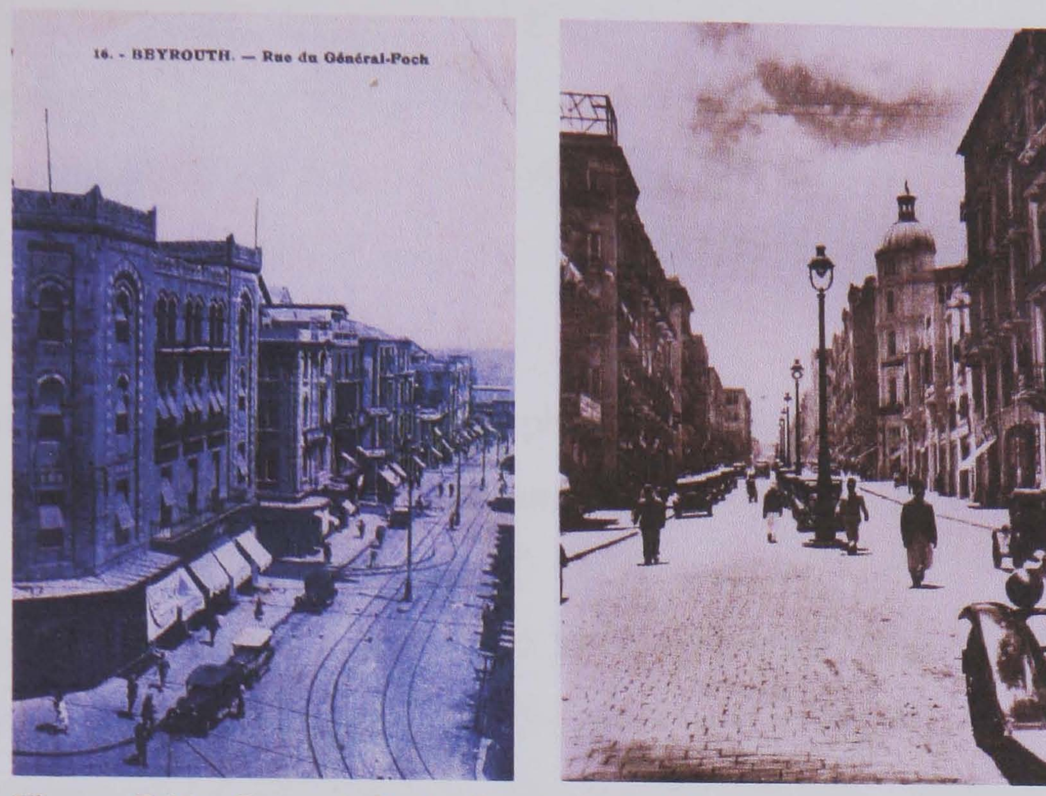


Figure 7.21. General Fosh Street and Allenby Street views as appeared in the postcards of the old Beirut (The Levant, 1994).

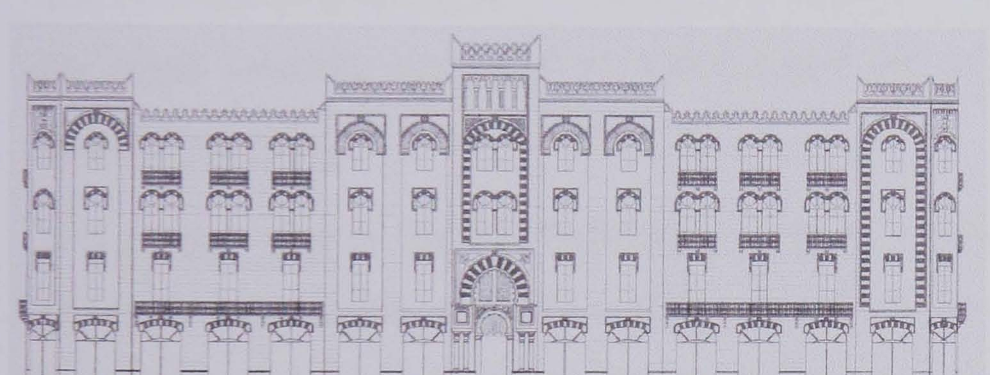


Figure 7.22. 'The Beirut Municipality' building main elevation (B03), D.O.C. 1925-1928.

Figure 7.23. 'Fosh 128' building main elevation (B04), D.O.C. 1925.

Figure 7.22 and Figure 7.23, which illustrate the main elevations of the two buildings, show how the two buildings share the same façade elements: the bay window, the French window and the main entrance door extended to two floors height, but the average wall to aperture ratios of the two buildings are quite different (0.33 for B03 and 0.20 for B04). This can be explained by the fact that openings, particularly French windows, were used to compose aesthetically and create some architectural order in the façade. Windows of different shapes have thus been used for aesthetic and not functional reasons, and which make the difference in wall to aperture ratios. It is notable that although B03 was originally built for office use, façade typology did not differ from that of residential or multiuse buildings. The wall to aperture ratio did not change from the average for buildings in the preceding phase (0.31 for B01 and 0.30 for B02). The explanation for this is that despite the use of the skeleton construction system architects were still using the same design methods as previously, limiting the openings to narrow vertical doors or windows separated by large solid walls.

The impact of façade typology and plan morphology on daylighting performance of the two buildings is illustrated in Figure 7.24 and Figure 7.25. In the two diagrams, the percentages of total area under curve for B03 and B04 are 57% and 53%, respectively. These figures are lower than the values found for buildings B01 and B02. Therefore the general daylighting performance inside the buildings has decreased, and has a median figure. The percentages of performance of 'Building Shape', 'Window / Façade', 'Window / Office' and 'Shading Devices' design variables of B03 / B04 are 44% / 88%, 42% / 33%, 60% / 50% and 100% / 50%, respectively. The dissimilarities in these figures are further proof of a transitional phase caused by changes in the construction system. The decrease in shading device percentage relates to the use of French windows in which the small veranda, increased in width, plays the role of horizontal overhang for the window beneath.

It is notable that in the two buildings, an open courtyard is used to illuminate the core (Porosity ratio is 2% for B03 and 9% for B04). The courtyard in B03 serves only to illuminate the circulation area but in building B04, the bigger courtyard illuminates the east / west office spaces.

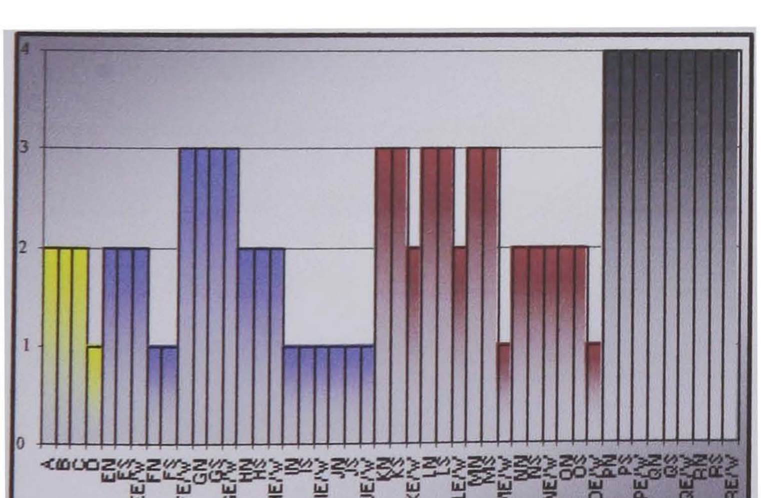


Figure 7.24. Diagrammatic Description of the 'Beirut Municipality' building (B03, D.O.C. 1925-1928).

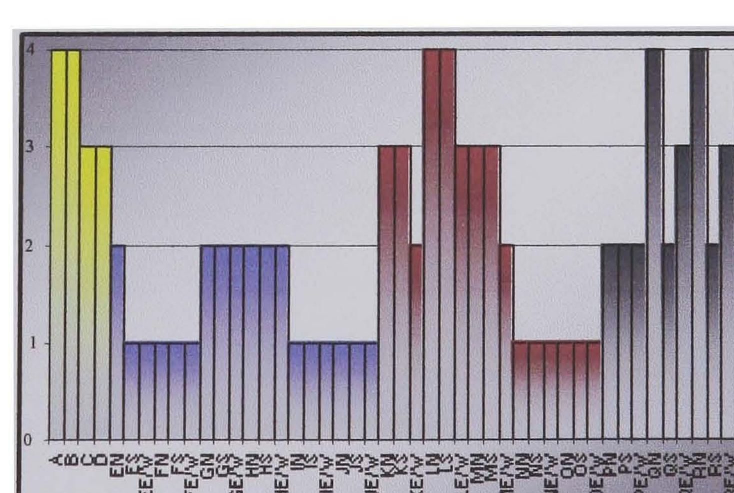


Figure 7.25. Diagrammatic Description of the 'Fosh 128' Building (B04, D.O.C. 1925).

7.3.3 Late Transitional and Early Modern Phase (1930- 1946)

In recent studies on Lebanese architecture (Saliba, 1998; Salam, 1998 and Tabet, 1998), the 1930s are usually considered in conjunction with the 1920s. On the other hand, according to Arbid (2002) in-depth analysis indicates that 1930s architecture witnessed several changes, which align the decade more with the 1940s and '50s.

With the arrival of the cement industry in Lebanon in 1931, concrete became the standard material of construction for urban buildings. The use of cement with skeleton construction systems was a way to overcome the increasing price of urban land; the construction of dense rental complexes increased, consisting of attached buildings and the stacking of small units on extremely restricted sites. However new building laws were enacted in 1940, regulating setback requirements, sanitary specifications, ventilation requirements and so on. They also determined the zoning coefficient, densities of occupation and property holding.

As in the analysis of previous phases, the development of residential buildings will also be reviewed in this section because office buildings were not widely spread, offices being still located in multi-use buildings. At the beginning of the 1930s, these buildings spread into the "Place de l'Etoile' area, which followed the urban development of General Fosh Street, Allenby Street and Weygand Street. Two case studies of this period will also be analysed in detail.

7.3.3.1 *Development of Residential Buildings*

The typological configuration on central hall house of the 1920s lasted until the 1940s, and would develop and change because of two major factors: intense urbanisation and the use of a new material, namely concrete. According to Saliba (1998), analysis of the central hall house reveals that the highly eclectic styles of the mid transitional period reached a maturation stage characterised by:

- Refinement of architectural ornamentation
- The adoption of contemporary styles, such as Art Deco and Art Nouveau
- A progressive simplification of forms under the impact of early modernism.

While the 1930s offered a rather elegant version with richly decorated protruding bays and loggias in concrete, the 1940s witnessed a simplification of the detailing, while generally keeping with the same organisation plan. French windows lost their framing and lintel mouldings, and the central bay was reduced to three rectangular openings. In later buildings, the central bay was expressed as a single glazed bay with simple subdivisions. Consequently, the increase of glazing to framing ratio and the higher area of glazing allowed a higher and deeper quantity of daylight. Figure 7.26 illustrates this consequent evolution of the central bay elevation in Beirut from the traditional to the early modern phase.

Focusing on the development of the central hall house, Saliba (1998) does not address other directions, already initiated in the 1930s, often by the same engineers and architects who designed theses houses. Another history could be written that would look at the major changes affecting architecture in more general terms, namely the extensive use of concrete as the standard construction material in that phase, and the fitment of electrical lifts which encouraged the vertical extension of buildings. According to Arbid (2002) who referred to a personal interview with Gabby Rayyes, the first elevator was installed in the 'Ibrahim Sursok' building in 1935. This building will be analysed later.

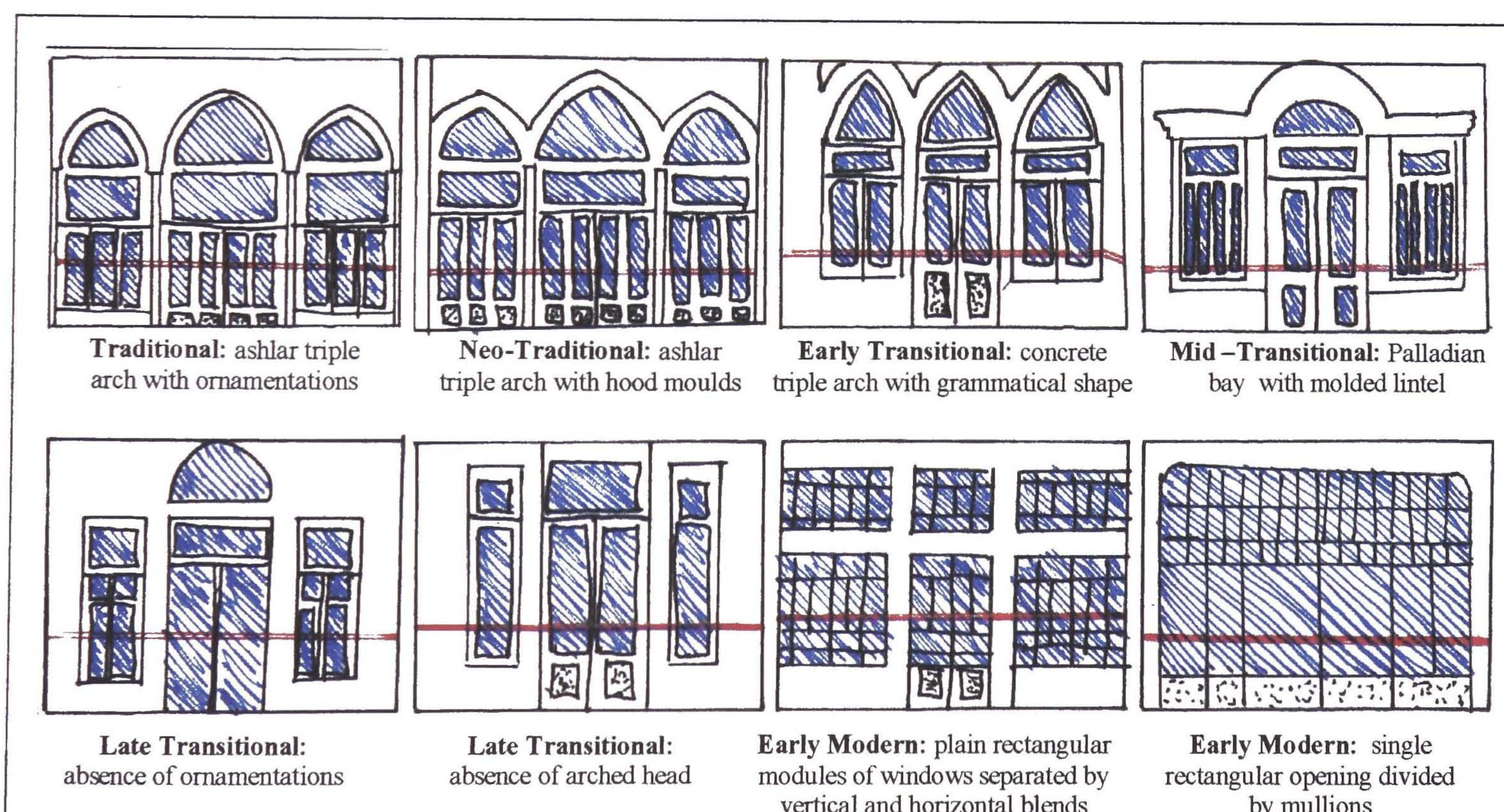


Figure 7.26. The development of the central bay from the traditional phase to the late modern phase.

7.3.3.2 *Development of Non-Residential Buildings*

To investigate the development of office buildings in this phase, two buildings with available data are extensively analysed. Figure 7.27 and Figure 7.28 give perspective views of 'Fosh 1153' building (B05) and 'Ibrahim Sursok' building (B06), respectively. Sheets 05 and 06 of Appendix I present detailed information about the two buildings.

Figure 7.27. 'Fosh 1153' Building (B05), D.O.C. 1932.

Figure 7.28. 'Ibrahim Sursok' Building (B06), D.O.C. 1935 (Arbid, 2002).

Built in 1932, 'Fosh 1153' represents a developed or 'modernised' version of the central bay façade typology. This is expressed by the use of the flat arches and semi circular arches only on the top floor, possibly to indicate the end of the vertical extension of the building. The bay window is more flattened, taking a simplified rectangular shape. The French window with its small veranda is another important feature of façade typology that continued in this phase, as in the previous one. Much simplification occurred to the lintel mouldings and veranda corbels. The framing of openings is only marked by a change of colour.

In 1935, Bahjat Abdulnour designed and built the 'Ibrahim Sursok' building, a landmark of early modernism in Beirut until it was demolished after the war during the reconstruction of the Beirut Central District (Arbid, 2002). The building was the first in its kind in the city, displaying a rational horizontal treatment of openings and a bold mass devoid of decoration. As has been mentioned previously, the use of a lift (for the first time) in this building permitted further vertical extension. The core of deep rectangular shape was an internal courtyard that afforded daylighting and natural ventilation of the internal offices and circulation spaces.

Despite the change in façade typology and architectural style, the two buildings described above had approximately the same window to aperture ratios (0.33 for B05 and 0.32 for B06). The 'modernity' in building B06 was limited to the simplification of detailing. Windows were changed from vertical to an intermediate shape. The same window unit was used in the four façades (constant window to wall ratio in all rooms), reflecting the same function behind. The window to wall ratio of B06 has doubled in comparison with almost all the analysed buildings from previous phases (0.14 for B05 and 0.30 for B06). This can be explained by the fact that each office was daylit by smaller or narrower surfaces of the elevation, but with bigger window area resulting in the increasing of window to wall ratio. The decrease in floor to ceiling height and the increased framing correction factor are other reasons that explain this increment in the window to wall ratio. On the other hand, the difference between the average fenestration factors of B05 and B06 was not at the same ratio (0.16 for B05 and 0.22 for B06). The total glazing area to office area ratio remains the same in the two buildings, but the use of simple glazing subdivisions increase the framing correction factor that in turn increases the fenestration factor.

The impact of façade typology and plan morphology on daylighting performance of the two buildings being studied is illustrated in Figure 7.29 and Figure 7.30. In the two diagrams, the percentages of total area under curves for B05 and B06 are 53% and 65%, respectively. These figures are approximately within the same range of figures for previous buildings. Thus at this time the simplification of façade typology and the use of a skeleton construction system, which frees solid walls from the load-bearing role, have slightly improved the general daylighting performance inside the buildings.

The percentages of performance of 'Building Shape', 'Window / Façade', 'Window / Office' and Shading Devices' design variables of B05 / B06 are 50%/81%, 46%/46%, 45%/55% and 83%/100%, respectively. 'Building Shape', 'Window / Façade', 'Window / Office' and variables contribute almost equally to daylighting performance in B05. In building B06, more consideration was given to 'Building Shape' variables that provide adequate daylight for the building, through the use of a deep plan with a central courtyard. On the other hand, less consideration was given to shading devices; the façades were treated the same without considering the orientation. B05 has better performance from its shading devices than building B06, because of the French windows which offer shading for some openings on the four façades.

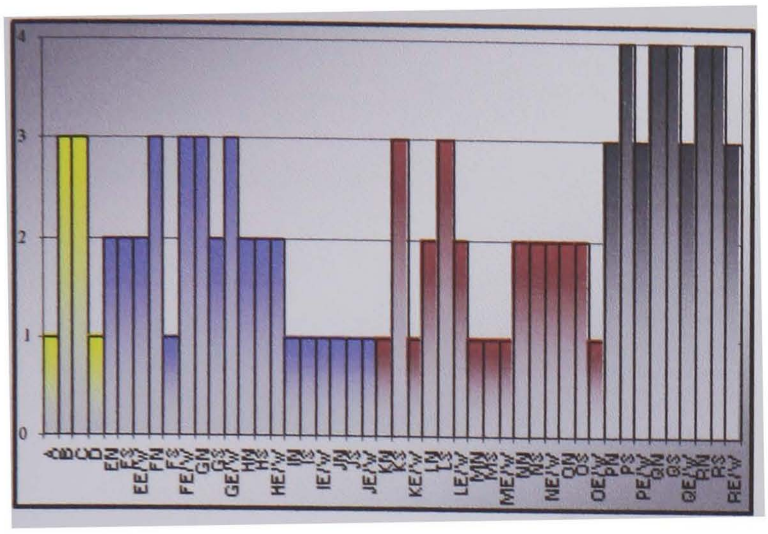


Figure 7.29. Diagrammatic Description of the 'Fosh 1153' building (B05, D.O.C. 1932).

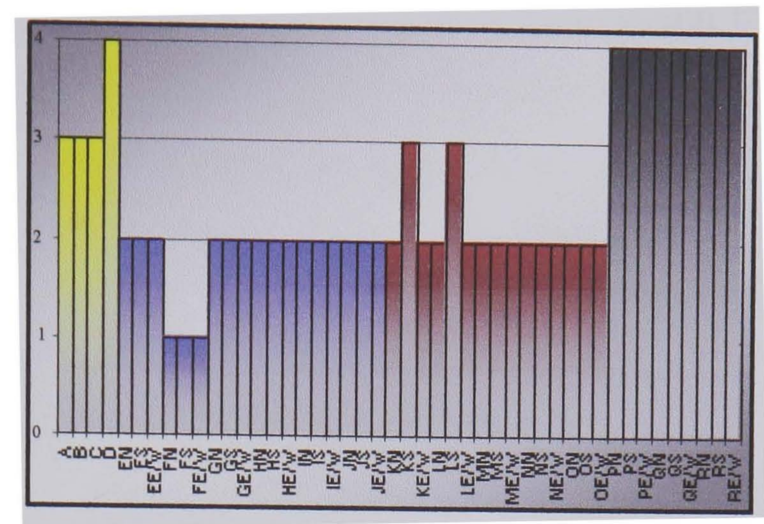


Figure 7.30. Diagrammatic Description of 'Ibrahim Sursok' building (B06, D.O.C. 1935).

7.3.4 The Early Years of Independence Phase (1946 - 1958)

After World War II the city continued in its role as a port for the territories of the French mandate, and maintained a slow and unspectacular growth until 1948. A number of external events provided impetus for Beirut's rapid and massive subsequent expansion. Most notable among these are the outbreak of the war in Palestine in 1948 and the political events in both Syria and Egypt, particularly after the Suez crisis in 1956. As a result of the loss of the port of Haifa, the port of Beirut became the unrivalled gate to the eastern side of the Mediterranean. The services sector developed rapidly, making Beirut a major regional centre for banking, air-sea-land transport and communication, tourism and professional services. This growth was further driven by the Suez Canal crisis of 1956, which resulted in the relocation of the overseas offices of several aviation companies, banks and oil companies to Beirut. All of these led to the inflow of investment from the Arabian Gulf, and an associated speculation in real estate.

As a result of this spectacular construction boom, 'Beirut began to lose its predominantly horizontal and even sky-line in the beginning of the 1950s - the first tangible evidence of intensive urbanisation' (Khalaf *et al.*, 1973). While in 1945 the Municipality of Beirut had issued 390 construction permits counting 626 floors with a total built-up area of 107246m^2, the figure increased to 1261 new permits in 1955, including 2730 floors and an area of 640593m^2 (Ministry of Planning, 1969). New constructions, mostly in the form of modern high-rise apartments and office buildings in reinforced concrete with impressive glass façades and prefabricated aluminium frames, began to overwhelm the urban scene (Figure 7.31). This will be further investigated later in this chapter, through the description and analysis of 10 office buildings constructed during this phase.

Figure 7.31. An example of a modern high-rise residential building, the 'Union National Building' (D.O.C. 1952; Tabet, 1998).

Despite this booming urban growth, Beirut continued to grow to meet its rising political and economic aspirations without the benefit of a master plan. It is notable here that in 1943, Ecochard's master plan for Beirut had been the first comprehensive study of land use with a zoning proposal that separated future industrial, business and residential development. However, this plan was never approved. Another plan was proposed by Egli in 1950. Essentially, it recommended the adoption of the Ecochard's plan and reduced the number of zones. However, like the Danger Plan (1932) and Ecochard's Plan (1942), it was never approved. Therefore, development was guided only by building laws. In 1954, under the pressure of an immense building boom, the municipal administration appointed a commission of experts to establish a plan. This was submitted and approved, but the plan was nothing except a network of roads. It provided no zoning, i.e. definitions of density, occupation and function in the various areas. Business and residential zones were not separated. As a result, offices continued to be located in apartment buildings and on ground floors of residential blocks. Office buildings were also built within residential areas. On the other hand Banks Street, which following the business extension of the old city of Beirut to the west, was also built during this phase. This district saw several office buildings and bank head-offices built along Riad Solh Road (also known as Banks Street), and on Riad Solh Square. Starting in the mid-1940s, this became a proper showcase of modern office buildings over the next two decades (Arbid, 2002). This extension was not enough to cope with the economic and urban growth. Important administrative and commercial areas were also developed. Hamra Street, situated to the west of the Beirut central district, constituted a main artery for business investments. Its development started in the mid 1950s.

Many examples of office building, mainly located in Banks Street and Hamra Street will be described and analysed in the following section. Most of these are considered key buildings of this phase, and have been selected after reference to local architects (Assem Salam, Wassek Adib, Sani Jamal, Robert Saliba, and George Arbid) interviewed by the researcher.

7.3.4.1 *Case Studies Description*

Table 7.1 lists ten office buildings that have been selected to study the development of office buildings in Beirut in the early years of independence phase. The last five columns of Table 7.1 illustrate the area under curve of the total design parameters, 'Building Shape' parameters, 'Window / Façade' parameters, 'Window / Office' parameters and 'Shading Devices' parameters impacting daylighting performance in these office buildings. Before giving an explanation of these figures, a brief description of each building will be given.

ID	D.O.C.	Building Name	Sheet No. in Appendix I	Area Under Curve				
				Total %	*Building Shape*	*Window / Façade*	*Window / Office*	*Shading Devices*
B07	1947	Assayli Building	Sheet 07	65%	75%	50%	55%	100%
B08	1949	Aboud Abdel Razzak Building	Sheet 08	63%	50%	46%	70%	100%
B09	1952	Pan American Building	Sheet 09	71%	75%	67%	75%	67%
B10	1955	Azarieh Building	Sheet 10	50%	50%	33%	70%	50%
B11	1956	Riad Solh 1374	Sheet 11	51%	63%	38%	40%	83%
B12		Starco Building (Northern Block)	Sheet 12	67%	31%	83%	60%	92%
B13		Starco Building (Sourthern Block)	Sheet 13	64%	31%	75%	60%	92%
B14	1957	Building Shaker Ouwayni	Sheet 14	68%	50%	75%	55%	100%
B15		Cinema Hamra Building	Sheet 15	78%	31%	92%	85%	100%
B16		Horseshoe Building	Sheet16	58%	38%	67%	60%	67%

Table 7.1. List of selected key office buildings constructed in the period between 1946 and 1958, and which more detailed information are presented in Appendix I (Sheet 07 to Sheet 16).

The Assayli Building (B07, Figure 7.32), also known as the Cinema Capitole building, was developed between 1947 and 1952 by Giorgio Ricci and Georges Aramane. Situated on Riad Solh Square, the building has a trapezoidal plot of approximately 2750 m^2 floor area, cored in the centre by an open courtyard extended along the 8 office floors. The ground and mezzanine floors were, and still are used for commercial purposes. The four elevations, chamfered on the corners are approximately identical, composed of a repetitive series of identical windows that have an intermediate rectangular shape, deprived of any articulation or ornamentation. This building have many similar design features to the Ibrahim Sursok building (B06) described in the previous section, except that this building was higher and larger in scale. This building might therefore be considered as a newer version of 'modern' office buildings at that time. It should be added that cranes were used in the construction of this building, probably for the first time in Lebanon (Arbid, 2002).

Figure 7.32. An old view of Assayli Building (B07), D.O.C. 1947 (Arbid, 2002).

In the Abboud Abdel Razzak Building (B08, Figure 7.33) built in 1949, the architect Bahjat Abdulnour revived the use of French windows, with ornamentation by marble classical columns reaching the whole height of the façades. In addition, the roof level was topped with the red tiles that marked Beirut architecture of the 19th and early 20th century. As for the openings, they remained rectangular in shape except in the mezzanine floor where semi-circular arches were used to mark the end of the building platform, consisting of commercial shops and the building entrance and the start of the office 'tower'.

Figure 7.33. Abboud Abdel Razzak building (B08), D.O.C. 1949.

The Pan American office building (B09, Figure 7.34) designed by Georges Rayyes and Theo Canaan, assisted by Assem Salam was built in 1952. This is a finely proportioned and well detailed building that draws its richness from appropriate understanding of, and response to, rational needs (Interview with Assem Salam on April 4, 2003). According to Sani Jamal interviewed by the researcher on 10 May 2003, George Rayyes was environmentally aware in his designs, expressing it by saying: "I need repose, as a human being". By repose, Rayyes meant that the 'indoor environment should be calm, the circulation tranquil, the lighting should be well distributed, with no violent sunlight entering the building, without huge contrast between sun and shadow which is annoying to the user and to his eyes, to the temperature inside, etc.' (Interview with Sani Jamal on May 10, 2003). This awareness of environmental and human comfort is quite obvious in the Pan American building façades, where the need to react differently in terms of sun control for the east and south elevations determined design choices. Simple stretches of horizontally shaded windows are used in the south façade, while in the eastern façade a concrete rectilinear grid is used to control sunlight. Attention is given to human scale and detailing in various aspects of the building, for example by the design treatment of the building corner. The shifting back of the eastern and southern walls at the corner aesthetically solved the intersection between the horizontal overhang stretches of the south façade and the egg-crate of the east façade, as well as enlarging the pedestrian way on the ground floor and defining the entrance.

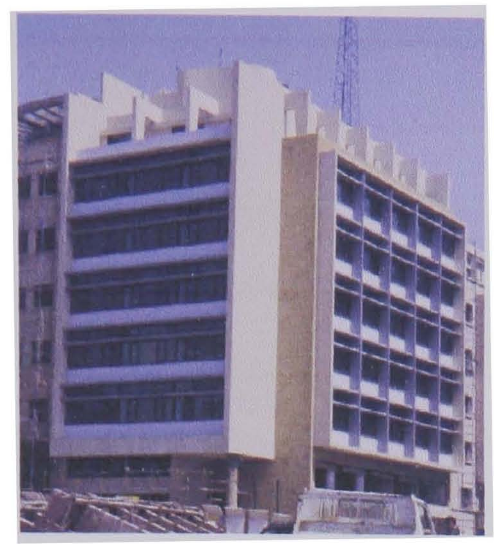


Figure 7.34. Pan American Building (B09), D.O.C. 1952.

In 1956, the 'Riad Solh 1374' building (B11, Figure 7.36) was constructed on the western side of the Pan American Building. Building façades were more similar to the Ibrahim Sursok Building (B06) and Assail Building (B07) than to the neighbouring buildings, with repetition of a similar window unit in the three façades of the 'almost' triangular building shape. There is no difference in façade treatment in accordance with orientation, as in the Pan American Building, despite the fact that the longest façade faces south and east. As for the ground floor, it is also used to house commercial shops and has a higher floor to ceiling height than the buildings previously described.

Figure 7.35. The Azarieh Buildings complex (B10), D.O.C. 1955.

Figure 7.36. 'Riad Solh 1374' Building (B11), D.O.C. 1956.

The façade treatment is also similar to the Azarieh commercial complex, constructed in the same period (B10, Figure 7.35). The Azarieh complex is a group of four buildings that enclose an internal courtyard, and which have identical façades. The difference from the previous building is that in this complex, the openings are simple rectangular windows but having an overhang that controls sunlight and provides some shade to the offices located on the four façades.

1956 was also the inauguration year of the Starco Centre (B12 and B13, Figure 7.37), an office building and commercial centre. Two levels of shopping are topped with two office towers: the Northern Block (B12) which is rectangular, and the Southern Block (B13) that has a square shape. The centre was undoubtedly high-tech by the time's standards, fully air-conditioned, with state-of-the-art electrical and mechanical systems. The columns, clad with black sheets of glass, give a floating appearance to the white masses of the two buildings. The uninterrupted horizontal bands of windows are made of double sheets of glass, with internal micro louvres for screening purposes. This was a device quite new at the time of construction. Indeed, the Starco is still considered the most innovative commercial centre of its time in the region.

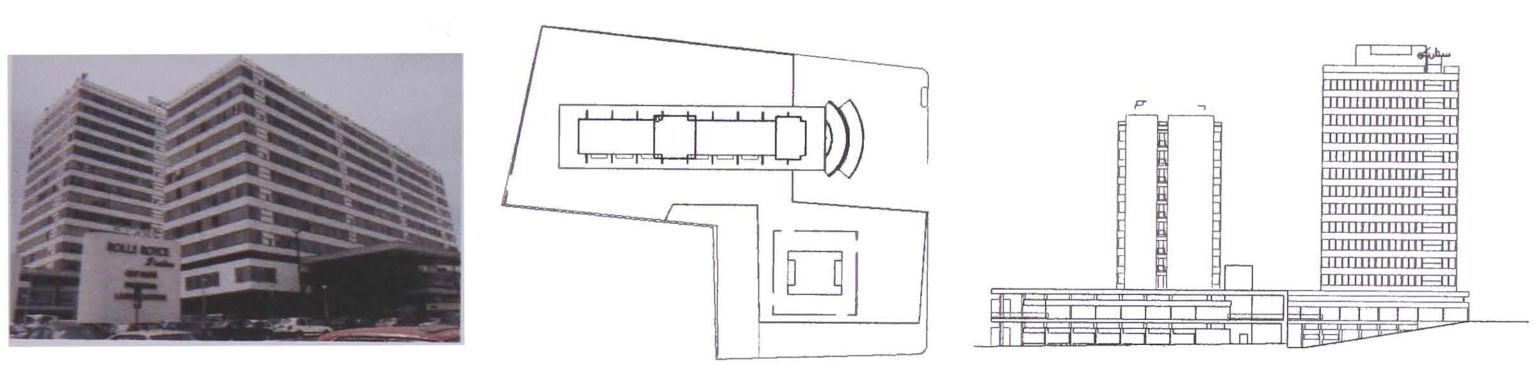


Figure 7.37. A perspective view, mass plan and section of the Starco Centre (B12 and B13), D.O.C. 1956-1961.

The Shaker Ouwayni Building (B14, Figure 7.38), designed in 1957 by Wafik Ouwayni is located on Riad Solh square, the same environment as B07, B09 and B11. The architect resolved the problem of the steep slope by recourse to pilotis (a French word which means 'a floor including only the structural columns of the building') to accommodate the difference in altitude between the upper part and the lower part. Above the pilotis, on the northern side, the openings are placed within a long horizontal band. On the eastern side, vertical dominance is achieved with a structure that is emphasised in the foreground, leaving the openings in a slightly recessed plane. This approach allows the control of sunlight entering eastern offices. The plan is functional, accommodating the need for office space with various directions dictated by the position of the building at the corner of two streets. This is emphasised by a recessed curved shape, enlarging the pedestrian passage on the ground level.

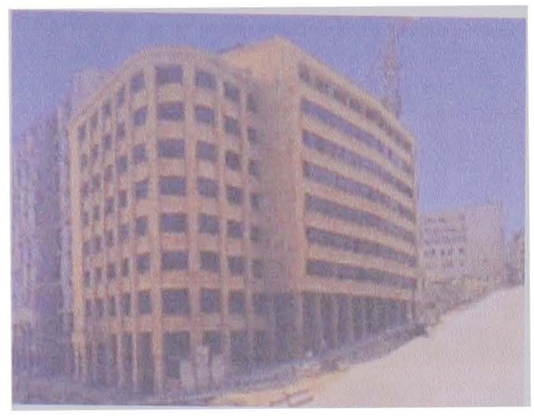


Figure 7.38. Shaker Ouwayni Building (B14), D.O.C. 1957.

Rayyes, the architect who designed the Pan American Building (B09) did not refrain from using large areas of glass when appropriate, such as in the Hamra Cinema and office building (B15, Figure 7.39). On the north façade, optimisation of light provision drove the architect to design offices with glass running from wall to wall and almost from floor to ceiling, while the southern side is protected by sunscreens. Being environmentally aware and obsessed with perfecting details, the architect created a steel and glass façade having a mechanism where window panels twisted and slid downwards, leaving a gap above and below for air exchange. For this period, such detailing is very unusual because it was man made, designed and manufactured. The architect designed the whole detail of the façade, because in the early 1950s local technology was unable to produce building components that departed from traditional crafts and skills. Tapline, an oil energy company, occupied this building. Sani Jamal interviewed on May 10, 2003 stated: "*The company that occupied this whole segment said: we will run the air-conditioning 24 hours. This is the most recent technology, and we don't run air-conditioning in bits and pieces anymore. We have oil and we have the power, we don't want natural ventilation, so weld the windows.*" Jamal continued that with this American philosophy, Georges Rayyes was forced by the requirements of the client to weld the windows closed, and the whole idea of ventilating the façade was defeated by these demands.

Figure 7.39. Cinema Hamra Building (B15), D.O.C. 1957.

The Horseshoe building in Hamra Street (B16, Figure 7.40), designed by Karl Schayer and partners in 1957, was the first building in Lebanon to have a curtain wall façade. It went one step further than the neighbouring building, the Cinema Hamra office building that was also under construction, and with which slab heights and continuity of horizontal lines were synchronised. For this building, curtain wall details were drawn full scale and tested on a prototype before being executed (Tabet, 1998).

Figure 7.40. The Horseshoe Building (B16), D.O.C. 1957.

It can be concluded from the brief description of the selected 10 buildings constructed in the 'Early Years of Independence' phase, that office building façades were no longer similar to those of residential buildings. The influence of 'Modernism' on architecture in Beirut increased from the 1940s (Arbid, 2002). This is quite clear from the simplification of office building façades and the freedom from ornamentation that existed in central bay buildings, except for a few such as the Abboud Abdul Razzak. Windows became simple in shape and occupied a larger proportion of the façade. In addition, with the development of glazing technology architects tried to apply it in their designs. Some of these architects were environmentally aware and used large panels where appropriate, or controlled sunlight penetration by using vertical and/or horizontal shading devices, which shaped the façade according to their orientation. In other buildings, façades were much more simple and similar in their design. The following section will evaluate the daylighting design parameters of the buildings described above.

7.3.4.1.1 Evaluation of daylighting design variables

Figure 7.41 illustrates the diagrammatic description of daylighting performance evaluation of the 10 selected office buildings described in the previous section. The diagram shapes of most of the buildings are very irregular, especially buildings B7, B11, B12, B13, B14, and B16. This irregularity is sharply apparent in B16, because the north and south façades have different façade treatment: the north façade is 94% glazing, while the south façade is only 15%. In his design, the architect of the Horseshoe building relied mainly on the north façade to illuminate office spaces, the south façade having smaller openings to illuminate and ventilate only circulation areas.

In Building B07, the courtyard is located in the middle of the building plan and stretched along all storeys. This increases the outer perimeter, which in turn increases the compactness ratio and porosity ratio and, hence, contributes the most to illuminating and naturally ventilating office spaces. Similar solutions are also apparent in B09 and B11, but with less influence as void volume is proportionally smaller than in B07.

In addition, when comparing the descriptive diagrams of the selected buildings illustrated in Figure 7.41, it can be concluded that buildings B08, B10, and B14 perform similarly in accordance to the 'Building Shape' parametric level. This is because the three buildings are similar in shape, having a 'unilateral / bilateral slabs' layout as described by Baker *et al.* (1993), and not having any void volume.

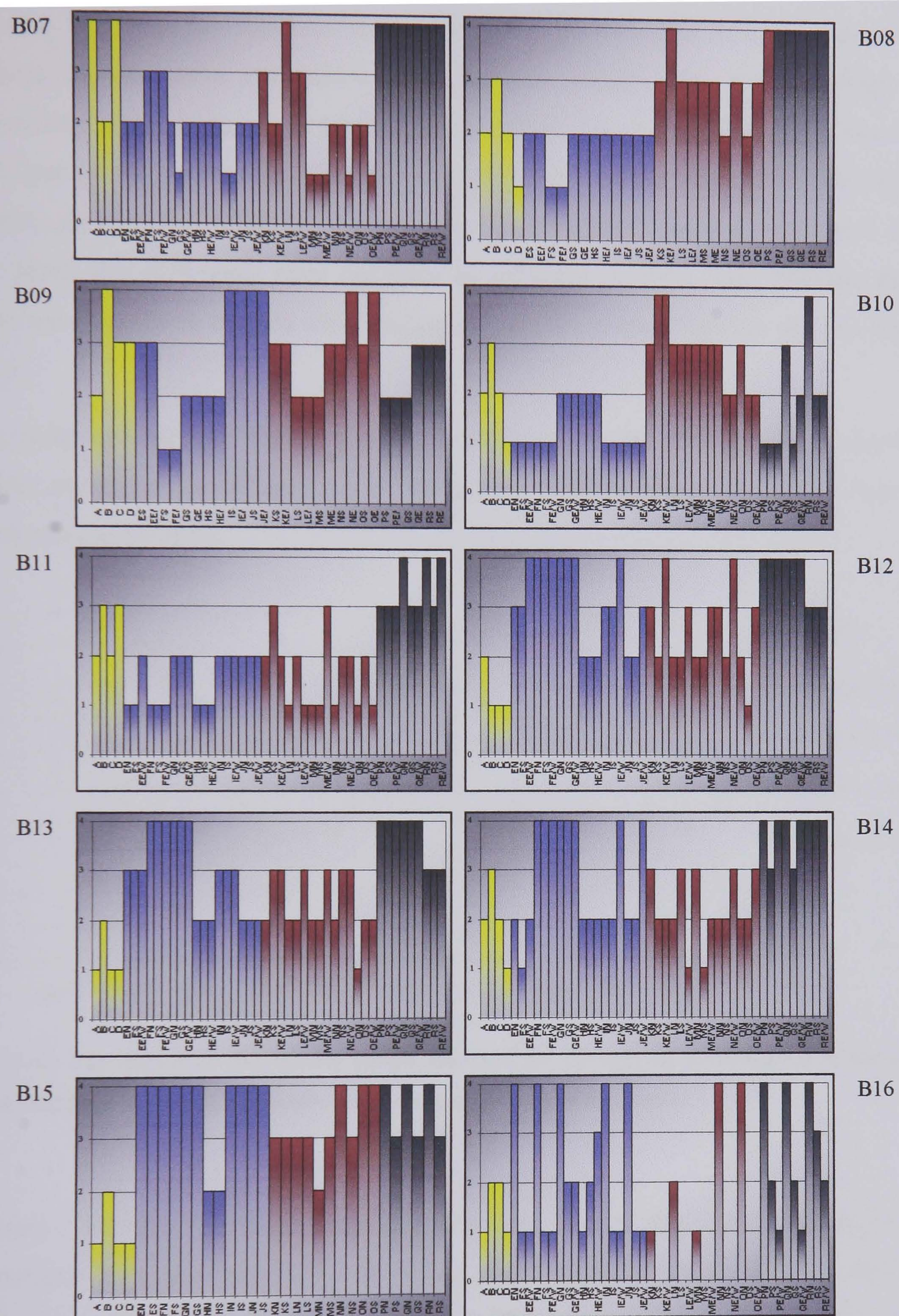


Figure 7.41 . Diagrammatic description of the selected office buildings built in the early years of independence phase.

It is also important to compare the performance of B12 and B13, as they are two buildings in the same commercial complex. In general, the two buildings have approximately the same performance figures. Only the compactness ratio and shape coefficient (Variable A and B) have difference performance, because the two buildings are different in shape. (B12 has a rectangular plan and B13 has a square plan). On the other hand, this difference does not exist in envelope to floor ratio, because the two towers are of different heights which balances the performance between the two building shapes.

For a better comparative analysis, Figure 7.42 illustrates the performance evaluation of the four parametric levels analysis of the 10 selected buildings, as well as their total performance evaluation.

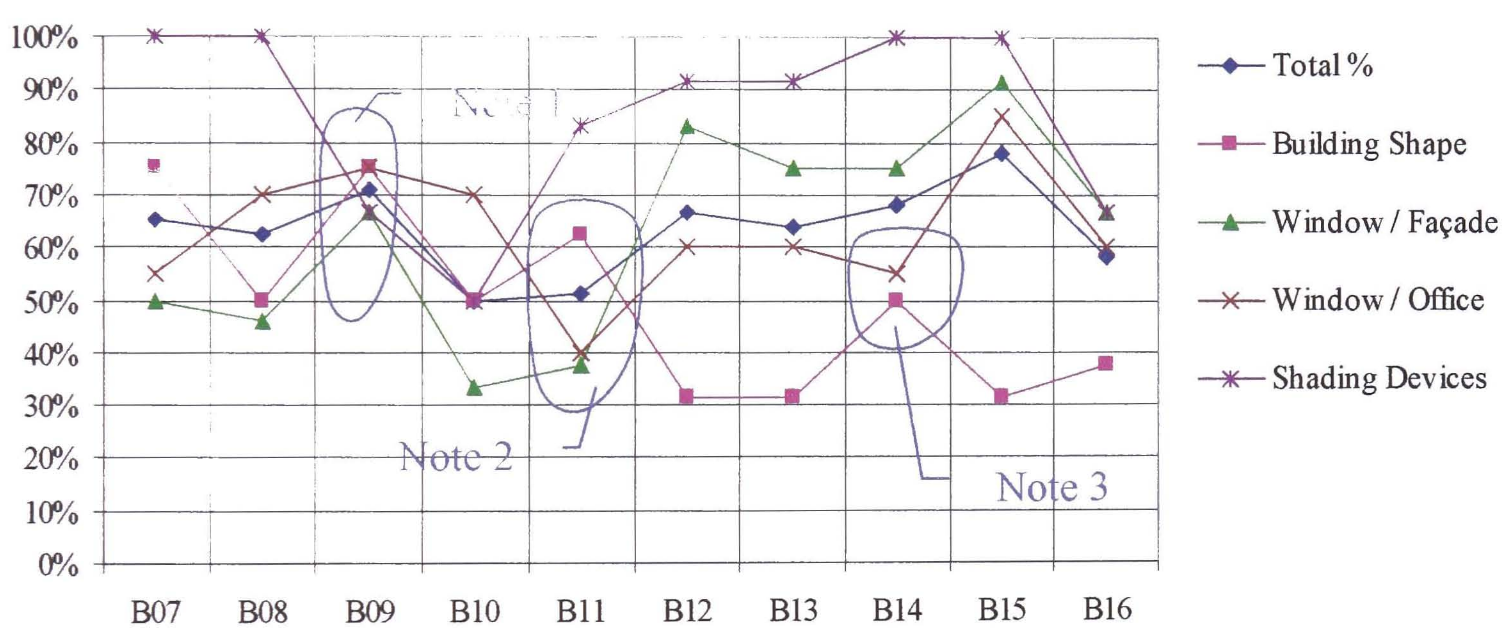


Figure 7.42. The impact of daylighting design variables on daylighting performance in the selected office buildings (B07 – B16), illustrated by percentage of area under curve.

'Window / Façade', 'Window / Office', 'Shading Devices' and Total area under curve percentages have approximately increasing linear figures, except for two distinctive points representing the buildings B09 and B11 (Figure 7.42, note 1 and note 2, respectively). As for the Building Shape parametric level, the performance percentage has a sinuous figure for buildings constructed between 1947 and early 1956; building shape performance percentage varies between 75% and 50%. Afterwards, the building shape area under curve decreases to become almost linear, except for building B14 (Figure 7.42, note 3) that has a higher value than the others because of the porosity volume it includes.

Compared to previous buildings of the same phase, the last 5 buildings studied have a lower building shape performance percentage, because buildings start to be more deep and lacking an internal courtyard, as well as the increase of building height which changed the building shape and dimensions. This might be explained by the suppression of the '21m building height' law in 1954.

The development of 'Window / Façade' parametric level performance, illustrated in Figure 7.42, shows that the percentage area under curve increased relatively from the beginning to the end of the studied phase. From 1947 to 1956, the analysis of studied buildings shows that 'Window / Façade' performance area under curve decreased from 50% to 33% (except for B09, marked by note 2 in Figure 7.42). This decrease is a consequence of the use of almost the same modular, simple and intermediate shaped openings of the 1940s, but with lower ceiling heights that decreased gradually from 3.8m, 3.5m, 3.3m, to 3.1m. Building 11(see note 2, Figure 7.42) appears to mark a transitional point, after which 'Window/ Office' performance increases remarkably to range between 75% and 92%. The use of new glazing technologies in that period is clear from the use of larger window openings all along the office space façade. The peak performance is in building B15, where clear, completely glazed façades have been used. This is not the case for building B16, where the architect used a tinted curtain wall (for the first time in Beirut).

Building B11 is also a transitional point, when considering 'Window / Office' parametric level. Buildings of the 1940s and early 1950s had an increasing 'Window / Office' performance area under curve, which varied from 40% to 75%. At this period of time, office areas and buffer zone depth were still small relative to the increasing aperture areas. Afterwards, 'Window / Office' performance decreased slightly because office depth increased, while on the other hand openings became bigger. Therefore the performance of 'window / Office' parametric level was balanced, tending to be more or less near the average.

By the beginning of the 1950s, the performance of shading devices had decreased to reach a lowest value. Among the studied buildings, this can be seen in B10 with its use of deep overhangs. With this period came the use of wider apertures, and the end of French windows that had marked previous periods. Performance further improved when tinted glazing came into use in 1957, (B16) permitting the control of excessive sunlight and related solar heat gain.

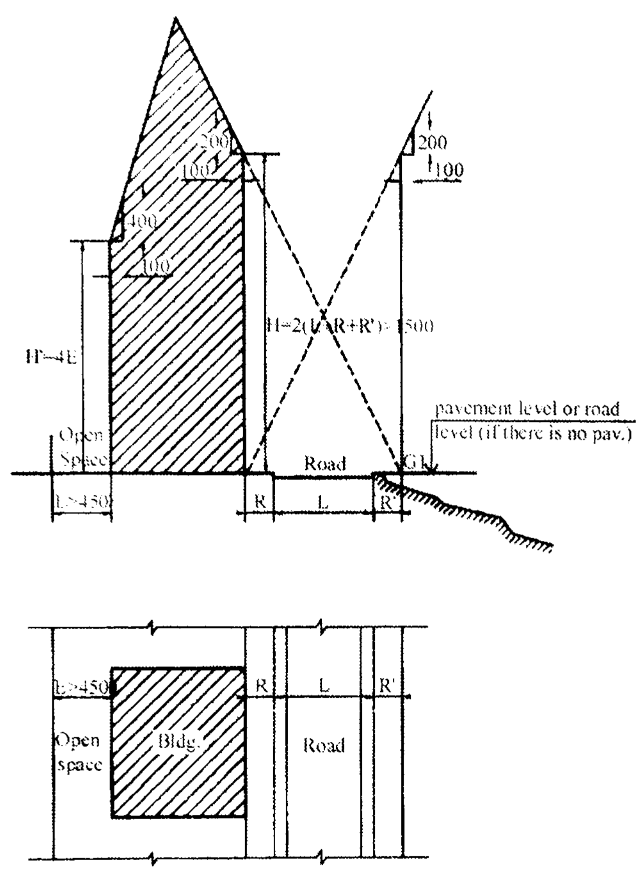
It can be concluded that 1956 was a transitional year for this phase. Before and after early 1956 the performance of daylighting parametric levels changed, other than building B09 which from analysis looks to be distinctive of its age. This was agreed by those people whom the researcher interviewed. They all considered the Pan American Building (B09) to be a remarkable, key office building from the 1950s.

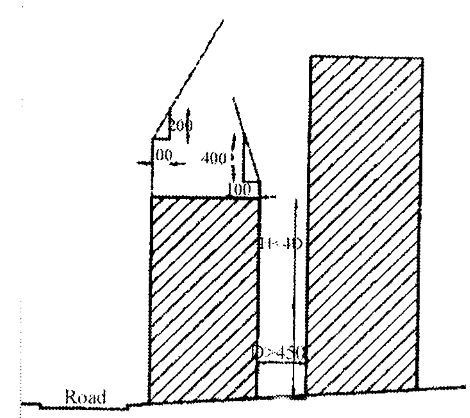
For a detailed daylighting analysis, 2 case studies of the 10 examined buildings will be selected: one representative of the period before 1956, and another built after 1956. The Pan American building (B09) also warrants careful consideration.

7.3.5 The Shihabist and Post-Shihabist Phase (1958 – 1975)

In urban terms, two major landmarks denote this period. First, there was preparation and approval of an urban plan covering all of Beirut, both the capital and its outskirts. Second, there was the drawing up of the legislation necessary for urban planning.

In 1963, the General Directorate of Urban Planning was created together with the High Council for Urban Planning, which was concerned mainly with Beirut's development. A plan drawn up by Ecochard was presented in 1964. The manipulation of the proposals led to some basic changes. The restrictions of the plan were severe; the densities approved gave greater Beirut the capacity to accommodate many millions of inhabitants, which was much too high. Building legislation was reformed twice, in 1964 and 1967. Despite these reforms, building legislation still did not mesh appropriately with urban planning and its development. Decree 59/71, issued on 13/9/1971, was the new building legislation that was applied in order to manage and satisfy urban growth. For the first time, new building rules were approved concerning rooms' daylighting and ventilation, and regulating building envelopes. The height of the building envelopes of street façades, or allowed in front of neighbouring buildings, was regulated in accordance with the following four factors: road width, new building setback, neighbour building setback and the extended field of vision width (Figure 7.43). The goal of this rule was to control the 'well' created between buildings and from where the internal spaces of buildings get their natural light, sun radiation and ventilation. Figure 7.44 explains the rules to be followed for daylight and ventilation provision for indoor building spaces. The recommended window area is calculated relative to the room area, and which restricts the maximum room depth. Each room should also have a minimum aperture opening onto an ‘extended field of vision’ which should be at least equal to 450cm x 550cm (Figure 7.45).





L = street width

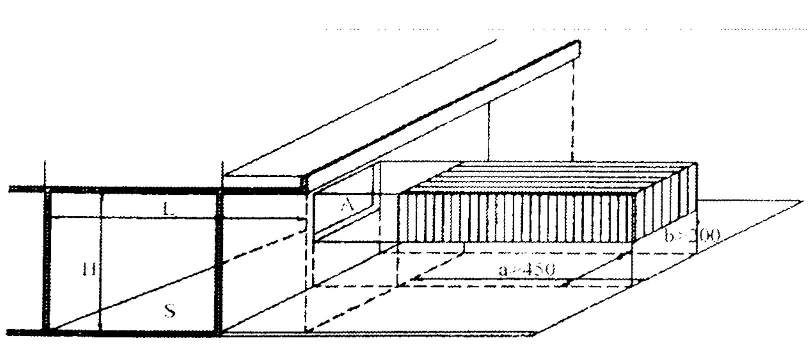
R = new building setback

R’= existing building setback

G1= Road building envelope

H = building envelope height from the road side

Figure 7.43. The building envelope regulation applied to street façades and between buildings façades (Order of Engineers and Architects, 1995).



Aperture area A ≥ Room area S/10

Room depth L≤ 5H

Extended vision field length a ≥ 4.50 m

Extended vision field width b ≥ 2.00 m

Figure 7.44. Regulation of room daylighting & ventilation (Order of Engineers et Architects, 1995).

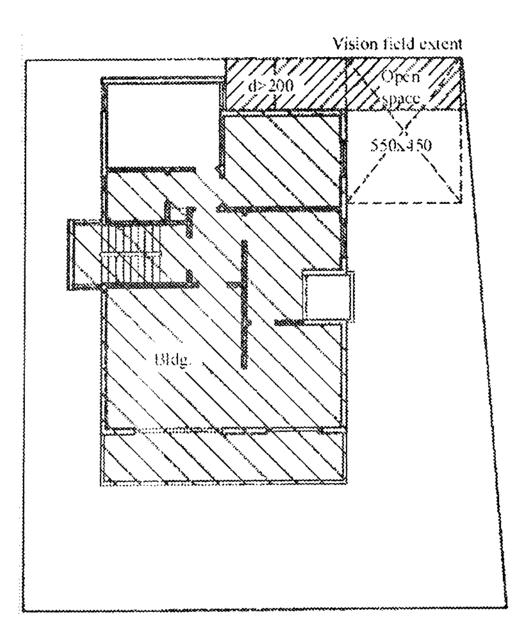


Figure 7.45. Extended field of vision regulation (Order of Engineers and Architects, 1995).

With the growth in urbanisation important administrative and commercial areas developed such as Hamra Street, situated in the west Beirut central district, constituting a main artery for business investment. Foreign investors built many office buildings. The development of office buildings of this period will be reviewed consecutively, through the description and analysis of office building case studies. The following section will describe eight selected buildings from this phase. The daylighting performance of their four parametric levels will be analysed subsequently.

7.3.5.1 *Case Studies Description*

Table 7.2 lists the buildings that have been selected to study the development of office buildings in Beirut, in the Shihabist and Post- Shihabist phase. This study will begin with a brief description of each building, followed by analysis of the associated daylighting performance evaluation figures.

ID	D.O.C.	Building Name	Sheet No. in Appendix I	Area Under Curve				
				Total %	*Building Shape*	*Window / Façade*	*Window / Office*	*Shading Devices*
B17	1959	Riad Solh 1216	Sheet 17	61%	44%	79%	60%	50%
B18	1960	Industry and Work Bank	Sheet 18	72%	38%	79%	75%	100%
B19	1961	Olivetti Building	Sheet 19	68%	44%	79%	60%	92%
B20	1964	Sabbagh Center	Sheet 20	72%	38%	83%	85%	75%
B21	1965	Electricity of Lebanon Headquarters	Sheet 21	63%	25%	71%	60%	100%
B22	1967	American Life Insurance Building	Sheet 22	50%	25%	88%	35%	33%
B23	1968	Arab Bank Building (BCD)	Sheet 23	69%	25%	88%	80%	75%
B24	1970	Verdun Center	Sheet 24	54%	31%	75%	40%	67%

Table 7.2. List of selected office buildings constructed in the period between 1958 and 1975, for which more detailed information is presented in Appendix I (Sheet 17 to Sheet 24).

The first building on the list is 'Riad Solh 1216' illustrated in Figure 7.46. The building is 7 floors in height, and is located in the banking street in Beirut Central District. It occupies the whole area of the lot. This fact explains the rectangular plan of 20m depth, having an inclined side to the north-east. Its three main elevations face east, north and west. On the south façade, which is adjoining the neighbouring building, the architect has used a brise-soleil (See Appendix I, Sheet 16); an exterior, fixed structure covering the complete pass-through component or a larger area (Baker *et al*, 1993). Elevated on the entire façade, where the architect has used large windows for the building service areas, the brise-soleil permits the passage of light by obstructing direct solar radiation, provides privacy from adjacent buildings and acts as an airshaft to ventilate associated spaces. As for the east and west, 115cm deep egg-crates are used to protect the 46% wall to aperture façades from direct sunlight. On the other hand, the north façade (which is also inclined to the east) has vertical windows with shallower fins, which may have been used for aesthetic reasons in order to keep continuity and harmony between façades.

Figure 7.46. 'Riad Solh 1216' building (B17), D.O.C 1959.

Figure 7.47. Work and Industry Bank building (B18), D.O.C. 1960.

Located on the same street as B17 and built in the same period, the 'Industry and Work Bank' building (B18, Figure 7.47) has different architectural characteristics to B17. According to Arbid (2002), the main contribution of Henry Eddeh, the architect of B18, to office building type is his search for appropriate elements, derived both from the economy of space and the possibilities offered by industrialization. This is quite clear in the studied building, where he was one of the first at that time to use dark grey tinted glazing. The architects aimed to replace the use of overhang and fins by what the glazing industry was then offering to protect the east and west façades from direct sunlight. Both façades consist of a modular array of intermediate window units, topped with black granite cladding. Light partitions allow flexibility in office area division, by which the architect's intentions for spatial economy in an office building were achieved.

Completed in 1961 the Olivetti Building, (B19, Figure 7.48) designed by Karl Schayer and Wassek Adib, relied on the idea of a curtain wall framed by two solid walls, which had been used previously by the same architects in the Horseshoe Building (B16). The resulting block was repeated in a perpendicular direction, and the building became a composition of those two elements of different heights. The south/north block is a double-loaded plan, with a 6m buffer zone depth allowing unilaterally daylit offices. As for the western block, it has a single loaded plan allocating 5.5m deep offices daylighted unilaterally.

Figure 7.48. The Olivetti Building (B19), D.O.C. 1961 (Arbid, 2002).

Figure 7.49. Sabbagh Centre (B20), D.O.C. 1964.

The owner of the 'Sabbagh Centre' (B20, Figure 7.49), a multipurpose centre including commerce, offices and a movie theatre, was seeking 'a building with character'. The design of the project was given to Alvar Aalto, who ended up designing it in partnership with the Swiss architect Alfred Roth. The building is more Roth's design than Aalto, except for the rear elevation (Interview with Pierre Nehmeh on May 15, 2003; Interview with Pierre El- Khoury on April 23, 2003 and Arbid, 2002), which is broken and treated with sharp-edged horizontal profiles acting as sun breakers. The other façades are treated differently, in a very simple, straightforward and well detailed approach by the Swiss architect (Arbid, 2002). The difference in façade treatments is solved by the use of absolutely solid façades on both eastern and western sides. As for the building shape, the architects used an L-shape plan to free the corner, giving way to the perpendicular streets and offering a piazza to the pedestrian quarter. The restricted horizontal extension on the site was replaced by 12 vertical storeys, since building height was no longer restricted by the '21m building height law'. This shape increases the perimeter of the building envelope and, hence, permits a greater number of offices of adequate depth (4- 4.5m depth) and accessibility, unilaterally daylighted.

New construction systems began to be introduced in this phase. In the Electricity of Lebanon Headquarters, (B21, Figure 7.50) designed by Pierre Nehmeh in 1966, a series of tall longitudinal slabs, lifted from the ground and linked with vaulted galleries was used. Influenced by the 'Brazilian version' of the International Style, the architect found a good precedent for responding to special climatic conditions and strong sunlight. A second skin made up of vertical and horizontal concrete linear elements was applied on the south façade but not on the north, where there is no sunlight. As for the west and east façades, small clerestory openings are used. The building has a unilateral, double loaded plan of 15m width. Each side provides cellular offices of 6.25m depth.

Figure 7.50. Electricity of Lebanon Headquarters (B21). D.O.C. 1965 (Tabet, 1998).

Figure 7.51. American Life Insurance Building (22). D.O.C. 1967.

The American Life Insurance Building, (B22, Figure 7.51) designed in 1967 by the British architects Irving and Jones, is different to the previously described building from the same phase. It might be summarily judged as one more example of the International Style office buildings that spread across the Arab world, wearing a regional make-up. However this one seems to wear it naturally, with elegance due to the refinement of detail, the rationality of the structure and the optimisation of space. The aluminium screen tinted in bronze, protecting the building like a '*musharrabiyah*', seems woven like fabric and adds to the general effect of lightness and elegance (Interview with Assem Salam on April 4, 2003 and Arbid, 2002). The building shape is a 3:1 rectangular slab, 4 storeys in height. The longer façades face east and west, housing open-plan offices of 9.60m depth. When interviewed, Assem Salam stated that the building was constructed according to American standards; i.e. a central chiller system was installed, and electrical sockets were located in the floor for space use flexibility. This building is now abandoned and stands unoccupied.

The site contours of the Arab Bank building (B23, Figure 7.52) define the plan layout of the building as a triangle, curved on the corners to avoid sharp edges. Located on the crossing corner of Riad Solh Square and the Banking Street, B23 is considered to be one of the modern buildings built between 1945 and 1970. Aluminium sheets and granite are used to clad all the façades. A standard size, double-glazed window is arrayed regularly along the envelope perimeter of four floors, with changes in shape at the last two floors indicating the end of the building's vertical extension. Medium size offices (15-25 m^2) are located along the building's perimeter. A few offices are located in the central core of the building, with the circulation elements and service areas.

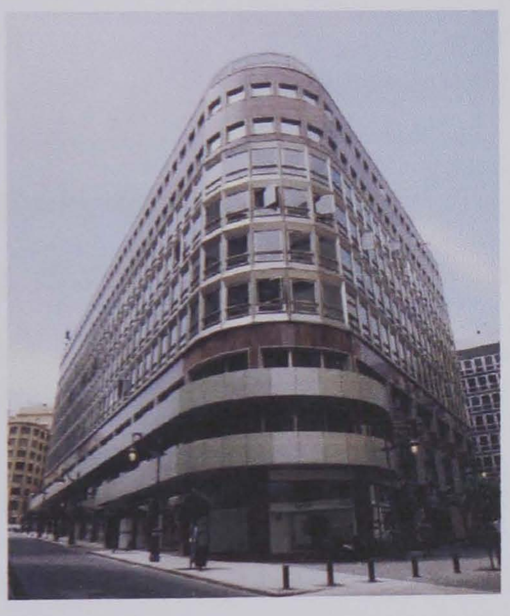


Figure 7.52. Arab Bank Building (B23). D.O.C. 1968.

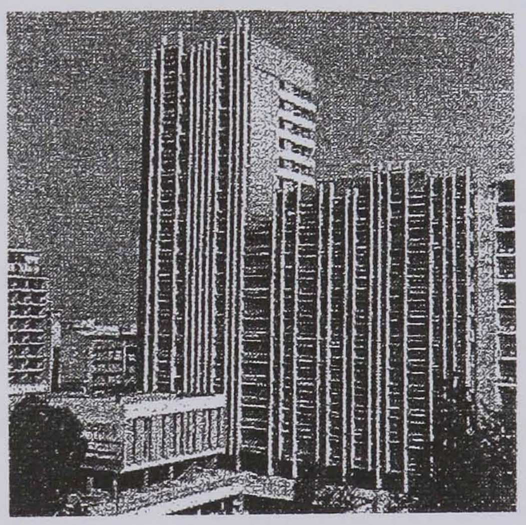


Figure 7.53. Verdun Centre (B24). D.O.C. 1970 (Arbid, 2002).

The search for new means of expression also took another form. Nehmeh tried to bypass the conventionality of brise-soleil treatments, by transforming them into decorative features in the Verdun Centre designed in 1970 (B24, Figure 7.53). Figure 7.54 illustrates the effect of horizontal and vertical shading devices on the south façade, diffusing solar radiation and reflecting light. The rear façade, which faces north, lacks any shading devices. The building shape is a 3:1 rectangular open plan slab, of 20m depth and 12-18 storeys height. Despite the depth of the building site, the architect preferred to increase the retreat distance from the street-site border to create a patio. This explains the reason for adopting a linear shape for this office building. In addition, in accordance with the building envelope regulations (Figure 7.43), the decrease in built up floor area allowed on the site permitted additional vertical extension in order to reach the permitted maximum built up area.

Figure 7.54. Detailed view of the brise-soleil used in B24 showing sunray diffusion and reflection of light.

To conclude, the description of the selected buildings has shown the changes in office building dimensions and the adoption of new building materials over those used previously. The International style is clear in many buildings. In addition, some of the studied buildings show that at least some architects of that period were considering the importance of climatic design and solar protection in their designs, and using shading devices. Others relied more on newly-available façade technologies to express *modernism* in their designs.

The differences in the applied design perspectives during the Shihabist and post-Shihabist phase will be also evaluated in relation to daylighting performance, in the following section.

7.3.5.1.1 Evaluation of daylighting design variables

Figure 7.55 illustrates diagrammatically the daylighting performance evaluation of the 8 selected office buildings built in the Shihabist and post Shihabist phase, which were described in the previous section.

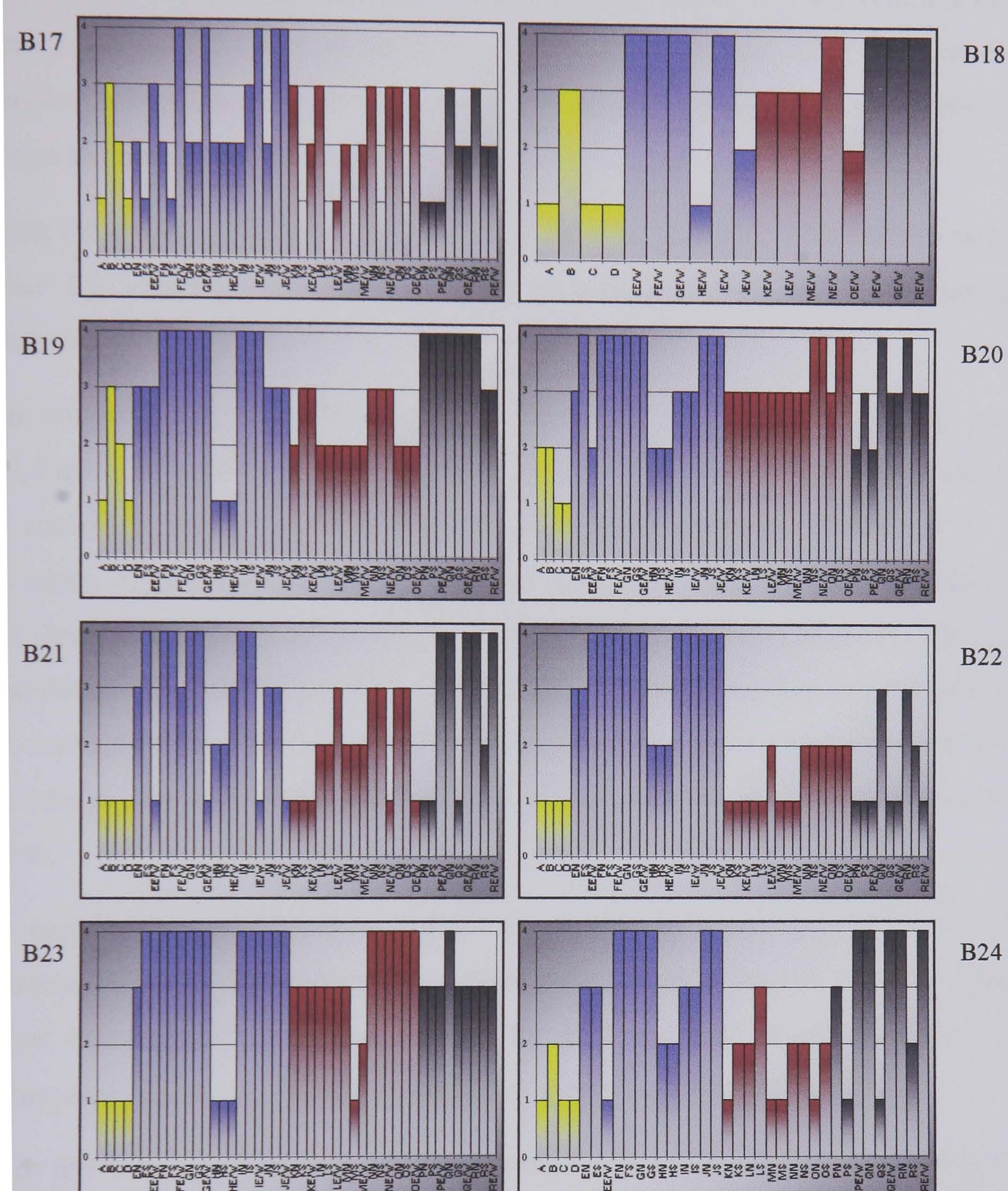


Figure 7.55. Diagrammatic description of the selected office buildings built in the Shihabist and Post-Shihabist phase (1958-1975).

The diagram shapes for most of the buildings are irregular, except for B20 and B23 which are more regular than the others. Irregularity is sharply apparent in B17 and B21, because of the difference in façade treatment: In building B17, the wall to aperture ratios of the north, south and east/west façades are 0.38, 0.09 and 0.46, respectively. The south façade is considered secondary for office illumination and ventilation, as the neighbouring building mostly blocks it. On the other hand, in building B21 which is a free-standing structure, the architect restricted the wall to aperture ratios of the east and west façades to only 0.23, and relied on the north and south façades to illuminate and ventilate the indoor spaces by doubling the wall to aperture ratio to 0.54 and 0.55, respectively. This difference in window areas also affected the other analysed variables, which consequently explains the irregularity of the diagram.

Among the studied buildings, the diagram illustrating building B20 looks to be the most regular. The values of all variables are very close to each other, and on the same range of evaluation.

When comparing the selected buildings in accordance to the 'Building Shape' parametric level, Figure 7.55 shows that all the buildings are compact and lack any void volume such as a courtyard, atrium etc. Only B20 has a less compact shape, because of its T-shape plan which in turn increases the building perimeter and improves the potential to capture more daylight than the other buildings. The large size and shape of the building site gave the architects freedom to articulate the building's shape. This was not the case for B21, B22, and B24 where the architects restricted their design to a rectangular box of more than 15m width. B17, B18, B19, and B23 plan layouts are controlled more by their site outline.

The contribution of 'Window / Façade' parametric level and 'Window / Office' parametric level to daylighting seems to be constant and relatively high for most of the studied buildings of this phase, except for B22 and B24 where 'Window / Office' performance is less significant because deep open plan offices are provided.

As for the 'Shading Devices' parametric level, the use of fixed shading devices on all the façades of B17 and B22 is more significant in protecting the indoor spaces from sunlight, heat and glare compared to the other buildings studied. The protection is slighter in B20 and B23, where shallower shading devices have been used. In B19, B21 and B24, shading devices are only used in the south façade. In B21 and B24, the east and west façades have clerestories to illuminate circulation and services areas, in which protection from the sun is less important. The use of double-glazing and windows with shallow fins looks to be significant for the daylighting performance of B23. However the use of tinted glazing in B18 reduces daylight penetration, because of the glazing's low light transmittance, and consequently reduces the shading device parametric level.

The study of parametric levels and their development during the Shihabist and Post Shihabist phase are shown in Figure 7.56. Generally speaking, 'Building Shape', 'Window / Façade' and Total performance are almost linear. The 'Building Shape' performance evaluation percentage has a descending range, between 44% and 25%. The similarities in building shapes described previously between B21, B22, B23, and (almost) B24 is quite apparent by the straight line. This is not the case for the other buildings, but the difference in performance is not great. 'Window / Façade' parametric level performance also varies within a limited range, between 71% and 88%. B17, B18, B19, and B20 have almost the same performance value (79%, 79%, 79%, and 83%, respectively), which slightly increases and decreases for the other buildings. This similarity is because in all the buildings studied, windows are located all along the office façades, with an intermediate sill height and relatively constant ceiling height. Consequently, the average of window to wall ratios and daylight aperture ratios of the 8 buildings varies within similar ranges.

The performance figures of 'Window / Office' do not show same linearity as the other parametric levels. 'Window / Office' performance evaluation has changing values, varying between a minimum of 35% (B22, note 1 in Figure 7.56) and a maximum of 85% (B20). Having almost similar 'Window / Façade' characteristics, the difference in buffer zone depth and office areas in accordance with window areas explains this irregularity. The deep open plan offices in B22 and B24 have decreased their performance to half, compared with B18, B20, and B23 that have small offices of 4-4.6m depth. The other buildings (B17, B19, and B21) have intermediate performance values because office spaces are intermediate in shape with deeper depth (5.80-7.0m). Therefore, it can be concluded that there are no clear or constant figures for 'Window / Office' variables in the Shihabist and Post-Shihabist phase.

The performance of 'Shading Devices' parametric level also does produce clear and linear figures. The values vary sharply, between 92% and 25%. It appears that at that period, there was an architectural movement in which the use of shading devices became an important feature of façade design. Other movements followed new glazing technologies, as in B18 and B19.

It can be concluded that the selection of two representative case studies from this phase, for extensive analysis needs to be based on 'Window / Office' and 'Shading Devices' parametric levels, because it has been proved that the other two levels show only minor differences in performance.

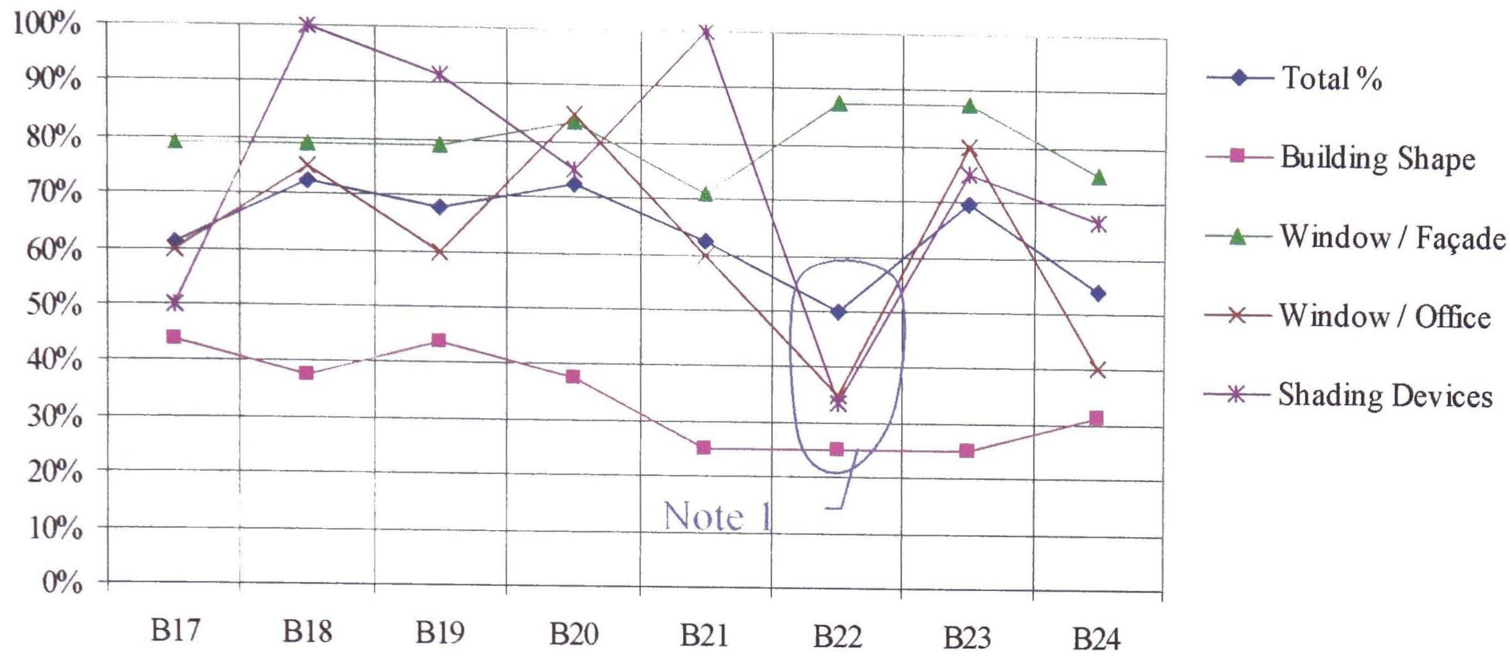


Figure 7.56. The impact of daylighting design variables on daylighting performance in the office buildings studied, (B17 – B24) expressed by the percentage of the area under curve.

7.3.6 The Civil War Phase (1975 – 1990)

The civil war revealed an administration too enfeebled to address the tasks of reconstruction. In 1977, the Council of Development and Reconstruction (CDR) was established; but the CDR, like other governmental agencies, became too fragmented. Building legislation was altered only once, in 1983. It was very superficial, aimed at organizing the procedure for construction permits, and defined the G.P.D. and G.D.R. for some previously unorganised areas. Sixteen years of war resulted in the destruction of much of Greater Beirut, and the Beirut Central District (BCD) in particular. All the businesses that were previously in the BCD had to move to other office buildings elsewhere in Greater Beirut, or relocate themselves in residential buildings.

The construction of office buildings and commercial buildings fell away, due to the economic and investment regression during the civil war. According to the majority of those architects that the researcher interviewed, who had been practicing architecture at the beginning and during the civil war in Lebanon, most demand was for small office units, consisting of 1-2 office spaces and services of 40-60m^2 area. In addition security, the possibility of destruction, and necessary maintenance were important factors that needed consideration while designing during the period (Interviews with: Pierre Khoury on April 23, 2003; Saiid Jazaiiri on April 29, 2003 and Pierre Nehmeh on May15, 2003).

The impact of the civil war on office building construction will be reviewed through the analysis of six buildings built during this phase (1975-1990). Similar to the reviews of previous phases, a brief general description of each building will precede the analysis of parametric levels according to daylight performance.

7.3.6.1 *Description of Case Studies*

Table 7.3 lists six office buildings that have been selected to study the characteristics of office buildings in Beirut in the Civil War period. This lasted for 15 years, and came after a period of prosperity in the modern history of Lebanon.

ID	D.O.C.	Building Name	Sheet No. in Appendix I	Area Under Curve				
				Total %	*Building Shape*	*Window / Façade*	*Window / Office*	*Shading Devices*
B25	1978	Koussa Building	Sheet 25	71%	69%	79%	75%	50%
B26	1982	Arab Bank Building (Mazraa)	Sheet 26	64%	50%	75%	70%	50%
B27	1982	El-Jazira Buiding	Sheet 27	76%	63%	92%	90%	42%
B28	1982	Unesco Center	Sheet 28	85%	69%	96%	80%	92%
B29	1983	El-Ghazal Tower	Sheet 29	57%	50%	33%	65%	100%
B30	1984	Intercontinental Bank Headquarters	Sheet 30	76%	63%	96%	70%	67%

Table 7.3. List of selected office buildings constructed in the period between 1975 and 1990, for which more detailed information is presented in Appendix I (Sheet 25 to Sheet 30).

The Koussa Building (B25, Figure 7.59), Arab Bank Building (B26, Figure 7.58) and El-Jazira Centre (B27, Figure 7.58) are three examples of office buildings from the first half of the war. They are enclosed buildings, located in the residential area of Mazraa; more specifically in Mazraa Avenue, a main arterial road in Beirut and which was developed during the war in order to be one of the dispersed replacements for BCD. The site location (enclosed site, corner site), area, shape and economics are important factors that influenced the building shapes. The three buildings have a rectangular, double loaded plan of approximately 10-12m width. The office areas range between 10-15m^{2}, and are daylit unilaterally from opposing orientations. In the three buildings, the opposite façades have different configurations. The front façades of B25, B26, and B27 have wall to aperture ratios of 0.52, 0.54, and 0.62, respectively. They are very similar in their window shapes and proportions, as well as sharing the use of fins to mark the window unit divisions. On the other hand, the rear offices open onto balconies. This configuration is much more similar to residential buildings. This can be explained by the fact that architects wanted to harmonize these rear façades with the surrounding residential buildings. In addition, architects and clients had financial reasons to exploit the building regulations that allow 20% of the floor area to be used as balconies, in order to increase the floor area to the legal maximum. This additional balcony area is not counted in calculating the permitted total built up area. These balconies were subsequently enclosed by aluminium and glazing units, and used as additional internal areas.

Figure 7.59. Koussa Building (B25), D.O.C. 1978.

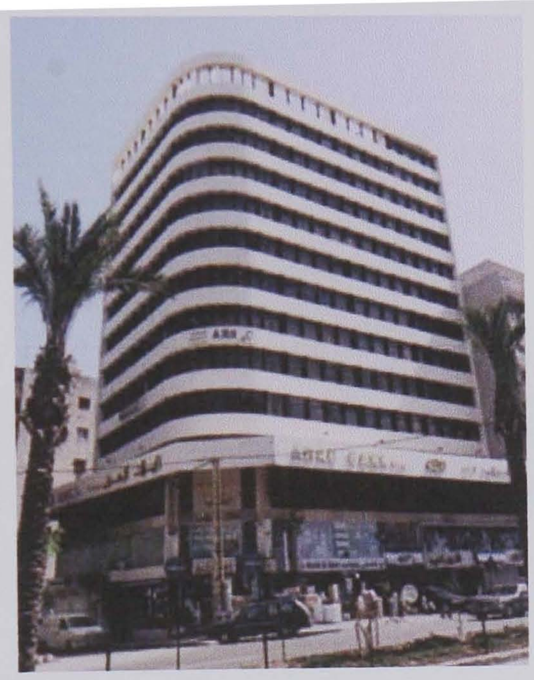


Figure 7.58. Arab Bank Building (B26), D.O.C. 1982.

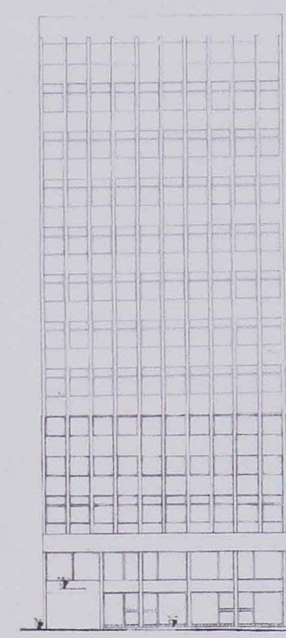


Figure 7.57. El-Jazira Centre (B27), D.O.C.

Figure 7.60. Unesco Centre (B28), D.O.C. 1982.

Figure 7.61. El-Ghazal Tower (B29), D.O.C. 1983.

Built in the same period, the Unesco Centre (B28, Figure 7.60) has a different configuration from the three buildings described above. Located on the corner of Verdun Street, an upmarket residential area, B28 has an enclosing L-shape plan. The façades are cladded with bronze reflective glazing, bordered at the edges by a concrete frame. The average office area is $20m^2$. According to the building's architect, Saiid Jazaiiri, the use of complete glazing on façades was not recommended during that period, for security and maintenance reasons. However, on this occasion the client was looking for an elaborate and trendy building. In his interview, Jazaiiri said that in one of his office building designs, and with increased fear of the destructive war, he had to exchange the use of a curtain wall to a lower wall to aperture ratio, to reduce potential damage. For him and for Pierre Khoury, who designed the following buildings (B29, Figure 7.61), 'war was part of everyday life at the time, and definitely part of how a building in a location like that should look'.

Built in 1983, Building B29 (Figure 7.61) was placed on the eastern side of the green line which divided Greater Beirut into Western and Eastern parts. The architect Pierre Khoury described his building in an interview conducted by the researcher: 'it is one simple rectangular block, standing like a fortress. It seems simple and easy, with the outside being composed of protruding vertical elements with all openings hidden in a manner to keep the inside safe from any sniper fire or shells exploding nearby'. According to the architect, the problem of security was the main concern in the design of El-Ghazal Tower. This could not be provided by façade glazing, otherwise the front façade could have readily been completely glazed without any protection because it faces north. For increased safety, the eastern and western elevations were designed to be completely solid and therefore the cellular offices are daylit unilaterally.

In the same area as B29, building B30 (Figure 7.62), now known as the Intercontinental Bank Headquarters, was built in 1984. The front façade faces south, and has a 0.55 wall to aperture ratio. A metal brise-soleil structure was used to obstruct direct sunlight, and at the same time increase the protection of glazed areas from shootings and damage. The rear elevation has 0.46 wall to aperture ratio, composed of intermediate shape windows separated by vertical concrete elements. For this façade, security was not a problem because the opposite building was enough to protect glazed areas and the people inside from damage. A typical floor has an open plan office in the south façade, with cellular offices of 13m^2 on the north. The façades were renovated by Bertrand Muller in 2002. The French architect replaced the metal structure with external, horizontal movable louvers (Figure 7.63). According to Muller interviewed by the researcher on May 3, 2003, adjustment of the louvers is manual because an automatic system would have been too expensive for the client's budget.

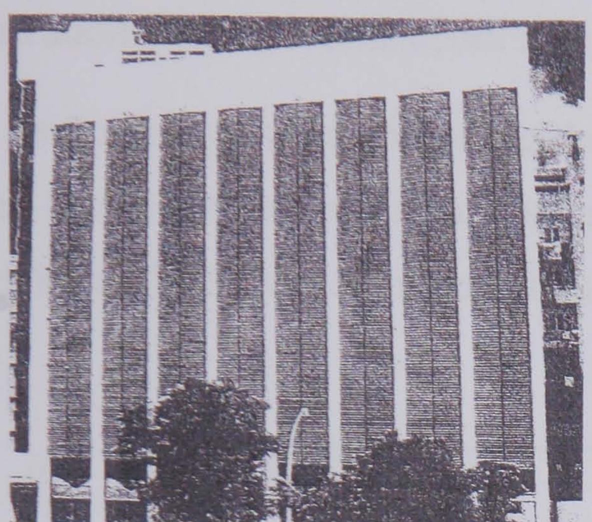


Figure 7.62. Intercontinental Bank Headquarters (B30), D.O.C. 1984 (from the achieve of the Architect Bertrand Muller).

Figure 7.63. View of the renovated south façade of B30.

It can be concluded from the brief description of these selected buildings that 'architectural modernism' as Arbid (2002) described in his thesis, and apparent in the buildings from the late 1950s and 1960s, was no longer the same during the Civil War. The concepts of façade design changed completely. The design of office buildings at this period could be categorised into *defensive* architecture (B29 and B30) and *low-investment* architecture, (B25, B26, B27 and B28). The properties and daylighting performance of such design trends will be examined in the following section, through the analysis of building parametric levels.

7.3.6.1.1 Evaluation of daylighting design variables

Figure 7.65 illustrates the diagrammatic description of daylighting performance evaluation of the six buildings reviewed above. The shapes of B25 and B26 diagrams are quite irregular, pointing up the differences of façade configuration between the front and the rear elevations. This difference is less clear for B27, where window to wall ratios are in the same range. The remarkable thing is that the maximal performance value of

'Window / Façade' and 'Window / Office' variables is associated with the good performance of shading devices. This is because vertical fins and/or overhangs (B25, B26, and B27), or brise-soleil (B30) were used to protect both the glazing and the people inside from gunfire, during that period. In addition balconies, which are considered in this case to be horizontal overhangs for the openings underneath, improved shading performance (B25, B26, and B27). In fact the role of these balconies was primarily to obtain additional floor area, more than to be a shading device or aesthetic element.

The performance evaluation of building B29 produces completely different figures. The strong irregularity of its diagram is because two of the four façades open to the exterior. In addition, the reduction in opening areas reduces the possible daylight performance by half.

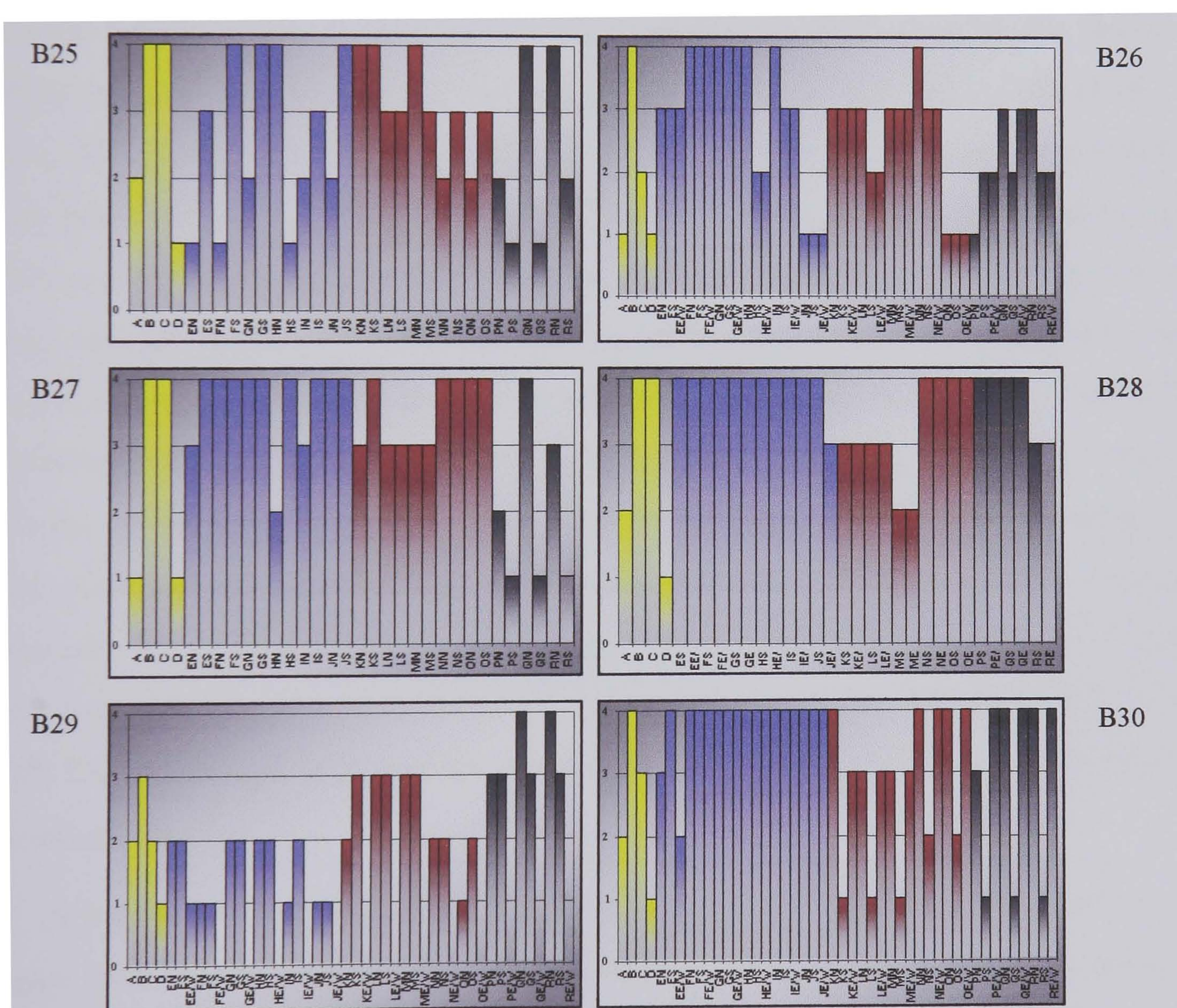


Figure 7.64. The impact of daylighting design variables on daylighting performance in the office buildings studied (B25 – B30), expressed by the percentage of area under curve.

In addition, it is remarkable how the building shape parametric levels have changed from those described in the previous phase. Shape coefficient (variable B) and Envelope to Floor Area Ratio (variable C) show a significant daylight performance, especially in B25, B27, B28, and B30 where they are maximal because of the low width, rectangular plan (less than 15m) and 8-9 floors height. This has increased the envelope surface area and total floor area in accordance with the volume and total envelope surface area, respectively. The porosity ratio is minimal, because office buildings have no void; this not being needed in low width plans.

In Figure 7.64, the performance evaluation of building B29 has misshapen the linearity of 'Building Shape' and 'Window / Façade' parametric levels. The 'Building Shape' level of B29 is lower, because the building has a wider rectangular plan but also is higher than the previous buildings (12 typical floors). The increase of solid areas in the façades has sharply reduced the 'Window / Façade' performance of B29, from 79% (B25), 75% (B26), 92% (B27) and 96% (B28 and B30) to 33%. The average wall to aperture ratio varies between 0.37 to 0.57 for all the buildings, except for B28 and B29 with the highest (0.89) and lowest values (0.16), respectively. These two extremes differ because of the design concept: the first building was seeking for a trendy and fancy look, and the second one for indoor security with reduced losses. Both buildings, B28 and B29, show better performance in their shading devices. In B28, reflective glazing was used on the south and east / west façades but this appears to be insufficient to protect the indoors from direct sunlight and possible solar heat gain. As for B29, the window recesses are comparatively small relative to the aperture dimensions. Solar protection is therefore inadequate. The situation is completely the reverse for buildings B25, B26, B27, and B29, where fins are enough to protect the narrow aperture, as well as the use of balconies in the rear elevations.

The 'Window / Office' parametric level performance of building B29 does not differ greatly from the other buildings, as only window area is decreased. The three office dimensions are no different from those found in the other buildings studied.

It can be concluded that building B29 is one of the buildings that illustrate the construction of secure office space during the civil war period. B25, B26, and B29 have a different design direction, where design targets are maximal spatial use, economic building and reduction of losses. These two directions have different daylighting performance. B29, and one of the other three buildings mentioned will be used as case studies representing the Civil War phase.

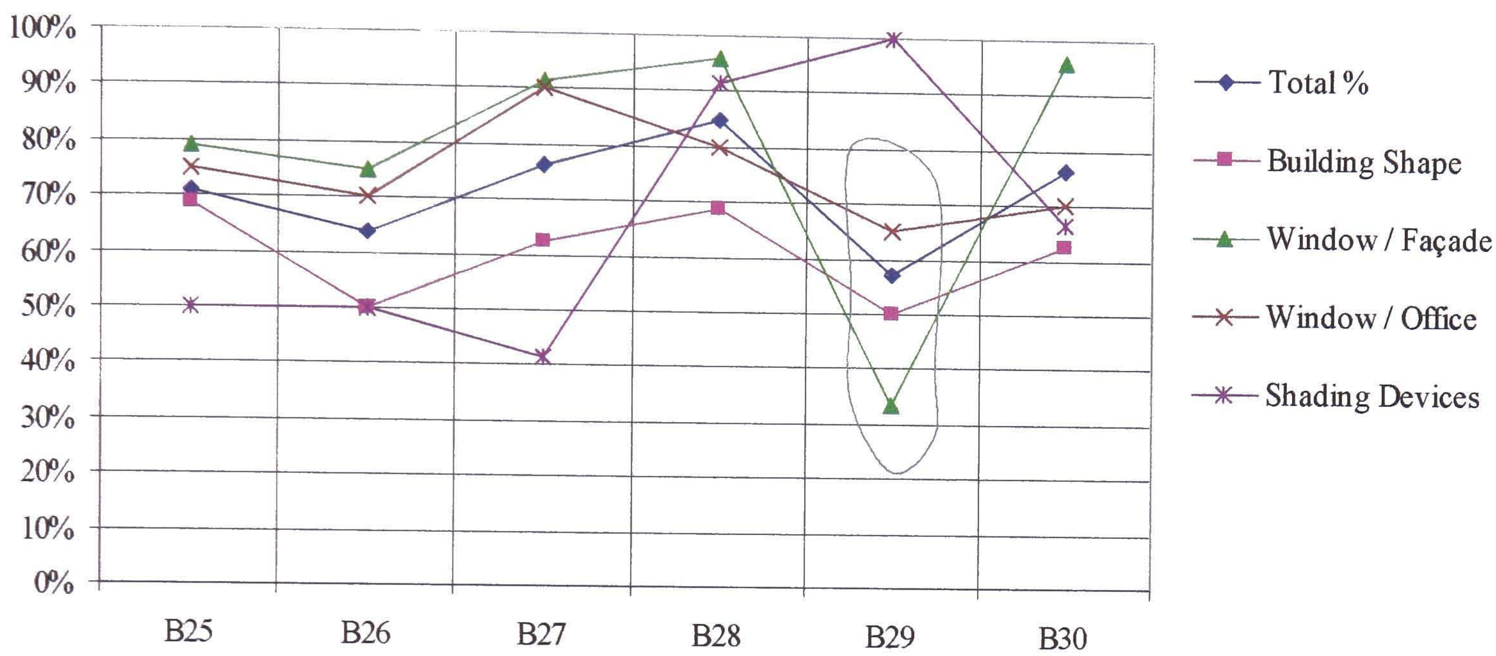


Figure 7.65. Diagrammatic description of the selected office buildings built in the Civil War phase (1975-1990).

7.3.7 The Post–War Reconstruction Phase (1990 – Present)

The pre-war boom years established real estate as a promising investment in Beirut. This was followed by massive investment in property in the 1990's, as demand was stimulated by war damage. The largest of the all country's development agencies is SOLIDERE, the real estate company that controls reconstruction of the damaged Beirut Central District. The proposed model is paradoxical, that retreats into the 'traditional' while also accepting 'futuristic' architecture.

According to Arbid (2002), who has studied architectural modernism in Lebanon during the period between 1946 and 1970, there is some misapprehension of the meaning of modernity and identity in many projects undertaken recently in Lebanon. Recent office buildings show both a pastiche of traditional architecture and a pastiche of modernism (Figure 7.66 and Figure 7.67). This architectural approach does not relate only to nostalgia for the past, but also encompasses some mimicry of 'pseudo-futuristic high-tech'. The smooth surfaced box is the almost omnipresent model for recent office building architecture in Lebanon (Figure 7.68).

Figure 7.66. The M.P.s Office building, D.O.C. 1994.

Figure 7.67. 'The Atrium' building, D.O.C. 1995.

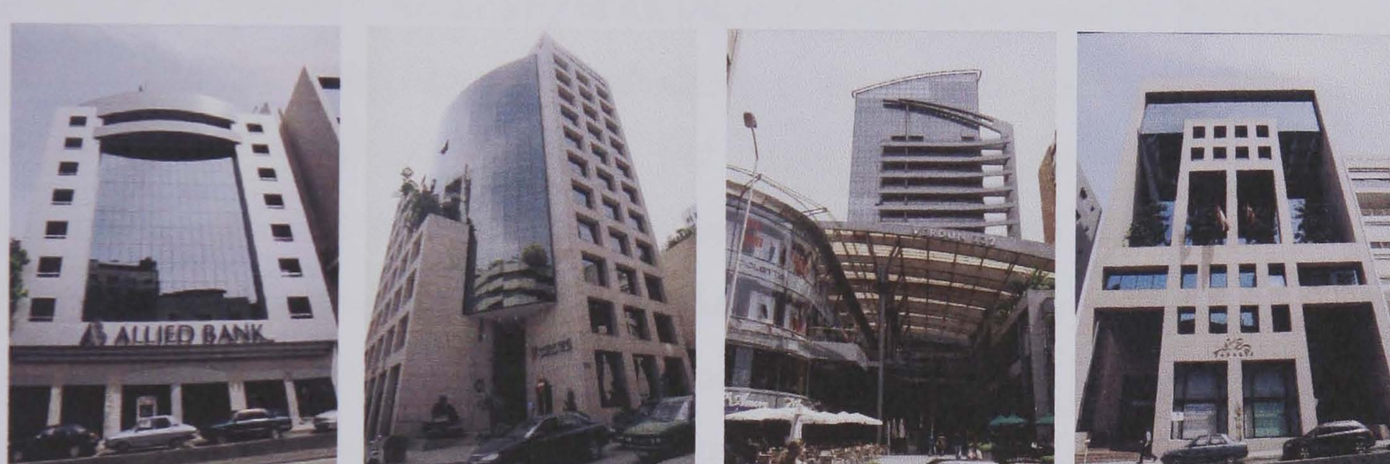
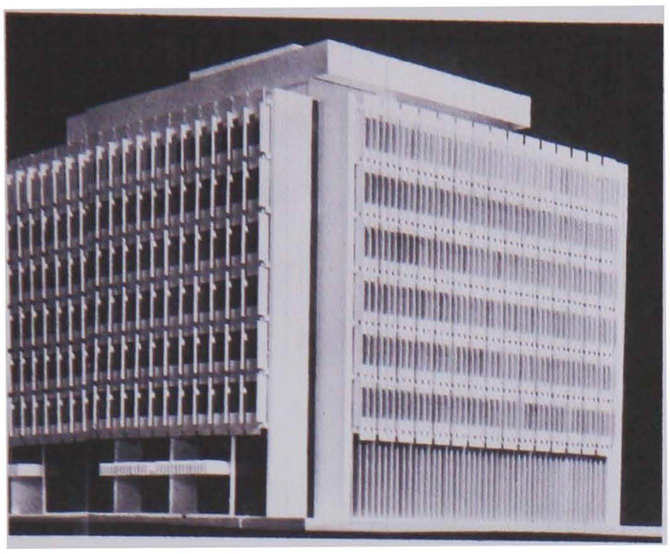


Figure 7.68. Examples of office buildings constructed during the last 5 years, in Beirut.

Not only has the trend influenced newly designed buildings, it has also affected buildings of the 1950s and 1960s. For example, the Sehnawi Building on Hamra Street, built in the 1960s, lost the aluminium sunscreens which protected it on the eastern and western elevations and was dressed in 1999 by a black, double tinted reflective curtain wall (Figure 7.69). According to the architect Pierre Nehmeh who renovated the building, the use of sun breakers was a trend in the 1960s and 1970s rather than an environmental element. Today, for clients and most of the architects in Lebanon, the use of the curtain wall is again to follow the trend for 'modernity'.



a- as built, 1960s (Arbid, 2002)

b- after renovation, 1999

Figure 7.69. Views of Sehnawi office building, before and after renovation.

Pierre Nehmeh, when interviewed on 15 May 2003, said that *"any technology starts to control human beings but after a time the human tries to accommodate technology in accordance to comfort."* According to all the architects interviewed by the researcher, the curtain wall is not a problem when advances in appropriate glazing technology can be used to control heat and sunlight. For them aesthetic considerations, financial considerations or client requirements are the factors that control their office designs, not ones related to efficiency or energy. For Arbid (2002), an architect in Lebanon now is only concerned with electro-mechanical studies concerning the size and location of the technical equipment he has to provide, in order to solve the problem he has created by blindly following the trend for glass boxes. Pierre Khoury, who is considered to have produced some distinctive designs for office buildings during the last 10 years, said when interviewed by the researcher on 23 April 2003: *"In my designs, I didn't really bother about energy efficiency and comfort efficiency because I have never been asked to. Here in Lebanon, we are following the trend without having this sort of thinking. Anyway, I must say honestly I did not really put this idea in my priorities."* It might be said that there is some unawareness, or irresponsibility among architects and clients when adopting a trend without studying its associated consequences such as energy efficiency issues. Today, specifically in 2002, a new energy standard project for Lebanon has been produced. This project is not yet finished. The first draft reports show that this energy code tends to be mostly concerned with thermal performance. The outline of this project will be discussed in more detail later.

From the previous investigation, it can be concluded that nowadays the design trend of office buildings in Beirut are either the *Modern* glass box or the *Imitative* or *Conservative* architecture mixed with *Contemporary* architecture features. In order to view clearly the ongoing architecture of office buildings in Beirut, five case studies will be investigated in the following section.

7.3.7.1 *Description of Case Studies*

Table 7.4 lists five office buildings constructed during the last decade. Some of these buildings are new constructions for SOLIDERE real estates. B31 and B34 are two buildings constructed in Beirut for the same client (Banque du Liban et d'Outre Mer, BLOM) and on adjacent sites. The reason for choosing both of these is to see the differences in façade design and plan typology between the first, built in 1993 and the second, built in 1999.

ID	D.O.C.	Building Name	Sheet No. in Appendix I	Area Under Curve				
				Total %	*Building Shape*	*Window / Façade*	*Window / Office*	*Shading Devices*
B31	1993	BLOM (Block A)	Sheet 31	61%	56%	46%	70%	83%
B32	1995	ESCWA Headquarters	Sheet 32	71%	44%	92%	60%	83%
B33	1996	The Atrium Building	Sheet 33	49%	44%	50%	25%	92%
B34	1999	BLOM (Block B)	Sheet 34	69%	75%	88%	35%	83%
B35	2002	El-Nahar Office Building	Sheet 35	67%	38%	100%	40%	83%

Table 7.4. List of selected office buildings constructed in the period between 1990 till now, and which more detailed information are presented in Appendix I (Sheet 31 to Sheet 35).

The concept and design development of the BLOM building (B31, Figure 7.70) were based on site limitations. The building stands on a triangular plan, with a large middle space and a sharp notch on one corner. Although it embodies one piece in volume, the notch is a transparent prism in glass and steel; with the rest mainly a block of solid greenstone, and a modular replication of vertical windows. The prism accommodates all the vertical circulation, with stairs and platforms suspended from a main bridge at the top. Adding to the architectural language of mixed media, specific forms define functions and spaces. A grand, two-level high transparent arch on the ground floor marks the retail bank, and a protruding disc-shaped volume on the seventh floor is the chairman's office. In the middle of the triangular plan, an open half-cylinder shaft stretching from ground floor to the sky provides zenithal lighting to the whole interior. Only on ceiling level at the retail bank on the ground floor, is it sealed with glass for noise and security reasons.

Figure 7.70. External and internal views of BLOM Building- Block A (B31), D.O.C. 1993.

BLOM Building – Block B (B34, Figure 7.71) is the new extension of B31. The second building has the same style as the first. It stands as an independent building, but also as a continuation in form and shape of the old one. The vertical circulation area is all in glass, and the same window unit is replicated marking the office spaces behind. Inside the triangular volume, open plan offices have an introverted view to an angular air-conditioned atrium, from one side through balconies and from the other through small openings. The atrium is also open on the top, and has an outer surface which is a curtain wall facing west. The building's architect Pierre Khoury believes that what he did is to "play with volumes, but the result is plenty of light which is more than the necessary" (Interview with Pierre Khoury on April 23, 2003). In the same interview, Khoury also added that "*in the two buildings, there is no problem with the north façades but he thinks that people working inside the other façades are suffering, because at 'that time glazing was not controlled enough*".

Figure 7.71. External and internal views of BLOM Building- Block B (B34), D.O.C. 1999.

The ESCWA (United Nations' Economic and Social Commission for Western Asia) Headquarters (B32, Figure 7.72) is a prominent landmark in Beirut Central District, due to its exposed location that allows it to be visible from several points and from some distance. The ESCWA building is claimed to be the first intelligent office building in Lebanon (Rowe *et al.*, 1998a). Following the brief, the town planning and building regulations imposed by SOLIDERE as well as the Beirut municipality, the building was designed with characteristics to maintain the atmosphere of old, traditional Beirut in a renovated and modernised context. It was required to have colours and shapes like the adjoining buildings and in addition, an architectural element that would help make it a landmark. Two of the three façades of the building, namely the east and west façades, were made to be in a sense a continuation of the adjoining structures, built between the 30's and the 60's. Similar in colour and form to the adjoining building (B14, Figure 7.38), 'flush" yellow granite and glass were used in a curtain wall system designed in horizontal patterns continuing along the curves of the site, symmetrically from both sides. The independent middle façade facing south had no direct context references, and was made therefore in a modern language with double-glazing reflective mirror film panels. According to the building's designer, Pierre Khoury, the glazing material initially selected for the south façade was bronze double glazing panels with internal micro sun breakers. Khoury believes that this glazing material would have completely cut the glare and heat from which people using the building, particularly those occupying the south oriented offices, are currently suffering (Interview with Pierre Khoury on April 23, 2003). The reason for not using this glazing technology is that it was too expensive for the client, SOLIDERE, who had already sold the building to the Lebanese Foreign Affairs Department. They in turn passed it on to ESCWA. B32 could have been a different building, not in its general shape but in the final material and energy performance.

As the expression changes in the use of material between the middle and side façades, two joints in the form of a volumetric indent clearly define the separation between them. In the south façade, the U shaped plan is enclosed by a 20m bridge, in the form of an arch with a height of 32m. The concept of this composition is a symbolic and modern revitalization of the old gates of Beirut Central District, mentioned previously. The flat arched elevation became the architectural feature that makes the building a landmark and provides an enclosure for the open space in the middle. The building's interior consists of three sets of cellular offices on both parallel sides of the U-shape; two sets of offices have direct access to daylight, while the other has no view to the outside. Its main source of light is artificial, with additional indirect daylight coming from internal partition clerestories. The third wing of the U-shape houses meeting rooms and services.

Figure 7.72. The ESCWA Headquarters, D.O.C. 1995.

Figure 7.73. 'The Atrium' Office Building, D.O.C. 1996.

Like the ESCWA building, the composition of 'The Atrium' office building's façades was regulated by SOLIDERE / Beirut Municipality building recommendations with the intention of respecting and being congruous with the adjacent 'traditional' building stock, while being rendered distinctive by some 'modern' features. Located at the corner of Maarad and Weygand Street, "The Atrium" office building (B33, Figure 7.73) is integrated with its surroundings through binary façade typologies: The one on Maarad aligns itself with the traditional row of arcades existing in that street. In the roof floor the architect Nabil Azar has introduced contemporary elements to the old model of the façade, avoiding duplication. The other façade is detached from the main volume by two transparent slots. Its expression is a total liberation from the traditional, imposing architecture of Maarad Street, yet respecting the old proportions in the design of the curtain wall and the glass openings (Interview with Nabil Azar on May 7, 2003). The atrium located in the centre of the rectangular plan is considered an essential feature of the building, and one after which the building was named. The architect, Nabil Azar, said that the concept of using the atrium was mainly aesthetic and intended to solve the problem of the large building depth. Only corridors open onto this atrium. All the office areas are located in the 10 - 12m buffer zone from the exterior and are open plan, flexible to accommodate change for the variety of different functions. Nevertheless, it is noticeable that in this building, façade composition and office partitioning are not harmonious. This discord is caused by an 'immature' use of French windows, especially in the west façade, which does not relate with the interior as it did in the buildings of the 1920s to 1940s.

El-Nahar office building (B35, Figure 7.74) is another example of newly constructed office buildings in the older context of the Beirut Central District. Unlike B32 and B33, the façade design was not limited by regulations imposed by SOLIDERE or the Beirut Municipality. On the contrary, the concept of the design was to create an outstanding structure, without any integration with the surroundings. The building stands openly and freely as a modern landmark in the old context of Weygand Street. The façades are made of glass panels and stone cladding, and follow the concept of being a detached membrane from the main structure of the building which is completely curtain wall. The interplay on volumes in the façades was mainly intended to 'serve as microclimate control of the interior' (Interview with Pierre Khoury on April 23, 2003). The back section of the building curves around a public garden in an animated way, mainly to provide the interior with a clear view of some open space. This view extends all the way to the 'Place des Canons'. The typical floor has four open plan offices, different in size and shape. The north and south offices are daylit multilaterally, but the east and west offices are lit unilaterally. Therefore, despite the high buffer zone depth in the south and north orientation, the 0.84 wall to aperture ratio and the location of openings on the three sides of the office gives a deeper daylight flow pattern. According to the architect Pierre

Khoury, the glazing material used in the façades is not appropriate to protect the indoor environment from excessive glare and heat gain due to high wall to aperture ratios. Nevertheless, the architect does not see any weakness in the design, but in the economic constraints of the client's budget.

Figure 7.74. External views of El-Nahar office building (B35), D.O.C. 2002.

It can be concluded that current office design trends in Beirut, identified previously as *Modern* glass box and *Imitative* or *Conservative* architecture mixed with *Contemporary* architectural elements, have mostly aesthetic concerns but no environmental or energy efficiency awareness. In fact, all architects in the last 10 years have tended to use a curtain wall in their façades. The wall to aperture ratio in the new structures located in the Central Beirut is controlled only for aesthetic reasons, not for environmental or energy related ones. Therefore, it is important to study the changes of façade typologies applied to the constant plan morphology of a building, as well as the differences between the two design directions regarding daylighting performance.

7.3.7.1.1 Evaluation of daylighting design variables

The descriptive diagrams of the five buildings, illustrated in Figure 7.75, show very clearly the variation in design of the same building façades. This variation is most clear in the B33 diagram, where the performance evaluation difference of 'Window / Façade' level variables is considerable, and between the different parametric levels as well. This irregularity is also clear in the B34 diagram, where the architect used the same façade feature of the extended building B31 to create the feeling of continuity in form and alignment, while on the other hand the side façade has a higher wall to aperture ratio.

B31 B32 B33 B34 B35

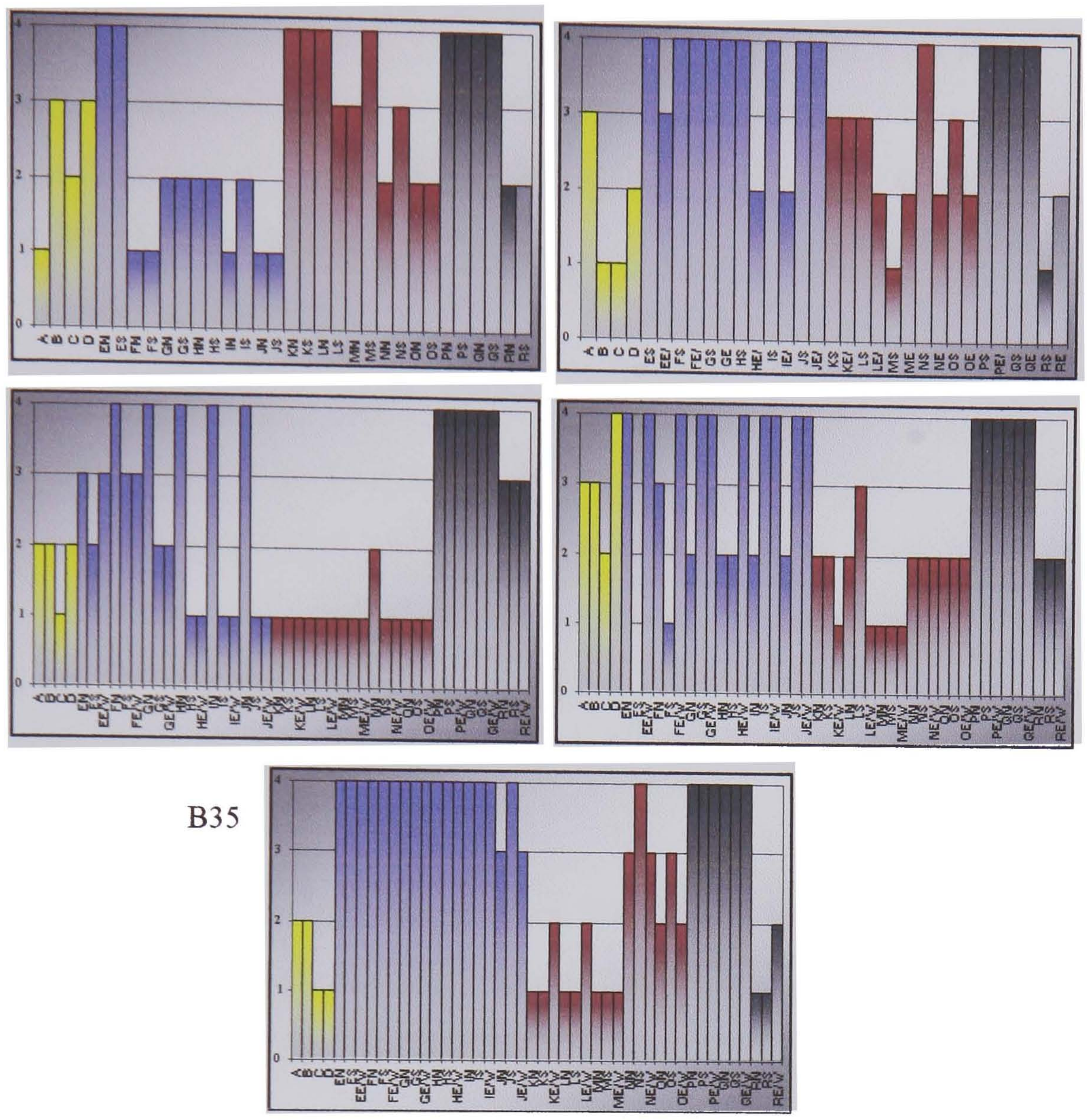


Figure 7.75. Diagrammatic description of the selected office buildings built in the post-war reconstruction period (1990-now).

B32 and B35 have more or less balanced performance, compared with the previous building. Despite the fact that in B32 the architect was trying to harmonise his design to the surrounding buildings with 0.40 wall to aperture ratio, his job was easier than that of Azar in B33, where the adjacent wall to aperture ratio average was 0.25. Adding a modern feature to the building, basically manifested by curtain wall use, caused not so much unbalanced performance in B32 as in B33.

Referring to B35, the performance here is quite constant because all the façades are similar in design. Daylight performance in the 'Window / Façade' parametric level is very high, which might be a sign of excessive glare and heat gain, but is less effective in 'Window / Office' parameter because of the use of open-plan offices.

When comparing buildings in accordance to 'Building Shape' parametric level, Figure 7.75 shows that buildings perform differently. This can be explained by the fact that each building is shaped in relation to its site outline. It is noticeable that in this phase, atrium and courtyard are important features of architectural modernism which have increased the performance evaluation of the 'Building Shape' parametric level. From Figure 7.76, it can be seen that B34 has the highest performance of all buildings because it has a relatively high porosity ratio, equal to 0.20.

On the other hand, the high performance levels of projection ratio and overhang ratio demonstrate how shading devices are no longer used, compared with previous phases. A lower performance evaluation of the Relative Solar Heat Gain variable shows that nowadays architects rely mainly on new glazing technologies to control sunlight penetration and solar heat gain, even though in some cases this protection might be not sufficient. Therefore the performance evaluation of the shading devices parametric level is linear, and almost constant (Figure 7.76).

Figure 7.76 shows how the development of total performance evaluation of the studied buildings shows linear and constant relative figures, except for B33 where 'Window / Façade' and 'Window / Office' performance evaluation decreases dramatically.

'Window / Façade' performance evaluation varies between 46% and 100%. This variation is not linear but sinuous, because today the façade design of some office buildings depends on the configuration of adjacent buildings, which limits the wall to aperture ratio. This rule is not applicable in all cases. In the absence of other constraints, a curtain wall is used in order to produce a more fashionable output.

Despite the increase of 'Window / Façade' performance values relevant to the increase of window area, the 'Window / Office' performance values have fallen below 40%. This is because the increase of window area is accompanied with an increase of buffer zone depth, and office area.

For a better understanding of the performance of current office buildings it has been necessary to select two case studies, each representing design trends or directions; B32 and B33 are included in one category, while B31, B34 and B35 represent the other direction. Nevertheless, B32 and B33 have different performance figures because the façades of each building were designed to be homogeneous with the surroundings. The neighbouring buildings of B32 and B33 were built in the early years of independence phase (1946-1958), and the late transitional and early modern phase (1930-1946), respectively.

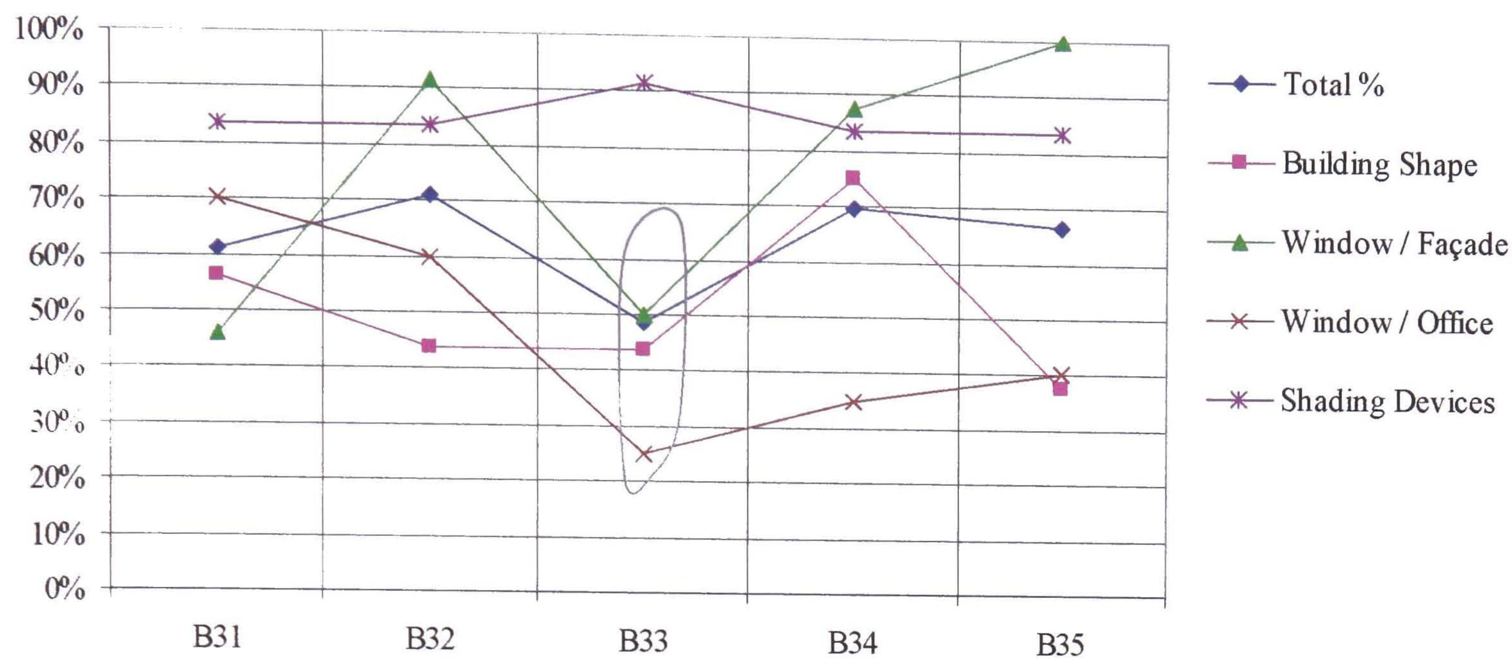


Figure 7.76. The impact of daylighting design variables on daylighting performance in the studied office buildings (B31 – B35), expressed by the percentage of area under the curve.

7.4 Summary and Conclusion

It has been proved that Beirut is fundamentally a city of the late 19th century, that being when the first true signs of urbanization began to appear. There was thus no need to go too far back into its past to discover the establishment of office-use buildings. Khans were the first form of commercial / office-use structures, appearing in the nineteenth century and later developing into exclusive corporate headquarters and speculative buildings. During the 20th century office buildings in Beirut passed through several stages, moving from the central bay buildings of the early 1920s to the excessive use of glazing that are considered the current trend in office buildings and the sign of modernism. The International Style is obvious during the period 1946 to 1975. Later, the civil war caused the emergence of two types of office edifice: defensive and low-investment office buildings. Two approaches to office building design are apparent today, chiefly in the BCD: imitative architecture, and the modern glass box.

These alterations in façade configuration and plan morphology have changed the daylighting performance of office buildings in Beirut. Figure 7.77 shows that the development of office building design during the period 1946 and 1975 improved the performance of daylighting inside office spaces. The period before is marked by lower daylight performance in office building design. Since 1975, despite the adoption of glazed façades and the development of façade technologies and glazing, the daylighting performance of office buildings in Beirut has decreased slightly from what it was before. As explained earlier, the construction of defensive buildings and imitative buildings has decreased daylighting performance. In each period 'Building Shape', 'Window / Façade', 'Window / Office', and 'Shading Devices' parametric levels have taken different performance evaluation values, which in turn changed the value of the total design daylighting performance. The following chapter will study extensively the impact of each parametrical level in general, and each design variable in particular, to identify their level of significance for the daylighting performance of office buildings in Beirut. This chapter will also include the developmental study of each design parameter.

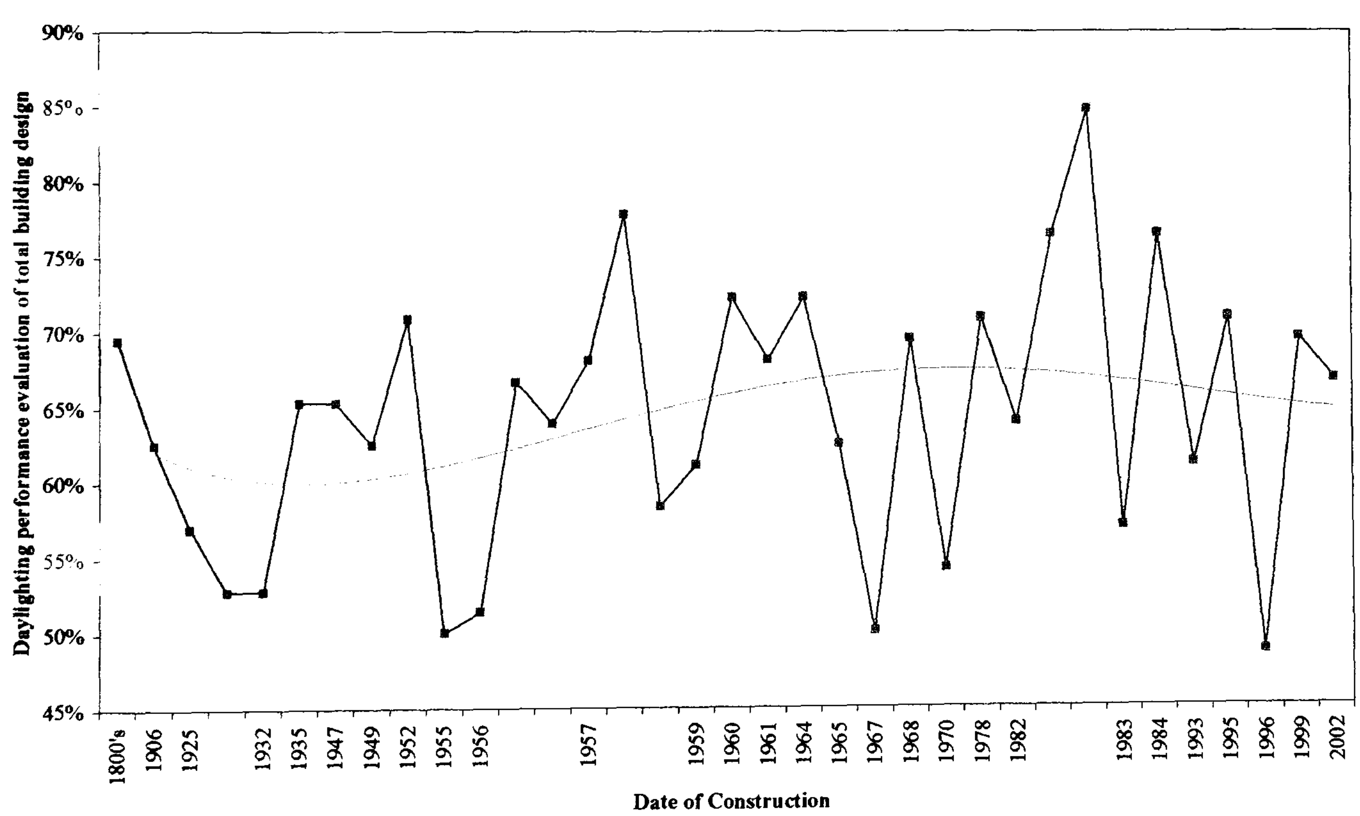
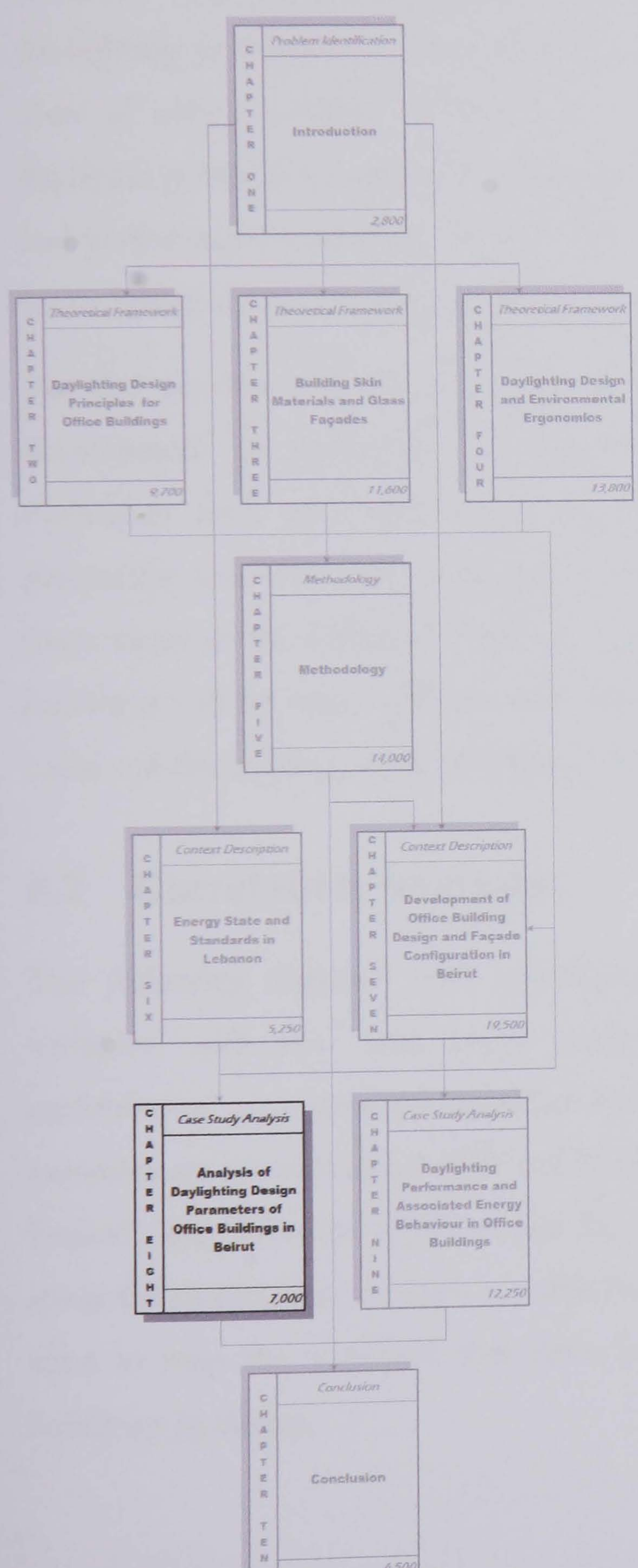


Figure 7.77. Development of daylighting performance evaluation of office building design in Beirut (1800's – 2002)

Analysis of Daylighting Design Parameters of Office Buildings in Beirut

8



Chapter Eight

8. Analysis of Daylighting Design Parameters of Office Buildings in Beirut

8.1 Introduction

In the previous chapter, 35 office buildings located in Beirut were described with particular emphasis on the impact of their façade configuration and plan morphology on daylighting performance. This chapter aims to draw a more detailed and comparative view of office building architecture in Beirut during the last century, in relation to daylighting design variables. Correlational analysis between daylighting design variables and performance evaluation is also vital, in order to define the variables that have been most significant for daylighting performance in the studied context.

The first section will review the development of each daylight design variable and the development of daylighting performance evaluation measured with the developed evaluation tool, and represented by the area under curve as a percentage of each parametric level. In these analyses, a focused comparative study of A1-OL and A1-O (base cases of the Lebanese Energy Standards project) corresponding to the 35 selected buildings will be done, with the aim of finding a relationship between the proposed base cases and the existing stock of office buildings.

8.2 Correlation Analysis

The following sections will investigate the correlation between daylighting design variables with the 'area under curve percentage', that indicates the daylighting performance evaluation of the office buildings studied. As mentioned previously, these variables are divided into 4 different levels or scales: the 'Building Shape', the 'Window / Façade', the 'Window / Office' and the 'Shading Devices'. The aim of this section is to study the significance of each variable to the proposed daylighting evaluation tool. It also aims to map the variables that have been mostly considered in the design of office buildings in Beirut.

8.2.1 'Building Shape' Variables

Table 8.1 illustrates the correlational relationship between 'Building Shape' variables and the corresponding area under curve, which evaluates the daylighting performance of the 'Building Shape' parametric level. Compactness ratio, envelope to floor area ratio and porosity ratio have significant (p=0.01) positive correlation with the 'Building Shape' area under curve (0.722, 0.808, and 0.691 respectively). 'Building Shape' area under curve correlates negatively with shape coefficient (-0.745 with p=0.01). Therefore, the four variables have significant impact on the daylighting performance of the 'Building Shape' scale. With the lowest Pearson r-value, porosity ratio is the building shape variable least considered in the design of office buildings in Beirut. The other three variables, which draw relationships between the perimeter, area, and volume of the buildings, have approximately equal correlational values. On the other hand the four 'Building Shape' variables do not correlate with the total area under curve, which in turn evaluates the total design performance. Therefore none of these variables has significant influence on daylighting performance in office building design in Beirut. Nevertheless among 'Building Shape' variables, shape coefficient shows the highest Pearson r = -0.288. Despite the fact that the footprint of the building might be controlled by the site layout, the relation between building inner volume and envelope area should be considered carefully in order to provide sufficient daylight to the building.

		Compactness Ratio	Shape Coefficient	Envelope to Floor Area Ratio	Porosity Ratio
'Building Shape' Area under Curve	Pearson Correlation	.722**	-.745**	.808**	.691**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	35	35	35	35
Total Area under Curve (North)	Pearson Correlation	.161	-.194	.169	-.005
	Sig. (2-tailed)	.395	.305	.373	.978
	N	30	30	30	30
Total Area under Curve (South)	Pearson Correlation	.174	-.186	.231	.077
	Sig. (2-tailed)	.332	.299	.196	.670
	N	33	33	33	33
Total Area under Curve (East / West)	Pearson Correlation	.159	-.241	.193	.098
	Sig. (2-tailed)	.411	.208	.315	.614
	N	29	29	29	29
Total Area under Curve (Average)	Pearson Correlation	.069	-.288	.218	-.036
	Sig. (2-tailed)	.695	.093	.208	.838
	N	35	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8.1. Correlational analysis of 'building Shape' variables with 'building shape' evaluation and total building design evaluation.

Section APII.1 in Appendix II illustrates all the correlational scatter plots of 'Building Shape' variables in accordance with the performance evaluation of 'Building Shape' parametric level and total building design respectively. Within these scatter plots the proposed base cases of the Lebanese Energy Standards project, A1-O and A1-OL, are marked by a square red point ■. It is noticeable from Figure 8.1 that the shape coefficient, envelope to floor area ratio and porosity ratio of A1-O and A1-OL have analogous values relatively to the existing building stock. On the other hand, the compactness ratios of A1-O and A1-OL are not similar to the other buildings, as their representative points are not in the middle of the points forming the scatter plot. This is explained by the fact that the two base cases, A1-O and A1-OL have a very compact rectangular shape of 5/7 and 2/3, respectively. In addition, the two base cases have a plan width greater than 15m, which is a good width for natural ventilation but on the other hand is the maximal value when considering daylighting and building users' health. This was discussed in Chapter 4. The disregard of daylighting as an energy efficient design factor is also emphasized by the nil porosity ratios, by which higher values could have improved daylight penetration to the deeper areas.

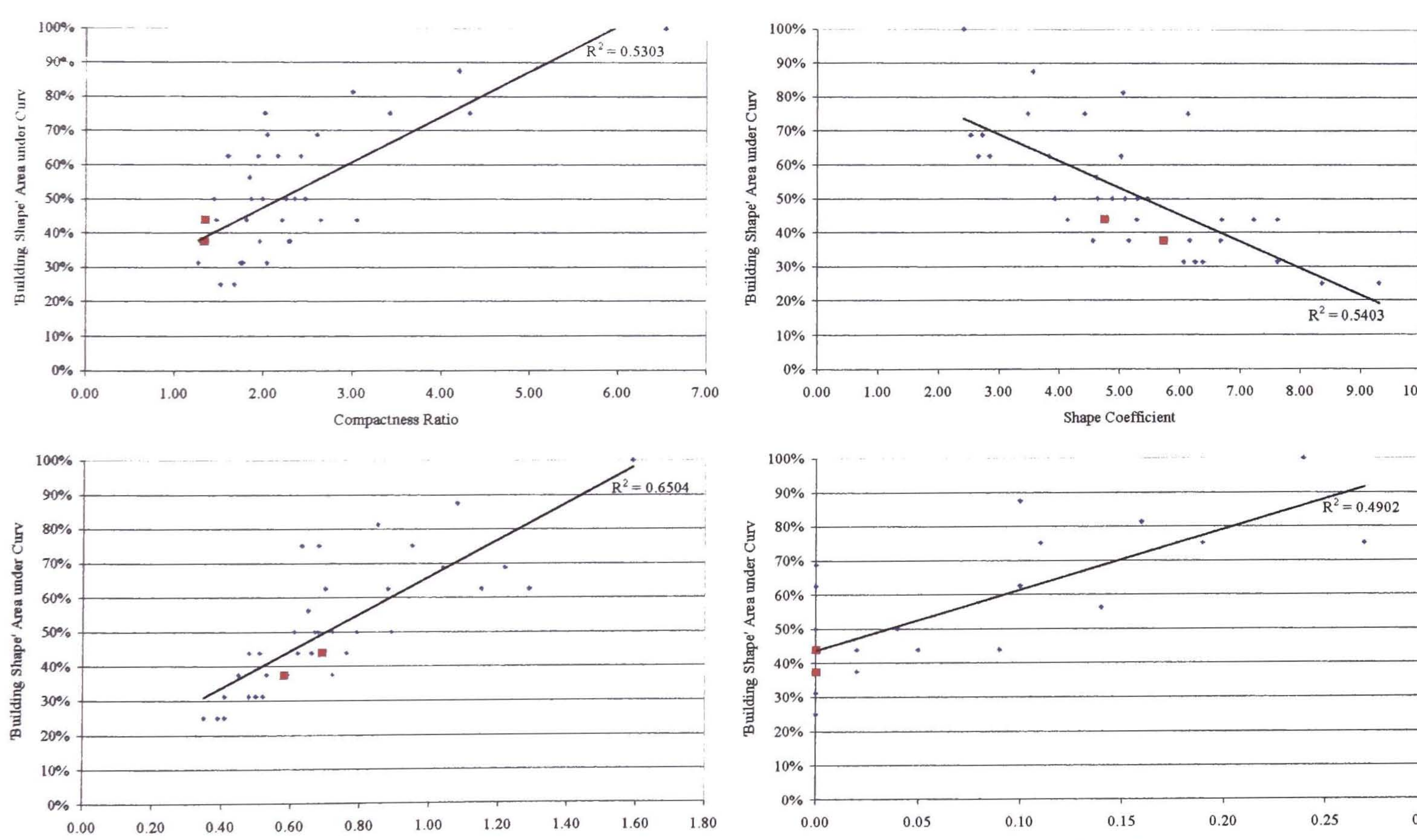


Figure 8.1. Correlational scatter plots of 'Building Shape' variables and 'Building Shape' daylighting performance evaluation.

However, shape coefficient is the most significant variable to the total building performance in the studied context. The scatter plots illustrated in Figure 8.2 show that the proposed base cases have shape coefficient values comparable to the existing building stock.

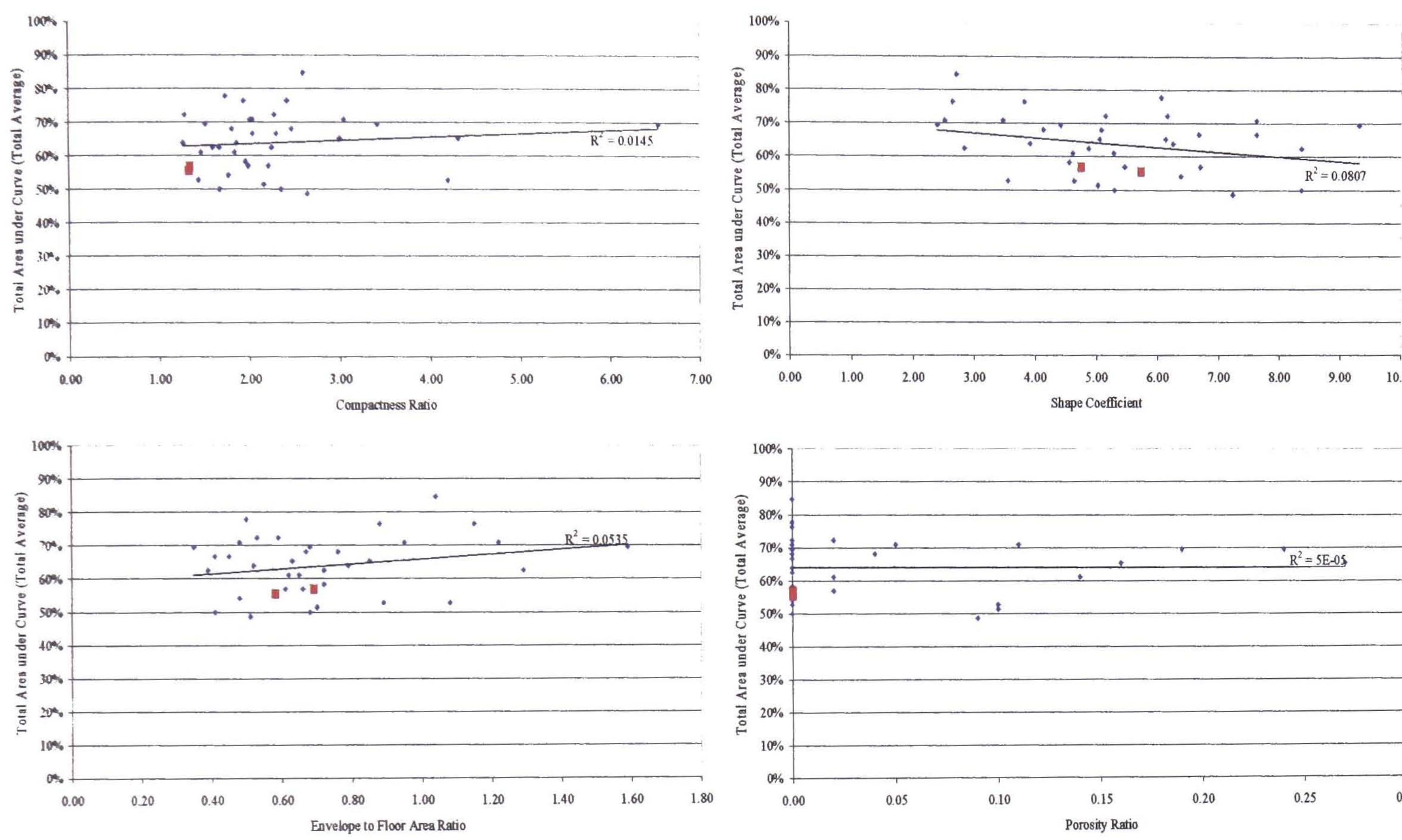


Figure 8.2. Correlational scatter plots of 'Building Shape' variables and the daylighting performance evaluation of the total building design.

8.2.2 'Window / Façade' Variables

Table 8.2 to Table 8.5 illustrate the correlational relationship between 'Window / Façade' variables and the corresponding area under curve calculated for the north, south and east / west façades respectively, as well as for the total building average. These tables show that all the variables of 'Window / Façade' parametric level, apart from window shape coefficient and windowsill height in the north façades, correlate with the 'Window / Façade' area under curve. The significance power of these correlations is 0.01 for all variables, except for windowsill height when total building average is considered. (r = -0.402 at p = 0.05, Table 8.5).

		Wall to Aperture Ratio (North)	Aperture Location (North)	Window Shape Coefficient (North)	Window Sill Height (North)	Window to Wall Ratio (North)	Daylight Aperture Ratio (North)
'Window / Facade' Area under Curve (North)	Pearson Correlation	.715**	.921**	.319	-.332	.919**	.824**
	Sig. (2-tailed)	.000	.000	.085	.073	.000	.000
	N	30	30	30	30	30	30
Total Area under Curve (North)	Pearson Correlation	.370*	.448*	-.025	-.316	.493**	.534**
	Sig. (2-tailed)	.044	.013	.896	.089	.006	.002
	N	30	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8.2. Correlational analysis of 'Window / Façade' variables with 'Window / Façade' design evaluation and total building design evaluation for the north façades.

		Wall to Aperture Ratio (South)	Aperture Location (South)	Window Shape Coefficient (South)	Window Sill Height (South)	Window to Wall Ratio (South)	Daylight Aperture Ratio (South)
'Window / Facade' Area under Curve (South)	Pearson Correlation	.855**	.865**	.239	-.560**	.937**	.823**
	Sig. (2-tailed)	.000	.000	.181	.001	.000	.000
	N	33	33	33	33	33	33
Total Area under Curve (South)	Pearson Correlation	.719**	.437*	-.078	-.530**	.530**	.390*
	Sig. (2-tailed)	.000	.011	.667	.002	.001	.025
	N	33	33	33	33	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8.3. Correlational analysis of 'Window / Façade' variables with 'Window / Façade' design evaluation and total building design evaluation for the south façades.

		Wall to Aperture Ratio (East / West)	Aperture Location (East / West)	Window Shape Coefficient (East /West)	Window Sill Height (East / West)	Window to Wall Ratio (East / West)	Daylight Aperture Ratio (East / West)
'Window / Facade' Area under Curve (East / West)	Pearson Correlation	.794**	.834**	.347	-.542**	.916**	.777**
	Sig. (2-tailed)	.000	.000	.065	.002	.000	.000
	N	29	29	29	29	29	29
Total Area under Curve (East / West)	Pearson Correlation	.624**	.399*	-.083	-.653**	.720**	.614**
	Sig. (2-tailed)	.000	.032	.670	.000	.000	.000
	N	29	29	29	29	29	29

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8.4. Correlational analysis of 'Window / Façade' variables with 'Window / Façade' design evaluation and total building design evaluation for the east / west façades.

		Wall to Aperture Ratio (Average)	Aperture Location (Average)	Window Shape Coefficient (Average)	Window Sill Height (Average)	Window to Wall Ratio (Average)	Daylight Aperture Ratio (Average)
'Window / Facade' Area under Curve (Average)	Pearson Correlation	.757**	.863**	.186	-.402*	.895**	.782**
	Sig. (2-tailed)	.000	.000	.285	.017	.000	.000
	N	35	35	35	35	35	35
Total Area under Curve (Average)	Pearson Correlation	.630**	.398*	-.254	-.448**	.680**	.546**
	Sig. (2-tailed)	.000	.018	.141	.007	.000	.001
	N	35	35	35	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8.5. Correlational analysis of 'Window / Façade' variables with 'Window / Façade' design evaluation and total building design evaluation of all façades average.

With regard to the other variables, windowsill height of the south-facing façades, east/west façades, and total building average have the lowest and least significant Pearson r in relation to the 'Window / Façade' area under curve. Nevertheless, this 'Window / Façade' variable correlates negatively with the south, east/ west and total area percentages under curve, respectively. Therefore, window sill height is a significant variable for daylighting performance in the total building design, as it defines the depth of daylight diffusion. This impact may be ignored on the north orientation, where daylight illuminance is constant.

The window shape coefficient does not correlate with the total area under curve of all orientations, and total building average, respectively. This can be explained by the fact that in the studied context, most of the cases have an intermediate window shape. It can be concluded that in the studied context window shape coefficient has a negligible impact on daylighting performance evaluation in office buildings.

Table 8.2 to Table 8.5 show that aperture location variable has a highly significant correlation with 'Window / Façade' performance evaluation in all orientation scenarios, as well as the total building average ($0.834 \leq r \leq 0.921$, $p = 0.01$). In addition, aperture location is influential on the daylighting performance of the total building design but has less impact than the other variables, as Pearson r ranges between 0.398 and 0.448 (i.e. level of significance $p = 0.05$)

Wall to aperture ratio, window to wall ratio and daylight aperture ratio (variables that relate glazing area to solid wall area with consideration of framing ratio and visible light transmittance) correlate significantly with both 'Window / Façade' area under curve, and Total area under curve. The correlation between wall to aperture ratio and total area under curve is less significant in the north façade scenarios than the south and east / west scenarios ($r = 0.370$ in north scenarios, $r = 0.719$ in south scenarios, and $r = 0.624$ in east / west scenarios). In addition, the correlation of wall to aperture ratio with 'Window / Façade' area under curve in the north scenarios is the least significant, relative to the other variables. This indicates that wall to aperture ratio is less influential on daylight availability in the north façades than in the south and the east/west façades. In north façades, more consideration should therefore be given to window location, window to wall ratio and daylight aperture ratio, which have the highest correlation values (0.921, 0.919 and 0.824, respectively). North facing façades usually have low luminosity levels, with constant illumination throughout the day. Therefore, aperture numbers and location (unilateral, bilateral, multilateral or complete glazing) are important for improving the distribution of daylight illumination at low luminosity levels in north-facing rooms. The proportion of opening to opaque areas should be also considered, as well as the visible light transmittance of the glazing used.

The analysis shows that in the south and east / west orientations, window to wall ratio and daylight aperture ratio are both very significant for the 'Window / Façade' parametric level performance and the total building performance. Pearson r values of window to wall ratio and daylight aperture ratio in accordance to the total building performance are the highest in east/west facing rooms, 0.720 and 0.614, respectively. It can be concluded that window area and the visible light transmittance of glazing used in the east/west facades are highly influential on daylighting performance of the building, where luminous levels differ greatly through the day.

Table 8.3 shows that in the south façade, the correlation of daylight aperture ratio with total area under curve is less significant than wall to aperture ratio and window to wall ratio (r = 0.390). This is explained by the fact that visible light transmittance of glazing is less influential on daylight availability in south façades, where daylight has high luminous levels.

Finally, it can be concluded from Table 8.5 that all 'Window / Façade' variables, except for window shape coefficient, affect daylight performance of the whole building. The most influential factors are the area of apertures in proportion to opaque surfaces, and the visible transmittance of glazing. This needs to be carefully selected in order to control illumination quantity as well as daylight quality, which can for example be affected by glazing tints.

Section APII.2 in Appendix II illustrates the correlational scatter plots of 'Window / Façade' variables regarding 'Window / Façade' area under curve, and Total area under curve. As in the analysis sequence of 'Building Shape' parametric level, the 'Window / Façade' parametric level will be investigated. The proposed base cases of the Lebanese Energy Standards project, A1-O and A1-OL, are again marked by two square red points ■.

It is noticeable from the scatter plots of the north-facing façades variables that the proposed base cases have different scenarios of wall to aperture ratios and daylight aperture ratios to the existing building stock (Figure 8.3). In A1-OL and A1-O it has been assumed that the north façade window to wall ratios are 0.11 and 0.13 respectively, which is not the case for the existing building stock. The south, east and west façades are assumed to have similar wall to aperture ratios, equal to 0.39, the uniformity of which to the existing building stock is shown in sections APII.2.2 and APII.2.3 of Appendix II. The reason for such a scenario may be that the ongoing project aims mostly to study the thermal behaviour of office buildings in Lebanon. In the two base cases the north façades, where solar heat gain and loss have fairly insignificant impact, are almost solid. The analysis of this scenario will give the peak and lowest point thermal behaviour of the building. In contrast, the proposed Lebanese Energy Standard project disregards the constant illumination of the north façade, and the consequent impact on lighting behaviour and energy performance of the building.

In addition the scatter plots of daylight aperture ratio variable with 'Window / Façade' area under curve and Total area under curve, shown in Section APII.2 of Appendix II, show dissimilarity between the two base cases and the existing building stock. Because window to wall ratios are comparable to the studied buildings, the differences in daylight aperture ratio are presumed to be due to the glazing type. The two base cases have 6mm, tinted single layer glazing with 0.50 visible light transmittance. Apart from the differences in the existing building stock, where multiple types of glazing are used, this assumption underlines the disregard of daylight; this having been replaced by increased use of electric lighting.

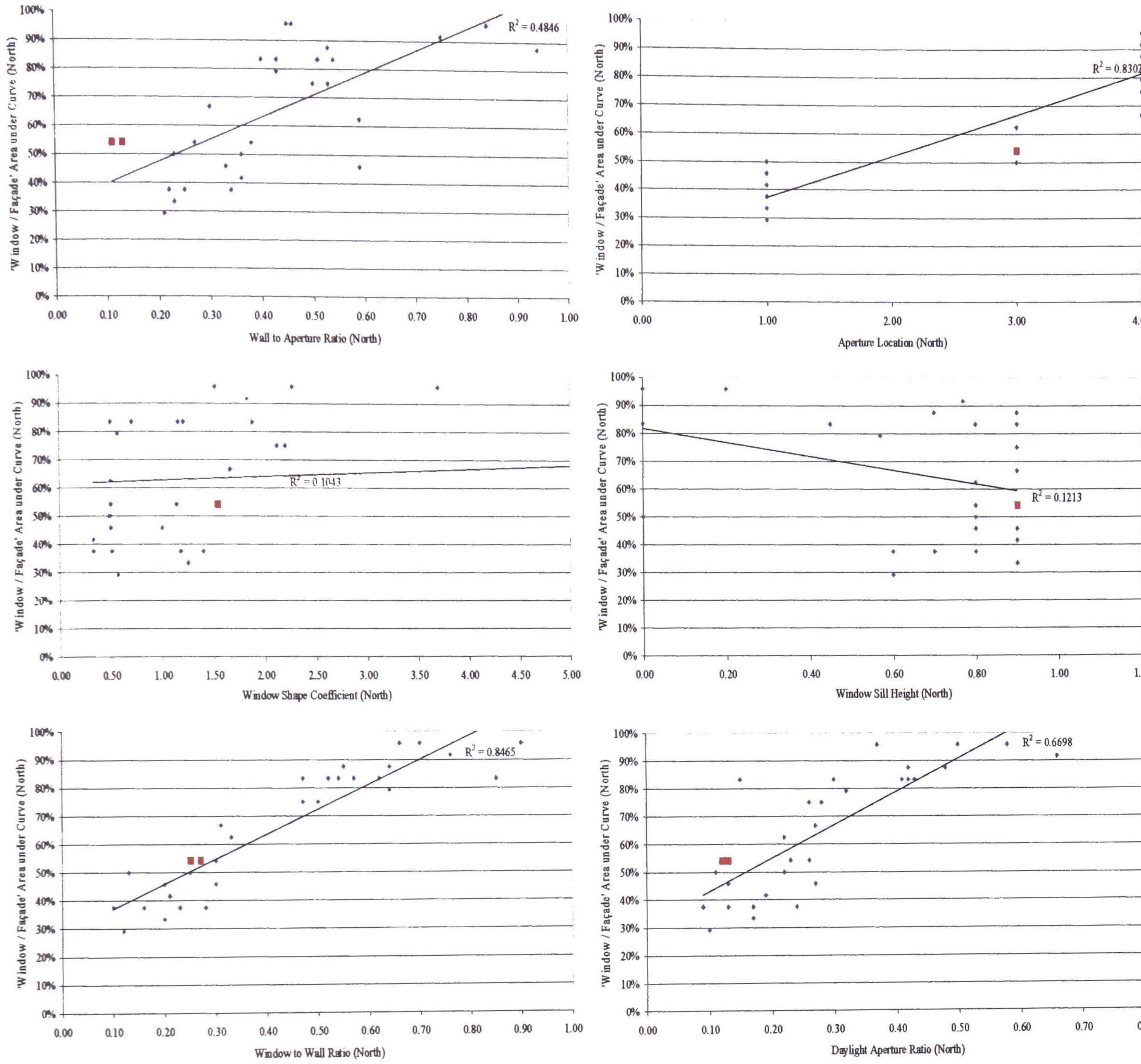


Figure 8.3. Correlational scatter plots of 'Window / Façade' variables and the daylighting performance evaluation of the 'Window / Façade' parametric level (north façade scenarios).

8.2.3 'Window / Office' Variables

Table 8.6, Table 8.7, Table 8.8, and Table 8.9 illustrate the correlational relationship between 'Window / Office' variables and the corresponding area under curve calculated for the north, south and east/west facing offices respectively, as well as for the total building average. Daylight buffer zone, room limiting depth rule and average office area have negative correlation with the 'Window / Office' area under curve for the north-facing offices. Among these variables, only daylight buffer zone has significant correlation with total area under curve of 0.05 power significance (Table 8.9). In addition, it is quite significant that using the south-facing offices condition, the first three

'Window/ Office' variables do not correlate with the 'Window / Office' area under curve. Although the offices facing south have different and variable 3-D configurations, correlations between fenestration factor and glazing ratio with 'Window / Office' area are still significant. This is mainly related to the Lebanese building regulations, which recommend a minimum fenestration factor of 0.1. In addition, it can be concluded that in the studied context the depth and area of offices in the north and east/west orientations were more appropriately designed in accordance with daylight than the south-facing offices. The statement of high luminous level of sunlight in the south might provide an explanation for the possible use of open plan offices in the south. However, deeper and bigger open plan offices are accompanied by bigger glazing areas, which have increased daylighting performance on the south facing façades.

Fenestration factor and glazing ratio are the two variables of 'Window / Office' parametric level which strongly correlate with the 'Window / Office' area under curve, and total area under curve in all the cases considered (north, south, east / west, and average office). It can therefore be considered that fenestration factor and glazing ratio should be considered carefully when designing office area and associated openings in all orientations.

Regarding the base cases of the Lebanese Energy Standards, the scatter plots illustrated in Section APII.3 of Appendix II show that the base case variables of the 'Window / Office' parametric level are not analogous to the existing building stock variables (Figure 8.4). In A1-OL and A1-O, the relationship between side aperture properties and associated office dimensions is different from the relationship found in the studied cases. Therefore these two base cases cannot be taken as representative of the existing stock when considering 'Window / Office' parametric level.

		Daylight Buffer Zone (North)	Room Limiting Depth Rule (North)	Office Average Area (North)	Fenestration Factor (North)	Glazing Ratio (North)
'Window / Office' Area under Curve (North)	Pearson Correlation	-.589**	-.524**	-.546**	.408*	.502**
	Sig. (2-tailed)	.001	.003	.002	.025	.005
	N	30	30	30	30	30
Total Area under Curve (North)	Pearson Correlation	-.294	-.287	-.149	.612**	.626**
	Sig. (2-tailed)	.115	.124	.433	.000	.000
	N	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8.6. Correlational analysis of 'Window / Office' variables with 'Window / Office' design evaluation and total building design evaluation of the north façades.

		Daylight Buffer Zone (South)	Room Limiting Depth Rule (South)	Office Average Area (South)	Fenestration Factor (South)	Glazing Ratio (South)
'Window / Office' Area under Curve (South)	Pearson Correlation	-.187	-.109	-.277	.668**	.699**
	Sig. (2-tailed)	.297	.548	.119	.000	.000
	N	33	33	33	33	33
Total Area under Curve (South)	Pearson Correlation	-.004	.053	-.105	.783**	.701**
	Sig. (2-tailed)	.982	.771	.560	.000	.000
	N	33	33	33	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8.7. Correlational analysis of 'Window / Office' variables with 'Window / Office' design evaluation and total building design evaluation of the south façades.

		Daylight Buffer Zone (East / West)	Room Limiting Depth Rule (East / West)	Office Average Area (East / West)	Fenestration Factor (East / West)	Glazing Ratio (East / West)
'Window / Office' Area under Curve (East / West)	Pearson Correlation	-.369*	-.110	-.375*	.770**	.760**
	Sig. (2-tailed)	.049	.572	.045	.000	.000
	N	29	29	29	29	29
Total Area under Curve (East / West)	Pearson Correlation	.033	.228	-.114	.838**	.759**
	Sig. (2-tailed)	.866	.234	.556	.000	.000
	N	29	29	29	29	29

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8.8. Correlational analysis of 'Window / Office' variables with 'Window / Office' design evaluation and total building design evaluation of the east / west façades.

		Daylight Buffer Zone (Average)	Room Limiting Depth Rule (Average)	Office Average Area (Average)	Fenestration Factor (Average)	Glazing Ratio (Average)
'Window / Office' Area under Curve (Average)	Pearson Correlation	-.692**	-.598**	-.591**	.511**	.536**
	Sig. (2-tailed)	.000	.000	.000	.002	.001
	N	35	35	35	35	35
Total Area under Curve (Average)	Pearson Correlation	-.380*	-.316	-.276	.569**	.483**
	Sig. (2-tailed)	.024	.065	.108	.000	.003
	N	35	35	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8.9. Correlational analysis of 'Window / Office' variables with 'Window / Office' design evaluation and total building design evaluation of all façades average.

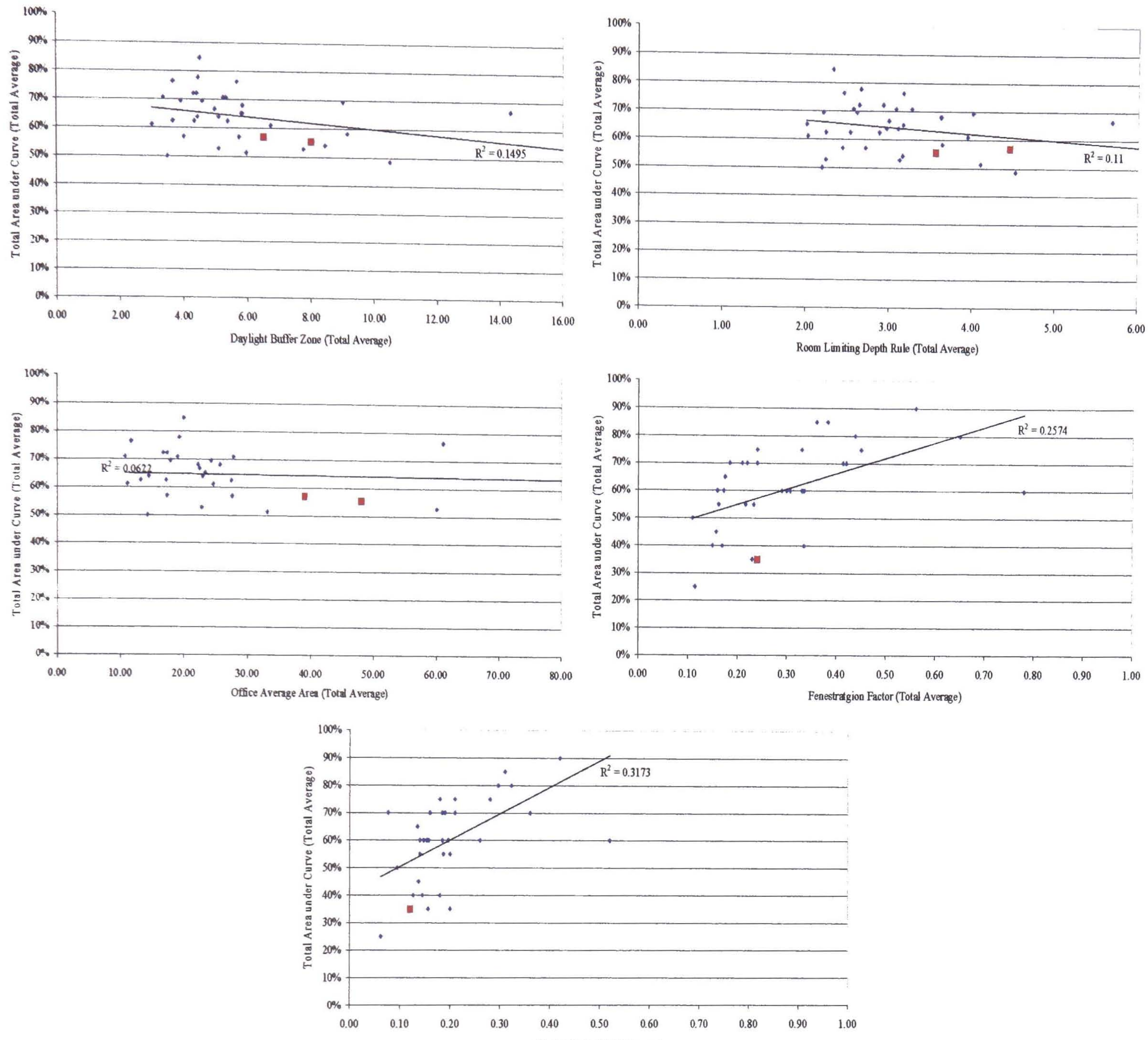


Figure 8.4. Correlational scatter plots of 'Window / Office' variables and the daylighting performance evaluation of the total building design.

8.2.4 'Shading Devices' Variables

Table 8.10, Table 8.11, Table 8.12, and Table 8.13 illustrate the correlational relationship between 'Shading Devices' variables and the corresponding area under curve calculated for the north, south and east/west façades respectively, as well as for the total building façades average. Projection ratio, overhang ratio and relative solar heat gain have significant correlation with 'Shading Devices' area under curve in the north, south, east/ west orientations and the total building average. Nevertheless, the three variables do not correlate with the total area under curve in the north and south orientations, but projection ratio and overhang ratio have significant correlation at the 0.01 power level with the total area under curve of the east / west scenarios. Therefore, the three variables have some bearing on the total daylight performance of the building, and should be considered while designing for the studied context. The existing office building stock has low but still significant correlation values of shading devices variables with total area under curve, which should be enhanced by using the appropriate shading devices, dimensions and/or glazing materials to control sunlight and solar heat gain.

The correlational analysis of projection ratio and overhang ratio show that this variable is most important in the east and west façades (Table 8.12), as it correlates with the total area under curve. On the other hand, the dimensions of overhang (or fins) in accordance to the glazing properties used in the east / west façades are not optimal to protect the façade from direct sunlight and solar heat gain, as relative solar heat gain total area under curve does not correlate.

In the north orientation the use of shading devices is considered less significant, as the three variables have lower Pearson r values than the south and east / west scenarios. Because daylight from the north has a low luminous level, the use of shading devices decreases daylight illumination levels. In addition, solar heat gain in the north façade is negligible.

Regarding A1-OL and A1-O, their performance is quite similar to the cases where no overhangs or fins are used (Section APII.4 of Appendix II). Solar protection is only achieved by the use of glazing with low SHGC values. Projection ratio and overhang ratio, which analysis proved significant on daylighting performance and which can be a good contributor in a thermal study, are not considered in the Lebanese Energy Standards Project (Figure 8.5).

		Projection Ratio (North)	Overhang Ratio (North)	Relative Solar Heat Gain (North)
'Shading Devices' Area under Curve (North)	Pearson Correlation	-.854**	.821**	.452*
	Sig. (2-tailed)	.000	.000	.012
	N	30	30	30
Total Area under Curve (North)	Pearson Correlation	-.272	.257	.046
	Sig. (2-tailed)	.146	.170	.808
	N	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8.10. Correlational analysis of shading devices variables with shading devices design evaluation and total building design evaluation for the north façades.

		Projection Ratio (South)	Overhang Ratio (South)	Relative Solar Heat Gain (South)
'Shading Devices' Area under Curve (South)	Pearson Correlation	-.913**	.932**	.802**
	Sig. (2-tailed)	.000	.000	.000
	N	33	33	33
Total Area under Curve (South)	Pearson Correlation	-.220	.277	.057
	Sig. (2-tailed)	.219	.119	.752
	N	33	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8.11. Correlational analysis of shading devices variables with shading devices design evaluation and total building design evaluation for the south façades.

		Projection Ratio (East / West)	Overhang Ratio (East / West)	Relative Solar Heat Gain (East / West)
'Shading Devices' Area under Curve (East / West)	Pearson Correlation	-.939**	.945**	.732**
	Sig. (2-tailed)	.000	.000	.000
	N	29	29	29
Total Area under Curve (East / West)	Pearson Correlation	-.555**	.565**	.278
	Sig. (2-tailed)	.002	.001	.144
	N	29	29	29

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8.12. Correlational analysis of shading devices variables with shading devices design evaluation and total building design evaluation for the east/west façades.

		Projection Ratio (Average)	Overhang Ratio (Average)	Relative Solar Heat Gain (Average)
'Shading Devices' Area under Curve (Average)	Pearson Correlation	-.905**	.879**	.640**
	Sig. (2-tailed)	.000	.000	.000
	N	35	35	35
Total Area under Curve (Average)	Pearson Correlation	-.246	.226	.075
	Sig. (2-tailed)	.154	.191	.670
	N	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8.13. Correlational analysis of shading devices variables with shading devices design evaluation and total building design evaluation for the total façades average.

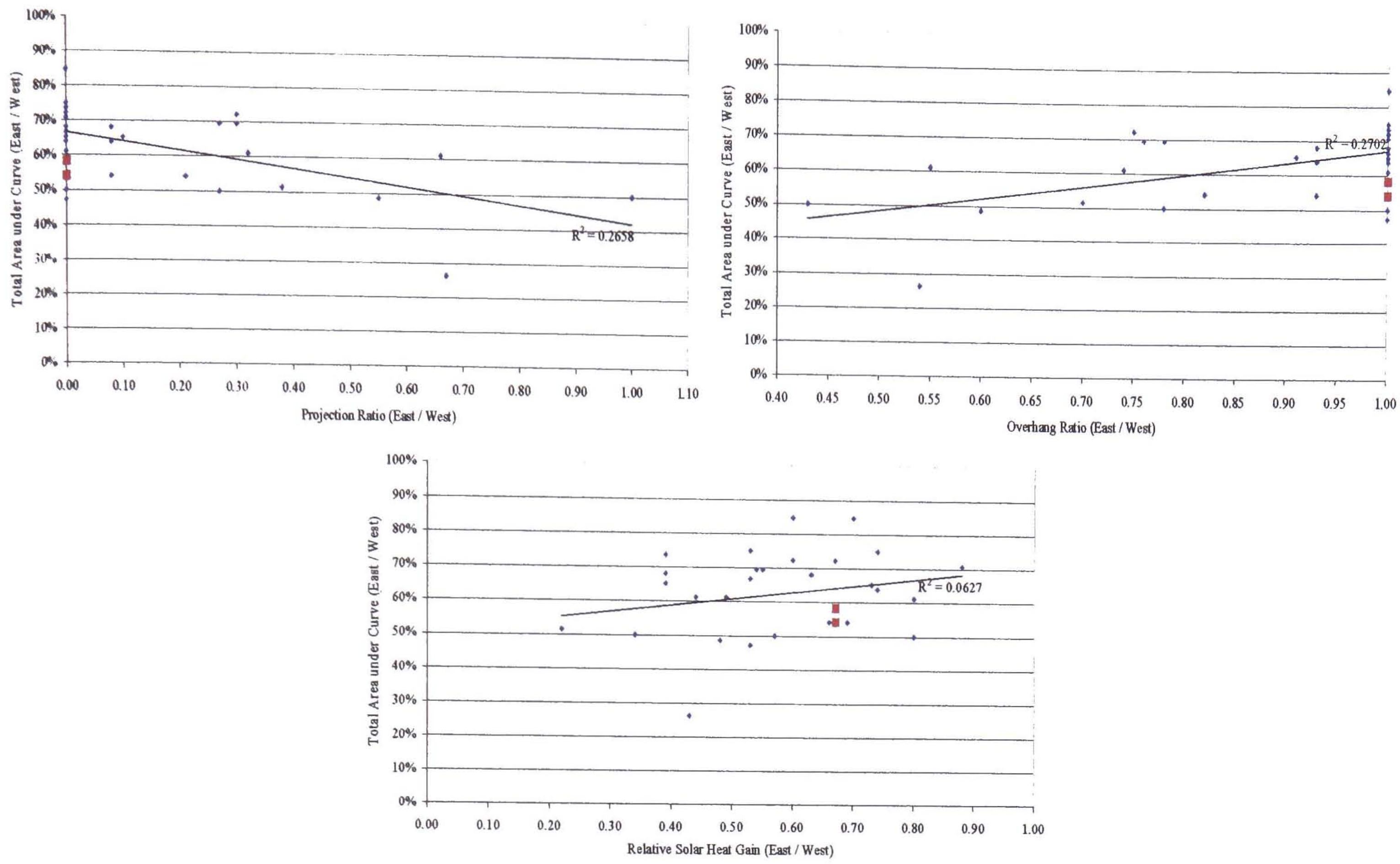


Figure 8.5. Correlational scatter plots of 'Shading Devices' variables and the daylighting performance evaluation of the total building design (east / west scenarios).

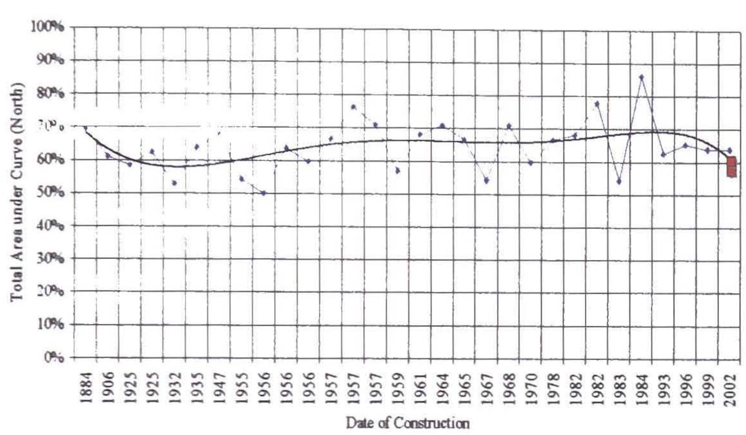
8.3 Evolution of Daylight Design Parameters in Office Buildings

In the previous section, correlational analyses of daylight design variables, previously divided into four different parametric levels, and daylight performance evaluation were examined in the studied context. This section will broadly investigate the evolution of the daylighting performance evaluation in office buildings in Beirut. This investigation is followed by a detailed analysis of the development of the four daylighting design parametric levels and their associated variables. The graphs illustrating these developmental studies are documented in Appendix III. The comparison of the two base cases of the Lebanese Energy Standards project, A1-OL and A1-O, with the 35 buildings case studies is also emphasised

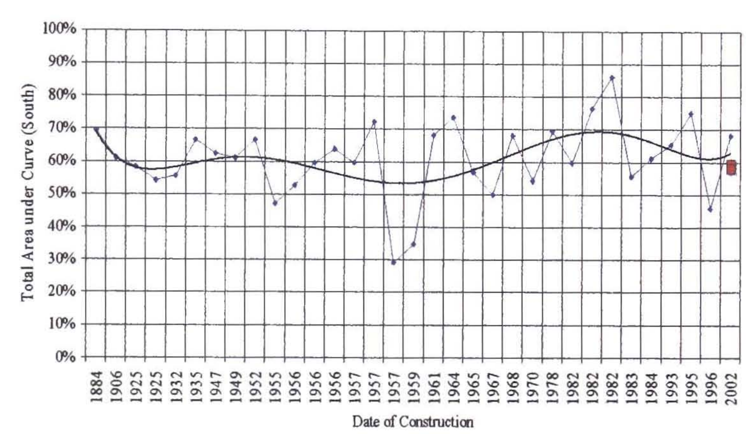
8.3.1 Evolution of Total Daylight Parametric Levels Performance Evaluation

Figure 8.6 shows that the daylight performance evaluation of the sum of all the considered variables (termed 'total area under curve') for office buildings in Beirut changed slightly during the period of study. These differences in performance are more apparent in the south and east / west scenarios (Figure 8.6b and Figure 8.6c). This does not mean that the development in office building configuration did not change daylight behaviour in internal spaces. Conversely, the following sections of this chapter will prove that considerable changes have occurred to each daylight parametric level in general, and the considered daylight design variables in particular.

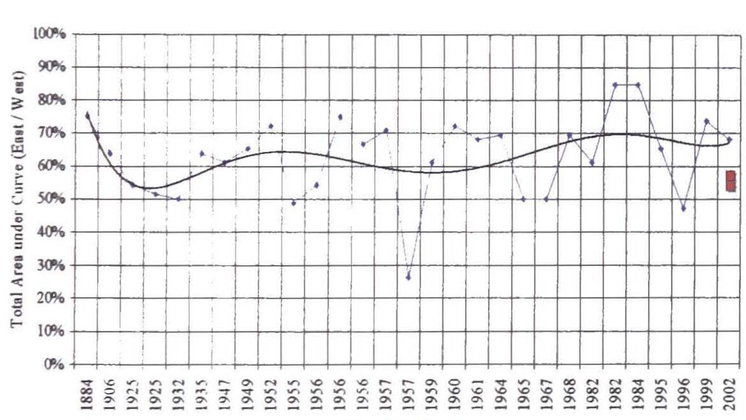
Total area under curve in all scenarios (north, south, east / west, total building average) ranges in average between 55% and 70%. The range of total area under curve gives only a broad and general idea of the performance evaluation average of office buildings in Beirut. It is of note that the two base cases of the Lebanese Energy Standards project, A1-OL and A1-O, fit within this range



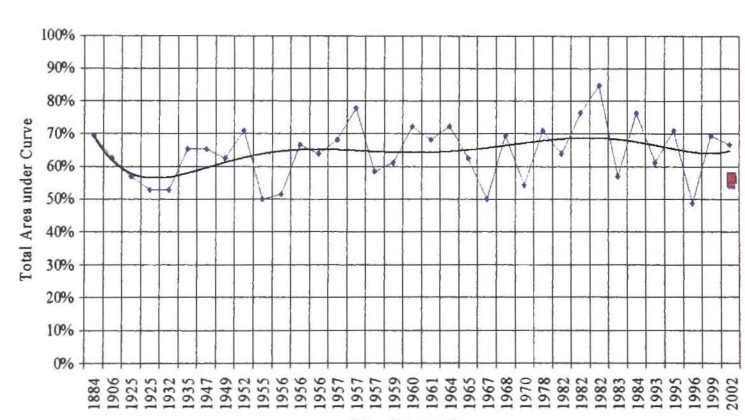
a- North Façades



b- South Façades



c- East / West Façades



d- Total Building Average

Figure 8.6. Evolution of all daylighting parametric levels performance evaluation for the north, south, east / west and total building average scenarios,

8.3.2 Evolution of 'Building Shape' Parametric Level

The development diagrams of 'Building Shape' variables are illustrated in Section APIII.2 of Appendix III. This section also includes the developmental diagram of the 'Building Shape' area under curve, which points up the impact of the 3-dimensional design of the building on daylighting performance.

The developmental diagram of compactness ratio in Figure 8.7 shows that in the first 4 historical phases (before 1920 – 1958) this variable sharply decreased, ranging between a maximum of 6.5 in the 19th century and a minimum value of 1.2 in the mid -1950s. In the 5th phase (1958 – 1975) of office building development in Beirut the general figure for compactness ratio is almost constant, increasing slightly in the civil war post-war reconstruction phases (1975 – present). Compact office buildings started to appear when the land price in Beirut increased, due to the growth of urbanisation after independence in 1943. Building shape mostly follows the site shape, and in almost all Beirut zoning areas the built up floor area to lot area ratio exceeds 0.9 (Lebanese Building Regulation, 1995). In addition, porosity ratio decreased to nil (or slightly higher) during the same period (Figure 8.8), which contributed to reduced building perimeters. Conversely the atrium, considered by some architects to be an aesthetic, fashionable and sophisticated architectural element, was used in some buildings during the Post-War Reconstruction period (Interviews with Nabil Azar on May 7, 2003 and Pierre Khoury on April 23, 2003). Accordingly these buildings are slightly less compact. Comparing A1-OL and A1-O with the existing office building stock in Beirut, the two base cases have the same compactness ratio; equal to the minimum value found in the 35 office buildings studied. A base case of less compact form could have been more representative of the existing office building stock than the two base cases that are similar in shape.

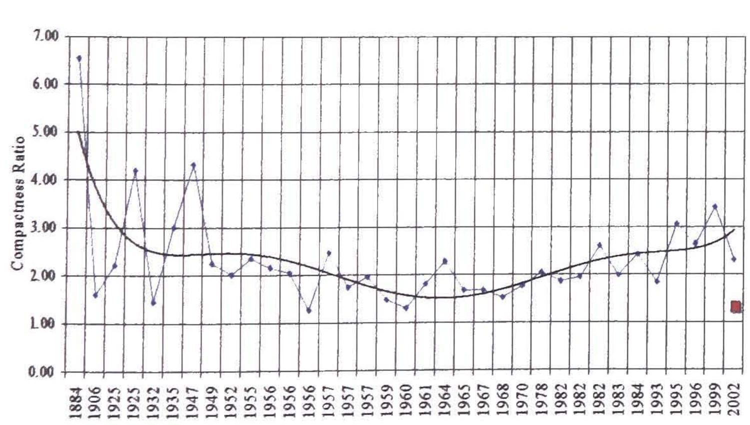


Figure 8.7. Evolution of compactness ratio

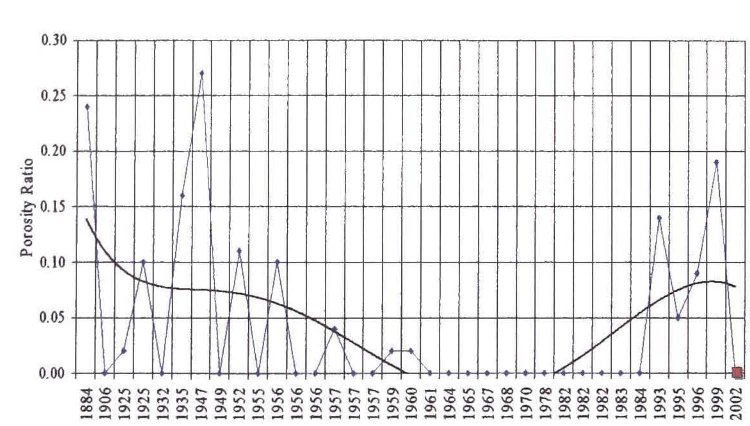


Figure 8.8. Evolution of porosity ratio.

The development of shape coefficient, the 'Building Shape' variable that most correlates with the total area under curve (Section 8.2.1), is shown in Figure 8.9. This variable draws the relation between the total building inner volume and the total envelope surface area. It increased during the first 5 phases, and then suddenly fell with the start of the Civil War in 1975. In the Shihabist and Post-Shihabist phase (1946 – 1958) the shape coefficient varied between 6.2 and 9.5, but during the Civil War the maximum shape coefficient value was less than 6.0. In the Post-War reconstruction period, shape coefficient values have increased but are still lower than those found in the 1960s. The decline in large investments during wartime may well explain this drop (Figure 8.10). Small office building projects were more normal, in response to reduced demand and limited budgets (Interview with Mohammad Saiidi on March 6, 2003 and Interview with Saiid Jazaiiri April 29, 2003). In addition, low shape coefficient values of buildings constructed at the end of the 19th century and early 20th century were caused by the construction systems and limitations placed upon vertical extension. However, the Assayli building, constructed in 1947 can be considered an exception for its time, perhaps indicating the appearance of large investments, later interrupted by political circumstances in the Middle East at that period. Subsequently a real boom in investments took place, making the 1960s a Golden Age for Beirut. Today, since the war, large investors are again beginning to revive the administrative and financial roles of Beirut in the area (Figure 8.10).

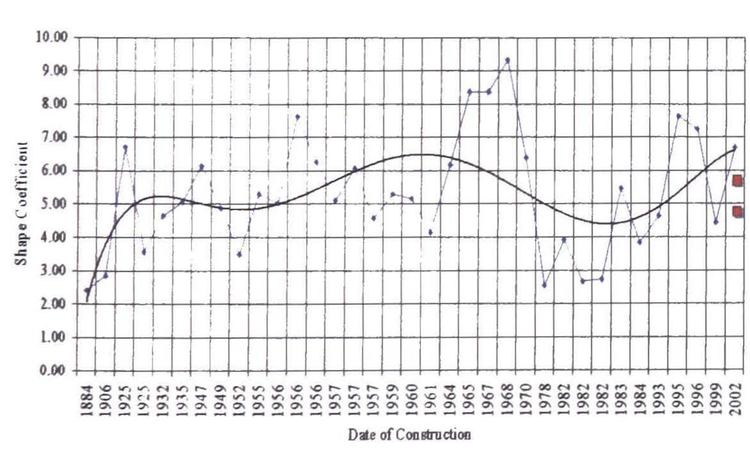


Figure 8.9. Evolution of shape coefficient

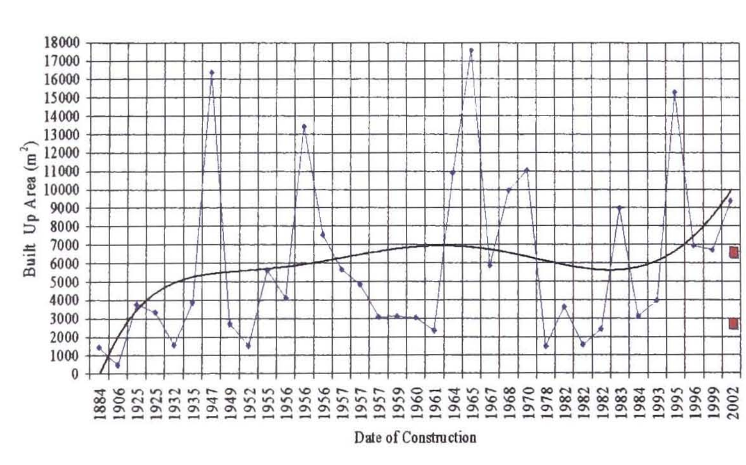


Figure 8.10. The development of office building investment in Beirut denoted by the total built up areas of built office buildings.

Regarding A1-OL and A1-O, both base cases have a shape coefficient in the same range (4.00-5.75). However, theses values can be considered the average of the existing building stock shape coefficient, as the representative points of base cases are very near to the curve (Figure 8.9).

In contrast to the shape coefficient, envelope to floor area ratio decreased gradually during the first 5 phases and has changed development figure during the Civil War period (Figure 8.11). In the last phase, envelope to floor area ratio has fallen again to similar levels as existed in the 1955-1970 period. The same interpretation of building shape development can explain envelope to floor area ratio development. In addition, the values of A1-Ol and A1-O have almost similar envelope to floor ratios, close to the building stock average.

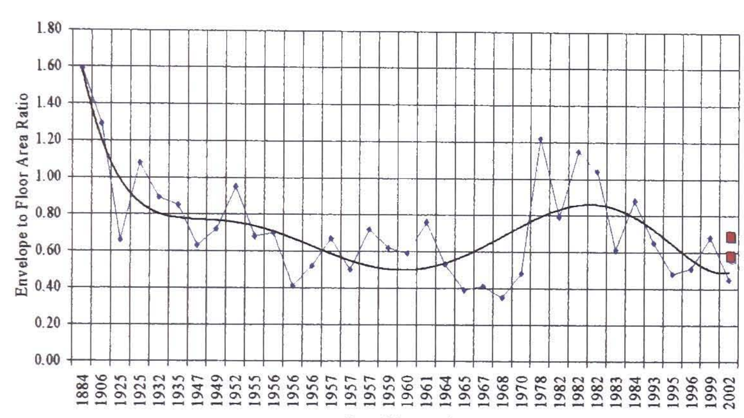


Figure 8.11. Evolution of envelope to floor area ratio

It can be concluded that when the 'Building Shape' parametric level is considered, the two base cases suggested by the Lebanese Energy code project are more or less similar and could be reduced to one base case only. The compactness ratio of the base cases should receive attention so as to become more representative of the existing office building stock.

Finally, the impact of 'Building Shape' parametric level on daylighting performance is illustrated in Figure 8.12. The Building Shape area under curve gradually decreased during the first 4 phases (1850s – 1958), as office buildings were becoming deeper and larger in shape and volume, with fewer void spaces. Office buildings constructed during the civil war showed better daylighting performance, because they were smaller. Today new office buildings are larger than those built during the war, but they have better daylighting performance than the ones built during the Shihabist and Post-Shihabist period as a result of the use of courtyards and atriums that permit daylight penetration to the core of the building.

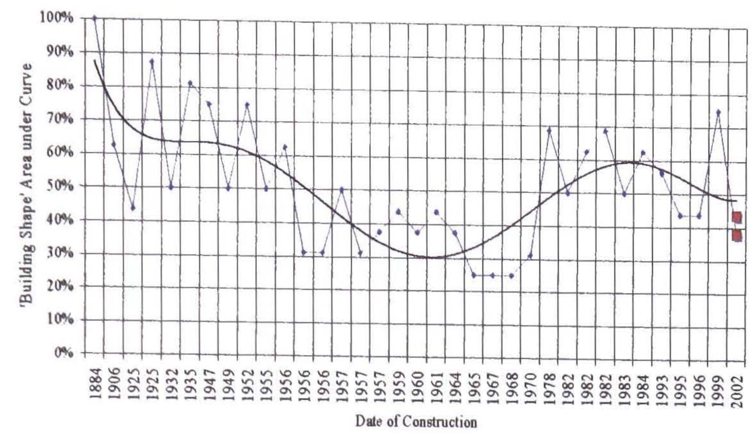


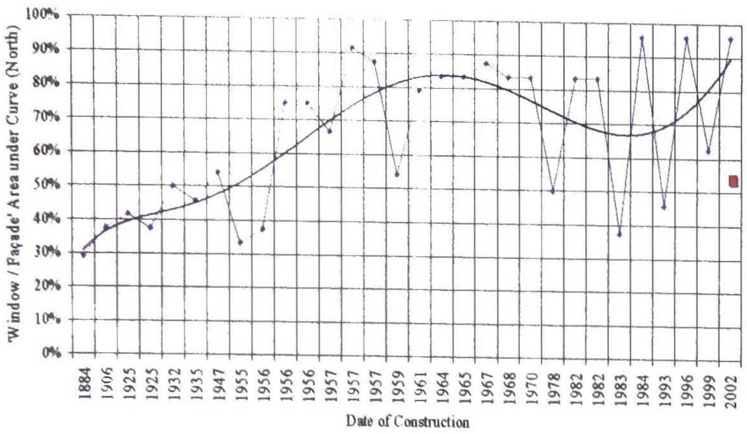
Figure 8.12. Evolution of 'Building Shape' performance evaluation

8.3.3 Evolution of 'Window / Façade' Parametric Level

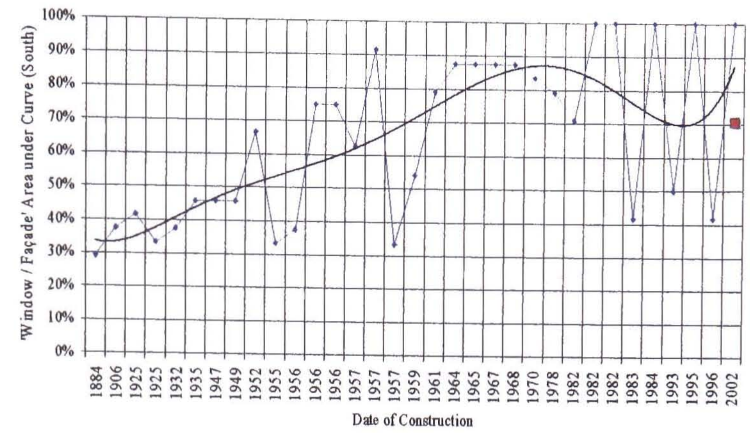
Following the same analysis sequence as the previous section, this section will study the development of the 'Window / Façade' variables and associated daylight performance evaluation in office buildings in Beirut. The development of each 'Window / Façade' variable is clarified by the diagrams shown in section APIII.3 of Appendix III.

8.3.3.1 *Evolution of 'Window / Façade' Performance Evaluation*

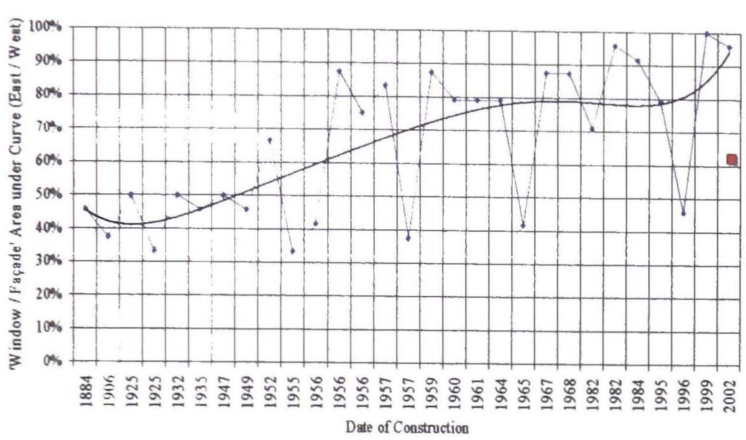
Figure 8.13 shows that the daylighting performance evaluation of 'Window / Façade' parametric level in all orientation and total building average scenarios gradually increased from 35% to 85% during the first 5 historical phases (1880s – 1975). During the civil war, the daylighting performance of 'Window / Façade' scale decreased to an average 70%, but began to improve again in the post-war reconstruction period (Figure 8.13d). The study of 'Window / Façade' variables development, mainly the variables that correlate with 'Window / Façade' area under curve', will explain the reasons for the alteration in performance of this daylight design parametric level.



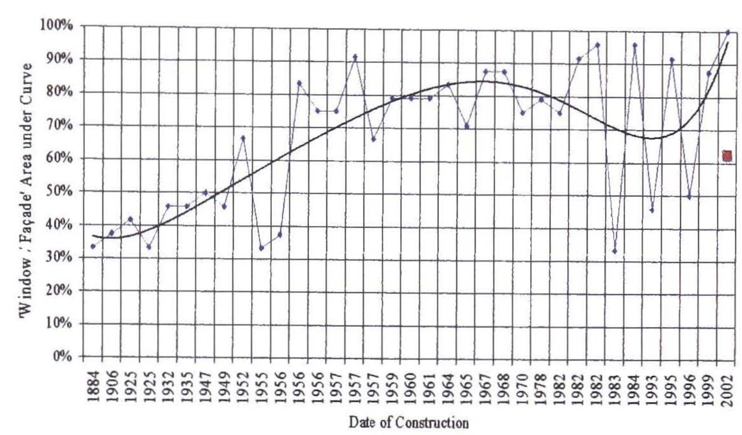
a- North Façades



b- South Façades



c- East / West Façades



d- Total Building Average

Figure 8.13. Evolution of 'Window / Facade' daylight performance evaluation

Comparing A1-OL and A1-O with the existing office building stock in Beirut, the two base cases have similar 'Window / Façade' performance values that are analogous to the average value of the building stock constructed in the last 25 years. This is particularly true in the south façade and total building average scenarios (Figure 8.13b and Figure 8.13d). Figure 8.13a and Figure 8.13c show that when considering the north and east / west façades, the performance evaluation of A1-OL and A1-O 'Window / Façade' parameter is very low compared to existing office building stock, or to that which has been constructed in the last three decades.

8.3.3.2 *Evolution of 'Window / Façade' Variables*

Wall to aperture ratio, aperture location, window to wall ratio and daylight aperture are the variables of 'Window / Façade' that most correlate with the associated performance evaluation (8.2.2). This section will therefore study only the development figures of these variables. The development diagrams of all 'Window / Façade' variables are illustrated in section APIII.3.2 of Appendix III.

Figure 8.14 shows that wall to aperture ratio, aperture location, and window to wall ratio have approximately the same development figures as 'Window / Façade' performance evaluation. The three variables had minimal value in the first phases (0.25, 1, and 0.12, respectively), increasing gradually to reach their peak (0.5, 4, and 0.55, respectively) during the Shihabist and Post-Shihabist phase (1958 - 1975). The use of cement in skeleton structures, and the improvements in glazing technology have replaced solid load bearing walls and narrow vertical windows (i.e. the central bay window and French windows). The named variables had lower values during the civil war phase (1975 – 1990) because of low investment and the defensive architecture produced in that period. In the last decade, with the trend for glass boxes and advances in glazing technology, these variables have started to achieve higher values ranging between 0.50 and 0.80 for wall to aperture ratio, and 0.45 - 0.75 for window to wall aperture

The development figure of daylight aperture ratio is somehow different from what has been described previously. More precisely, Figure 8.14c and Figure 8.14d show that window to wall ratio (net glazing area / window-wall area) and daylight aperture ratio (net glazing area x visible light transmittance / window-wall area) do not have the same development figure or rate. Despite the continuous increase of window to wall ratio, the use of different glazing technologies of lower visible light transmittance since the mid 1950s explains the linearity of daylight aperture ratio development (values average equal to 0.3) with a slight increase in the last decade (values average equal to 0.45.). In the last decade, despite the advances in glazing technology such as the low–e glazing of high or optimized visible light transmittance (Hammarberg *et al.*, 2003), some architects have only considered the thermal behaviour of the glazing while the optical performance has been neglected. In addition new glazing technologies have mostly been avoided or not considered during the design process, nor by the buildings' owners, because of the high cost in Lebanon (Interview with Pierre Khoury on April 23, 2003).

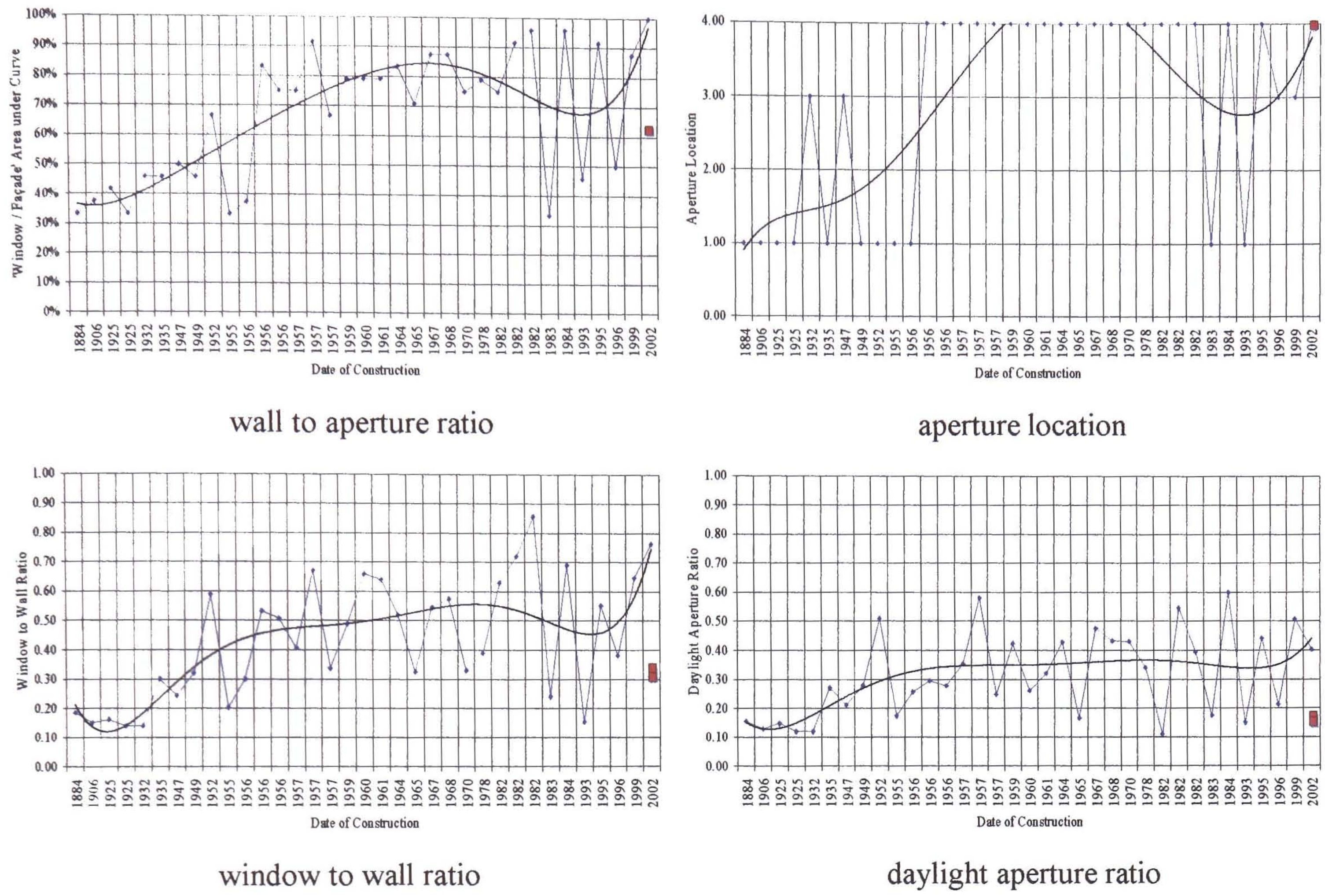


Figure 8.14. Evolution of wall to aperture ratio, aperture location, window to wall ratio and daylight aperture ratio (total building average)

Regarding A1-OL and A1-O their 'Window / Façade' variables, particularly the variables of the north and east / west façades, have very low values compared to the existing building stock (See Section APIII.3 of Appendix III). The use of tinted glazing, which has a visible light transmittance equal to 0.5, has also disregarded the potential energy savings from available daylighting and the optimized use of electric lighting. This is quite clear in the development diagrams of daylight aperture ratio for all orientation scenarios and total building average (Section APIII.3.2.6 of Appendix III).

8.3.4 Evolution of 'Window / Office' Parametric Level

As in the previous study of 'Building Shape' and 'Window / Façade', the development of 'Window / Office' variables and associated daylight performance evaluation in office buildings in Beirut are also investigated. The development diagrams for the variables studied are illustrated in section APIII.4 of Appendix III.

8.3.4.1 *Evolution of 'Window / Office' Performance Evaluation*

Figure 8.15 shows the daylighting performance evaluation of 'Window / Office' parametric level in all scenarios. The performance of this parametric level gradually increased from approximately 55% after 1946, and reached a peak average equal to 75% during the civil war due to low investment in architecture. The lowest 'Window / Office' performance evaluation occurred during 1920-1946, (55%) and in the last decade (35%). The period between 1920 and 1946 is considered a transitional phase between traditional and modern architecture, marked by the change in the structure system, the freedom of walls from their load bearing role and the increase of aperture area. Today, the increase in glazing surfaces is also accompanied by larger or open-plan offices. To understand these performance evaluation figures better, the development of each 'Window / Office' variable is examined separately. Regarding A1-OL and A1-O, their 'Window / Office' performance evaluation is similar to the minimal value occurring today.

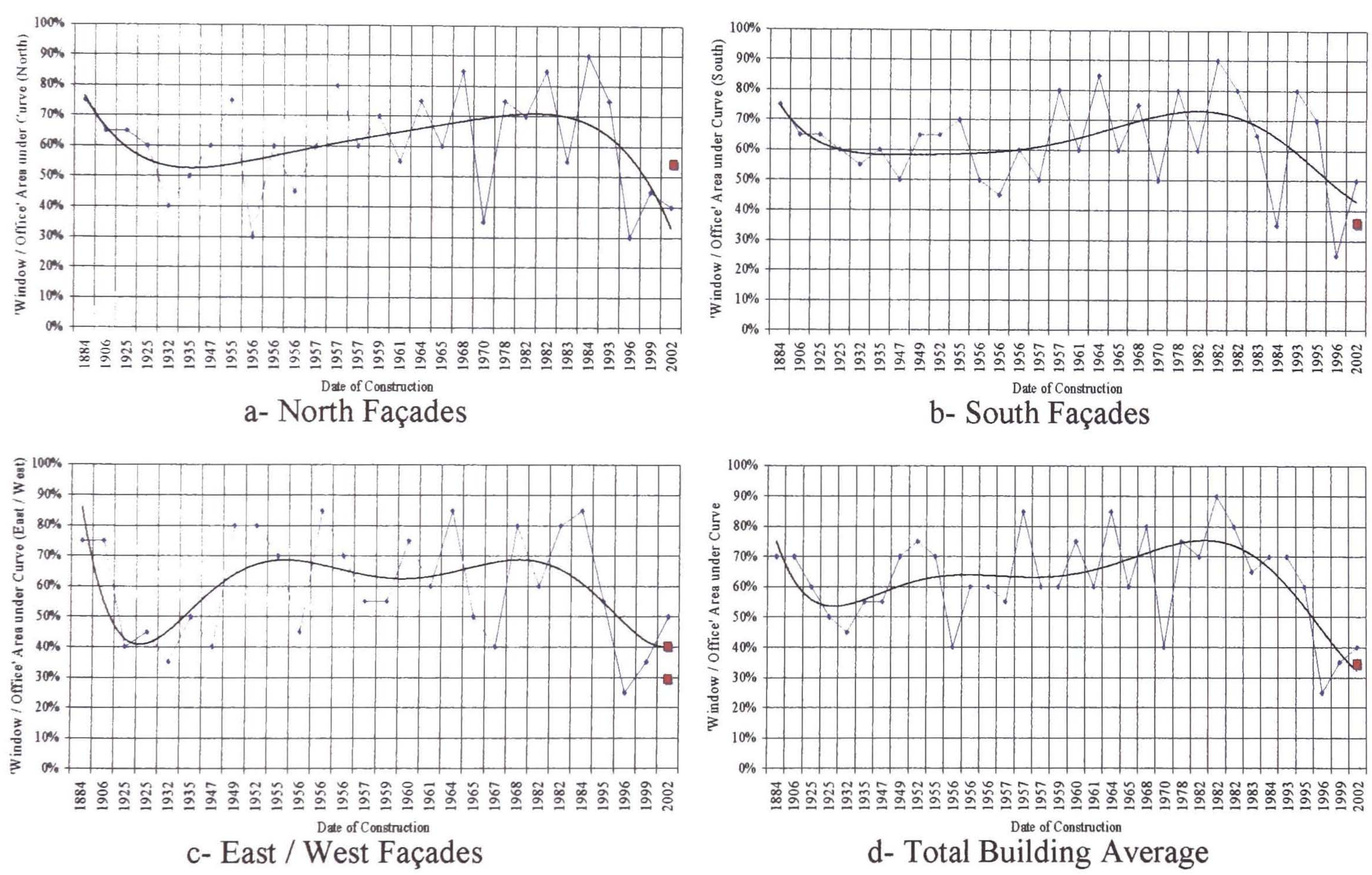


Figure 8.15. Evolution of 'Window / Office' daylight performance evaluation.

8.3.4.2 *Evolution of 'Window / Office' Variables*

The diagrams showing 'Window / Office' variables development for all orientation scenarios and total building average are shown in section AP.III.4.2 of Appendix III.

Section 8.2.3 showed that all the variables of this parametric level correlate with its performance evaluation ('Window / Office' area under curve). Accordingly, the development of all the considered variables that relate the window properties and dimensions to the corresponding internal daylit area are discussed in this section.

Figure 8.16 shows that the daylight buffer zone in office buildings in Beirut has, in most cases, varied on average between 4m and 6m. This range has been exceeded during the last decade, where the average daylight buffer zone values have increased from 6m to 16m. This is explained by the replacement of cellular offices with open-plan offices. It is of note here that the Lebanese building regulation has limited the maximum room depth to 5 times the ceiling height, which should not be less than 2.8m; i.e. the depth of a room having a 2.8m ceiling height should be less than 14m. This rule does not consider the psychological and health concerns related to the distance of users from a window, as discussed in Chapter 4.

Figure 8.17 demonstrates that in the last decade, the average area of an office space in Beirut has increased from 15-30m^2 to more than 150 m^2. The implementation of open-plan offices started in Beirut in the late 1950s, with the large investment projects that took place then. Such projects are again taking place, especially in Central Beirut, and where open-plan offices provide flexibility in the interior design. A1-OL and A1-O are mostly comparable to the recently constructed building stock, as they have a daylight buffer zone deeper than 6m with large office areas (40 to 80 m^2, Section APIII.4.2.3 of Appendix III).

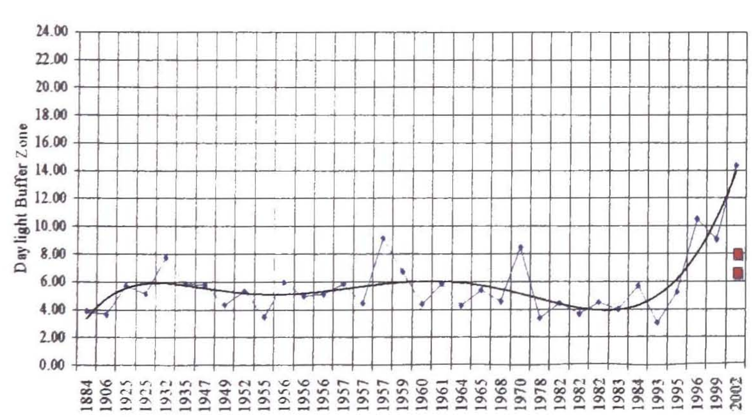


Figure 8.16. Evolution of 'daylight buffer zone' variable (total building average)

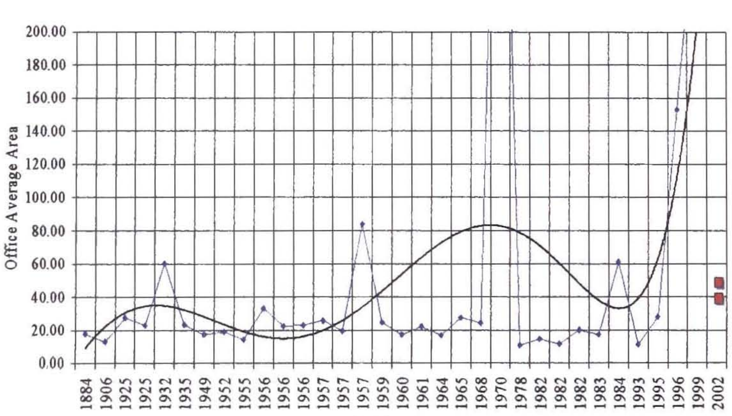
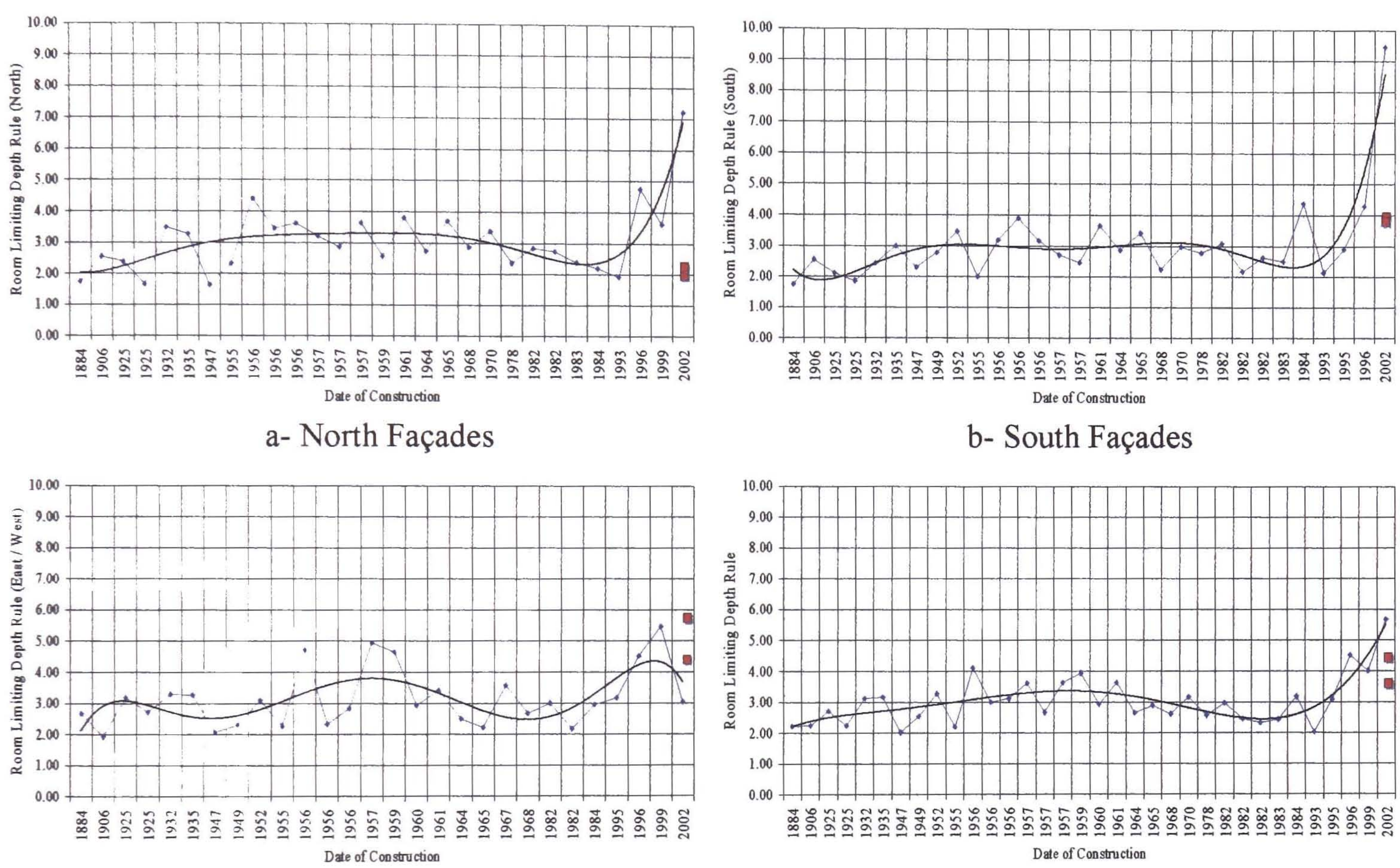


Figure 8.17. Evolution of office average area (total building average)

The limiting depth rule, which controls the room depth to obtain a space that is successfully daylit unilaterally, has in most cases ranged between 2 and 4 (Figure 8.18).

According to the British Standard Daylight Code (1992), the depth of a typical office of an average reflectance R_b equal to 0.5 should not exceed 4 (i.e. the product of $2/(1-R_b)$). Today, this range has been exceeded and the limiting depth increased to 7 or 9 (Figure 8.18a and Figure 8.18b). In addition, even the east- and west-facing rooms of A1-O and A1-OL have limiting depth values above 4. This fact indicates that in newly constructed office buildings, as well as in the proposed energy code, the potential lighting savings due to uniform daylight distribution are disregarded.



a- North Façades

b- South Façades

c- East / West Façades

d- Total Building Average

Figure 8.18. Evolution of the 'room limiting depth rule' variable for all orientation scenarios and the total building average.

The development diagrams of fenestration factor and glazing ratio are illustrated in Section APIII4.2.4 and Section APIII4.2.5 of Appendix III, respectively. Figure 8.20 shows that the fenestration factor in office buildings in Beirut has varied in most cases between 0.1 and 0.4. From the late 1950s some office buildings in Beirut had a fenestration factor higher than 0.4, which would cause problems for thermal comfort and glare. This is quite clear in the low-investment office buildings built during the civil war (1975 – 1990), where small office areas are illuminated by large openings. Nowadays excessive use of glazing in office buildings and similar have a low fenestration factor, because of their large open plan offices.

Glazing ratio has ranged between 0.05 and 0.30 in most office buildings (Figure 8.19). Office buildings of high fenestration values have glazing ratios ranging between 0.30 and 0.55, depending on the type of glazing used.

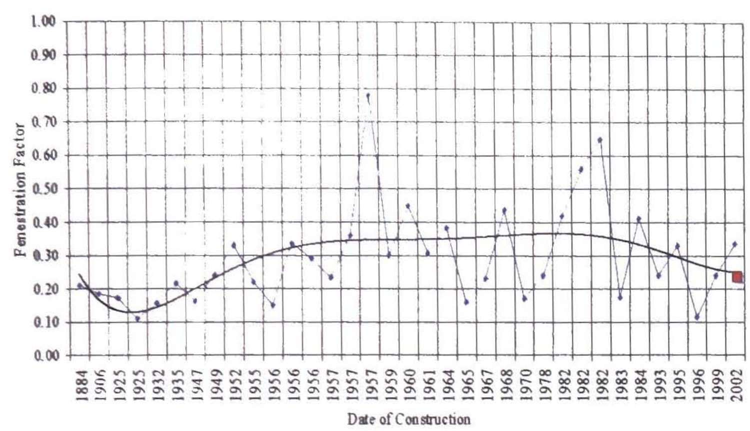


Figure 8.20. Evolution of 'fenestration factor' variable (total building average).

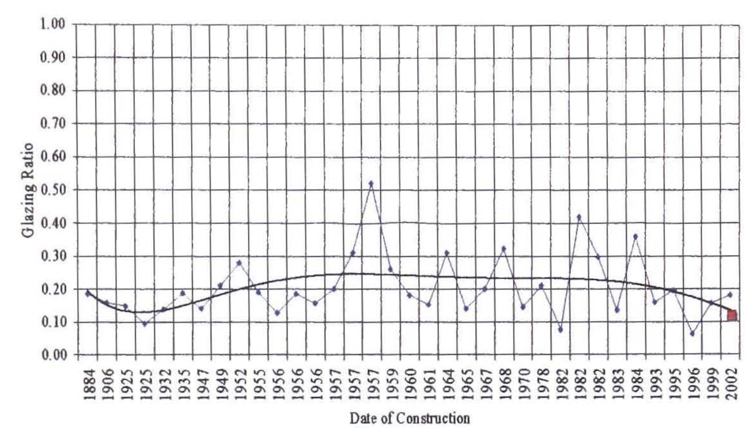


Figure 8.19. Evolution of 'glazing ratio' variable (total building average).

8.3.5 Evolution of 'Shading Devices' Parametric level

The use of shading devices to control daylight and reduce direct sunlight radiation in office buildings in Beirut is studied in this section. The development of 'Shading Devices' variables, and associated daylight performance evaluation in office buildings in Beirut are investigated. The development diagrams of the studied variables are illustrated in section APIII.5 of Appendix III.

8.3.5.1 *Evolution of 'Shading Devices' Performance Evaluation*

Figure 8.21 shows that the daylighting performance evaluation of 'Shading Devices' parametric level in all scenarios has an indefinite shape. Sunlight control has been considered in some office buildings, either by the use of overhangs and / or fins, or they have relied on the material to reflect or diffuse sunlight. The study of 'Shading Devices' variables will give a better view of this.

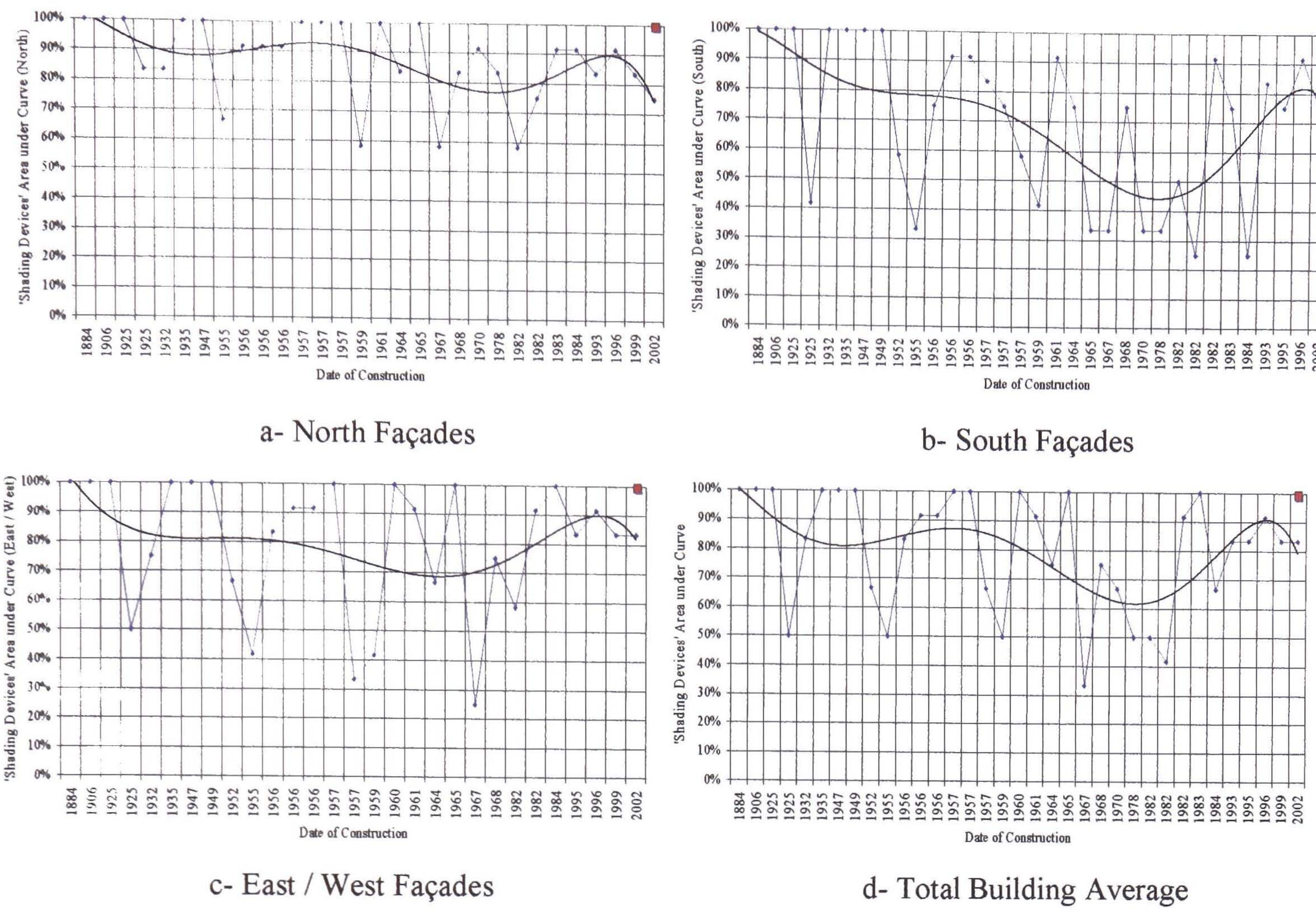
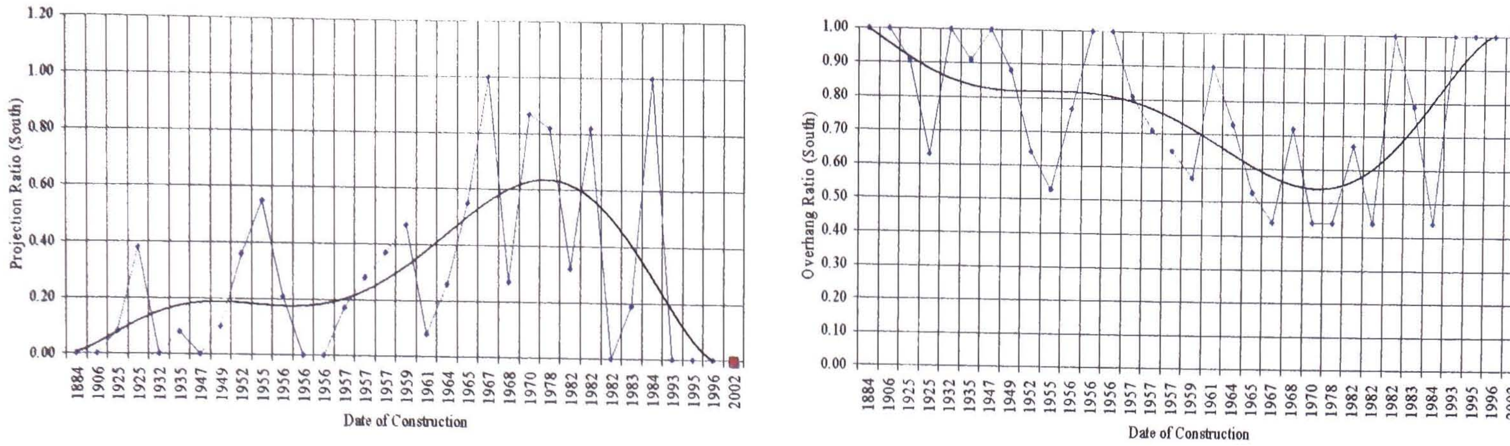


Figure 8.21. Evolution of 'Shading Devices' performance evaluation.

The development diagrams of the 'projection ratio' and 'overhang ratio' shows that overhangs and fins have been a component of the façade configuration in all the stages of office building development (Figure 8.22). They have changed in form, starting from the small balcony of the French window to the concrete overhang, fin or egg-crate, and cantilevered wide balconies that marked the rear façades of the civil war period. The use of shading devices was at times more aesthetic than protective. In such cases, overhangs and fins were also applied to the north façades where there is no need for sun protection (See section APIII.5.2.1 and section APIII.5.2.2).

Figure 8.22 also shows that in recent decades shading devices have ceased to be an element of façade configuration. Protection from solar radiation is mostly now achieved by glazing with an enhanced solar heat gain coefficient (SHGC). This is proved by the decreasing values of relative solar heat gain shown in Figure 8.23. In the proposed Lebanese Energy code, the two base cases also have no shading devices and sun control is only achieved by the properties of the glazing.



projection ratio (south) overhang ratio (south)

Figure 8.22. Evolution of 'projection ratio' and 'overhang ratio' (ex.: south orientation).

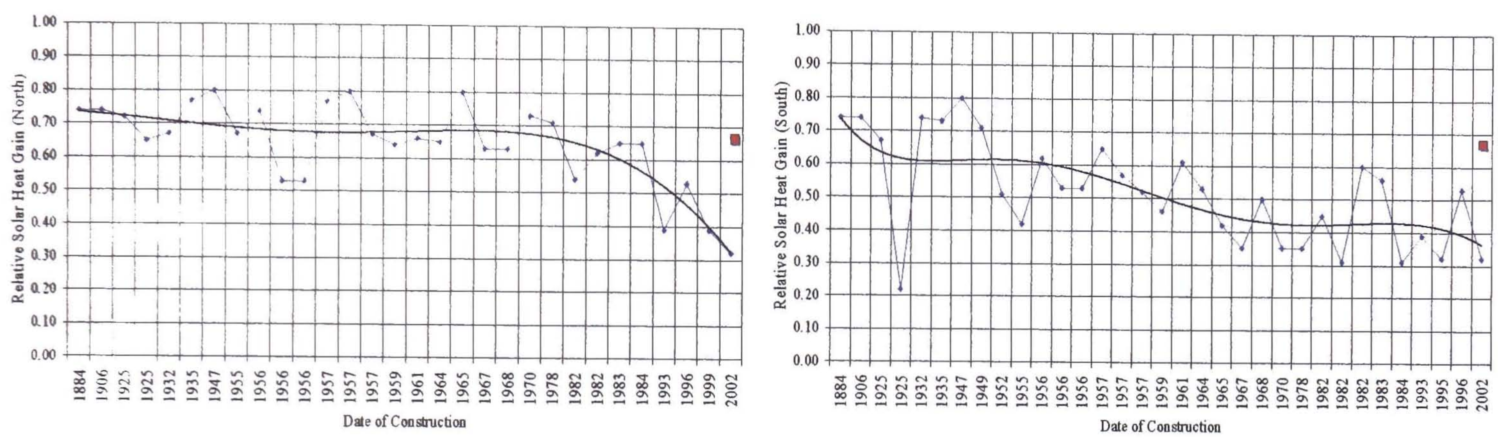


Figure 8.23. Evolution of 'relative solar heat gain' variable (north and south façades).

8.4 Conclusion

This chapter has examined the daylighting design variables that have been considered or disregarded in the design of office buildings in Beirut during the last century. The Chapter has also investigated their impact on daylighting availability and performance in interior spaces.

The three-dimensional analyses of the building shape, and the review of the building codes have proved that the impact of the building shape on lighting or ventilating the building has largely been disregarded. The building shape or the plan layout of the building has been controlled by the site shape, and the full use of the permitted built up surface area and gross area.

The daylighting performance of the 'Window / Façade' parametric level has gradually improved with the advances in façade technology. Today the high performance of 'Window / Façade' is definitely creating glare and visual discomfort, as well as uncomfortably high thermal levels. According to the results gained from the distributed questionnaire, many users of newly constructed buildings are unhappy about glare in their work places (Chapter 4). They say that they could not manage without Venetian blinds and air conditioning in the summer months.

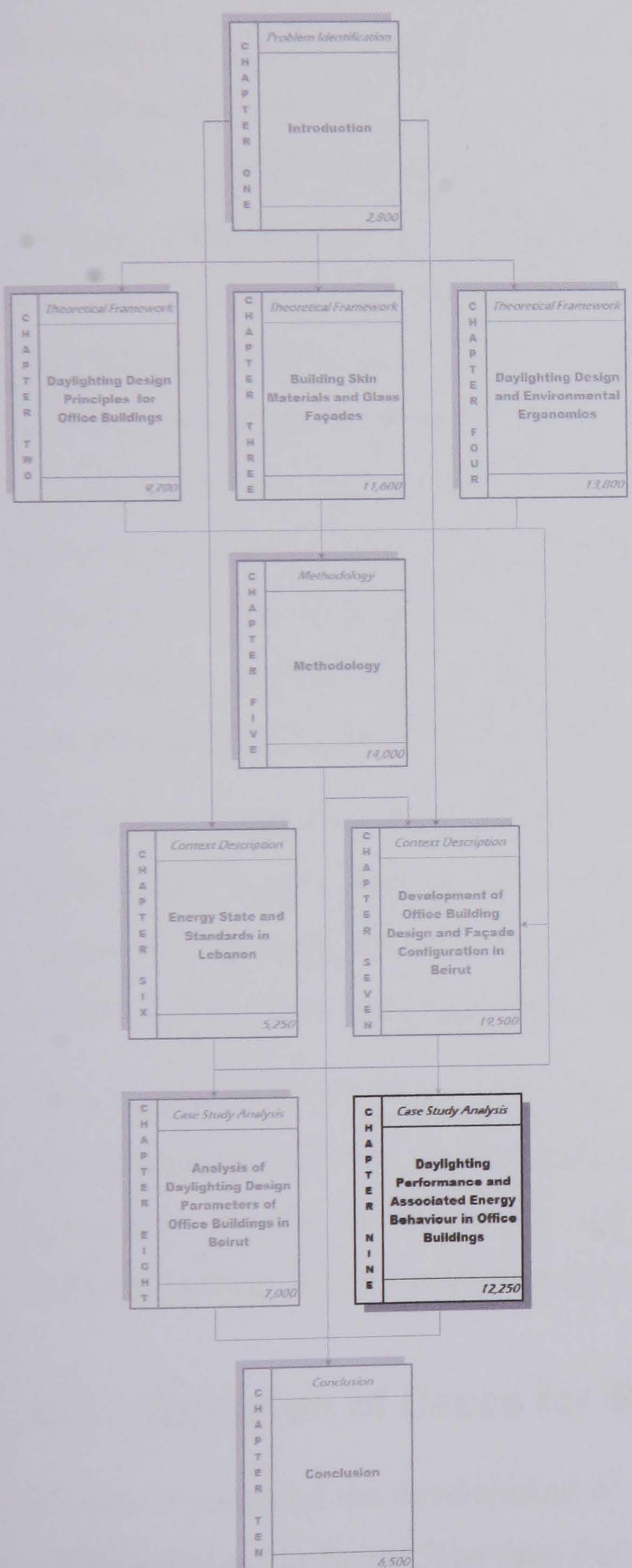
The adoption of highly glazed façades and new façade technologies is not controlled by any rule or code that protects the building's users from discomfort. The on-going Lebanese Energy Code Project has suggested two base cases for office buildings in Beirut. These two base cases are almost identical, and most of their variables are not analogous to the existing building stock. This finding denies the statement of one of the project team asked by the researcher during a seminar discussing the mentioned project, who said: 'the two base cases are representative of the office building stock built in the last 20 years'. In addition some of their variable values, such as low building compactness and daylight aperture ratio, confirm that the role of façade configuration and plan morphology on daylighting performance and associated energy potential savings have been disregarded in the new Lebanese energy standards.

The analysis of 'Window / Office' has proved that only fenestration factor and glazing ratio have a significant relationship with the daylighting performance of the total building. This is explained by the fact that the fenestration factor is the only variable considered in the Lebanese regulations to provide daylighting to a space. In all cases studied the minimum fenestration factor value is 0.10, that being the minimum value set by the building regulations. On the other hand, the maximum fenestration factor found is 0.80, which is generally considered very high and can cause optical discomfort. This is due to the lack of any threshold for this variable in the building regulations to prevent excessive daylighting. In addition, the room depth in accordance to the room width and window dimension is not considered in the design of office buildings in Beirut nor in the Lebanese building regulations. This has been proved by the lack of correlation between performance evaluation and daylighting buffer zone, and the room depth limiting rule, respectively.

Finally, the use of shading devices has been the subject of design trends and façade articulation. Today, architects in Lebanon are trying to exchange the protective role of shading devices for new glazing technologies, which are still too expensive for projects that may not have the necessary budgets.

Daylighting Performance and Associated Energy Bahaviour in Office Buildings

9



Chapter Nine

9. Daylighting Performance and Associated Energy Behaviour in Office Buildings

9.1 Introduction

The critical review of façade configuration and office building design carried out in the previous theoretical framework chapters (Chapters 2, 3, and 4) has led to a set of design variables that influence the daylighting performance of office buildings. These variables, as illustrated in Chapter 5, are classified into four parametric levels: 'Building Shape', 'Window / Façade' relationship, 'Window / Office' space relationship and 'Shading Devices'. These parametric variables have been utilised to develop a preliminary tool to evaluate the daylighting performance of office buildings in Beirut. The significance of each parametric level in general, and each variable in particular, on potential daylighting availability and total design performance has been studied in Chapter 8. This chapter aims to investigate the impact of such variables, with associated evaluation on the energy patterns of office buildings. The relationships between daylighting design variables, and simulated energy consumption and potential energy savings, are respectively examined in this chapter. Subsequently, simulated potential energy consumption and savings are compared and validated with empirical energy data.

Advanced Daylighting and Electric Lighting Integrated New Environment software (ADELINE) is used to perform the lighting simulations, and to produce comprehensive figures for electric lighting consumption and possible savings resulting from the use of electric lighting control strategies that operate in response to the level of interior daylight.

This chapter is divided into three major sections. The first section discusses the criteria for the selection of cases for simulation. The following section sets the boundaries for the simulation. Finally, the simulation outputs are investigated and analysed in accordance with daylighting design variables as discussed in Chapter 5.

9.2 Selection of Cases for Simulation

Chapter 7 reviewed the development of the façade configuration and plan morphology of office buildings in Beirut. The time framework, extending from the late 19th century until the present, was selected following a brief review of Beirut's history from social, economic and political viewpoints. Seven historical phases were adopted. The development of office building architecture was investigated through the analysis of 35 case studies of different construction date, documented as follows:

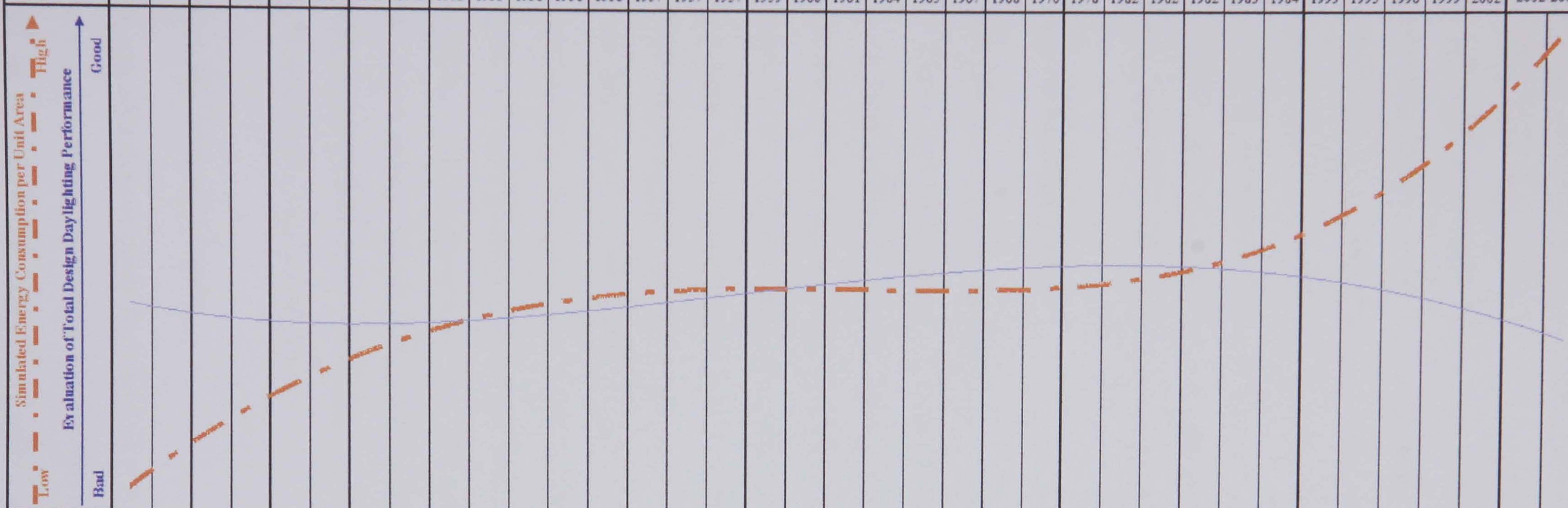
- Phase I (Before 1920): 2 case studies (B01 and B02)
- Phase II (1920-1930): 2 case studies (B03 and B04)
- Phase III (1930-1946): 2 case studies (B05 and B06)
- Phase IV (1946-1958): 10 case studies (B07 to B16)
- Phase V (1958-1975): 8 case studies (B17 to B24)
- Phase VI (1975-1990): 6 case studies (B25 to B30)
- Phase VII (1990 – present): 5 case studies (B31 to B35)

In addition to these case studies, two additional office buildings, A1-OL and A1-O, have also been analysed. These two additional cases are the office building base cases (associated with the coastal climatic zone A1) of the Lebanese Energy Standards Project.

The aim of this section is to discuss the criteria for the selection of cases for simulation. It was decided to select two different cases from each historical phase in order to allow some comparative analysis within the same phase, as well as to give a wider view of the daylight behaviour of office building architecture during each phase. This decision was restricted by there being insufficient data from the first three phases. Three cases were selected to represent the period before 1946 (Phases I, II and III).

Table 9.1 summarizes the daylight behaviour evaluation of the 35 cases studies illustrated by the diagram of total design performance evaluation, the simulated energy consumption per unit area and the additional measures that have been considered in the selection of cases for simulation. Building condition and percentage of building occupation can affect empirical data availability and accuracy, as well as the possibility of conducting a POE questionnaire in the building. Accordingly, the selected cases are marked by ✓ in the last row of Table 9.1. These were not however the only criteria. The following sections explain the reasons for selection in each historical phase.

Phase	I		II		III		IV										V								VI						VII					Energy Standard Project	
	... - 1920		1920-1930		1930-1946		1946-1958										1958-1975								1975-1990						1990-Now						
Building ID	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21	B22	B23	B24	B25	B26	B27	B28	B29	B30	B31	B32	B33	B34	B35	B36	B37
DOC	1884	1906	1925	1925	1932	1935	1947	1949	1952	1955	1956	1956	1956	1957	1957	1957	1959	1960	1961	1964	1965	1967	1968	1970	1978	1982	1982	1982	1983	1984	1993	1995	1996	1999	2002	2002-2004	
Condition	D	D	R	R	R	D	R	R	R	R	R	R	R	R	AB	AB	R	AB	Da	AB	AB	AB	R	AB	AB	AB	AB	AB	AB	R	AB	AB	AB	AB	AB	BC	BC
Percentage of Occupation	0	0	100	0	25	0	20	0	0	5	10	45	60	10	30	30	10	50	0	0	100	0	62	30	45	50	40	80	85	100	100	100	0	70	0	0	0
Selected Cases	✓		✓			✓			✓							✓					✓		✓			✓		✓	✓			✓	✓			✓	✓



Abbreviations and Symbols						
AB	As Built	Da	Damaged	R	Renovated	✓ Selected Case for Simulation
BC	Base Case	D	Demolished	DOC	Date Of Construction	

— · — Simulated energy consumption per unit area

——— Evaluation of the total design daylighting performance

Table 9.1. Criteria for the selection of cases for simulation.

9.2.1 Phase I' Selected Cases

There is very little literature and information about non-residential buildings built prior to the 1920s. The Petit Serail (B01) and the Imperial Ottoman Bank (B02) are the most prominent and best-remembered buildings that were designed for office use, in the historical literature of the 1st phase. B01 and B02 were both demolished during the first half of the 20th century; consequently, empirical data and POE analysis are unobtainable. Related energy analysis can thus only be done through building simulation modelling. In addition, a typical plan drawing of B02 was not found in the literature; daylighting variables of B02 were obtained from perspective and elevation views only. For this reason, only building B01 was selected for simulation.

9.2.2 Phase II' Selected Cases

B03 and B04 are the examples investigated to review the development of office buildings in Phase II. These two buildings are among those buildings of their age that survived the destruction of Beirut Central District during the Lebanese civil war. Today those two buildings have been renovated by SOLIDERE. B04 is located in Fosh Street, which is the earliest extension of the Beirut port area, and where multi-use buildings were constructed during that period. B04 is still vacant, which constrains any energy and POE studies. As for the Beirut Municipality (B03), it has been re-used since February 2002. B03 was considered by most of the national architects interviewed (R. Saliba, G. Arbid, P. Nehmeh and A. Salam) to be a key building of its time. Accordingly, it was valuable to select B03 for simulation. The energy data obtained from Electricity of Lebanon (EDL) is limited to the consumption of the shops that occupy the ground floor. Beirut Municipality, which occupies the floors above, has no power meter as yet, so there are no recorded data of the total building consumption. In this building, 27 POE questionnaires were distributed, but only 17 were returned to the researcher.

9.2.3 Phase III' Selected Cases

In Phase III the selection of cases for simulation is limited to two examples, B05 and B06. Each of the two buildings represents a different direction in architectural design from that period. B05 is a simplified version of the bay window building that characterised residential façade configuration. On the other hand, B06 is considered to be a landmark of modernism and the first of its kind in Beirut at that period; a bold mass, devoid of decoration, with rational horizontal treatment of openings. B06 was vacant and unused during the war as it was located in the green line area, and was demolished in early 1990s during reconstruction of the Beirut Central District. Thus empirical data and POE study could not be obtained. Obtaining details of the electrical consumption in B06 before the war proved difficult, because the 'Electricity du Liban' (EDL) archives were destroyed during the civil war. As for B05, its renovation has only recently been completed. Only the shops on the ground floor are fully occupied, the office floors not yet being entirely occupied; more precisely, the firms in this building have only recently moved in. While the researcher was distributing the POE questionnaires the upper parts of the building were unoccupied, and the electricity bills recorded by EDL were restricted to consumption by the commercial shops. According to all the previously reviewed criteria, and as daylighting performance evaluation of the two buildings is approximately similar, (Table 9.1) one of the two buildings could be selected for simulation. B06 was therefore selected as it has been designed to be purely an office building.

9.2.4 Phase IV' Selected Cases

The development study of office building architecture during Phase IV showed that two design approaches were being followed: energy conscious or climate conscious architecture, confirmed by the use of shading devices (B09, B10 and B14); and the International Style, which suggests that architecture should be applied purely with no extras: no decoration or other adornments. In other words, this architecture tended to be strictly professional; strictly for business (B07, B10, and B11). In the most recent cases new and modern building materials, especially glazing, began to be exploited (B12, B13, 15 and B16). In addition, the analyses in Section 7.3.4.1.1 showed that 1956 was a transitional year. Buildings built before and after 1956 had very different levels of daylighting performance, except for B09 which looked to be distinctive. In the second half of the 1950s, more concern was given to glazing profiles and glass material used. Therefore, two cases from Phase IV were required for simulation; one representative from the period before 1956, another built after 1956. A third case was taken as an example of climate-conscious architecture.

The analyses, and interviews with earlier practitioners and contemporary architects showed that B09 is considered a key building of its age, so this building was selected for simulation. However, this building is now vacant, despite having been renovated during the last decade. Accordingly comparison of simulated results with true empirical data and POE studies cannot be done.

B16 is the second case selected, because it is the first office building in Lebanon where the curtain wall was applied. In addition, B16 almost meets the average value for the total building area under curve for the case studies constructed after 1956 (Table 9.1). Empirical data have been collected for this building by the researcher. Concerning the POE study, the researcher experienced problems in getting replies to the questionnaire. None of the building users showed any interest, and refused to respond to the survey.

9.2.5 Phase V' Selected Cases

In Phase V, office buildings can also be divided into two categories. The first category encompasses office buildings with a double skin façade consisting largely of horizontal openings with a fixed brise-soleil structure covering and protecting the whole façade (B17, B21, B22 and B24). In the second category, the adoption of the International Style is more apparent; new technologies for glazing (i.e. double or tinted glazing) and building materials such as granite and aluminium cladding have replaced stone cladding (B18, B19, B20 and B23). A case from each category needed to be selected for simulation. From the group B17, B21, B22, and B24, B21 was selected for simulation because of complete architectural data availability and in order to examine the effects of differences in façade treatment on daylight performance and energy consumption. This building is the headquarters of 'Electricity of Lebanon' (EDL). According to Maher Itani (2003), a departmental director at EDL, a power meter was recently installed to the building. There are no earlier recorded electrical consumption data for B21. As for the POE study, the researcher was not able to obtain permission for questionnaire distribution to the EDL employees occupying B21. Regarding the other buildings in the same category, B17 and B22 were not selected because both buildings remain unoccupied, i.e. empirical data are not available. Additionally they are not representative of the vertical extension that began to take place during that period. B24 was not selected because cinemas, restaurants and commercial shops occupy a considerable proportion of the total building area. This multi-use function can lead to inaccurate figures for the energy consumption in an office building. In addition, the typical office floors are not occupied. For the same reasons, B20 was not selected for simulation as an example of the second category. Instead, B23 was selected as an example of the International Style in Beirut of its period, and one where new building materials were applied. The building is also occupied, and data readily available. Regarding B18 and B19, the design of the first building was limited by its enclosure, while the second is now damaged.

9.2.6 Phase VI' Selected Cases

The analyses of office buildings constructed during the Civil War period (Phase VI, 1975 – 1990) showed that the design of office buildings could be categorised into *defensive* architecture (B29 and B30) and *low-investment* architecture (B25, B26, B27 and B28). *Defensive* office buildings are characterised by opaque, low wall to aperture ratios, and protective façades. These buildings were mainly constructed in the green line areas. *Low-investment* office buildings, located mostly within residential areas, were built in response to the demand from small businesses. From B29 and B30, B29 was selected because of clear opacity in its façades and the availability of complete data. B30 was discounted, because many changes were made to its main façade by renovation in 2002. From B25, B26, B27 and B28, B26 and B28 were selected for simulation because they represent different design directions. Empirical data are only available for B26. Regarding the POE study, 5 out of 10 questionnaires distributed in B28 were returned to the researcher but no questionnaires were completed in B26.

9.2.7 Phase VII' Selected Cases

Finally, for a better understanding of the most recent office buildings design it was important to select two cases each representing a design trend or direction; the *Modern* excessive use of glazing (B31, B32, B34, and B35) and the *Imitative* or *Conservative* architecture mixed with *contemporary* architectural features (B32 and B33). In B32 the design of the façades has more or less combined the two identified styles, because its east and west façades are imitative of the International Style of the 1960's. B32 can thus be seen as representative of the two mentioned design directions. On the other hand, the façades of B33 were designed to be identical to 'traditional' façades of buildings constructed in 1930s - 1940s period, but with different plan morphology. For this reason, it was worth selecting B33 for simulation. Empirical data are only available for B32, which is entirely occupied. On the other hand, the researcher failed to conduct the POE study in B32 because the building manager of ESCWA, the organisation that occupies the building, refused to cooperate in that. Building B33 is still vacant, which limits any empirical and POE studies.

9.3 Setting Simulation Boundaries

To establish the effects of daylighting on a building's energy performance, it is necessary to quantify the amount of energy supplied for supplementary lighting purposes in relation to the amount of daylight available. In this context, it is of interest where and when daylight supplies fall below the required rated workplace illuminance. Only during these periods, supplementary lighting must be switched on or dimmed to keep up the nominal illuminance level. It is therefore essential to use tools that can simulate the complex and dynamic behaviour of buildings under realistic conditions of use and operation. The ADELINE software (Advanced Daylighting and Electric Lighting Integrated new Environment) offers possibilities for the integration of analysis of daylighting, artificial lighting and lighting control strategies with energy analysis.

Adeline is made up of several integrated programs, as illustrated in Figure 9.1. The program integrates a DXF converter (CAD input), a Simple Input module (Simple shape modeller) and the Scribe Modeller, which is a micro computer-aided system for modelling production of detailed two and three-dimensional drawings.

PLINK is used to associate photometric properties with each component of the model described with Scribe Modeller. A material database has been created in PLINK which includes opaque surfaces (concrete, bricks, wood, metal, painted areas, etc.), and transparent or translucent surfaces (a large choice of glass or plastic materials).

SUPERLINK and RADLINK are programs used to obtain estimates of the interaction between daylighting, artificial lighting and the dynamic thermal performance of the building, (lighting aspects only). The simulation is based on daylighting calculations with SUPERLITE or RADIANCE. SUPERLINK and RADLINK produce hourly values for additional artificial lighting input into a building over a complete year, taking into account:

- several lighting control strategies,
- desired work surface illuminance,
- user-defined work time schedule,

- hourly sunshine probability.

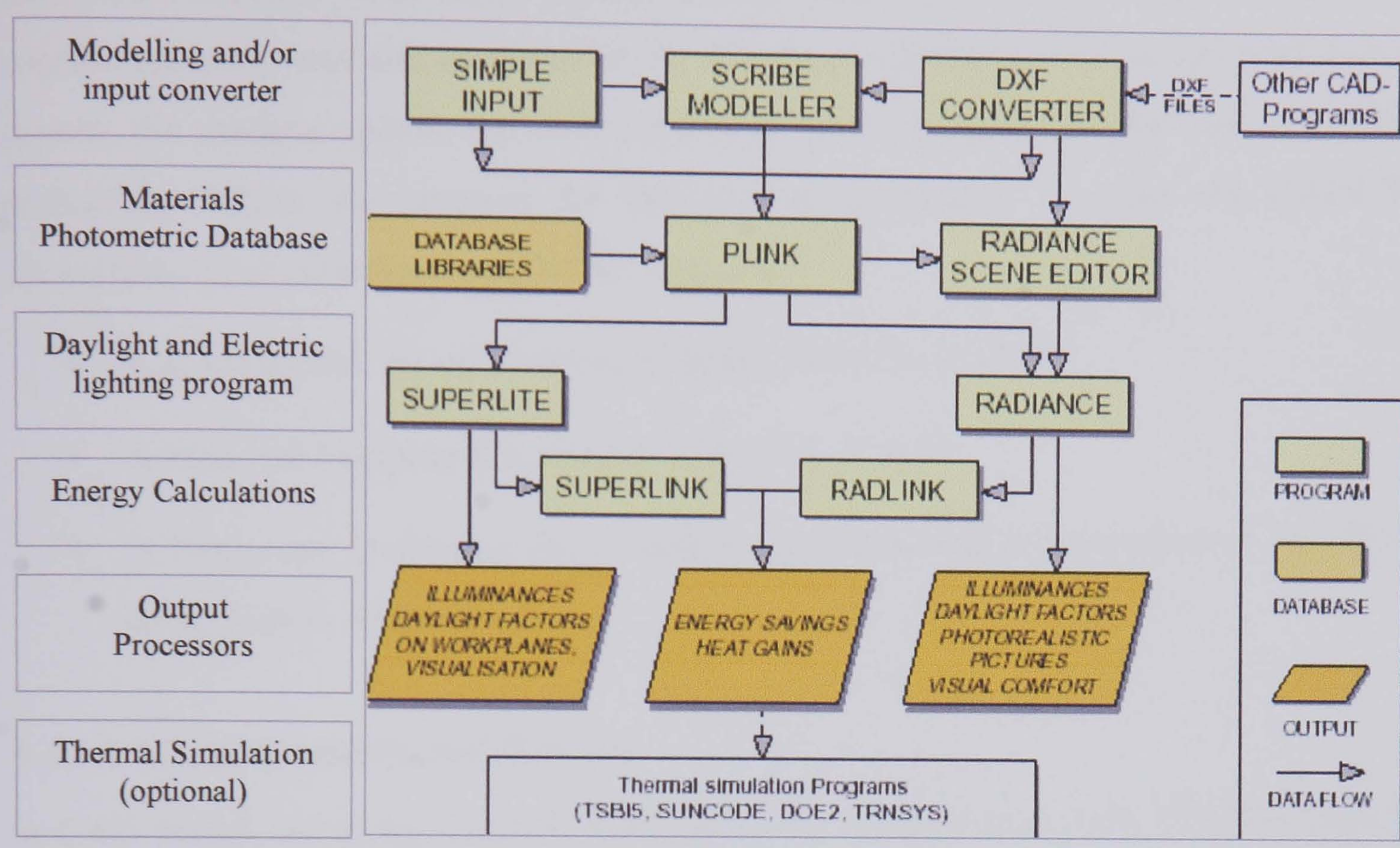


Figure 9.1. The structure of the package ADELINE 3.0.

RADLINK is the foremost tool used in this research, along with RADIANCE that performs daylighting calculations, to obtain figures for electric lighting consumption and the possible savings due to the integration of daylight and electric lighting. RADLINK allows simulation of complicated spaces, which is not the case with SUPERLINK / SUPERLITE software. DXF Converter, Scribe Modeller and PLINK are used to draw and assign the associated materials to models of the selected 14 cases.

The above paragraphs are a general description of the ADELINE integrated environment, and the tools that have been used in this research. ADELINE requires a variety of data (including geometric, photometric, climatic, optic and human response data, lighting system) to perform lighting simulations and to produce comprehensive numeric and graphical information. The following sections will describe in detail the programs and data inputs used to perform the simulation in the selected cases. Finally, the simulation outputs are illustrated and these will be investigated later in this chapter.

9.3.1 Model Inputs

RADLINK requires valid input models for the RADIANCE simulation. These models contain geometry and site information. In addition, information on the artificial lighting system, the shading system, the utilization of the room and special data such as sunshine probability values are required for the analysis procedure. To start the RADLINK simulation, three essential data files are required:

- A CAD model, set up by using SCRIBE Modeller (*.mod)
- A Material Mapping file, created by PLINK (*.tex)
- A Parameter Definition file (*.def); the contents and a description of this file are to be seen in Appendix IV.

9.3.1.1 *Model Geometry and Material*

A CAD model, set up by using SCRIBE Modeller is required as input to RADLINK. Due to limitations of the software, the simulation had to be carried out per room and not for the whole building. To save time, the researcher made use of the available 2D AutoCAD drawings. Following the drawing rules of SCRIBE modeller, such as the importance of line direction and layer code, AutoCAD 2000 was used to trace each room separately in 2D. Each room model was exported separately to a dxf file, which in turn was converted to SCRIBE format via dxf2mod. In due course a worksheet was designed to standardize the procedure of the drawing and conversion of the model geometry (Figure 9.2). This worksheet includes a key plan of rooms with their ID, the CAD layer names and the SCRIBE layer codes. It is to be noted here that layer codes in SCRIBE modeller are of great importance. They are the means by which the model or drawing relates to any other data such as specifications, attributes and numerical non-graphic characteristics; and so they are the principal link between the raw geometric data and the material specifications. Afterwards, the room is extruded and transformed into a 3D model using the SCRIBE Modeller, and room components (windows, working plane etc.) are given the right base and heights.

In the following step, PLINK is the conversion program used within ADELINE to generate RADLINK input files from the SCRIBE model. Geometric entities are attributed with material properties via the so-called material mapping files, which are SCRIBE Modeller text files (Building_ID.Tex). Material mapping files contain references to material identifiers defined in the material database, or so-called "parametric" material descriptions that allow for the direct specification of transmission. The assigned materials and their specifications were also included in the modelling worksheet (Figure 9.2).

B03 - BEIRUT MUNICIPALITY (1925 - 1928)											
CAD Layer Name	DxfConv Layer Code	Scribe Modeller Layer Code	Base	Height	Type	Material					
						Name	Description	Reflectance	Transmittance	Chromacity Values	
										x	y
0 / RAD. VIEW	70	2000	1.7	0	-	-	-	-	-	-	-
N-90WIN	81	20	0.90	2.80	window_b	clear_glass_4	-	-	93.4	0.340	0.342
N-CEILING	78	90	4.00	0.00	surface	2K205	off-white paint	67.50	-	0.330	0.347
N-DOOR	76	30	0.00	2.50	partition	2K219	ivory	64.40	-	0.335	0.359
N-FLOOR	79	95	0.00	0.00	surface	%G45.0	white marble	45.00	-	-	-
N-FWIN	77	25	0.00	3.70	window_a	clear_glass_4	-	-	93.4	0.340	0.342
N-OVERHANG	82	85	4.20	0.00	enclosure_a	%G45.0	white marble	45.00	-	-	-
N-PART	74	40	0.00	4.00	partition	2K205	off-white paint	67.50	-	0.330	0.347
N-PART2	75	45	2.50	1.50	partition	2K205	off-white paint	67.50	-	0.330	0.347
N-WALL	72	50	0.00	4.00	surface	2K205	off-white paint	67.50	-	0.330	0.347
N-WALL1	80	55	0.00	0.90	surface	2K205	off-white paint	67.50	-	0.330	0.347
N-WALL2	73	60	3.70	0.30	surface	2K205	off-white paint	67.50	-	0.330	0.347
N-WORK	71	99	0.80	0.00	work surface	-	-	-	-	-	-

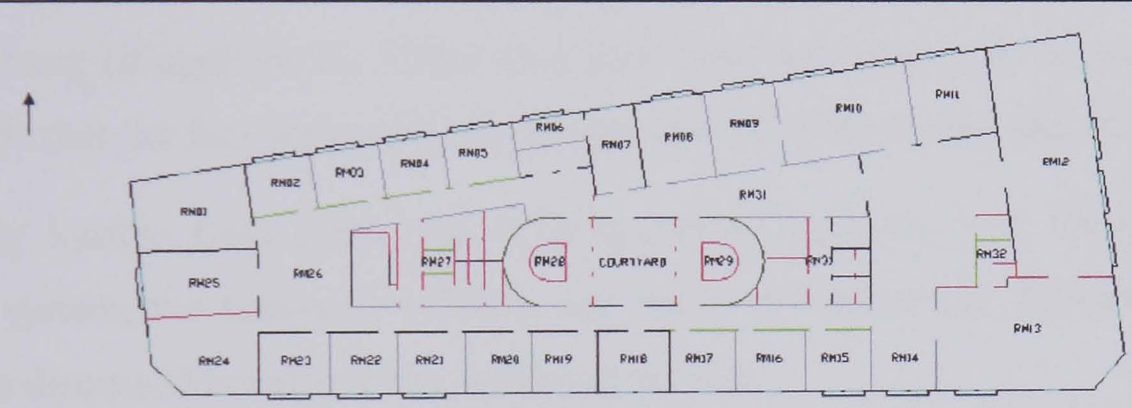


Figure 9.2. Example of the standardized worksheet used for the geometric modelling and conversion of the CAD model to RADLINK format

9.3.1.2 *Parameters Definition*

Additional information in form of a parameters definition file (*.def) is needed for RADLINK simulation. This file, of which a detailed description is given in Appendix II, includes the following:

General parameters related to the daylighting calculations (weather model and sky conditions), the simulation accuracy and the output format. These data are attached to all the cases selected for simulation.

Window data and Shading System data describe the glass recess, the glass shading properties, the maintenance and cleaning frequency for the glazing. The figures for glass recess and shading properties are variable according the façade configuration of the building being considered. As for the maintenance factor, it is assumed to be the same for the 14 simulated cases (value equal to 0.5).

Geographic data, atmospheric data, sunshine probability and Link turbidity data are all related to the geographic site or location of the cases under consideration, this being the city of Beirut. These data are therefore the same for all the case studies. Details of these data and their sources are included in the section containing the description of the parameters definition file, in Appendix IV.

Time loop data specify the month, date and time for daylighting calculations. These data are only needed for SUPERLITE, which has not been used in this study. Default results have been used in all the case simulations.

Overhang data describe the type, properties, measurements, reflectance and transmittance of overhang (if applicable). These data vary from one case study to another, depending upon whether the façades include overhangs; and their associated specifications.

Lighting System Data define the lighting control type, the task illuminance, the total power system, the luminous efficacy and the base load of any dimming system. These data are discussed broadly in the following section.

Occupancy and Holiday data are required in order to calculate for rooms of a given utilization. Daily, weekly and yearly working or occupancy schedules are required. In all cases, it was considered that all rooms are used 5 workdays per week, from 8:00am to 5:00pm; this being the case in most office buildings in Beirut. Holiday periods are not considered, and it is assumed that the weekly schedule is valid throughout the whole year.

9.3.1.3 *Lighting System Data*

As mentioned in the previous section, the lighting system data required to run RADLINK simulations should include information about the task illuminance, the total power system, the luminous efficacy, lighting control type, and the base load of the dimming system.

9.3.1.3.1 Task illuminance

The desired worksurface illuminance (at desk level, 75 cm above the floor) is normally based on the nature of activities, and national codes or recommendations (such as IES Illuminance Guidelines, and CIBSE Codes) for daylight and artificial lighting in working rooms. Typical office, meeting room, circulation and service areas will have a desired worksurface illuminance equal to 500 lux, 300 lux and 100 lux, respectively (Rea, 2000 and Steffy 2002). These values have been adopted in this research for case study simulations.

9.3.1.3.2 Total power system

The total power of the lighting system (in Watts) defines the power output of the selected artificial lighting system in the room. According to Steffy (2002), the required power rates per unit area, depending on the use of space, are as follows:

- 14.0 W/m^2 in typical offices
- 19.1 W/m^2 in conference rooms
- 7.5 W/m^2 in corridors and services.

These have been adopted for this research. The total power of the lighting system is therefore the result of multiplying the appropriate power per unit area by the room area. These variables and the calculation procedure are included in the simulation results worksheet described later.

9.3.1.3.3 Luminous efficacy

The luminous efficacy of a lighting system (lm/W) refers to the efficiency of the system selected. Different electrical light sources produce different kinds of light, and vary significantly in their efficiency. While luminous efficacy is normally defined for the light source itself, it may be defined by a simple formula (Erhorn, 2000a):

η = (desired surface illuminance * floor area of considered space) / total power of lighting system

Luminous efficacy for each room was calculated manually using a spreadsheet, and included in the simulation results worksheet discussed below.

9.3.1.3.4 Lighting control

In RADLINK, the user can select seven different types of lighting control strategies for the specified system defined in Lighting System Data. These artificial lighting controls function in two different ways, on/off-switching and dimming.

The on / off switching controls are:

- The automated light switch on/off (LSOO): lights are turned off when the interior illuminance from daylight is equal to or above the designed illuminance level. The lights are turned on when the daylight level falls. Using this type of light control, there are no intermediate steps between having all the lamps on and having them all off.
- A multi-step on/off control system can supplement the electric lighting output with daylighting. In RADLINK, these are two-steps on/off (2SOO), three steps on/off (3SOO) and four steps on/off (4SOO). As shown in Figure 9.3, the systems are defined by a power step reduction related to the supplement of natural light.

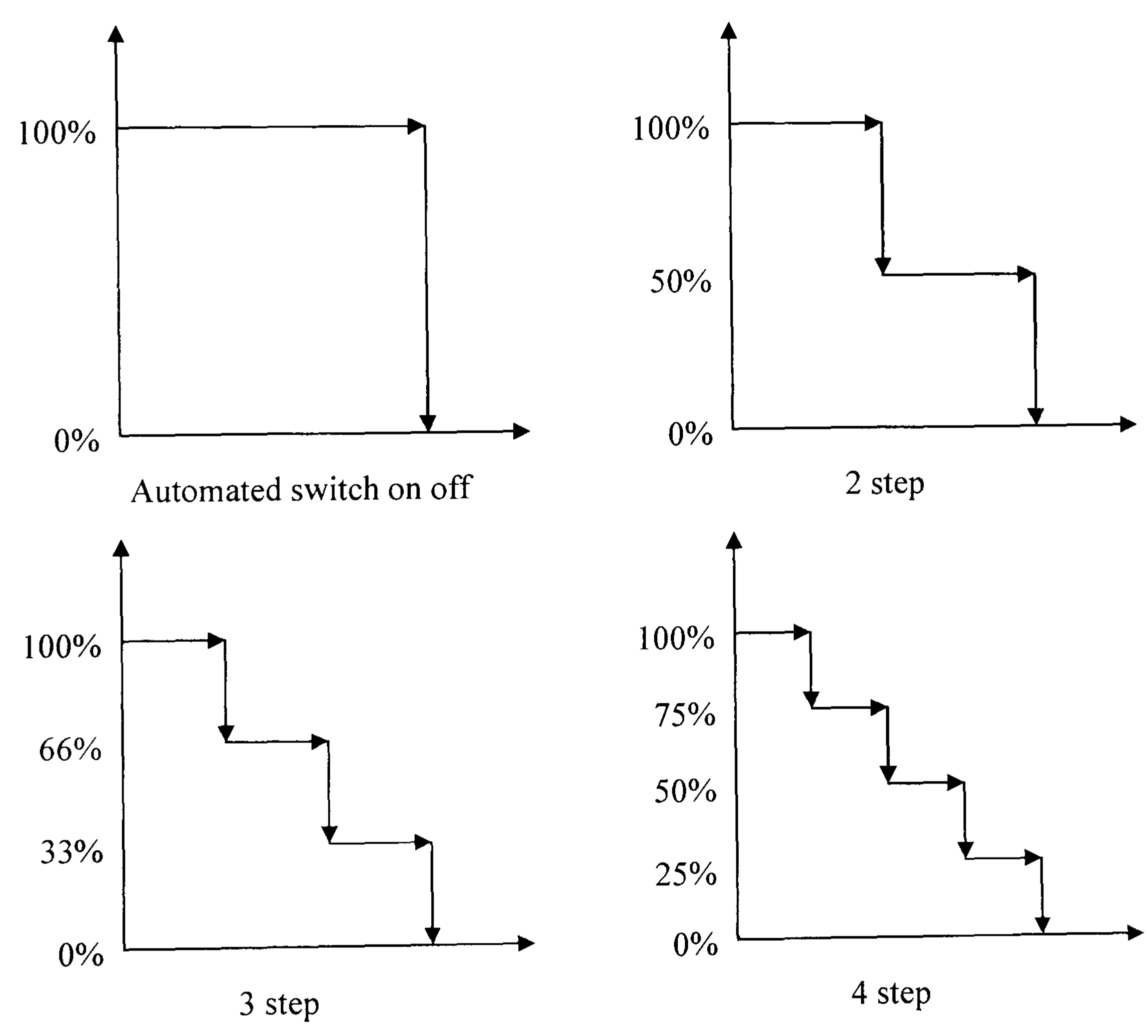


Figure 9.3. On/Off and multi-step control systems

- Manual On/Off Probability (MOOP): Erhorn (2000b) referred to a study done in England, in which Hunt (1980) predicted the probability for use of artificial lighting in a manually operated on/off-switching control system. The method is based upon patterns of switching behaviour observed in field studies. Hunt found that the probability of someone switching on the artificial lights in a space is correlated with the minimum daylight illuminance on the working plane. From the data set of the field study, an empirical algorithm was defined and illustrated as a curve (Figure 9.4).

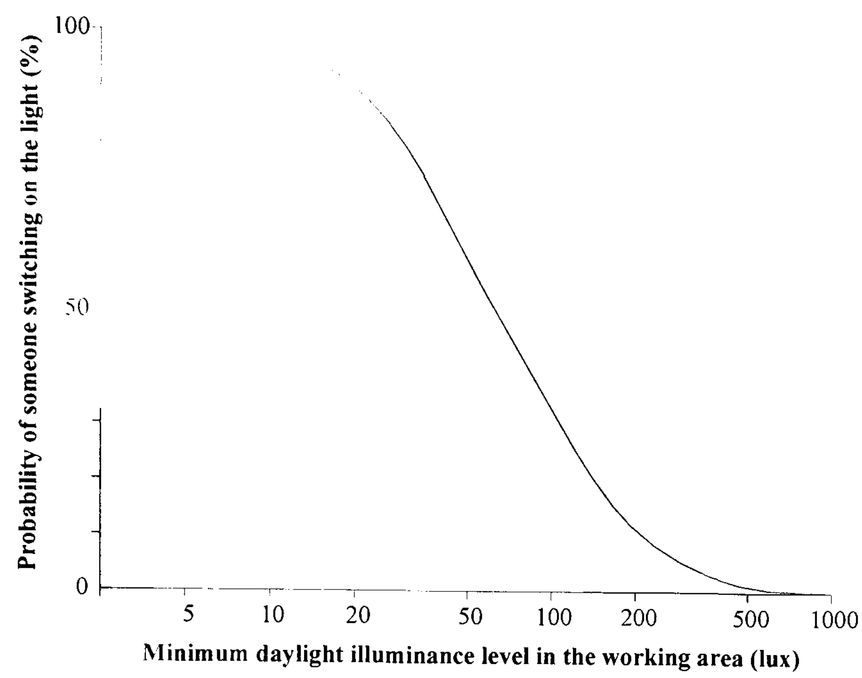


Figure 9.4. The probability for use of artificial lighting in a manually operated on / off switching control system (Erhorn, 2000b)

The use of continuous dimming gives a better-controlled combination of artificial and daylighting. The potential saving using a dimming control system is generally higher than with a switching control system, because the interior illuminance generated by electric light is varied in full response to the level of interior daylight. There are two different continuous dimming control systems in RADLINK:

- The ideal continuous dimming for all reference points (ICD)
- The continuous dimming at reference point (CDRP).

Each lighting control (of the seven types previously described) is used for the simulation of the 14 case studies in order to examine the savings potential of each lighting system in accordance with the daylighting design variables. Therefore each room has seven lighting control scenarios, and its energy simulation is run seven times in sequence.

9.3.1.3.5 Base load of dimming system

Continuous dimming systems adjust the interior illuminance generated by the electric lighting system in response to the level of interior daylight, down to a base load depending on the ballast type used. Base load of the dimming system (%) defines the minimum fraction of power to which the lighting system can be reduced. The base load of conventional ballast ranges from 15 to 25%, depending on the system, whereas electronic ballast has a base load of approximately 0%. In this study, the default value of 1.4% has been adopted for all the simulations.

9.3.2 Simulation Output

The results gained in RADLINK simulations are stored in two different files. The *.sum file contains monthly values for potential energy savings (Figure 9.5) and the *.hea file, hourly values for internal heat loads due to lighting and (daylight optimized) shading coefficients. The latter file type may be used for linking RADLINK results to thermal simulation programs, but that is not the aim of this research.

The *.sum files may be displayed in the form of two-dimensional curves using the *Energy Plot* integrated tool (Figure 9.6). Using the ADELINE Energy plot tool, only rooms and / or room scenarios can be compared with each other. In this research, it is required to study the energy saving potentials of the whole building design, to compare the 14 case studies to each other, and to analyse rooms / buildings according to their orientation and daylighting design variables. A spreadsheet is used to perform the calculation and analysis of the simulation results. The results of RADLINK simulations of all rooms have been copied from the *.sum file and pasted into Excel worksheets. Accordingly, each simulated case study has a set of worksheets designed as the example shown in Appendix V, and described below. The data interpretation and analysis are presented in later sections of this chapter.

```
[ADELINE 2.1]
              Electrical Energy
      Month   Saved[kWh/mon]     Consumed[kWh/mon]

        1      0.0003     97.6497
        2      0.0002     88.1998
        3      0.0003     97.6497
        4      0.0002     94.4998
        5      0.0003     97.6497
        6      0.0002     94.4998
        7      0.0003     97.6497
        8      0.0003     97.6497
        9      0.0002     94.4998
       10      0.0003     97.6497
       11      0.0002     94.4998
       12      0.0003     97.6497
SAVED ELECTRICAL ENERGY          :    0.00 [KWh/a]
(BASE 100 IGHT ON AT WORKINGTIME)

TOTAL YEARLY WORKING HOURS         :  3285.00 [h/a]
TOTAL YEARLY LAMP OPERATING HOURS  :  3285.00 [h/a]
TOTAL YEARLY SWITCH-ON HOURS       :  3285.00 [h/a]
NO ART. LIGHT REQUIRED REFERRING TO WORKING TIME : 0.0 [%]
```

Figure 9.5. Example of *.sum file generated by RADLINK as a result of one room simulation.

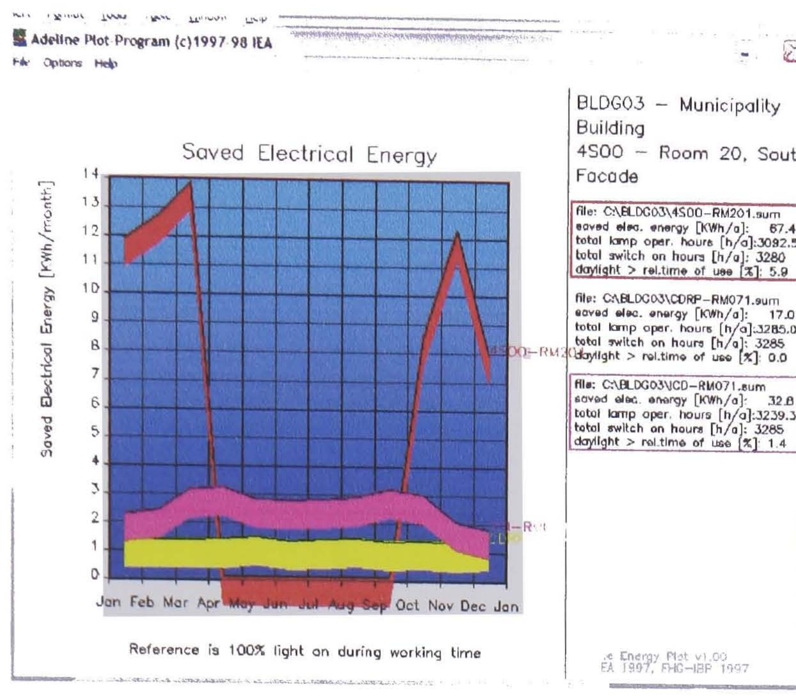


Figure 9.6. Exemplary display of *.sum file

9.3.2.1 *Rooms Data*

Seven worksheets cover the simulation outputs in the seven scenarios of lighting control strategy (Appendix V). In each worksheet, the area and the required power density (W/m^2), total power (in W), work surface illuminance (in lux) and luminance efficacy (in lm/W) of each room are first assigned. Secondly, the monthly values of the total electrical energy saved and energy consumed (in kWh) are imported from RADLINK output files for all the rooms, and consequently the monthly total energy saved and energy consumed in the whole building are calculated. Afterwards, the electrical energy saved and energy consumed per square meter (in kWh/m^2/month) are calculated separately for each room, and for the whole building. It is to be noted that the rooms have been put in order and classified according to their orientation (North, South, East / West, and internal rooms). The RADLINK energy output includes calculation of the total yearly working hours, total yearly lamp operating hours, total yearly lighting switch-on hours, and the percentage of hours from total working hours when no artificial lighting is required. These data are given in the last four rows of the results worksheet, but not used in the analysis because these values cannot be summarised or generalised while considering the whole building.

9.3.2.2 *Building Data*

The eighth worksheet of Apeendix V includes the energy performance of the total building. Five different tables and charts describe the monthly pattern of the total electrical energy saved and consumed, in kWh/month, the electrical energy saved and consumed per unit area, in kWh/m^2/month, and the percentage of energy saved from consumed energy, for the seven different lighting control scenarios. These scenarios are compared to the worst case, where electric lighting is on continuously during working time without any consideration of the available interior daylight levels (abbreviated in the tables as 'No. Cont.'). The percentages of energy saved are also calculated according to the consumption in the worst case scenario.

9.3.2.3 *Data of Rooms with Different Orientation*

The ninth worksheet of Appendix V includes the energy performance of rooms according to their orientation. In this worksheet, tables and charts describe the pattern of monthly energy consumption and potential savings per unit area of north rooms, south rooms, east / west rooms and internal rooms. Consecutively, the percentages of possible savings in each orientation for the seven scenarios are also calculated.

The last worksheet of this data set consists of graphs comparing the energy pattern (saved and consumed per unit area) of each façade orientation for the seven lighting control scenarios.

9.4 Investigation and Analysis of Simulation Output

This section aims to illustrate and critically analyse the simulation results of the 14 selected office buildings in Beirut. As mentioned previously, the electric lighting performance of seven different lighting control scenarios is assessed. The relationships between the simulation results and daylighting design variables and performance evaluation studied in Chapters 7 and 8 are respectively checked.

9.4.1 Daylight Performance Evaluation / Energy Pattern

The relationship between daylight performance evaluation of office building designs in Beirut, and the simulation results of their energy patterns is illustrated in Figure 9.7.

Figure 9.7a draws the relation between the simulated energy consumption and daylighting performance evaluation of the total building design. The two curves have clear inverse shapes; i.e. the increase of consumed energy for lighting office buildings in all historical phases is constantly coupled with a decrease of daylighting performance evaluation figures obtained from the developed tool in Chapter 8. This result in some ways validates the designated method for evaluating the daylighting performance of office buildings in Beirut described in chapter 5.

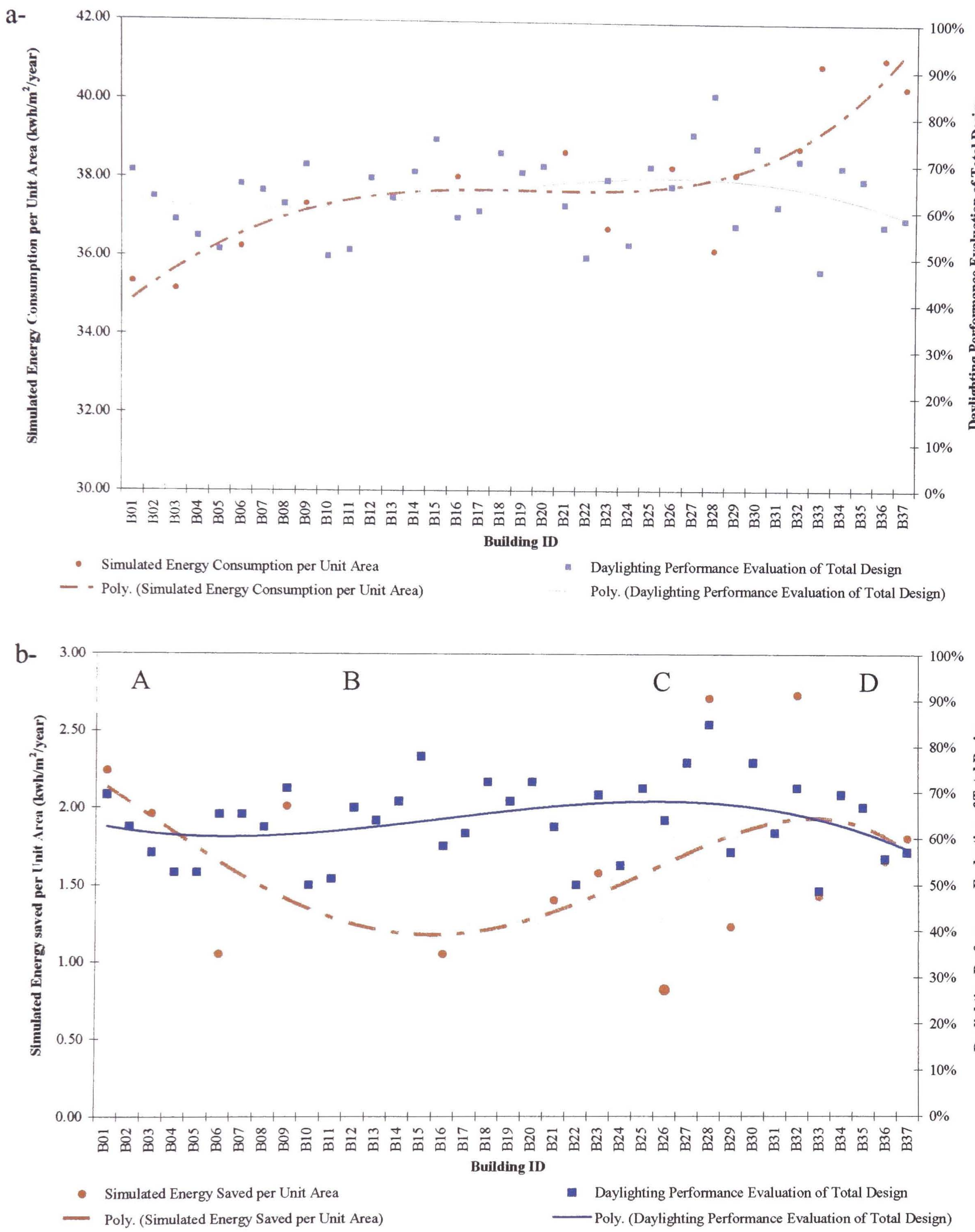


Figure 9.7. Relationship between daylighting performance evaluation of total the building design and: a- simulated energy consumption per unit area; b- simulated energy potential savings per unit

Figure 9.7b draws the relationship between potential energy savings, due to daylight and electric light integration, and the daylighting performance evaluation of the total design of office buildings in Beirut. The relationship between these two parameters is multifaceted; accordingly the graph shown in Figure 9.7b can be divided into 4 sections referred to as A, B, C and D. In section A, potential energy savings are high and daylighting performance evaluation is low, due to small and narrow windows in these early stage buildings. The combination of small openings with shallow office spaces explains the high potential savings. In Section B, the change in façade design produced an improvement in daylighting performance, which results in low savings with extra efficient measures. Section C is a peculiar case, where evaluation shows good lighting but savings seems to be high. This can be explained in the light of the discussion in Sections 7.3.5 and 7.3.6, as the buildings of this period have exceeded levels of daylighting due to the uncontrolled use of large glazing areas. The surprisingly low daylight efficiency of buildings in section D led to low levels of potential lighting savings, with the application of lighting efficiency measures. This is due to the 'Imitative' architecture discussed in Section 7.3.7, where façade configuration and plan morphology are not congruent. In addition, the base cases that were analysed by the Lebanese Energy Standards Project do not take daylighting as a factor that helps reduce electric lighting consumption. Potential savings due to optimal thermal performance of office buildings are the main concern of the cited project. The impact of façade configuration and plan morphology on daylighting performance was not considered in the base cases design, so possible lighting savings due to daylight and electric lighting integration have been disregarded.

9.4.1.1 *The Impact of Orientation on Energy Pattern*

In general, different wall orientations receive different amounts of sunlight during the day and throughout the seasons; the optimal window design will differ for each orientation, as will the lighting controls. Hence, before studying the relationship between the diagrammatic description of buildings' daylighting performance and their potential savings pattern, it is essential to study the impact of orientation on the monthly electric lighting potential savings pattern for each lighting control scenario.

In the simulation results worksheets (Appendix V), the potential savings of rooms simulated separately are classified according to room orientation; i.e. north, south, east/

west and internal rooms. An example of such analyses is shown in Figure 9.8. The same analyses have been done for the 14 selected buildings for simulation.

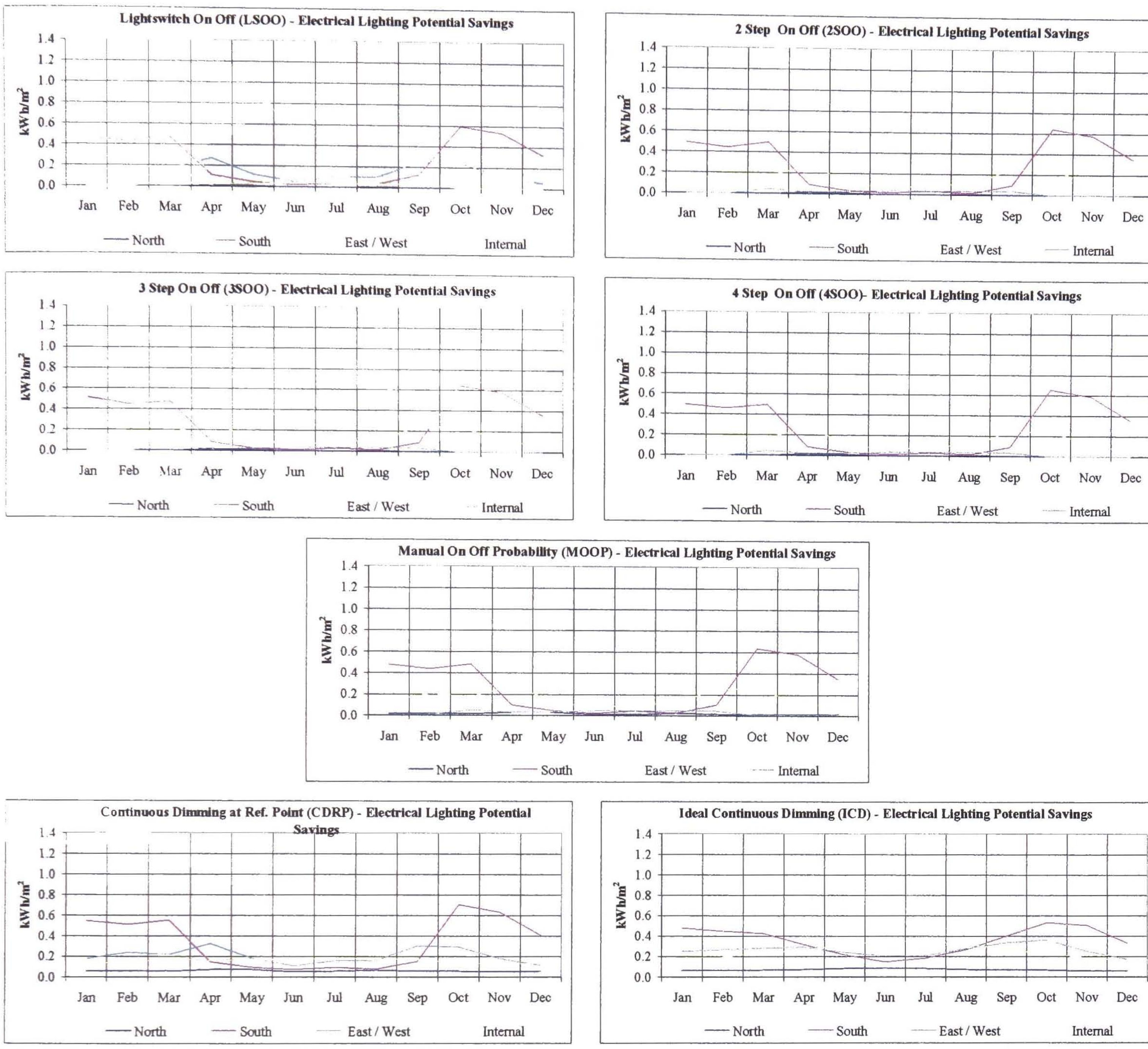


Figure 9.8. Example of simulation results illustrating the impact of orientation on the monthly electrical lighting potential savings for the seven lighting control scenarios.

The analysis of all the simulated buildings shows that the potential savings in the north façade rooms, and for all the lighting control scenarios are almost constant and negligible; the potential savings in most cases does not exceed 0.1 – 0.2 kWh/m^2/month. In addition, the percentage of possible savings from simulated electric lighting consumption does not pass 2.5% in most cases. Since the sun only strikes a north-facing window in early morning and late evening during midsummer, the near-constant availability of diffuse skylight can provide uniform daylighting without controls.

The potential savings pattern of the south facing rooms does not follow the pattern of savings in the north facing rooms, because south facing windows provide high luminous levels and somewhat variable illumination. The potential savings in electric lighting of the south rooms are higher in winter months than summer months (Figure 9.8). For most cases the possible savings in electric lighting drop in March - April, then become almost constant and for some cases negligible in the summer months, especially when lightswitch controls are applied. In September – October potential savings increase, and change slightly during October and November. The lowest potential savings in winter months occur in December, when there is the shortest period of daylight in a day and sunlight exposure is the least. In addition possible electric lighting savings are higher in winter months than summer months, because of the lower sun angle. Daylight penetrates deeper into the interior spaces, and the possible savings become higher.

The possible savings in the east and west rooms have approximately the same pattern as the south rooms, but with lower values. Daylight variability is high, since these orientations provide only half-day exposure to sunlight; the east orientation provides a high level of illumination in the morning, while that to the west is high in the afternoon. On the other hand, it is difficult to control daylight penetration in east and west facades because of low sun angles throughout the year. Figure 9.8 shows that potential savings are higher during the vernal (March – April) and autumnal (September –October) periods, and decrease in winter and summer months. However, the variation of potential savings between winter and summer months does not show a strong drop.

As for the internal rooms, in most cases where there is no daylit core, potential savings are nil. However when a building has a considerable porosity ratio, potential savings would have a different pattern. In Figure 9.8, the Ideal Continuous Dimming (ICD) scenario shows that potential savings increase gradually throughout the year to reach their maximum in June, and decrease again to reach the minimum possible savings in December.

The above paragraphs have given a general description of the possible electric lighting savings of each façade orientation. Some case studies have shown slightly different results. A more comprehensive view is described in the following sections, where the potential savings in each building are described in more detail and are related to the daylighting performance of the total building design.

9.4.1.2 *Diagrammatic Description of Daylighting Performance Evaluation / Energy Pattern Relationship*

In this section, the relationship between the shape of the descriptive diagram curve and the shape of energy potential savings curves of the 14 simulated cases is examined. The aim of this analysis is to set guidelines to predict the pattern of monthly potential energy savings, by preliminary evaluation of daylighting performance of the total building design.

In previous sections, daylight and lighting potential savings have been performed for seven different scenarios of electric lighting control strategies; five on / off lightswitch control scenarios, (LSOO, 2SOO, 3SOO, 4SOO and MOOP), and two dimming control scenarios (ICD and CDRP). It is quite clear, in the 14 simulated cases that the potential savings due to the adoption of on / off lightswitch control show almost the same performance pattern. The potential savings of the Manual On / Off Probability (MOOP) scenario are slightly higher than the possible savings of the automated on / off lightswitch (LSOO) and multi-step lightswitch (2SOO, 3SOO and 4SOO) scenarios. The potential savings of the Continuous Dimming at Reference Point (CDRP) and Ideal Continuous Dimming (ICD) scenarios are higher than the on / off lightswitch control strategies, because the interior illuminance generated by electric light is varied in full response to the level of interior daylight. In all the cases selected for simulation, the CDRP scenario has the same pattern of monthly potential energy savings as on / off lightswitch control scenarios, because daylight and electric integration is calculated according to the same reference point of the working plane. The monthly potential savings pattern of the ICD control strategy is different from the other six scenarios, because daylight and artificial lighting integrate according to the level and distribution of daylight at the considered reference points of the interior space (nodes density: 0.5m between two adjacent nodes, see Appendix IV). Accordingly, the difference of ICD potential savings pattern from the other lighting control scenarios patterns warrants examination. The difference in pattern of monthly potential savings between ICD scenario and the other lighting control scenarios identified seven categories of buildings. Buildings of categories A and B for example have almost constant ICD potential savings along the year while monthly potential savings of lightswitch control and CDRP vary (Figure 9.9 and Figure 9.10). On the other hand, ICD monthly potential savings of category C buildings have the same patterns as the other lighting control scenarios. The similarity or difference in Lighting control strategies performance are therefore compared to the performance evaluation diagram of the buildings. A detailed explanation of the seven identified categories is given below.

- Category A (Figure 9.9): The high performance evaluation of 'Building Shape', 'Window / Office', and 'Shading Devices' parameters, along with the low performance evaluation of 'Window / Façade' parameter, generate minimal electrical lighting potential savings during the vernal and autumnal equinox months (March and September). Potential savings increase to reach maximal values in January and June (Solstices). The potential savings in winter months are high, because the entire east / west variables and the southern 'Window / Office' variables have good daylighting performance evaluation. In addition, the high porosity ratio of the building shape which in turn increases building shape and envelope to floor area ratios, increases the possible lighting savings during summer months as well. The potential electric lighting savings pattern of the ICD scenario is linear, when compared to lightswitch and CDRP lighting control scenarios. In addition to the previous explanations, this linearity is due to the high daylighting performance evaluation of 'Window / Office' variables. This high performance indicates better lighting distribution in the interior spaces. Accordingly, the recommended illumination level is available at all reference points, and electric lighting savings are possible throughout the year.

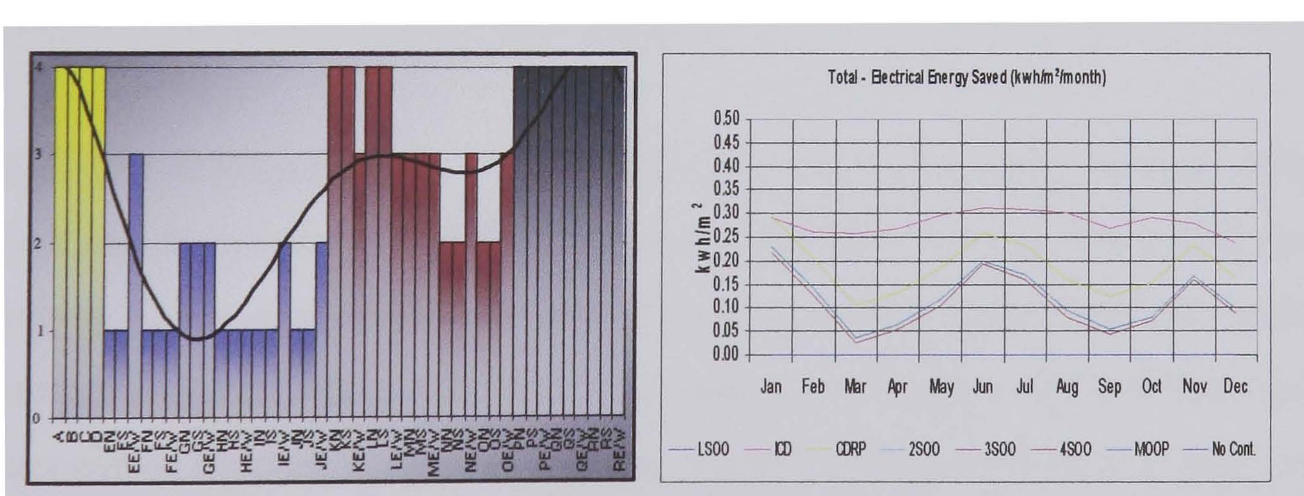


Figure 9.9. Category A of the descriptive diagram / lighting potential savings curves shape classification, which includes B01.

- Category B (Figure 9.10): Compared to category A described previously, the building in this category somehow shows an inverse potential savings pattern in summer months. The average performance evaluation of 'Building Shape', 'Window / Façade', and 'Window / Office' parameters, along with the high performance evaluation of the 'Shading Devices' parameter, generate maximal potential savings during winter months and minimal during the period between May and August. Compared with category A, the change in summer potential savings is due to the decrease in 'Building Shape' variables performance evaluation.

The potential savings pattern of the ICD scenario is almost linear along the year, or more precisely the difference in potential savings is not large. This can be explained by the high performance evaluation of 'Window / Office' variables, and window shape coefficient due to the use of vertical windows. Consequently, daylight flows deeper into the interior space and enough daylight is available during the whole year.

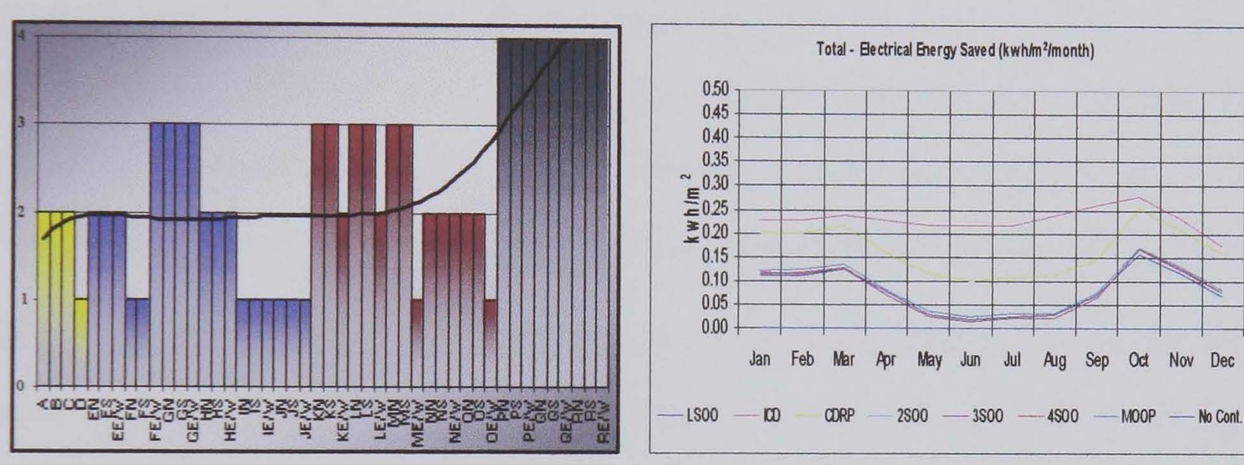


Figure 9.10. Category B of the descriptive diagram / lighting potential saving curves shape classification, which includes B03.

- Category C (Figure 9.11): In this category potential lighting savings, rather like category B, are maximum in January and February. Savings start to decrease in March, reach minimal values during summer months until September when they start to increase again, and reach high values in October. The difference between categories B and C is that all lighting control scenarios show the same potential savings pattern, including ICD. The diagrammatic description shows that the performance evaluation of 'Building Shape', 'Window / Façade', and 'Window / Office' parameters mostly vary between 2 and 3. The control of sunlight on the south and east façades by shading devices diffuses sunlight into the interior and makes the daylight flow pattern uniform. Accordingly daylight illumination is approximately similar at different reference points, and the possible savings due to ICD strategy are in turn the same as the other lighting control strategies.

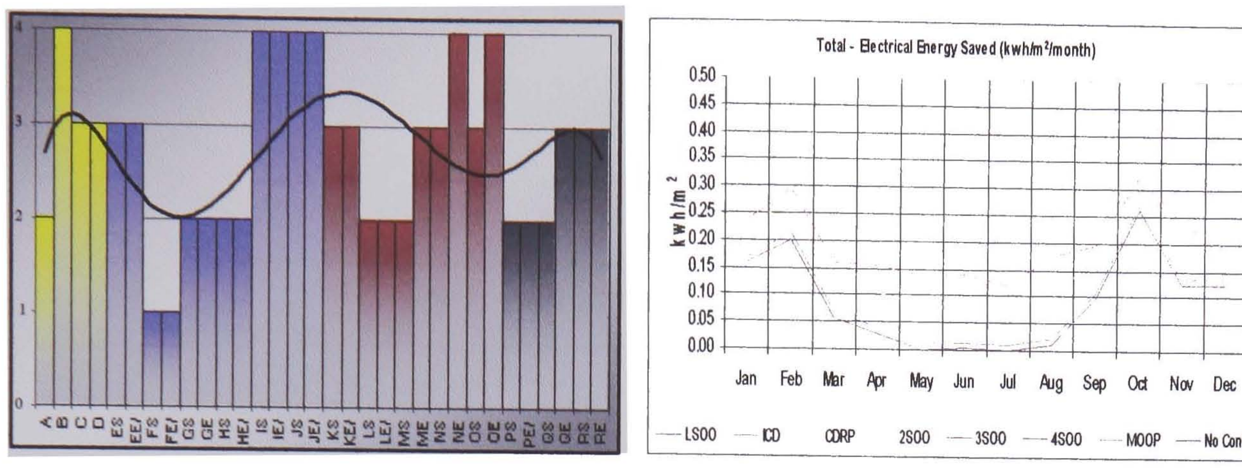


Figure 9.11. Category C of the descriptive diagram / lighting potential savings curves shape classification, which includes B09.

- Category D (Figure 9.12): The potential savings patterns due to on/off lightswitch control and CDRP of this category are almost similar to categories B and C, but have slightly different shape with ICD. Potential savings are maximal in January, drop in February-March period to minimal values, persist almost constant until September – October period, and increase again in November and December.

  The potential savings produced by the Ideal Continuous Dimming Strategy are also highest in winter months and lowest in summer months, but the decrease between months is gradual. In all the buildings in this category, the smallest possible savings from ICD lighting strategy occur between May and July. Potential savings in electric lighting are higher in autumn and spring seasons.

  Analysing the descriptive curves of daylighting performance evaluation, it is found that in the four cases, the performance evaluation of 'Window / Façade' and 'Shading Devices' parametric levels are prominent. The same potential savings behaviour results for B28, where design analysis shows high performance evaluation of all parametric levels, as revealed by the curve altering between values 3 and 4 (second case of Figure 9.12). In this case, the potential savings of on/off lightswitch control scenarios are higher than the other cases where evaluation curves vary between values 2 and 3 (B21, B36, and B37; Figure 9.12). On the other hand, the difference in potential savings pattern between B21 and the other buildings of the same category is explained by the irregularity of the evaluation diagram. The application of shading devices in the north and south façades is another factor changing the potential savings pattern.

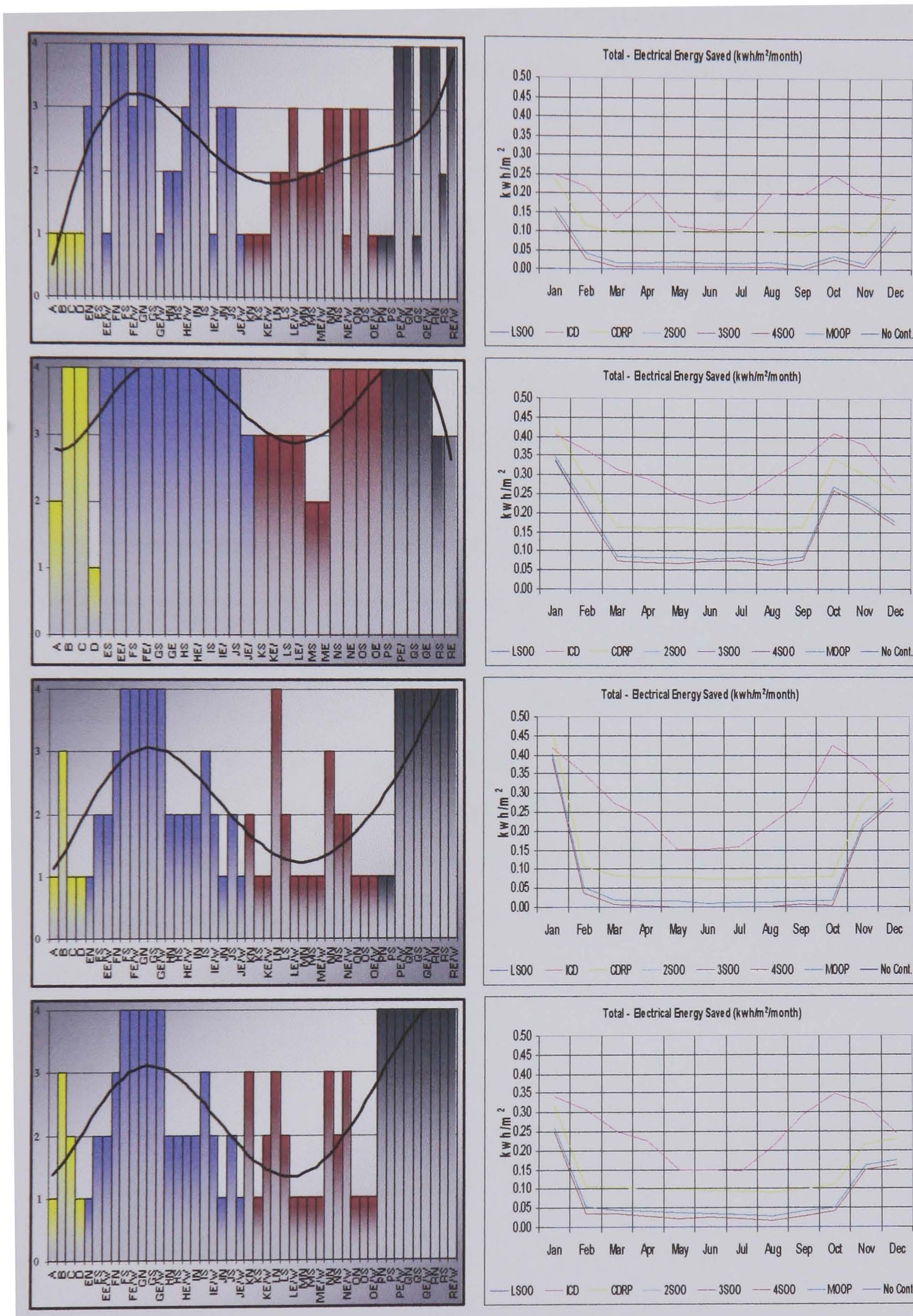


Figure 9.12. Category D of the descriptive diagram / lighting potential savings curves shape classification, which includes B21, B28, B36 and B37 (order from top to bottom).

- Category E (Figure 9.13): simulation results of this category shows that electric lighting potential savings are almost uniform during the whole year for all electric lighting control scenarios, including ICD. The descriptive curves of daylight performance evaluation of the three buildings do not follow the same shape. Nevertheless, the cases listed in this category have some similarities in their daylighting performance evaluation. The first building is marked by high daylight performance evaluation of 'Building Shape' and 'Shading Devices' parametric levels, accompanied by moderate performance (evaluation equal to 2) of 'Window / Façade' and 'Window / Office' parametric levels. The high performance evaluation of porosity ratio, daylight buffer zone and limiting depth rule in the south offices allow a better daylight distribution in the building throughout the year. Compared to B06, the other two cases of this category (B32 and B33) only have a good performance evaluation of compactness ratio, porosity ratio, projection ratio and overhang ratio. B32 has higher performance evaluation of 'Window / Façade' and 'Window / Office' parametric levels. This results in further possible electric lighting savings but of similar pattern to B06 and B33. Regarding B33, the maximal performance evaluation of only the northern 'Window / Façade' variables and the low performance evaluation of 'Window / Office' parametric level justify the high and almost constant possible lighting savings throughout the year.

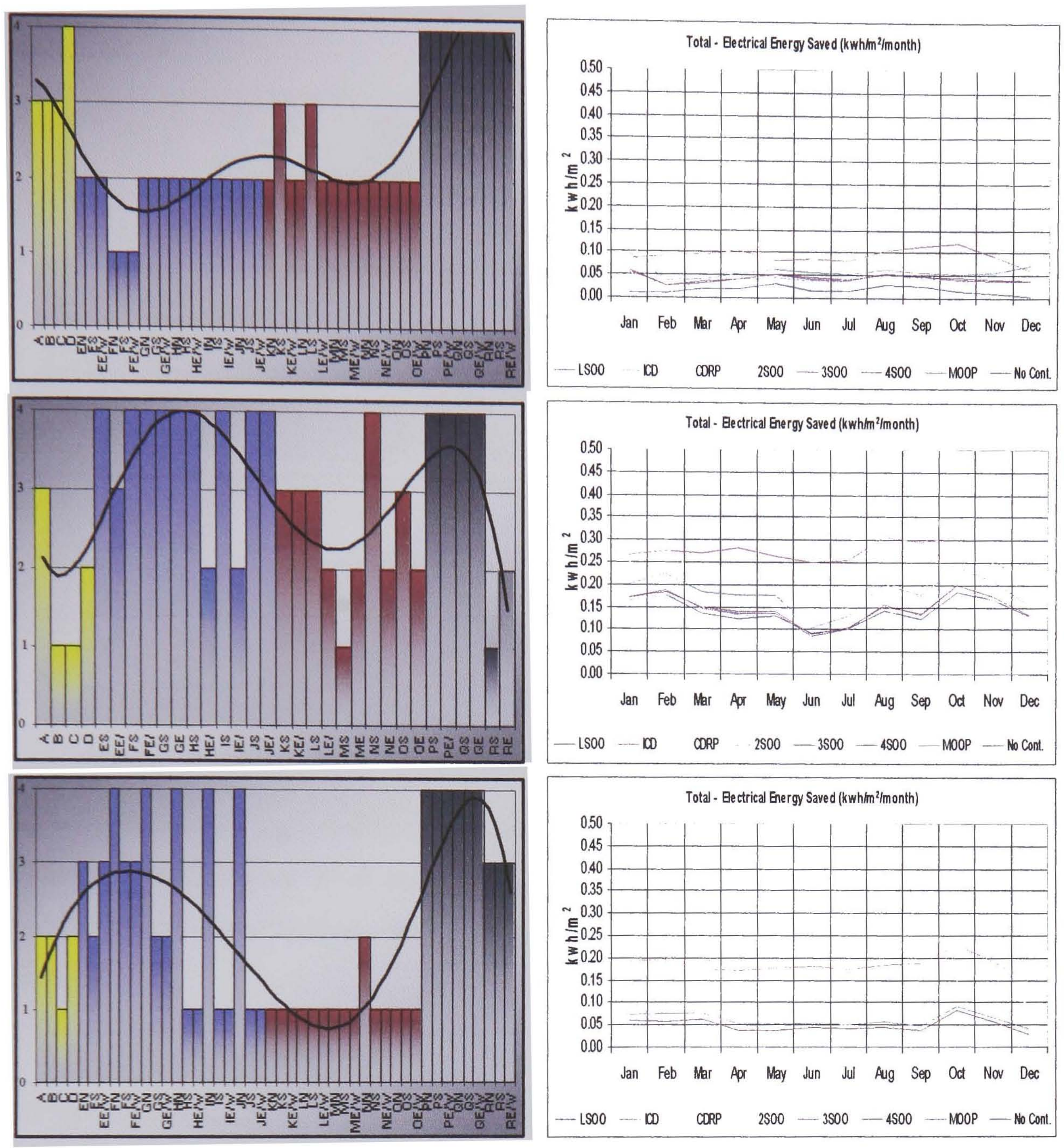


Figure 9.13. Category E of the descriptive diagram / lighting potential savings curves shape classification, which includes B06, B32 and B33 (order from top to bottom).

- Category F (Figure 9.14): regardless of having almost the same diagrammatic description curve as B32 (Figure 9.13), B23 and B26 have different electric lighting potential savings. The difference is that buildings of this category have minimal performance evaluation of compactness ratio and porosity ratio, as well as inferior 'Shading Devices' performance. Despite the high performance evaluation of 'Window / Façade' and 'Window / Office' variables, the potential lighting savings are relatively low because of the deep building shape and controlled daylight penetration due to shading devices; the potential savings of B26 are lower than B23, because B26 has lower 'Window / Office' and 'Shading Devices' performance evaluation.

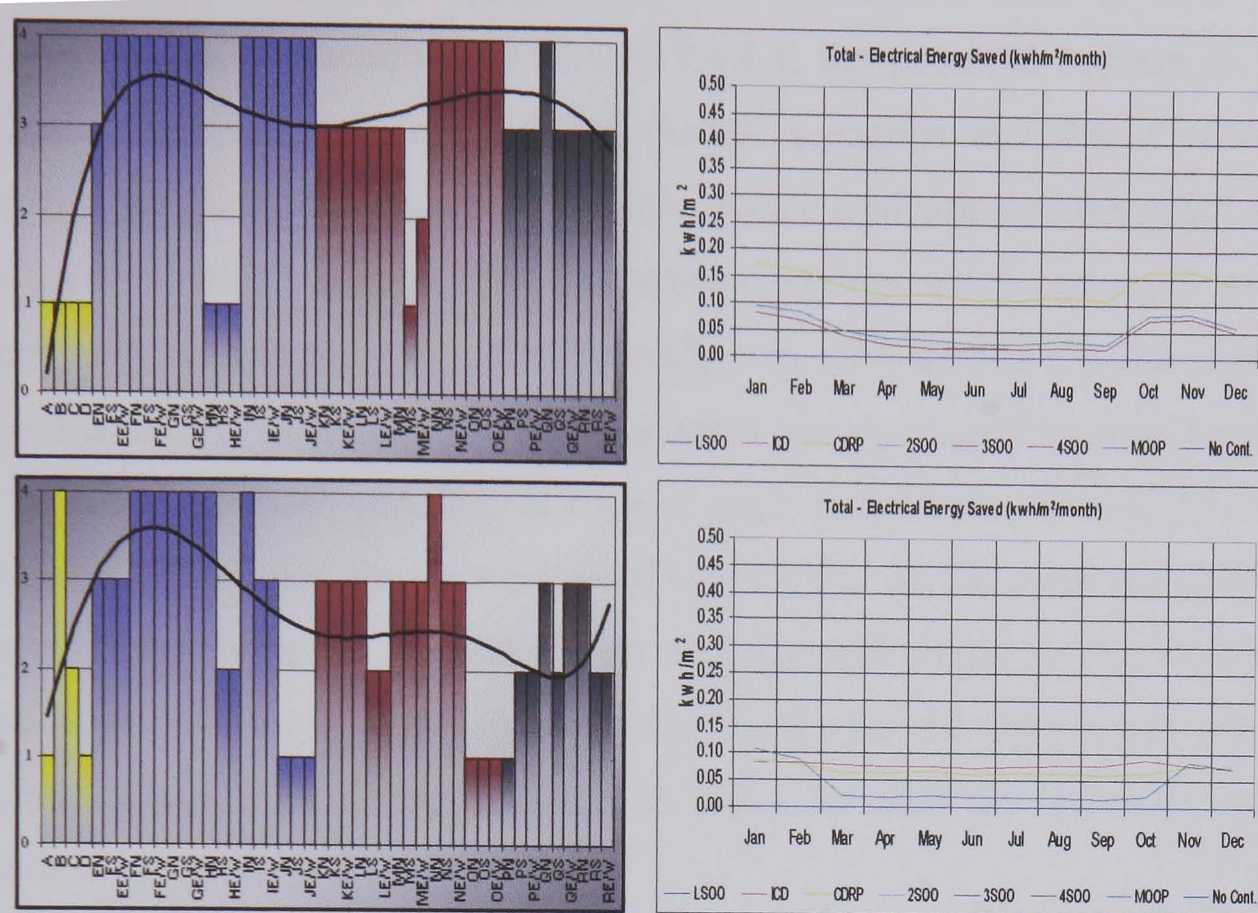


Figure 9.14. Category F of the descriptive diagram / lighting potential savings curves shape classification, which includes B23 and B26 (order from top to bottom).

- Category G (Figure 9.15): In this category, the potential electricity savings due to on / off lightswitch control are almost negligible throughout the whole year. This is not the case for continuous dimming strategies. The simulation results of continuous dimming at reference point scenario (CDRP) for both cases show considerable and constant potential savings throughout the year. As for ideal continuous dimming strategy (ICD), the potential savings are similar to CDRP for building B16 but largely increase and change in pattern in the second building of this category (B29). Having a north / south orientation with zero porosity ratio, building B29 has a different ICD potential savings pattern from that described in section 9.4.1.1. Potential savings of ICD strategy are almost constant between January – March, increase to reach peak savings in June, and decrease gradually to reach their minimal value in December.

Comparing the daylighting performance evaluation diagrams (Figure 9.15), the two buildings show noticeable irregularity among their different façade orientations. In building B16 the performance evaluation of most variables varies between values 1 and 2, except for most north orientation variables that have maximal values (except daylight buffer zone K_N and limiting depth rule L_N). Nevertheless, as described in section 9.4.1.1, the potential savings in the north façade rooms for all the lighting control scenarios are almost constant and negligible. Accordingly, with low performance evaluation of the south and east / west orientation variables, lighting potential savings are constant and low, and do not vary even in the case of ICD strategy. In B29, despite the low performance evaluation of 'Window / Façade' variables, the good performance evaluation of 'Window / Office' variables permits a good distribution of daylight in internal spaces. In addition, the application of vertical fins on the north and south façades allows the reflection of east / west sunlight and improves the distribution of daylight into the interior space. Accordingly, the possible availability of task illumination level through the day is higher at different reference points, and therefore potential savings increase.

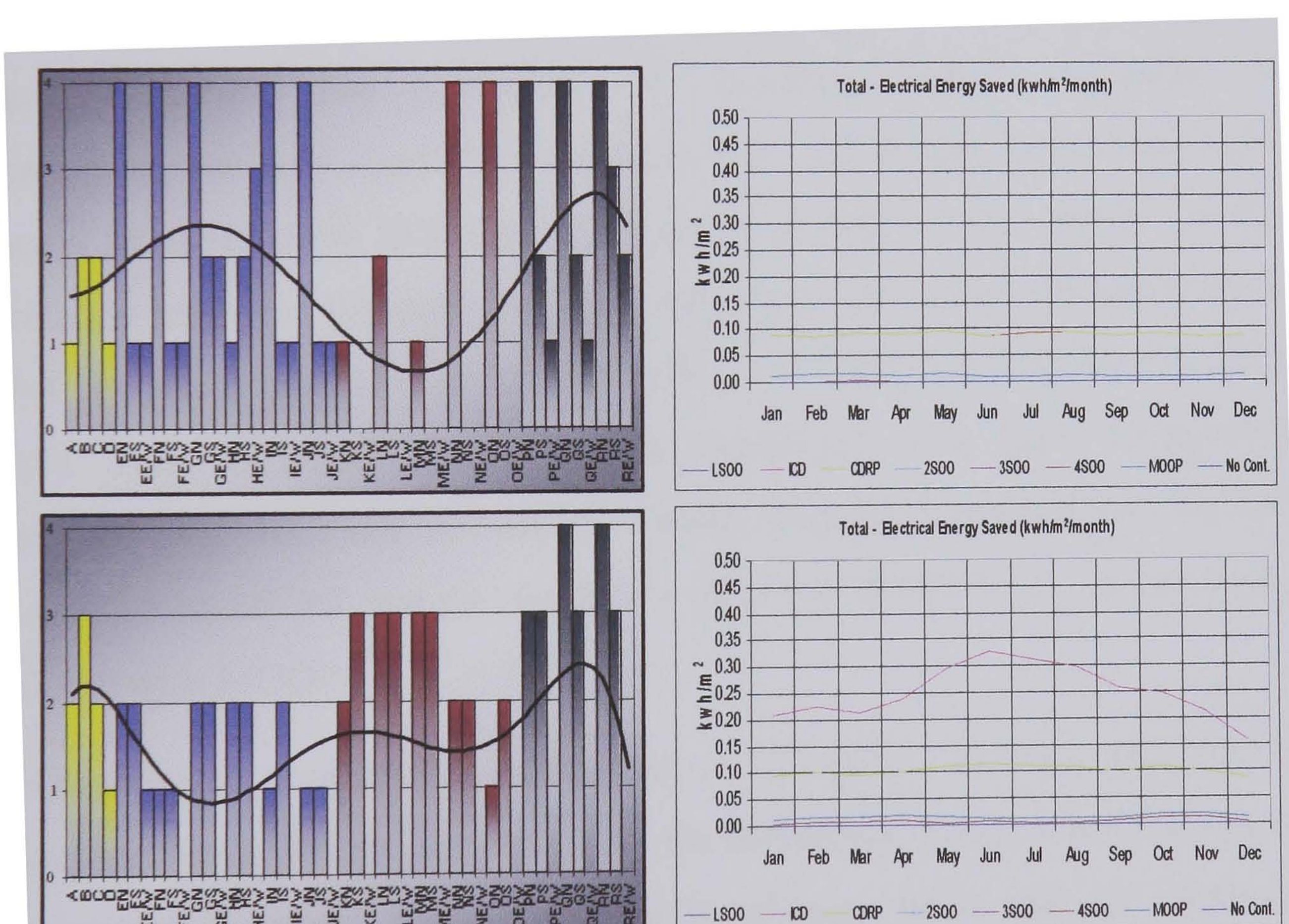


Figure 9.15. Category G of the descriptive diagram / lighting potential saving curves shape classification, which includes B16, and B29 (order from top to bottom).

9.4.1.3 *Daylighting Performance Evaluation and Energy Behaviour Relationship*

Correlation of daylighting performance evaluation of each parametric level with simulation outputs (total energy consumed, total potential savings and percentage of potential savings from energy consumption) has been examined for the seven different scenarios of lighting control strategies. Pearson's correlation values are illustrated in Table 9.2, Table 9.3, and Table 9.4. In these tables, the level of significance of Pearson's r is marked according to a 2-tailed test: * correlation is significant at 0.1 level when $r \geq 0.458$, ** correlation is significant at 0.05 level when $r \geq 0.532$, *** correlation is significant at 0.02 level when $r \geq 0.612$, and **** correlation is significant at 0.01 level when $r \geq 0.661$ (Price, 2000). It is to be noted that in scientific and social research, the acceptable level of correlation significance should not be more than 0.05.

9.4.1.3.1 Correlation of daylighting performance evaluation with simulated electric lighting consumption

Table 9.2 shows that 'Window / Office' and 'Building Shape' performance evaluation values have high correlation values with the simulated total electric lighting consumption per unit area. Both parameters correlate negatively with total consumption, in all lighting control scenarios. The correlation of 'Building Shape' evaluation with energy consumption has only significant values in on / off lightswitch control scenarios, where Pearson's r varies from -0.553 to -0.580 (level of significance = 0.05). On the other hand, correlation between 'Window / Office' evaluation and energy consumption is the highest with Continuous Dimming at Reference Point (CDRP) lighting control. (Pearson's r = -0.718). This correlation becomes less significant with Ideal Continuous Dimming (Pearson's r =-0.586) and on / off lightswitch strategies (Pearson's r= -0.549 with 2SOO, r = -0.634 with LSOO, and r = -0.668, r = -0.664 with 3SOO, r = -0.664 with 4SOO and r = - 0.660 with MOOP).

The daylighting performance evaluation of 'Window / Façade' and 'Shading Devices' parametric levels do not correlate with the simulated energy consumption per unit area, respectively. However, these correlational analyses show that the highest Pearson's r occurs in the Ideal Continuous Dimming scenario (Table 9.2). The variables of 'Window / Façade' parametric levels, which draw the relationship between the window opening and the office as a volume, are indicators of daylighting flow pattern in the interior space. In addition, the presence of shading devices affects the distribution of reflected sunlight and diffuse daylight into the interior spaces. Accordingly, energy consumption in the ICD scenario, where lighting simulation is performed in accordance to daylight availability at multiple reference points, has higher correlation values with Window / Façade' and

'Shading Devices' parametric levels evaluation than that of the on/off lightswitch scenarios.

The simulated results of energy consumption show correlation of low significance (level of significance 0.1) with daylighting performance evaluation of all the designs of office buildings in Beirut (Table 9.2). Continuous Dimming at Reference Point (CDRP) scenario has the highest correlation value, 0.05 level of significance, between the abovementioned variables. Therefore, it can be concluded that the proposed method of daylighting performance evaluation can barely predict the consumption of the building. However, correlational analysis of performance evaluation and potential energy savings showed different results.

Correlation Analysis of Total Energy Consumed (kWh/m²/year) with Daylighting Performance Evaluation Values						
Lighting Control Scenarios		Total	Building Shape	Window / Façade	Window / Office	Shading Devices
Switch On / Off	Automated (LSOO)	-0.499 *	-0.580 **	-0.182	-0.634 ***	-0.081
	2 Step (2SOO)	-0.469 *	-0.554 **	-0.182	-0.549 **	-0.159
	3 Step (3SOO)	-0.526 *	-0.564 **	-0.148	-0.668 ****	-0.064
	4 Step (4SOO)	-0.511 *	-0.560 **	-0.162	-0.664 ****	-0.061
	Manual Probabililty (MOOP)	-0.476 *	-0.553 **	-0.181	-0.660 ***	-0.014
Continuous Dimming	at Reference Point (CDRP)	-0.545 **	-0.519 *	-0.092	-0.718 ****	-0.014
	Ideal (ICD)	-0.461 *	-0.462 *	-0.205	-0.586 ***	-0.298

Table 9.2. Correlation analysis of simulated total electric lighting consumption ($kWh/m^2/year$) with daylighting performance evaluation values.

9.4.1.3.2 Correlation of daylighting performance evaluation with potential savings

Table 9.3 and Table 9.4 show that the total design performance evaluation of office buildings in Beirut has significant correlation with simulated electric lighting potential savings for all lighting control scenarios, except ICD. Therefore, the daylighting performance evaluation of the total design of office buildings, i.e. the sum of the four parametric levels evaluation, can be considered an indicator for predicting the possible electric lighting savings due to the integration of daylighting and electric lighting. Nevertheless, this evaluation method is not accurate enough to predict the potential savings due to the application of the ICD strategy. In addition, to predict potential savings the evaluation of the four parametric levels should be considered together and not separately, as Table 9.3 and Table 9.4 show no significant correlation between the potential savings and evaluations of the four considered parametric levels, respectively. However, the correlation values of 'Building Shape' and 'Window / Façade' parameters evaluations with potential savings are higher than correlation values of 'Window / Office' and 'Shading Devices' evaluations (Table 9.3 and Table 9.4). It is of note that 'Shading Devices' performance evaluation correlates with the potential savings only in the ICD scenario. Therefore, the control of daylight has a greater effect on the distribution of daylight than does the available illumination level in interior spaces. Accordingly, the 'Building Shape' and 'Window / Façade' variables should be more significant for potential savings. Accordingly, these relationships are studied extensively in the following sections.

Correlation Analysis of Total Energy Saved (kWh/m²/year) with Daylighting Performance Evaluation Values							
Lighting Control Scenarios		Total	Building Shape	Window / Façade	Window / Office	Shading Devices
Switch On / Off	Automated (LSOO)	0.562 **	0.346	0.313	0.111	0.256
	2 Step (2SOO)	0.581 **	0.399	0.292	0.105	0.288
	3 Step (3SOO)	0.581 **	0.395	0.296	0.104	0.286
	4 Step (4SOO)	0.583 **	0.397	0.296	0.104	0.286
	Manual Probabililty (MOOP)	0.615 ***	0.378	0.378	0.147	0.156
Continous Dimming	at Reference Point (CDRP)	0.588 **	0.275	0.346	0.194	0.259
	Ideal (ICD)	0.287	0.160	0.044	0.022	0.565 **

Table 9.3. Correlation analysis of total electric lighting potential savings (kWh/m²/year) with daylighting performance evaluation values.

Correlation Analysis of Percentage Energy Saved from Consumed Energy with Daylighting Performance Evaluation Values						
Lighting Control Scenarios		Total	Building Shape	Window / Façade	Window / Office	Shading Devices
Switch On / Off	Automated (LSOO)	0.581 **	0.360	0.305	0.147	0.257
	2 Step (2SOO)	0.601 **	0.417	0.282	0.141	0.291
	3 Step (3SOO)	0.601 **	0.414	0.286	0.139	0.298
	4 Step (4SOO)	0.602 **	0.415	0.286	0.139	0.290
	Manual Probabililty (MOOP)	0.642 ***	0.403	0.369	0.191	0.157
Continous Dimming	at Reference Point (CDRP)	0.628 ***	0.288	0.344	0.280	0.239
	Ideal (ICD)	0.335	0.189	0.037	0.067	0.556 **

Table 9.4. Correlation analysis of percentage potential savings from simulated energy consumption with daylighting performance evaluation values.

9.4.2 The Impact of Daylighting Design Variables on Energy Behaviour

In this section, correlational analyses of energy simulation outputs with the considered daylighting design variables are investigated. The aim of this section is to examine the variables that have impact on lighting energy behaviour in office buildings in Lebanon. Accordingly, the relationship of daylighting variables of each parametric level are correlated separately with simulated electric lighting consumption, and potential savings of artificial lighting (potential savings per unit area and percentage of possible savings from simulated lighting consumption) respectively, using lighting control strategies.

9.4.2.1 *The Impact of 'Building Shape' Variables*

In previous sections it has been shown that 'Building Shape' performance evaluation correlates with simulated electrical lighting consumption, but has insignificant correlation with potential savings. In order to understand these relationships better, the correlation between energy behaviour and the four 'Building Shape' variables is investigated.

9.4.2.1.1 <u>Correlation of 'Building Shape' variables with simulated electric lighting consumption</u>

Pearson's correlations of 'Building Shape' variables with simulated electric lighting consumption are illustrated in Table 9.5. The correlation results show that electric lighting consumption per unit area correlates most with envelope to floor area ratio, and compactness ratio. These two variables have the highest Pearson's correlations with 'Building Shape' performance evaluation (Table 8.6). Therefore, building compactness ratio and envelope to floor area ratio are the most significant variables of 'Building Shape' parametric level that determine the electric lighting consumption pattern of office buildings in Beirut. It is to be noted that these two variables are not sufficiently accurate to predict the energy consumption when artificial lighting is controlled using continuous dimming strategies.

On the other hand, shape coefficient and porosity ratio are not significant enough to predict electric lighting consumption behaviour, as the two variables have insignificant Pearson's correlations with electric lighting consumption in all scenarios.

Correlation Analysis of Total Energy Consumed (kWh/m²/year) with 'Building Shape' Variables					
Lighting Control Scenarios		Compactness Ratio (A)	Shape Coefficient (B)	Envelope to Floor Area Ratio (C)	Porosity Ratio (D)
Switch On / Off	Automated (LSOO)	-0.530 *	0.348	-0.572 **	-0.414
	2 Step (2SOO)	-0.477 *	0.437	-0.612 ***	-0.330
	3 Step (3SOO)	-0.540 **	0.377	-0.594 **	-0.371
	4 Step (4SOO)	-0.544 **	0.368	-0.591 **	-0.378
	Manual Probabililty (MOOP)	-0.556 **	0.345	-0.577 **	-0.400
Continous Dimming	at Reference Point (CDRP)	-0.481 *	0.273	-0.522 *	-0.378
	Ideal (ICD)	-0.471 *	0.276	-0.493 *	-0.255

Table 9.5. Correlation analysis of simulated total electrical lighting consumption (kWh/m²/year) with 'Building Shape' variables.

9.4.2.1.2 Correlation of 'Building Shape' variables with potential lighting savings

Table 9.6 and Table 9.7 show no correlation between all the variables of 'Building Shape' parametric level and potential savings. Nevertheless, the Pearson's r values of envelope to floor area ratio and compactness ratio with potential savings are higher than the r values of shape coefficient and porosity ratio. In addition, continuous dimming scenarios show weaker correlation of 'Building Shape' variables with potential savings than do the on / off lightswitch control scenarios.

Therefore, it can be concluded that the compactness of the building and its envelope area are significant in shaping the electric lighting consumption of the building, but their values alone cannot envisage on their own the possible savings due to daylighting and electric lighting integration.

Correlation Analysis of Total Energy Saved ($kWh/m^2/year$) with 'Building Shape' Variables					
Lighting Control Scenarios		Compactness Ratio (A)	Shape Coefficient (B)	Envelope to Floor Area Ratio (C)	Porosity Ratio (D)
Switch On / Off	Automated (LSOO)	0.398	-0.207	0.354	0.246
	2 Step (2SOO)	0.422	-0.215	0.372	0.303
	3 Step (3SOO)	0.422	-0.203	0.361	0.304
	4 Step (4SOO)	0.423	-0.200	0.359	0.307
	Manual Probabililty (MOOP)	0.412	-0.201	0.334	0.282
Continous Dimming	at Reference Point (CDRP)	0.366	-0.135	0.291	0.169
	Ideal (ICD)	0.247	-0.121	0.216	0.014

Table 9.6. Correlation analysis of total electric lighting potential savings ($kWh/m^2/year$) with 'Building Shape' variables.

Correlation Analysis of Percentage Energy Saved from Consumed Energy with 'Building Shape' Variables					
Lighting Control Scenarios		Compactness Ratio (A)	Shape Coefficient (B)	Envelope to Floor Area Ratio (C)	Porosity Ratio (D)
Switch On / Off	Automated (LSOO)	0.409	-0.218	0.373	0.247
	2 Step (2SOO)	0.435	-0.228	0.393	0.307
	3 Step (3SOO)	0.435	-0.217	0.382	0.310
	4 Step (4SOO)	0.436	-0.214	0.380	0.312
	Manual Probabililty (MOOP)	0.427	-0.220	0.361	0.290
Continous Dimming	at Reference Point (CDRP)	0.374	-0.135	0.309	0.164
	Ideal (ICD)	0.271	-0.133	0.247	0.020

Table 9.7. Correlation analysis of percentage potential savings from simulated electric lighting consumption with 'Building Shape' variables.

9.4.2.2 *The Impact of 'Window / Façade' Variables*

Previous analyses have demonstrated that 'Window / Façade' performance evaluation does not have a significant correlation with the simulated electrical lighting consumption nor the potential savings. However, this section will study the strength of correlation relating each variable of this parametric level, which draw the relationship between window opening with the exterior façade of the building in general (wall to aperture ratio) and the office in particular, with the electric lighting behaviour. This comparative analysis of Pearson's correlation values will permit us to distinguish the variables that have more impact on the electric lighting behaviour.

9.4.2.2.1 Correlation of 'Window / Façade' variables with simulated electric lighting consumption

Table 9.8 illustrates the Pearson's correlations of 'Window / Façade' variables and simulated electric lighting consumption per unit area. The six variables of this parametric level do not have any significant correlation with simulated electric lighting consumption.

Nevertheless, aperture location has the highest negative Pearson's r value with lighting consumption per unit area, followed by window shape variable, which in turn correlates positively with the simulated consumption. It is of note that these two variables have higher Pearson's r in continuous dimming scenarios than in on / off lightswitch control scenarios. This can be explained in the light of the variable's role as determinant of the spread and depth of daylighting flow pattern in the interior spaces.

Correlation Analysis of Total Energy Consumed (kWh/m²/year) with 'Window / Façade' Variables							
Lighting Control Scenarios		Wall to Aperture Ratio (E)	Aperture Location (F)	Window Shape Coeff. (G)	Window Sill Height (H)	Window to Wall Ratio (I)	Daylight Aperture Ratio (J)
Switch On / Off	Automated (LSOO)	-0.139	-0.415	0.263	0.110	-0.068	-0.055
	2 Step (2SOO)	-0.105	-0.317	0.278	0.073	-0.124	-0.053
	3 Step (3SOO)	-0.185	-0.375	0.265	0.144	-0.035	-0.053
	4 Step (4SOO)	-0.165	-0.383	0.264	0.128	-0.054	-0.045
	Manual Probabililty (MOOP)	-0.116	-0.392	0.272	0.085	-0.087	-0.020
Continuous Dimming	at Reference Point (CDRP)	-0.202	-0.396	0.204	0.149	-0.014	-0.210
	Ideal (ICD)	-0.104	-0.388	0.332	0.129	-0.136	-0.037

Table 9.8. Correlation analysis of simulated total electric lighting consumption (kWh/m²/year) with 'Window / Façade' variables.

9.4.2.2.2 Correlation of 'Window / Façade' variables with potential lighting savings

Wall to aperture ratio, windowsill height, and daylight aperture ratio are the three variables of 'Window / Façade' parametric level that have the highest Pearson's correlations, respectively, with potential electric lighting savings (Table 9.9 and Table 9.10). However, the level of significance of these correlational relationships is only 0.1.

Wall to aperture ratio has significant correlation with the percentage of potential savings from electrical lighting consumption in three lighting control scenarios: 3SOO, MOOP and CDRP. In ideal continuous dimming scenario, Pearson's r of window to aperture value has lower value than on/off lightswitch control and CDRP scenarios. Therefore, wall to aperture ratio can be an indicator of the possible percentage of electric lighting savings when daylighting is considered at a certain reference point, but is not significant enough to define daylighting flow pattern in the interior spaces.

Daylight aperture ratio, the product of window to wall ratio and glazing light transmittance, shows low-significance correlation with potential electric lighting savings. On the other hand, window to wall ratio does not correlate with the potential savings. Therefore, it can be concluded that window to wall ratio is not sufficient as an indicator to predict of potential savings. The visible light transmittance of glazing is an important factor that should be also considered to predict the potential electric lighting savings in office buildings in Beirut.

Regarding the ideal continuous dimming scenario, none of the 'Window / Façade' variables has significant correlation with the potential artificial lighting savings (Table 9.9 and Table 9.10). However, the highest Pearson's r values are associated with window shape coefficient and window sill height, which are determinant variables of daylight distribution in the workspaces.

Correlation Analysis of Total Energy Saved (kWh/m²/year) with 'Window / Façade' Variables							
Lighting Control Scenarios		Wall to Aperture Ratio (E)	Aperture Location (F)	Window Shape Coeff. (G)	Window Sill Height (H)	Window to Wall Ratio (I)	Daylight Aperture Ratio (J)
Switch On / Off	Automated (LSOO)	0.513 *	0.045	-0.331	-0.493 *	0.317	0.441
	2 Step (2SOO)	0.503 *	0.000	-0.355	-0.486 *	0.303	0.456
	3 Step (3SOO)	0.500 *	0.000	-0.353	-0.480 *	0.301	0.462 *
	4 Step (4SOO)	0.500 *	0.000	-0.354	-0.480 *	0.302	0.465 *
	Manual Probabililty (MOOP)	0.547 **	0.075	-0.374	-0.502 *	0.382	0.458 *
Continuous Dimming	at Reference Point (CDRP)	0.523 *	0.063	-0.270	-0.464 *	0.317	0.490 *
	Ideal (ICD)	0.184	0.000	-0.377	-0.373	0.041	0.126

Table 9.9. Correlation analysis of total electric lighting potential savings (kWh/m²/year) with 'Window / Façade' variables.

Correlation Analysis of Percentage Energy Saved from Consumed Energy with 'Window / Façade' Variables							
Lighting Control Scenarios		Wall to Aperture Ratio (E)	Aperture Location (F)	Window Shape Coeff. (G)	Window Sill Height (H)	Window to Wall Ratio (I)	Daylight Aperture Ratio (J)
Switch On / Off	Automated (LSOO)	-0.526 *	-0.030	0.341	0.503 *	-0.318	-0.439
	2 Step (2SOO)	-0.515 *	-0.017	0.366	0.495 *	-0.302	-0.453
	3 Step (3SOO)	-0.565 **	-0.017	0.365	0.489 *	-0.301	-0.459 *
	4 Step (4SOO)	-0.512 *	-0.017	0.366	0.489 *	-0.300	-0.462 *
	Manual Probabililty (MOOP)	-0.563 **	-0.075	0.391	0.517 *	-0.385	-0.457 *
Continuous Dimming	at Reference Point (CDRP)	-0.551 **	-0.039	0.275	0.492 *	-0.327	-0.508 *
	Ideal (ICD)	-0.213	-0.040	0.393	0.407	-0.051	-0.148

Table 9.10. Correlation analysis of percentage potential savings from simulated energy consumption with 'Window / Façade' variables

9.4.2.3 *The Impact of 'Window / Office' Variables*

In 9.4.1.3.1 and 9.4.1.3.2 it has been shown that daylighting performance evaluation of 'Window / Office' parametric level has the highest correlation with the simulated electric lighting consumption, but the lowest correlation with the potential electric lighting savings. To understand these relationships, correlational analysis of 'Window / Office' variables with energy behaviour is conducted in this section.

9.4.2.3.1 Correlation of 'Window / Façade' variables with simulated electric lighting consumption

Among the 'Window / Façade' variables, room limiting depth rule and daylight buffer zone correlate the most, respectively, with the simulated electric lighting consumption (Table 9.11). These two variables have the strongest Pearson's correlations with 'Window / Office' performance evaluation (Table 8.14).

The room limiting depth rule has the strongest correlation (level of significance 0.01) in all simulated lighting scenarios, including ICD. This variable is, therefore, a strong indicator for predicting the consumption of office buildings in Beirut. Regarding the correlation of the simulated consumption per unit area with daylight buffer zone, this is less significant (level of significance 0.05) than that with the room limiting depth rule. The level of significance is still acceptable in all lighting control scenarios. Therefore daylight buffer zone can be considered an influential variable, but less significant than the limiting depth rule, on lighting consumption in the office buildings of Beirut.

The average office area has a significant positive correlation with simulated consumption only in the continuous dimming scenarios and 2 Step on / off lightswitch scenario. The cutting of lighting consumption in big offices becomes less convenient with 3SOO, 4SOO and MOOP; switching time becomes longer in 3SOO, 4SOO and in the MOOP scenario. The probability of users controlling their environment becomes less with bigger office spaces.

Fenestration factor and glazing ratio do not correlate with the simulated consumption per unit area. It can therefore be concluded that daylight buffer zone or the depth of the room in relation to the window opening is more important than the ratio of the opening to the daylit area in determining the lighting consumption of the space.

Correlation Analysis of Total Energy Consumed (kWh/m²/year) with 'Window / Office' Variables						
Lighting Control Scenarios		Daylight Buffer Zone (K)	Rm. Limiting Depth Rule (L)	Office Average Area (M)	Fenestration Factor (N)	Glazing Ratio (O)
Switch On / Off	Automated (LSOO)	0.552 **	0.717 ****	0.512 *	0.199	0.102
	2 Step (2SOO)	0.562 **	0.560 **	0.542 **	0.167	0.080
	3 Step (3SOO)	0.567 **	0.743 ****	0.513 *	0.230	0.133
	4 Step (4SOO)	0.568 **	0.743 ****	0.514 *	0.220	0.121
	Manual Probabililty (MOOP)	0.577 **	0.733 ****	0.527 *	0.191	0.091
Continous Dimming	at Reference Point (CDRP)	0.611 **	0.766 ****	0.551 **	0.263	0.149
	Ideal (ICD)	0.600 **	0.759 ****	0.539 **	0.106	0.000

Table 9.11. Correlation analysis of simulated total electrical lighting consumption (kWh/m²/year) with 'Window / Office' variables.

9.4.2.3.2 <u>Correlation of 'Window / Office' variables with potential lighting savings</u>

Table 9.12 and Table 9.13 show that 'Window / Office' variables do not have significant correlation with electric lighting potential savings. Nevertheless, as discussed in the previous section, daylight buffer zone, room limiting depth rule and office average area are the most influential upon electric lighting potential savings.

Regarding fenestration factor and glazing ratio, a comparative analysis of the different lighting control scenarios shows that Pearson's correlations of these two variables with potential savings are the highest with the ideal continuous dimming strategy (Table 9.12 and Table 9.13). Therefore, fenestration factor and glazing ratio should be considered more with the ICD strategy than on/off lightswitch control.

Correlation Analysis of Total Energy Saved (kWh/m^2/year) with 'Window / Office' Variables						
Lighting Control Scenarios		Daylight Buffer Zone (K)	Rm. Limiting Depth Rule (L)	Office Average Area (M)	Fenestration Factor (N)	Glazing Ratio (O)
Switch On / Off	Automated (LSOO)	-0.217	-0.166	-0.178	0.000	-0.026
	2 Step (2SOO)	-0.224	-0.168	-0.197	-0.026	-0.044
	3 Step (3SOO)	-0.224	-0.167	-0.199	-0.028	-0.046
	4 Step (4SOO)	-0.226	-0.168	-0.200	-0.028	-0.046
	Manual Probabililty (MOOP)	-0.256	-0.159	-0.229	0.000	-0.010
Continous Dimming	at Reference Point (CDRP)	-0.280	-0.263	-0.225	-0.051	-0.026
	Ideal (ICD)	-0.270	-0.200	-0.193	-0.222	-0.231

Table 9.12. Correlation analysis of total electric lighting potential savings (kWh/m^2/year) with 'Window / Office' variables.

Correlation Analysis of Percentage Energy Saved from Consumed Energy with 'Window / Office' Variables						
Lighting Control Scenarios		Daylight Buffer Zone (K)	Rm. Limiting Depth Rule (L)	Office Average Area (M)	Fenestration Factor (N)	Glazing Ratio (O)
Switch On / Off	Automated (LSOO)	-0.240	-0.205	-0.196	-0.010	-0.010
	2 Step (2SOO)	-0.247	-0.208	-0.217	0.000	-0.032
	3 Step (3SOO)	-0.248	-0.206	-0.218	-0.010	-0.033
	4 Step (4SOO)	-0.249	-0.207	-0.220	-0.010	-0.035
	Manual Probabililty (MOOP)	-0.287	-0.205	-0.256	-0.014	0.000
Continous Dimming	at Reference Point (CDRP)	-0.335	-0.347	-0.272	-0.107	-0.066
	Ideal (ICD)	-0.333	-0.290	-0.243	-0.175	-0.199

Table 9.13. Correlation analysis of percentage potential savings from simulated energy consumption with 'Window / Office' variables

9.4.2.4 *The Impact of 'Shading Devices' Variables*

In 9.4.1.3.1 and 9.4.1.3.2, it has been shown that daylighting performance evaluation of 'Shading Devices' parametric level does not correlate with the simulated electric lighting consumption and electric lighting potential savings. However, the previous results show that 'Shading Devices' performance evaluation is only significant for electric lighting potential savings when the ideal continuous dimming strategy is adopted. To understand these relationships, correlational analysis of 'Shading Devices' variables with energy behaviour is conducted in this section.

9.4.2.4.1 Correlation of 'Shading Devices' variables with simulated electric lighting consumption

Table 9.14 shows that none of the 'Shading Devices' variables correlate with the simulated electric lighting consumption. Nevertheless, the correlation of relative solar heat gain ratio with electric lighting consumption has the highest Pearson's r among 'Shading Devices' variables in all lighting control scenarios. In addition, the Pearson's correlation of the ICD scenario is the highest when compared to the CDRP and on/off lightswitch control scenarios. This variable, which takes into consideration shading devices dimensions, orientation and SHGF of glazing, is more significant to daylight availability and distribution in interior spaces than the other two variables. On the contrary, this variable is not significant for predicting the possible savings of electric lighting (-0157 < Pearson's r ≤ 0.119, Table 9.15).

Correlation Analysis of Total Energy Consumed (kWh/m²/year) with 'Shading Devices' Variables				
Lighting Control Scenarios		Projection Ratio (P)	Overhang Ratio (Q)	Relative Solar Heat Gain (R)
Switch On / Off	Automated (LSOO)	0.049	-0.552 **	0.362
	2 Step (2SOO)	0.041	-0.042	0.422
	3 Step (3SOO)	0.042	-0.046	0.321
	4 Step (4SOO)	0.051	-0.055	0.322
	Manual Probabililty (MOOP)	0.101	-0.093	0.288
Continous Dimming	at Reference Point (CDRP)	0.142	-0.177	0.285
	Ideal (ICD)	0.174	-0.141	0.391

Table 9.14. Correlation analysis of simulated total energy consumption (kWh/m²/year) with 'Shading Devices' variables.

9.4.2.4.2 Correlation of 'Shading Devices' variables with potential lighting savings

Projection ratio is the variable of 'Shading Devices' parametric level that has significant negative correlation with electric lighting potential savings in automated and multi-step on/off lightswitch control, and continuous dimming scenarios (Table 9.15 and Table

9.16). The manual on/off probability (MOOP) scenario shows low significant correlation between projection and potential savings. On the other hand, projection ratio and overhang ratio are influential on electric lighting potential savings. This is explained by the highly significant correlation of the two variables with electric lighting potential savings (Table 9.15) and percentage potential savings from simulated consumption (Table 9.16).

Correlation Analysis of Total Energy Saved (kWh/m²/year) with 'Shading Devices' Variables				
Lighting Control Scenarios		Projection Ratio (P)	Overhang Ratio (Q)	Relative Solar Heat Gain (R)
Switch On / Off	Automated (LSOO)	-0.567 **	0.217	-0.150
	2 Step (2SOO)	-0.591 **	0.528 *	-0.113
	3 Step (3SOO)	-0.592 **	0.530 *	-0.125
	4 Step (4SOO)	-0.593 **	0.531 *	-0.125
	Manual Probabililty (MOOP)	-0.493 *	0.479 *	-0.257
Continous Dimming	at Reference Point (CDRP)	-0.545 **	0.468 *	-0.173
	Ideal (ICD)	-0.732 ****	0.681 ****	0.119

Table 9.15. Correlation analysis of total energy potential savings (kWh/m^2/year) with 'Shading Devices' variables.

Correlation Analysis of Percentage Energy Saved from Consumed Energy with 'Shading Devices' Variables				
Lighting Control Scenarios		Projection Ratio (P)	Overhang Ratio (Q)	Relative Solar Heat Gain (R)
Switch On / Off	Automated (LSOO)	-0.556 **	-0.240	-0.130
	2 Step (2SOO)	-0.582 **	0.519 *	-0.088
	3 Step (3SOO)	-0.583 **	0.521 *	-0.100
	4 Step (4SOO)	-0.584 **	0.522 *	-0.100
	Manual Probabililty (MOOP)	-0.491 *	0.468 *	-0.231
Continous Dimming	at Reference Point (CDRP)	-0.500 *	0.424 *	-0.148
	Ideal (ICD)	-0.701 ****	0.650 ****	0.138

Table 9.16. Correlation analysis of percentage potential savings from simulated energy consumption with 'Shading Devices' variables

9.4.3 Empirical Analysis of Energy Behaviour

The aim of the empirical analysis is to validate the simulation results and to compare the lighting potential savings to the total energy consumption of office buildings in Beirut. Obtaining electrical consumption data of all the simulated case studies was one of the research constraints. Some of these restrictions were discussed in section 9.2. In addition, Electricity Du Liban (EDL) offered only a restricted amount of help to the researcher, and this limited the number of buildings for which empirical data could be provided to only seven. These buildings are the following:

- Municipality of Beirut (B03, D.O.C. 1925-1928): a case study of Phase II, 1920 – 1930
- Pan American Building (B09, D.O.C. 1952-1953): a case study of Phase IV, 1946 – 1958
- The Horseshoe Building (B16, D.O.C. 1957-1958): a case study of Phase IV, 1946 – 1958
- Arab Bank Building / BCD (B23, D.O.C. 1968-1970): a case study of Phase V, 1958 – 1975
- Arab Bank Building / Mazraa (B26, D.O.C. ...-1982) a case study of Phase VI, 1975 – 1990
- El-Ghazal Tower (B29, D.O.C. ...-1983): a case study of Phase VI, 1975 – 1990
- The ESCWA Headquarter (B32, D.O.C. 1995-1996): a case study of Phase VII, 1990– Present.

The energy consumption data obtained for B03 is only related to the commercial shops located on the ground floor. As mentioned in section 9.2.2 the other 3 floors, occupied by the municipality of Beirut, do not yet have a meter to record their consumption. Accordingly these data cannot be considered in the empirical analysis. In addition, the energy consumption of B09 obtained from EDL is nil, as this building is now completely vacant. In conclusion, the empirical analysis is restricted to only five case studies.

In addition, the data acquired concerning the five buildings is also limited to the monthly consumption during one year only (2002), despite the fact that the researcher asked for the monthly consumption over 3 years.

9.4.3.1 *Simulated Energy Consumption vis-à-vis Empirical Data*

In different lighting control scenarios, the percentages of simulated electric lighting consumption from actual total consumption are constant. However, buildings show different lighting consumption figures. From Figure 9.16, it is apparent that there are two categories of buildings that can be identified by their energy behaviour pattern and the percentage values of their electric lighting consumption. In buildings which are air-conditioned, the total simulated consumption for lighting is 20-25% (B29 and B32). This result confirms the typical research in air-conditioned office buildings in Lebanon, which shows that lighting represents 20% of the total energy consumption. Other offices that are not air-conditioned show a higher share percentage of electricity consumed by for lighting. B23 for example shows as much as 62% consumption by electric lighting, which can be reduced to 55% if ideal continuous dimming is applied to control lighting with regard to the available daylighting level.

Figure 9.16 shows that the lighting consumption of B23 and B26 increased during the period between March and June. The increase resulted from the reliance on electric lighting only; and the occupants of these two buildings complained about excessive glare during this period. Accordingly, daylighting was blocked by lowering internal shading devices (curtains, Venetian blinds etc.).

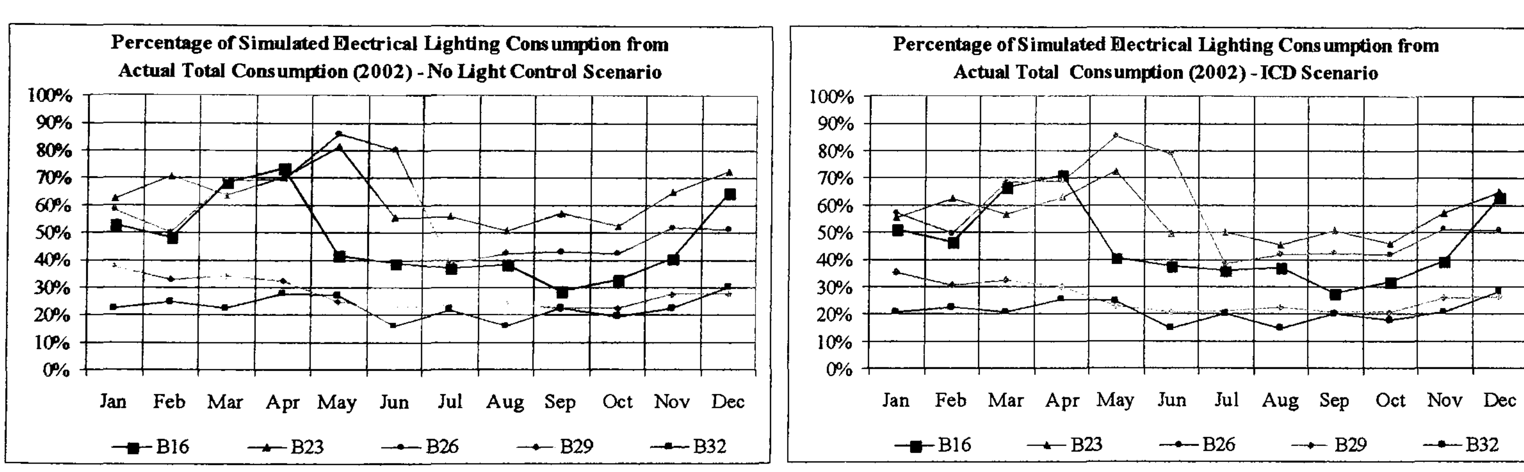


Figure 9.16. Percentage of simulated lighting consumption from total actual consumption: a- no lighting control scenario and b- ideal continuous dimming scenario (ICD).

9.4.3.2 *Simulated electric lighting potential savings vis-à-vis empirical data*

Figure 9.17 illustrates the percentage of potential savings in electric lighting from the total consumption. As mentioned earlier, savings increase with the use ICD. The percentage of these savings can vary between 1% and 4.5%, depending on the impact of façade configuration on daylighting performance. For example, a building of low daylighting performance such as B29 (total performance evaluation = 57%), which is an example of the defensive architecture built during the civil war, the electric lighting potential might be equivalent to 2-2.5% of the total energy consumption. This percentage should definitely increases with façade configuration of higher daylighting performance such as B23 (total performance evaluation = 69%), where lighting potential savings can be 4% of the total energy consumption

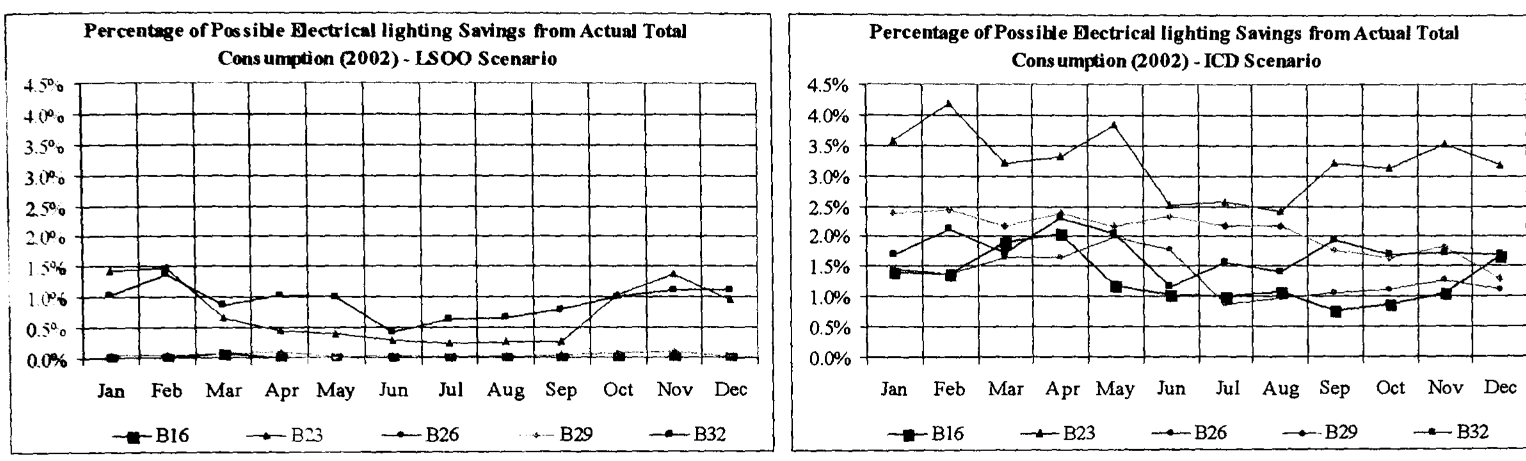


Figure 9.17. Percentage of simulated electric lighting potential savings from total actual consumption: a- lightswitch on/off lighting control scenario (LSOO) and b- ideal continuous dimming scenario (ICD).

9.5 Conclusion

This chapter started by establishing criteria for the selection of cases for lighting simulation. Accordingly, 12 office buildings were selected as well as the two base cases from the ongoing Energy Standards for Building in Lebanon. Section 9.3 set the boundaries of simulations run with ADELINE. Section 9.4 illustrated simulation results that were critically analysed in accordance to the daylighting performance evaluation of the studied buildings, and correlated with their façade design variables.

It was found that in all the studied cases, the decrease in daylighting performance evaluation was constantly linked to an increase of consumed energy for lighting. Accordingly, this conclusion has validated the designated method for evaluating daylighting performance of office buildings façade configuration in Beirut. However, the correlation of low significance between simulated electrical consumption with total performance evaluation showed that the proposed evaluation tool of the total parametric levels could barely predict the amount of energy required to light the building. The daylighting performance evaluation of the 'Window / Office' and 'Building Shape' parametric levels respectively could be more significant in predicting the extent of electric lighting consumption. This was proved by the significant correlational relationship between the simulated energy consumption and the daylighting evaluation values of 'Window / Office' and 'Building Shape' parametric levels. On the other hand, the significant correlation between total design performance evaluation and electric lighting potential savings confirmed the ability of this tool to prefigure the potential savings due to lighting control strategies.

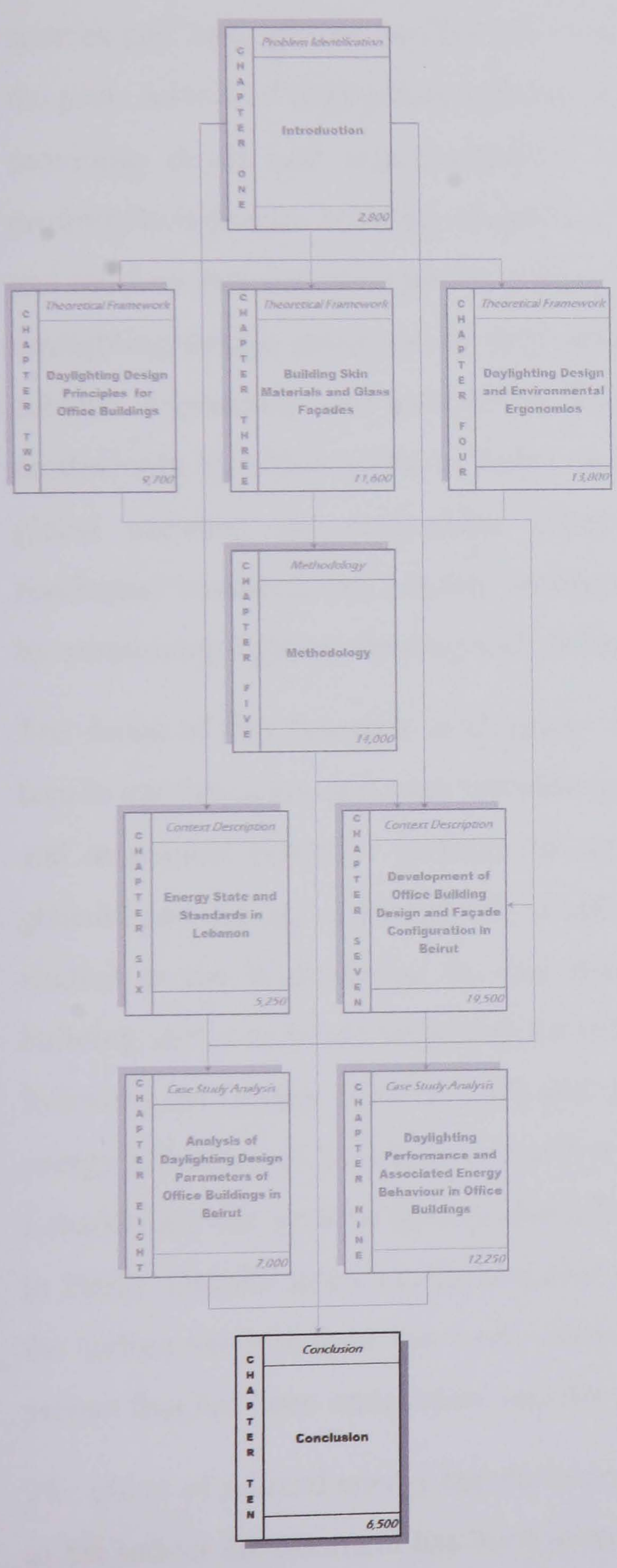
The study of potential lighting savings in office buildings constructed during the 20th century showed 4 phases of development. In the first phase (before 1930) the daylighting performance evaluation of buildings was relatively low, but potential energy savings were high due to shallow office spaces daylit by small and narrow windows. In the second phase (1930 – early 1960s), the change in façade configuration produced an improvement in daylighting performance that produced low savings with extra efficient measures. The period between 1960s and early 1990s showed good lighting but savings seemed to be high. This is due to greater levels of daylighting due to the uncontrolled use of large glazing areas. In the last decade, that of 'Imitative' architecture where façade configuration and plan morphology are not harmonious, the adoption of the open plan office concept has led to low levels of potential lighting savings, with the application of lighting efficiency measures.

Section 9.4.1.2 examined the relationship between the diagrammatic building description and the potential energy savings pattern. Accordingly seven categories of buildings were identified which could be considered as a reference against which any office building in the studied context could be compared, making it possible to predict its monthly lighting potential savings just by drawing its daylighting evaluation diagram.

The correlational analyses of the simulation results and daylighting design variables showed that the limiting depth rule and daylighting buffer zone have the strongest correlation with electric lighting consumption, followed by the envelope to floor area ratio and compactness ratio (variables of the 'Building Shape' parametric level). The projection ratio of shading devices also has a significant correlation with the electric lighting consumption of buildings. In the 'Window / Façade' parametric level, wall to aperture ratio and daylight aperture ratio are also significant for building energy behaviour. Therefore, it would seem important to give these variables the greatest consideration in regulations to rationalise the energy consumption of office buildings in Beirut.

CONCLUSION

10



Chapter Ten

10. Conclusion

10.1.1.1 *Introduction*

The relationship between daylight, buildings and people is intimate. Daylight has the potential to bring life, variation and drama into otherwise banal spaces. Throughout the history of civilization, buildings have expressed this relationship. Efficient, artificial light sources and fully glazed façades have liberated designers from the design constraints of the past. Advanced daylighting systems and control strategies are another step forward in providing daylit and energy-efficient buildings. Daylight as a design variable can profoundly influence building orientation, form, scale, the character of the interior space, and the way that interior space is perceived. Building occupants are also affected by the daylighting design generated by appropriate architectural and / or technical solutions to achieve a pleasant and productive built environment, often resulting in improved productivity by office workers. Today, in a world newly anxious about carbon emissions, global warming and sustainable design, the deliberate use of daylighting in non-residential buildings has become an important approach to improving energy efficiency by minimizing lighting, heating and cooling loads.

The focus of this research is to assess the daylighting performance of office building façade configuration and plan morphology that contributes to the best use of daylighting and associated potential lighting savings in Beirut. Energy efficiency in buildings in general, and the use of daylighting in office buildings in particular, have been extensively studied in the West during the last three decades. They have been recognised in the building sector as being important for reduced energy consumption and GHG emissions, following the energy crisis of 1973 and growing awareness of global warming. However energy efficiency in buildings is a new topic of study or discussion in Lebanon, although Lebanon has the greatest energy shortage in the Eastern Mediterranean region (525GWh in 2002). Despite this fact, the potential of daylighting for saving energy and optimizing the indoor environment has been marginalised in both the national Energy Standards project that has been undertaken, and the applied mandatory building regulations.

The effect of relaxed energy standards and building codes concerned with general aspects of the indoor environment has been investigated in the development of office buildings in Beirut. It was found that during the last century the design of office building in Beirut underwent an accelerated functional and physiognomic change, from its origins as a converted dwelling space through its gradual transformation into a multi-use commercial centre. Interior spaces have been subject to increasing specialization and particular efficiency, while the exterior has evolved from stone jacketing and bay window façades to curtain walling and glass boxes. The current rehabilitation of office buildings in Beirut's Central District, in contrast, aims at preserving the historic envelope while 'modernizing' the interior. These developments in façade configuration and plan morphology have changed the daylighting potentials and energy behaviour of office buildings built during the course of the century.

In this research, a preliminary daylighting evaluation tool has been developed to assess the daylighting performance of office buildings in Beirut. The development of this assessment tool was based on the review of existing daylighting theories and assessment methods. This tool consists of four sets of variables that look into the interaction between the building shape, façade configuration, office dimensions and shading devices, to bring daylight into the building. A brief overview on the evolution of Beirut as an urban city frames the period of study (late 1880s – today) and identifies seven historical stages through which the architectural evolution of office buildings has been described. The evaluation tool has assisted the comparative and developmental analyses of 35 office buildings of different dates of construction, and two office "base cases" from an ongoing project setting new energy standards in Lebanon. A simulation technique has been used to assess the energy behaviour of 14 selected case studies. Using Adeline, lighting consumption and the potential savings due to daylighting / electric lighting integration were simulated. The simulation outputs were correlated to the daylighting design variables considered in the evaluation tool, and the daylighting assessment results from the studied buildings. Correlational and comparative analyses were validated by empirical data and a POE pilot study. Subsequently, the study identifies those design variables that have been considered or disregarded in designing office buildings in Beirut. The analysis also identifies the significant design variables that should be considered when designing a well-daylit, energy-efficient office building in Beirut.

The key findings of the whole research are summarized in the following section. This summary is followed by a list of recommendations for building codes and Lebanese energy standards, which emphasise the use of daylight. The final section offers some suggestions for future research.

10.2 Summary

Chapter Two reviewed the basic principles and schemes of daylight design in office buildings. The review identified those variables of building façade and plan layout that are useful to assess daylighting in indoor spaces. The product of this chapter is a list of variables, grouped into four different categories. The first level considered is the 'Building Shape' or the meso scale. The 'Window / Façade' and 'Window / Office' parametric levels study the relationship between the window and window-wall and office volume, respectively. The last level of analysis concerns the application and properties of shading devices.

Chapter Three reviewed the properties of building façades, with more emphasis on envelope materials that have bearing on daylighting. This review was preceded by a discussion about the definition and interpretation of 'building envelope', 'building skin' and 'façade'. Chapter 3 also reviewed the development of glazing technologies, and their response to daylighting and thermal conditions. Finally a table listed the most common advances in glazing, summarizing their performance with regards to daylight, view, solar control and thermal behaviour.

Chapter Four provided some background about the effects of the indoor physical environment on workspace occupants' comfort, health and performance. This review was particularly concerned with the potential contributions of windows and daylight to improved working conditions and performance of office workers. It was concluded from the reviewed literature, and the findings of the POE pilot study conducted in some office buildings in Beirut that office workers strongly prefer a daylit environment, and enjoy the benefits associated with windows. The existence or absence of windows in a workplace, as a source of light and view to the outside, proved to be significant to workers' preferences, moods, satisfaction, stress, orientation in time and space, physical health, comfort and work productivity. The technical possibilities for saving energy by using efficient electric lighting are meaningless if the users' reaction is negative. An optimal lighting design of workspace is required, to create a balance between user satisfaction and energy use parameters.

Chapter Five set out the methodological approaches adopted in this research. Different research methods for daylighting and energy-related assessment are reviewed. This chapter also reviewed the approaches used in the previous historical studies of architectural developments in Lebanon. Data sources and data collection techniques were identified. A detailed discussion of daylighting / energy studies identified the main outputs that contribute to the assessment of daylighting and associated energy in office buildings. Based on the 'morphological box' method adopted by Baker *et al.* in 1993, a daylighting evaluation tool has been developed to quantify daylight availability in office buildings in Beirut. This tool includes 18 variables, identified earlier in Chapter 2. Each variable was divided into 4 ranges of values associated to the studied context, and these ranges were given a score between 1 and 4. This method permitted a descriptive diagram to be drawn for each case study of an office building. The morphological descriptive diagrams assisted the comparative analysis of office buildings in Beirut, with reference to the daylighting performance of their four parametric levels as identified in Chapter 2. Correlational analyses were used to study the relationship between simulated energy outputs and daylighting variables.

Chapter Six reviewed the state of energy in Lebanon in general, and in Beirut and the building sector in particular. It also discussed energy conservation awareness in the Eastern Mediterranean in general, and the developed or implemented energy standards, predominantly in Lebanon. The energy state study highlighted the dramatic growth of electricity use between 1980 and 2002, when energy demand increased from 2674GWh to 8591MWh; a 15% annual increase. This sharp growth was accompanied by a continuous shortage of reserve power, which peaked in 1996 and constituted 21% of the total power production. In 2002, the annual energy shortage was equal to 525.4 GWh, equivalent to 7% of power production. Beirut consumes 70% of the electrical production capacity, of which 70% is consumed by the building sector. 7.5% of the building sector requirement in Beirut is consumed by commercial buildings, which in turn use 20-25% of their supplied energy for electric lighting. With the acute shortage of energy supplies in Lebanon, this study has highlighted the immediate need to rationalise consumption in the building sector. An investigation of the ongoing project entitled 'The Lebanese Energy Standards for Buildings' showed that it places more emphasis on the thermal performance of office buildings, and marginalises the role of daylighting in saving energy. The role of daylighting is also largely ignored in the Lebanese building regulations.

Chapter Seven reviewed the emergence and development of office buildings in Beirut. This review was preceded by a brief historical sketch of urban development in the city. This review demonstrated that Beirut is fundamentally a product of the late 19^{th} century, when the first true signs of urbanization began to appear. There was therefore no need to go too far back into its past to discover the establishment of office-use buildings. Accordingly, the review of major political, social, economic and cultural events framed the period of study, and divided it into seven stages through which the architectural development of office buildings could be described. The description of 37 case studies, including the two office base cases of the Lebanese Energy Standards projects, marks the differences that have occurred in the façade configuration and plan morphology of office buildings, with more emphasis on their effects upon daylighting performance.

Chapter Eight examined the daylighting design variables that have been considered (or disregarded) in the design of office buildings in Beirut during the last century. The tool developed for evaluating daylighting performance was used to investigate the impact of façade configuration variables on daylight availability in interior spaces.

Chapter Nine investigated the energy implications of façade configuration with regards to daylighting in indoor spaces. The significance of façade design variables for the potential savings in electric lighting was also examined.

The last three chapters provided in-depth investigation of daylighting performance and associated energy patterns in the office buildings of Beirut, leading to a series of conclusions which are explained in the following sections.

10.3 Development of Office Building Design and Daylighting / Energy Implications

10.3.1 Introduction

The object of the research into the development of office building architecture in Beirut was not so much an exhaustive analytical and theoretical construct as a first inquiry, as meaningful as it might be, of façade aesthetics in relation to available technology of façade construction and building materials used. In-depth analysis has been directed more towards the development of façade configuration and plan morphology, and their impact on daylighting performance in office buildings. A comprehension of this relationship may contribute to a more conscious position, reducing the gap between the desirable future with more energy efficient office buildings and the past experiences of façade configuration design. More importantly, this investigation aimed to identify the design factors that practitioners should consider to improve the daylighting conditions of a workspace.

10.3.2 Stages of Office Building Development in Beirut

From khans and central bay buildings to excessive use of glass, this study highlighted that office buildings in Beirut have gone through seven stages of development. This developmental study focused mainly on façade configuration, which influenced daylighting performance in the indoor environment. This research into the architectural development of office buildings in Beirut may well represent the first enquiry of its kind in Lebanon, where most architectural studies have focused on the aesthetic and functional development of domestic buildings. The story of office buildings in Beirut, and the development façade configuration during the 20th century are summarised below.

Khans were the first forms of commercial / office-use structures, appearing in the traditional and neo-traditional phase (before 1920), then developing into exclusive corporate headquarters and speculative rental buildings. The main aspects that affected daylighting performance in these buildings were the building shape which was mainly narrow or opened onto a courtyard, and the tall narrow openings which were enough to illuminate small rooms with a limited daylight buffer zone.

During the transitional phase (1920 – 1930), openings remained narrow and vertical, separated by large, solid walls despite the starting use of concrete as a new façade construction technology. The French window was an important feature of façade composition, with its associated small veranda increasing in width that played the role of horizontal overhang for the window beneath it.

The period between 1930 and 1946 is considered to be an early stage of architectural modernism in Beirut. The launch of a cement industry in Lebanon in 1931 prompted a new stage of architectural development. Contemporary styles, such as Art Deco and Art Nouveau, were adopted and progressive simplification of forms and refinement of architectural ornamentation resulted in the façade configuration. Bay windows disappeared gradually from the façade, being replaced by a rational treatment of openings and a bold mass devoid of decoration.

With the early years of independence, 1946 to 1958, modern office buildings in reinforced concrete with impressive glass façades and prefabricated aluminium frames began to overwhelm the urban scene of Beirut. Office building façades were no longer similar to those of residential buildings. The influence of 'Modernism' on architecture, or the International Style, increased in Beirut. The façades were simply made with repetition of similar window units, perhaps stretched along the façade. New glazing technologies started to appear, such as double-glazing, tinted glazing, and glazing with integrated louvres. The environmental awareness of some architects is quite clear from the use of shading devices in the façade.

In the Shihabist and Post-Shihabist phase (1958 – 1975), the implementation of a building envelope regulation applied to street façades resulted in high-rise buildings with a smaller plan layout and width. This was particularly apparent in office buildings having a large site area. The International Style was used in many buildings. In addition, there was an architectural movement in which the use of shading devices became an important feature of façade design. The use of newly available façade technologies further expressed the '*modernist*' design perspective in office buildings. Modern ideas did not only impact façade configuration, but also on office plan morphology. The concepts of flexibility and special economy shaped the design of deep, open plan offices divided by light partitions.

The architectural modernism apparent in buildings from the late 1950s and 1960s was ended by the Civil War (1975-1990). The concepts of façade design changed completely. Security, the possibility of destruction, and the necessity for easy maintenance were important factors demanding consideration while designing buildings during this period. Accordingly, office buildings of this period may be classified using two design concepts, *defensive* office buildings and *low-investment* office buildings.

Since the end of the civil war in 1990, two design trends have been seen in the office buildings of Beirut. These trends are identified as *modern* glass boxes and *imitative* architecture mixed with some *contemporary* feature, predominantly a curtain wall façade. Both trends are mostly concerned with aesthetics, expressing no awareness of environmental or energy efficiency. Open plan offices are again predominant in plan morphology. It is noticeable that in this phase, atrium and courtyard have become important features of architectural modernism. Nowadays architects rely mainly on new glazing technology to control sunlight penetration and solar heat gain, even though in some cases this protection might be not sufficient.

The alterations in façade configuration and plan morphology during the last century have changed daylighting performance in the indoor environment. The designed daylighting evaluation tool permitted examination of the implications of such development on daylighting availability in workspaces. The tool permitted the researcher to identify whether an office building in Beirut had a daylight-rejecting design, or a highly daylight-collecting design. The key findings of this study are presented in the following section.

10.3.3 Office Building Design and Daylighting Implications

The investigation of the impact of office building development on daylighting performance identified four parametric levels for analysis:

- The 'Building Shape' set of variables includes compactness ratio, shape coefficient, envelope to floor area ratio and porosity ratio.
- 'Window / Façade' set of variables studied the relationship between the window and the window-wall through investigation of wall to aperture ratio, aperture location, window shape coefficient, window-sill height, window to wall ratio and daylight aperture ratio.
- 'Window / Office' set of variables looked into the relationship between the window and the office dimensions through investigation of daylight buffer zone, room limiting depth rule, office average area, fenestration factor and glazing ratio
- 'Shading Devices' set of variables includes projection ratio, overhang ratio and relative solar heat gain.

A summary of the key findings resulting from the analysis of the above parametric levels and their implications on daylighting performance in office buildings in Beirut is given below.

10.3.3.1 *Building Shape*

The daylighting performance of the 'Building Shape' parametric level gradually decreased during the first 4 phases (1850s – 1958). The use of courtyard and the limitation due to the used structural system resulted in uncompact and narrow building layout. Since 1946, office buildings were becoming deeper and larger in shape and volume with fewer void spaces. This was due to the rapid growth of urbanisation after the 1950s, and increased land prices in Beirut. Office buildings constructed during the civil war (1975 – 1990) showed better daylighting performance, because they were smaller and less compact. Today new office buildings are larger than those built during the war, but they have better daylighting performance than the ones built during the Shihabist and Post-Shihabist period. Today, in a post-war reconstruction period, the atrium has been reconsidered, being for some architects and their clients an architectural element that makes a building more fashionable and sophisticated. The adoption of this feature has helped to increase the availability of daylight in newly constructed office buildings.

The correlational analyses showed that compactness ratio, envelope to floor area ratio, shape coefficient and porosity ratio all have a significant impact on the daylighting performance of the 'Building Shape' scale. Conversely, none of the four 'Building Shape' variables has a significant influence on the daylighting performance of office building designs in Beirut. The three-dimensional analyses of the building shape and the review of the building codes proved that the impact of building shape on lighting or ventilating the building has largely been disregarded. The building shape or plan layout of the building has been controlled by the site shape, with full use of the permitted built up surface area and gross area.

10.3.3.2 *Window / Façade*

The daylighting performance evaluation of 'Window / Façade' parametric level in office buildings in Beirut increased gradually from 35% to 85% during the first five historical phases (1880s – 1975). During the civil war, the daylighting performance of 'Window / Façade' level decreased to an average of 70% because of defensive architecture, but began to improve again in the post-war reconstruction period with the trend of excessive use of glass.

The study of 'Window / Façade' variables shows that wall to aperture ratio, aperture location, and window to wall ratio had minimal values in the first historical phases, increasing gradually to reach their peak during the Shihabist and Post-Shihabist phase (1958 - 1975). The use of cement in skeleton structures, and the advances in glazing technology replaced solid load bearing walls and narrow vertical windows (i.e. the central bay window and French windows). The named variables were lower during the civil war phase (1975 – 1990), because of low investment and the defensive architecture produced in that period. During the last decade, with the trend for highly glazed façades and advances in glazing technology, these variables have started to achieve higher values, ranging between 0.50 and 0.80 for wall to aperture ratio, and 0.45 - 0.75 for window to wall aperture. Despite the continuous increase of window to wall ratio, the use since the mid 1950s of different glazing technologies of lower visible light transmittance explains the linearity of daylight aperture ratio development (average values equal to 0.3) with a slight increase in the last decade (average values equal to 0.45.). While increasing wall to aperture ratio, most architects have only considered the thermal behaviour of the glazing. The optical performance has been disregarded. In addition new glazing technologies have mostly been avoided or not considered during the design process, by architects and the buildings' owners, because of their high cost in Lebanon. Accordingly, the high performance factor of 'Window / Façade' is definitely creating glare and visual discomfort, as well as uncomfortably high thermal levels. This conclusion was supported by the results of the POE pilot study. Many users of new buildings in Beirut expressed their frustration caused by excessive glare in their work places. For them Venetian blinds and air conditioning are essential, especially in summer months.

Correlational analysis has shown that all 'Window / Façade' variables, except for window shape coefficient, affect the daylighting performance of the whole building. The most influential factors are the area of apertures in proportion to opaque surfaces, and the visible transmittance of the glazing. This needs to be carefully selected in order to control illumination quantity as well as daylight quality.

10.3.3.3 *Window / Office*

After 1946 the daylighting performance of 'Window / Office' gradually increased from approximately 55%, reaching a peak average equal to 75% during the civil war due to the construction of low investment office building architecture. The lowest 'Window / Office' performance evaluation occurred during 1920-1946, (55%) and in the last decade (35%). The period between 1920 and 1946 is considered a transitional phase between traditional and modern architecture, marked by changes in the structural system, the freedom of walls from their load bearing role and the increase of aperture area. Today, the increase in glazing surfaces also accompanies larger or open-plan offices. However, in the building regulations there is no threshold for the area of the workspace, but the depth of the room is limited to 5 times the ceiling height. This should not be less than 2.8m; i.e. the depth of a room is limited to 14m. This rule does not consider the psychological and health concerns related to the distance of users from a window, as discussed in Chapter 4.

The development of the fenestration factor in office buildings in Beirut has varied, in most cases between 0.1 and 0.4. From the late 1950s some office buildings in Beirut had a fenestration factor higher than 0.4, which would cause problems for thermal comfort and glare. This is quite clear in the low-investment office buildings built during the civil war (1975 – 1990), where small office areas are illuminated by large openings. Nowadays highly glazed office buildings \have a low fenestration factor, because of their large open plan offices.

Glazing ratio has ranged between 0.05 and 0.30 in most office buildings. Office buildings of high fenestration values have glazing ratios ranging between 0.30 and 0.55, depending on the type of glazing used.

The correlational analysis of 'Window / Office' has proved that only fenestration factor and glazing ratio have a significant relationship with the daylighting performance of the whole building. This is explained by the fact that the fenestration factor is the only variable considered in the Lebanese regulations to provide daylighting to a space. In all cases studied the minimum fenestration factor value is 0.10, this being the minimum value set by the building regulations. On the other hand, the maximum fenestration factor found is 0.80, which is generally considered very high and can cause optical discomfort. This is due to the lack of any threshold for this variable in the building regulations, to prevent excessive daylighting. In addition, the room depth in accordance to room width and window dimensions is disregarded in the design of office buildings in Beirut, and in the Lebanese building regulations. This has been proved by the lack of any correlation between performance evaluation and daylighting buffer zone, and the room depth limiting rule, respectively.

10.3.3.4 *Shading Devices*

The development of 'Shading Devices' and their impact on daylighting performance has followed an indefinite shape in the studied context. The use of shading devices in office buildings in Beirut has been subject to design trends and façade articulation. Today, architects are trying to exchange the protective role of shading devices for new glazing technologies, but these are still too expensive for many projects.

10.3.4 Daylighting Performance and Energy Implications

The simulation of lighting consumption, and saving potentials of office buildings during different periods of the 20th century revealed four phases of development. In the first phase (before 1930) the daylighting performance evaluation of buildings was relatively low, but potential energy savings were considerable. This performance figure resulted from shallow office spaces, daylit by small and narrow windows. In the second stage of development (1930 – early 1960s), the change in façade configuration increased daylighting performance in indoor spaces, but potential lighting savings remained relatively low. The period between 1960s and early 1990s showed good lighting, but savings seemed to be high. The uncontrolled use of large glazing areas surpassed the required levels of daylighting, which increased the amount of energy that could be saved from controlled electric lighting. In the last decade, imitative architecture in which façade configuration and plan morphology were not harmonious, and the adoption of the open plan office, led to low levels of potential lighting savings with the application of lighting efficiency measures.

In all the studied cases, the decrease in daylighting performance was linked to an increase of energy consumed by lighting. This conclusion validated the designated method for evaluating daylighting performance of the façade configuration of office buildings in Beirut. However, the correlation of low significance between simulated electrical consumption with total performance evaluation showed that the proposed evaluation tool for total parametric levels was ineffective for predicting the amount of energy required to light the building. The daylighting performance evaluations using the 'Window / Office' and 'Building Shape' parametric levels were more useful for predicting electric lighting consumption. This was proved by the significant correlational relationship between the simulated energy consumption and the daylighting evaluation values of 'Window / Office' and 'Building Shape' parametric levels, respectively. On the other hand, the significant correlation between total design performance evaluation and electric lighting potential savings confirmed the ability of this tool to prefigure the potential savings from lighting control strategies.

The limiting depth rule and daylighting buffer zone were found to be significant for electric lighting consumption figures, as were the envelope to floor area ratio and compactness ratio. The projection ratio of shading devices could also alter electric lighting consumption. In the 'Window / Façade' parametric level, wall to aperture ratio and daylight aperture ratio were also significant to the building energy behaviour. It would be important to give these variables the greatest consideration in building regulations intended to rationalise the energy consumption of office buildings in Beirut.

10.4 Recommendations for Building Regulations and Energy Standards

10.4.1 Recommendations for Building Regulations

The review of Lebanese building regulations showed that few codes relate to the provision of daylighting in buildings (Figure 7.43, Figure 7.44 and Figure 7.45). In addition, there are no special guidelines or codes regarding the design of workspaces or dealing with occupants' health and safety. Elsewhere, for example in the Netherlands and in Germany, there are regulations requiring that the staff in workplaces must not be located more than six metres from a window (Ander, 2003). In addition, this study showed that blind import, adoption of glass boxes and new façade technologies are not controlled by any rule or code to protect the building's users from discomfort. The Lebanese building regulations include only minimum recommendations for window size or fenestration factor and room depth; the mandatory building code does not include any threshold value for these variables. Setting such thresholds would help prevent discomfort in workspaces and improve indoor environmental conditions, as well as enhancing the energy efficiency of buildings.

The analysis of façade configuration and plan morphology variables and their impact on daylighting performance in workspaces suggested some design recommendations that would significantly improve conditions in the working environment.

In the literature review in Chapter 2, it was proved that the building envelope regulation recommended by the Lebanese regulations for urban buildings could lead to completely obstructed façades and overshadowed buildings, as the profile angle may be lower than 30°. The amendment of this would be difficult, especially in the capital Beirut, where most roads are relatively narrow (less than 12m in width). The high price of land in Beirut is another constraint limiting the vertical extension of office buildings.

Despite the fact that the footprint of the building might be controlled by the site layout, it is recommended to consider the building shape compactness ratio and envelope to floor area ratio that define the relationship between the building inner volume and envelope area, in order to provide sufficient daylight to the building. As mentioned earlier, these two variables of the 'Building Shape' parameter are significant for the energy behaviour of the building. According to the developed tool for evaluation of daylighting performance, a compactness ratio above 2.00 and envelope to floor ratio above 0.70 help to provide sufficient daylight into the building interior (See Appendix II, Section APII.1.10)

Setting rules to control wall to aperture ratio or window to wall ratio would be difficult, since it would constrain an architect's creativity in shaping building façades. However, setting a lower threshold for window to wall ratio of 0.25 is important for ensuring adequate daylight and a satisfactory view, which have a great impact on worker's health, their psychological state and work productivity (See Appendix II, Section APII.2.4). In addition, excessive daylighting could be controlled by appropriate glazing technology or shading devices. However, the use of advanced glazing technologies might be expensive for some office projects. Therefore, a study is recommended to explore the visual (and thermal) performance of highly glazed, large office building projects with high budgets. In those projects the façades should have appropriate glazing materials that assure optimum thermal and visual comfort, as well as being energy efficient.

On the subject of 'Window / Office' parametric level, it is notable that the Lebanese building regulations limit the maximum room depth to 5 times the ceiling height, which should not be less than 2.8m; so the depth of a room having a 2.8m ceiling height should be less than 14m. This rule does not consider the psychological and health concerns related to the distance of users from a window, as discussed in Chapter 4. Additionally, the rule does not consider the dimensions of the window. Adopting the limiting depth rule proposed in the British code would be a significant change. On the other hand, the building regulations recommend that the fenestration factor should not be less than 0.10. This value is quite low to permit enough daylighting to the interior, and it would be better to increase this limit to 0.25 to provide a satisfactory 'Window / Office' daylighting performance (See Appendix II, Section APII.3.4.1).

10.4.2 Recommendations for Energy Standards

The ongoing project concerned with Energy Standards for Buildings in Lebanon proposed two base cases to study the energy behaviour of office buildings in the coastal climatic

Zone A1. In this project, emphasis is given to the building thermal performance and associated savings. Potential energy savings from daylighting / electric lighting integration strategies are completely neglected. The simulation of the two base cases A1-O and A1-OL showed 2% and 8% potential savings, with on / off lightswitch controls and an ideal continuous dimming strategy, respectively. Nevertheless, using the developed evaluation tool the analysis of the two base cases A1-O and A1-OL showed low daylighting performance using the proposed designs (56% and 57%, respectively). Taking account of daylight to increase potential savings could be vital for office buildings in coastal climatic zone A1.

On the other hand, comparison of the two base cases with each other showed that they are almost identical (See Appendix III). There are only small dissimilarities in their shape coefficient and envelope to floor area ratio, because of the difference in building height, but their porosity ratio and compactness ratio are identical. In fact the two base cases could have been reduced to only one, as they would not show any significant differences in their energy behaviour. This conclusion was confirmed by the Energy Standards project manager Matilda Elkhoury, when she was interviewed on 4 January 2004. She added that the project committee was sceptical about the simulation results of A1-O and A1-OL, where savings associated with thermal performance were not as high as in the cases representing the other four climatic zones.

For this study, A1-O and A1-OL were also compared to the 35 case studies. This comparative study showed that the two base cases were neither representative nor analogous to the existing building stock, as was claimed by the research group in one of the 'Energy Standards for Buildings' project seminars.

Compared to the building stock, the minimal building compactness ratio and daylight aperture ratio confirm that the role of façade configuration and plan morphology on daylighting performance and associated energy potential savings has been disregarded. It is also apparent that the north-facing façades have low wall to aperture ratios and daylight aperture ratios. This assumption has disregarded the advantages of constant illumination, free of solar energy gain which is available in north facing façades. In addition, because window to wall ratios are comparable to the studied buildings, the differences in daylight aperture ratio are presumed to be due to the glazing type. The two base cases have 6mm, tinted single layer glazing with 0.50 visible light transmittance. Apart from the differences in the existing building stock, where many types of glazing are used, this assumption underlines the disregard of daylight.

In conclusion, it is recommended that new office building base case(s) are developed for Zone A1, with more emphasis given to daylighting and associated potential energy savings. The guidelines for design variables presented in Table 10.1 could be helpful in developing the suggested additional base case(s).

DESGN VARIABLES		Existing Base Cases		Suggested Base Cases	
		A1-O	A1-OL	A1-Day_O	A1-Day_OL
BUILDING SHAPE PARAMETERS	Compactness Ratio	1.34	1.33	2.00-2.75	2.75-3.50
	Shape coefficient	4.75	5.73	5.75-7.50	4.00-5.75
	Envelope to Floor Area Ratio	0.69	0.58	0.60-0.85	0.85-1.10
	Porosity Ratio	0.00	0.00	0.05-0.10	0.10-0.15
WINDOW / FAÇADE PARAMETERS	Wall to Aperture Ratio	0.33	0.32	0.25-0.40	0.40-0.55
	Aperture Location	c. glazing	c. glazing	c. glazing	c. glazing
	Window Shape	1.54	1.54	0.50-2.00	c. glazing
	Window Sill Height	0.90	0.90	0.75-1.60	c. glazing
	Window to Wall Ratio	0.31	0.34	0.25-0.40	0.40-0.55
	Daylight Aperture Ratio	0.15	0.17	0.20-0.30	0.30-0.40
WINDOW / OFFICE PARAMETERS	Buffer Zone Depth	6.50	8.00	6.00-8.00	4.00-6.00
	Room Limiting Depth Rule	4.45	3.56	3.00-4.00	2.00-3.00
	Office Average Area	39.00	48.00	20.00-30.00	10.00-20.00
	Fenestration Factor	0.24	0.24	0.15-0.25	0.25-0.35
	Glazing Ratio	0.12	0.12	0.14-0.21	0.21-0.28
SHADING DEVICES PARAMETERS	Projection Ratio	0.00	0.00	scenarios	scenarios
	Overhang Factor	1.00	1.00	scenarios	scenarios
	Relative Solar Heat Gain	0.67	0.67	glazing scenarios	glazing scenarios

Table 10.1. Design guidelines to develop base case(s) of office buildings in Zone A1, where daylighting could be considered as an energy efficiency factor.

10.5 Recommendations for Future Research

10.5.1 Office Building Architecture in Beirut

Research into the history of architecture in Lebanon in general, and in Beirut in particular, is mostly confined to short, comprehensive overviews or to the epilogues of books dealing with regional architecture in Lebanon. Most of these studies have been conducted by non-architects, mainly historians, and have focused on the domestic architecture of the 18th and 19th centuries. Saliba (1998 and 2004) undertook a more holistic and detailed review of domestic architecture in Beirut, but his study was limited to the period between 1920 and 1940. More recent historical researches have investigated the modernity and identity of architecture in Lebanon between 1946 and 1970 (Tabet, 1998 and Arbid, 2002). The latest publication concerning the history of architecture in Lebanon is the work by Gebran Yacoub '*A dictionary of 20th century architecture in Lebanon*', published in October 2003. This 'dictionary' lists many architectural features of the last century, such as buildings, distinguished architects, events, competitions, etc. The author's aim was to create a reliable reference book of architectural data, and this prevented his work from any critical analysis.

It can be concluded that there is a gap in the historical review of architecture in Beirut which needs to be filled. Previous researches did not tackle the architecture of the period between 1900 and 1920 nor the architecture of the civil war (1975 – 1990). Indeed, most researchers were concerned with domestic buildings or the aesthetic aspects of architecture. This study has opened research into the development of office buildings in Beirut, widening the analytical interpretation from being concerned only with aesthetics to giving greater concern to the impact of façade design on environmental conditions.

10.5.2 Amendment of the Daylighting Design Evaluation Tool

The daylighting design assessment tool developed within this research may be considered no more than a preliminary effort. It needs amendments if it is to become more precise in assessing daylighting availability and associated lighting conditions, whether in the office buildings of Beirut or any other area of the same climatic zone. Additional work on the scoring and weighting techniques for the adopted variables is needed. Once developed, this tool could help architects to evaluate their office building designs during the preliminary stages.

10.5.3 Application of the Daylighting Evaluation Tool to International Office Buildings

The tool developed for daylighting evaluation permitted the user to identify whether a building has a daylight-rejecting design, adequate daylight-collecting design or a highly daylight-collecting design. The associated descriptive technique allowed the comparison of various façade configurations, and their impact on daylighting performance. For this research, the tool was used to assess the daylighting performance of office buildings in Beirut during a century of architectural development. A more all-embracing study, that might include examples of office buildings representing different climatic areas and cultures, would certainly be valuable. A comparison of office building practice in Beirut with distinguished daylit or 'climate-adapted' office buildings elsewhere would also be of great interest.

10.5.4 Field study of Applied Glazing Technologies in Beirut

Despite the various new glazing technologies that exist for improved daylighting and thermal performance in buildings, architects in Lebanon seem to have a very limited knowledge of the appropriate glazing materials to use in their designs. The cost of such features might be another reason preventing the use of advanced glazing in the studied context. A field survey of the glazing technologies used in office buildings in Beirut would produce some important information. This could be followed by a cost-effectiveness study, comparing the benefits of optimal façade glazing designs with associated financial implications.

10.5.5 Energy for Heating / Cooling vs. Daylighting in Beirut

The clear sky and temperate climate in Beirut are all good reasons for taking advantage of daylight, as a free resource to make better use of energy in buildings and to improve working conditions in offices. Indeed, daylight might well prove to be more important than heat gain in Beirut. However, this is a matter for further future research.

Bibliography

Abi Saiid, S. (1999) *Electricite du Liban (EDL): Technology overview & future plans.* Beirut: Electricite Du Liban.

Aburdene, M. F. (1988) *Computer simulation of dynamic systems.* Dubuque, Iowa: Wm. C. Brown.

ACEPT - The Arizona Collaborative for Excellence in Preparation of Teachers, (1999) Colour and light [online]. ACEPT. Available at: <http://acept.la.asu.edu/PiN/rdg/color/color.shtml> [26 June 2004].

Ackroyd, S. (1992) *Data collection in context.* 2nd ed. London: Longman.

Advanced Building Technologies and Practice Organization (2000) Building structure: spectrally selective glazings [online]. The Advance Building Technologies and Practice Organization. Available at: <http://www.advancedbuildings.org/main_t_building_spec_glazings.htm> [10 October 2000].

AETS - APAVE SUD (2003) "Climatic zones for building energy standards in Lebanon." *LEB/99/G35 - Climatic Zones 1*, Beirut: The General Directorate of Urban Planning in Lebanon.

Aizlewood, C., S. Coward, L. Hamilton, G. Raw and D. Wilde (2002) The impact of humidity on health and comfort in an office building, In Indoor Air 2002, Vol. 4, Monterey, California, June 30 – July 5, 2002. pp. 671-676.

Aizlewood, M. E. and P. J. Littlefair (1996) Daylighting prediction methods: a survey of their use, In CIBSE National Lighting Conference, Bath, UK, March 31 – April 3, 1996. pp. 126-140.

ALME - Association Lebanaise pour la Maitrise de L'Energie (1998) "State of the energy in Lebanon." Beirut: ALME.

Altman, D. (1996) Randomised trials In (Greenfield, T. (Ed.)) *Research methods. guidance for postgraduates.* London: Arnold.

Amorim, C. N. (2000) Commercial buildings and energy efficiency: the role of daylighting, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 119-123.

Ander, G. D. (1995) *Daylighting performance and design.* New York: Van Nostrand Reinhold.

Ander, G. D. (2003) *Daylighting performance and design.* 2nd ed. New Jersey: John Wiley & Sons.

Anshel, J. (1998) *Visual ergonomics in the workplace.* London: Taylor and Francis.

Arbid, G. J. (2002) Practicing modernism in Beirut: architecture in Lebanon, 1946-1970. Doctor of Design, Harvard University, Graduate School of Design.

Arnold, J., C. L. Cooper and I. T. Robertson (1998) *Work psychology: understanding human behaviour in the workplace.* 3rd ed. Harlow: Financial Times Management.

ASHRAE - American Society of Heating Refrigeration and Air Conditioning Engineers (1985) *Handbook of fundamental.* Atlanta: ASHRAE.

ASHRAE - American Society of Heating Refrigeration and Air Conditioning Engineers (1989) *ASHRAE standard 90.1: energy standard for buildings except low-rise residential buildings.* Atlanta: ASHRAE.

ASHRAE - American Society of Heating Refrigeration and Air Conditioning Engineers (1992) Workshop on indoor air quality, In Baltimore, September, 1992. ASHRAE.

ASHRAE - American Society of Heating Refrigeration and Air Conditioning Engineers (1997) *1997 ASHRAE handbook fundamentals - SI edition.* Atlanta: ASHRAE.

ASHRAE - American Society of Heating Refrigeration and Air Conditioning Engineers (1999a) *ASHRAE handbook: HVAC application.* Atlanta: ASHRAE.

ASHRAE - American Society of Heating Refrigeration and Air Conditioning Engineers (1999b) *ASHRAE standard 62-1999.* Atlanta: ASHRAE.

Athienitis, A. K. and A. Tzempelikos (2000) "A methodology for detailed calculation of room illuminance levels and light dimming in a room with motorized blinds integrated in an advanced window." Montreal, Canada: Centre for Building Studies, Concordia University.

Athienitis, A. K. and A. Tzempelikos (2002) A methodology for simulation of daylight room illuminance distribution and light dimming for a room with a controlled shading device, *Solar Energy,* 72 (4), 271-281.

Atif, M. R. (1994) Integrated daylighting systems: potential and limitations for optimum energy savings, In International Daylighting Workshop, Sydney, Australia, 1994.

Atif, M. R., J. A. Love and P. Littlefair (1997) Daylighting monitoring protocols & procedures for buildings [online]. National Research Council of Canada. Available at: <http://www.nrc.ca/irc/ircpubs> [19 December 2001].

Attenborough, M. and A. Goodwin (1996) "A review of methods for the evaluation of the energy contribution of daylight in buildings." *ETSU S/N3/00262/REP*, London: Harwell Laboratory, Energy Technology Support unit.

Au, L. S.H. (1999) Daylighting: a practical approach. PhD thesis, The University of Western Australia, School of Architecture and Fine Arts.

Baechler, M. C., T. J. Marseille, D. L. Hadley, R. D. Stenner and M. R. Peterson (1991) *Sick building syndrome: sources, health effects, mitigation.* New Jersey: Park Ridge.

Baird, G., J. Gray, N. Isaacs, D. Kernohan and G. McIndoe (1996) *Building evaluation techniques.* New York: McGraw-Hill.

Baker, N. (2000) We are all outdoor animals, In Architecture City Environment, PLEA 2000, University of Cambridge, Cambridge, 2000. James & James Science Publishers Ltd., pp. 553-555.

Baker, N., A. Fanchiotti and K. Steemers (Eds.) (1993) *Daylighting in architecture: a European reference book,* London: James & James Science Publishers Ltd.

Baker, N. and K. Steemers (2000) *Energy and environment in architecture: a technical design guide.* London: E & FN Spon.

Baker, N. and K. Steemers (2002) *Daylight design of buildings.* London: James & James Science Publishers Ltd.

Baldwin, R., A. Yates, N. Howard and S. Rao (1998) *BREEAM 98 for offices: an environmental assessment method for office buildings.* London: BRE.

Bank of Lebanon (1999) "1999 Annual report." Beirut: Bank of Lebanon.

Barkstrom, B. R. (2000) NASA surface meteorology and Solar Energy [online]. Atmospheric Sciences Data Centre, NASA Langley Research Centre. Available at: <http://eosweb.larc.nasa.gov/HPDOCS/access_data.html> [12 January 2004].

Barr, S., A. Steel and M. Barnsley (2001) Inferring urban land-use through a structural analysis of digital land cover map data [online]. University of Wales Swansea. Available at: <http://bruni.swan.ac.uk/map_data_paper/p1.html> [29 June 2003].

Barthakur, A., M. Schiler and P. Koenig (1999) The thermal behaviour of atria: measured data compared with a computational fluid dynamics model of the Bradbury building [online]. University of Southern California, School of architecture. Available at: <http://www.usc.edu/dept/architecture/mbs/papers/ecs/97_cfd/ases97cfd.html> [26 June 2003].

Bartlett, R., M. A. Halverson and D. L. Shankle (2003) "Understanding building energy codes and standards." *PNNL-14235*, Washington: Building Energy Codes.

Bean, A. R. and R. I. Bell (1992) The CSP index: a practical measure of office lighting quality as perceived by the office workers, In National Lighting Conference, UMIST, Manchester, April 5 - 8, 1992. CIBSE, pp. 63-75.

Bean, R. (2004) *Lighting: interior and exterior.* Amsterdam: Architectural Press.

Beaud, M. (1998) *L'art de la these: comment preparer et ridiger une these de doctorat un memoire de D.E.A. ou de maitrise ou tout autre travail universitaire.* 2nd ed. Paris: La Decouverte.

Begemann, S. H. A., G. J. van den Beld and A. D. Tenner (1994) Daylight, artificial light and people, In The 39th IES Convention, Sydney, Australia, 1994.

Begemann, S. H. A., G. J. van den Beld and A. D. Tenner (1995) Daylight, artificial light and people, part 2, In The 23rd Session of the Commission International de L'Eclairage (CIE), New Delhi, India, November 1 - 3, 1995. pp. 148-151.

Begemann, S. H. A., G. J. van den Beld and A. D. Tenner (1996) Daylight, artificial light and people: part 3, visual and biological responses, In CIBSE National Lighting Conference, University of Bath, Bath, March 31 – April 3, 1996. CIBSE, pp. 141-146.

Begemann, S. H. A., G. J. van den Beld and A. D. Tenner (1997) Daylight, artificial light and people in an office environment, overview of visual and biological responses, *Industrial Ergonomics,* 20 (1997), 231-239.

Belcher, C. and R. Helms (1997) Electronic lighting textbook [online]. The University of Kansas. Available at: <http://www.arce.ku.edu/book/eye/color.htm#start> [15 July 2001].

Benya, J. R. (1988) Practical philosophies of lighting psychology [online]. Architectural Lighting Magazine. Available at:
<http://www.lightforum.com/library/design/psychology/practicalphilosophies.html>
[2 July 2001].

Berrutto, V., P. Avonac-Bastie, M. Fontoynont and C. Belcher (1994) An experimental assessment of the office workers' preferences regarding some energy saving artificial lighting strategies, In The European Conference on the Energy Performance and Indoor Climate in Buildings, Lyon, France, November 24 - 26, 1994. pp. 834-840.

Beya, J. R. and J. C. Wbster (1977) Energy conservation and lighting: the facts and the follies, *Lighting Design and Application,* 16 (8), 40-44.

Black, D., S. Brown, A. Day and P. Race (1998) *500 tips for getting published: a guide for educators, researchers and professionals.* London: Kogan Page.

Bodart, M. and A. D. Herde (2002) Global energy savings in offices buildings by the use of daylighting, *Energy and Buildings,* 34 (5), 421 - 429.

Bordass, W. and A. Leaman (1993) User and occupant control in buildings, In Proceedings of the International Conference on Building Design , Technology and Occupant Well-Being in Temperate Climates, Brussels, February 17-19, 1993. ASHRAE, pp. 12-25.

Bordass, W. T., A. K. R. Bromley and A. J. Leaman (1995) "Comfort, control and energy efficiency in offices." *IP 3/95*, Garston, Watford: Building Research Establishment.

Borg, W. R. and J. P. Gall (1996) *Educational research: an introduction.* 6th ed. White Plains, New York: Longman Publishers.

Boubreki, M., R. Hullev and L. Boyer (1991) Impact of window size and sunlight penetration on office workers' mood and satisfaction: a novel way of assessing sunlight, *Environment and Behaviour,* 23 (4), 474-493.

Boyce, P. R. (1981) *Human factors in lighting.* London: Applied Science Publishers.

Boyce, P. R. (1996) Numerical criteria - a help or a hindrance in lighting design: visual performance criteria, In CIBSE National Lighting Conference, University of Bath, Bath, March 31 – April 3, 1996. CIBSE, pp. 62-64.

Boyce, P. R. (1997) Illumination In (Salvendy, G. (Ed.)) *Handbook of human factors and ergonomics.* New York: John Willey.

Boyce, P. R. (1998) Why daylight?, In 'Daylighting' 98, Ottawa, Ontario, Canada, May 11 - 13, 1998. Natural Resources Canada, pp. 359 - 366.

Boyce, P. R., J. W. Beckstead, N. H. Eklund, R. W. Strobel and M. S. Rea (1997) Lighting the graveyard shift: the influence of a daylight–simulating skylight on the task performance and mood of night shift workers, *Lighting Research and Technology,* 29 (3), 105-142.

Boyce, P. R. and N. H. Eklund (1998) Simple tools for evaluating lighting, In CIBSE National Lighting Conference, Lancaster University, 1998. CIBSE, pp. 255-275.

Brainard, G. C. (1995) Effects of light on physiology and behaviour, In The 23rd session of the CIE, Vol. 1, New Delhi, November 1 - 8, 1995. International Commission on Illumination (CIE), pp. 16.

BRE - Building Research Establishment (1986) *Designing for natural and artificial lighting: estimating daylight in buildings, an aid to energy efficiency.* Garston, Watford: BRE.

BRECSU - Building Research Energy Conservation Support Unit (1997) *Biceps module: lighting and energy efficiency.* Garston, Watford: BRESCU.

BRECSU - Building Research Energy Conservation Support Unit (1999) "Lighting for people, energy efficiency and architecture: an overview of lighting requirements and design." *272*, Garston, Watford: The Department of the Environment, Transport and the Regions' Energy Efficiency Best Practice programme.

Breeding, D. C. (1997) Surveying office illumination [online]. Mead Hatcher. Available at: <http://www.meadhatcher.com/illum.php3> [28 July 2001].

Brown, R. D. and T. J. Gillespie (1995) *Microclimatic landscape design: creating thermal comfort and energy efficiency.* New York: John Wiley & Sons.

Bryman, A. (1984) The debate about quantitative and qualitative research: a question of method for epistemology, *British Journal of Sociology,* 35 (1), 75-92.

BSI - British Standard Institution (1992) *Code of practice for daylighting - British Standard BS 8206: Part 2:1992.* London: BSI.

Burgt, P. J. M. v. d. and J. T. C. v. Kemenade (1992) Designing for the individual: can all be satisfied in lighting design?, In National Lighting Conference, UMIST, Manchester, April 5 - 8, 1992. CIBSE, pp. 76-84.

Burkett, R. (1999) Building quality lighting specifications [online]. Architectural Lighting Magazine. Available at:
<http://www.lightforum.com/library/design/designspec/buildingquality.html>
[2 July 2001].

Burns, R. B. (2000) *Introduction to research methods.* 4th ed. London: Sage publications.

Burton, S. (Ed.) (2001) *Energy efficient office refurbishment,* London: James & James Science Publishers Ltd.

Buson, M. and M. Romero (2000) Analysis of the Brasilia's building construction code concerning daylight, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 837-838.

Butler, D. and P. Biner (1989) Effects of setting on window preference and factors associated with those preferences, *Environment and Behaviour,* 21 (1), 17-31.

Button, D. and B. Pye (Eds.) (1993) *Glass in buildings: a guide to modern architectural glass performance,* Oxford: Pilkington with Butterworth Architecture.

Cakir, A. and G. Cakir (1998a) Light and health, influences of lighting on health and well-being of office and computer workers [online]. Ergonomic Institute for Occupational and Social Sciences Research Company. Available at: <http://www.healthylight.de> [30 June 2002].

Cakir, A. and G. Cakir, (1998b) Light and health: the most comprehensive study on the impact of office lighting on humans [online]. Ergonomic Institute for Occupational and Social Sciences Research Company. Available at: <http://www.healthylight.de> [30 June 2002].

California Energy Commission (2001) "The nonresidential manual for compliance with the 2001 energy efficiency standards." *P400-01-023*, California: California Energy Commission.

California Energy Commission (2003) "Windows and offices: a study of office worker performance and indoor environment." *P500-03-082-A-9*, California: California Energy Commission.

Capeluto, I. G. (2003) The influence of the urban environment on the availability of daylighting in office buildings in Israel, *Building and Environment,* 38 (5), 745 - 752.

Carter, D., T. Moor and A. Slater (2000) Lighting in offices: the comfort factor, *Light and Lighting*. (15 May 2000), 41-43.

Cawthorne, D. (1995) Daylighting and occupant health in buildings. PhD thesis, University of Cambridge, Department of Architecture.

CEN - European Committee for Standardization (1998) "Ventilation for buildings: design criteria for the indoor environment." *CR 1752*, Brussels: CEN.

Central Administration of Statistics (1996) *Statistical studies: the city of Beirut, results of buildings and establishments survey.* Beirut: Lebanese Republic.

Chadderton, D. V. (1995) *Building services engineering.* 2nd ed. London: E & FN Spon.

Chappell, D. (1984) *Report writing for architecture.* London: The Architectural Press Limited.

Chase, V. D. (1977) Lighting and energy efficiency, *Lighting Design and Application,* 7 (9), 14-18.

Chauvel, P., J. B. Collins, R. Dogniaux and J. Longmore (1982) Glare from windows: current views of the problem, *Lighting research and technology,* 14 (1), 31-46.

Chedid, R. B. and R. F. Ghajar (2004) Assessment of energy efficiency options in the building sector of Lebanon, *Energy Policy,* 32 (2004), 647-655.

Chen, K. (1999) *Energy management in illuminating systems.* London: CRC Press.

Cheong, K. W. and K. Y. Chong (2001) Development and application of an indoor air quality audit to an air-conditioned building in Singapore, *Building and Environment,* 36 (2), 181-188.

Christoffersen, J. and K. Johnsen (1999) SBI-report 318 Windows and daylight in *International Daylighting Newsletter,* Vol. 2 Danish Building and Urban Research, Horsholm, Denmark, pp. 11.

Christoffersen, J., E. Petersen, K. Johnsen, O. Valbjørn and S. Hygge (1999) Windows and daylight - a post-occupancy evaluation of offices [online]. Danish Building and Urban Research. Available at: <http://www.sbi.dk/udgivelser/appetitvaekkere/sbi-rapport_318/> [19 July 2001].

Christofferson, J., K. Johnsen, E. Petersen and O. Valbjorn (2000) Daylighting and window design: post-occupancy studies in office environments, *Light and Lighting,* 19 November (2000), 31-33.

CIBSE - Chartered Institution of Building Services Engineers (1987) *Applications manual: window design.* London: CIBSE.

CIBSE - Chartered Institution of Building Services Engineers (1994) *CIBSE code for interior lighting.* London: CIBSE.

CIBSE - Chartered Institution of Building Services Engineers (1997) *Natural ventilation in non-domestic buildings: application manual AM 10.* London: CIBSE.

CIBSE - Chartered Institution of Building Services Engineers (1999) *Daylighting and window design: lighting guide.* London: CIBSE.

Cidell, J. (2003) The conversion of military bases to commercial airports: existing conversions and future possibilities, *Journal of Transport Geography,* 11 (2), 93-102.

CIE - Commission Internationale de l'Eclairage (1970) Daylight, *CIE Publications,* 16 (1970).

Clarke, J. A., J. W. Hand, J. Hensen, K. Johnsen, K. Wittchen, R. Compagnon and C. Madsen (2000) "Integrated performance appraisal of Daylight-Europe case study buildings." Danish Building Research Institute.

Clarke, J. A. and M. Janak (1997) Simulating the thermal effects of daylight-controlled lightings [online]. Energy Systems Research Unit, University of Strathclyde. Available at: <http://www.strath.ac.uk/Departments/ESRU> [20 December 2001].

Clarke, L. A. (2001) *Energy simulation in building design.* 2nd ed. Oxford: Butterworth-Heinemann.

Clarke, N. G. (1998) Light and health, In The Importance of Light: Light, Colour and Health - Design for Reduced Stress in the Workplace, The Institution of Civil Engineers, London, October 29, 1998. Clearvision International, pp. 10-18.

Clements-Croome, D. (2000) Indoor environment and productivity In (Clements-Croome, D. (Ed.)) *Creating the productive workplace.* London: E & FN Spon.

Clements-Croome, D. and Y. Kaluarachchi (2000) Assessment and measurement of productivity In (Clements-Croome, D. (Ed.)) *Creating the productive workplace.* London: E & FN Spon.

Collard, B. and A. DeHerde (2001) Technology module 1: office building typology [online]. Mid-Career Education: Solar Energy in European Office Buildings, University College Dublin. Available at: <http://erg.ucd.ie/mid_career/pdfs/tech_mod_1.pdf> [13 June 2003].

Collins, B. (1989) "Post-occupancy of several U.S. government buildings." *NISTIR 89-4175*, Gaithersburg. USA: Department of Commerce, National Bureau of Standards.

Commission, H. a. S. (1992) "Workspace: Health safety and welfare Regulations 1992." *Approved code of practice and guidance L24*, London: HMSO.

Commission of the European Communities - Directorate-General XVII for Energy (1999) *A green Vitruvius: principles and practice of sustainable architectural design.* London: James & James Science Publishers Ltd.

Compagno, A. (1999) *Intelligent glass façades: material, practice, design.* 4th ed. Boston: Birkhauser-Verlag.

Cooper, H. M. (1989) *Integrating research: a guide for literature reviews.* 2nd ed. Newbury Park, California: Sage Publications.

Correa, G. and R. Almanza (2004) Copper based thin films to improve glazing for energy-savings in buildings, *Solar Energy,* 76 (2004), 111-115.

Cosmides, L., J. Tooby and R. Kurzban (2003) Perceptions of race, *Trends in Cognitive Sciences,* 7 (4), 173-179.

Creswell, J. W. (2003) *Research design: qualitative, quantitative, and mixed methods approaches.* 2nd ed. Thousand Oaks: Sage Publications.

Cuttle, G. C. (1983) People and windows in workplaces, In The People and Physical Environment Research Conference, Wellington, New Zealand, 1983.

Davie, M. and L. Nordiguian (1987) L'habitat urbain de Bayrut al-qadimat au 19eme sciecle, *Berytus,* XXXV .

Davie, M. F. (1987) Maps and historical topography of Beirut, *Berytus,* 35 141-164.

Dawson, L. (1995) Light spirited, *Design Review,* 197 (1171), 21.

de Bower, J. and H. Erhorn (1998) "Survey of simple design tools." Galve, Sweden: International Energy Agency (IEA).

DeMarco, T. and T. Lister (1987) *Peopleware productive projects and teams.* New York: Dorset House Pub.

Demers, C. M. H. (2000) Light and the digital image: a proposed framework for design and analysis, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 605-610.

Department of Psychology - University of Toronto (1996) Dark adaptation [online]. CQUEST. Available at: <http://www.cquest.utoronto.ca/psych/psy280f/ch3/drkadapt/da.html> [15 July 2001].

Department of statistics and Economics Research (1996) Annual report 1996 [online]. Central Bank of Lebanon. Available at: <http://www.bdl.gov.lb/bdl/pub> [18 April 1998].

Department of statistics and Economics Research (1999) Recent Economic Developments: Real Sector [online]. Central Bank of Lebanon. Available at: <http://www.bdl.gov.lb/bdl/pub> [19 February 1999].

Department of studies (1999) "Electricite du Liban." Beirut: Electricite du Liban.

DiLouie, C. (2000) New research offers possibilities of light as a nighttime simulant [online]. Architectural Lighting Magazine. Available at: <http://www.lightforum.com/library/design/psychology/stimulant.html> [2nd July 2001].

DiLouie, C. (2000) Quality metrics [online]. Architectural Lighting Magazine. Available at: <http://www.lightforum.com/library/design/psychology/qualitymetrics.html> [2 July 2001].

DOE - U.S. Department of Energy (2001) Building energy software tools directory [online]. Energy Efficiency and Renewable Energy Network, US Department of Energy. Available at: <http://www.eren.doe.gov/buildings/tools_directory/> [8 August 2002].

DOE - U.S. Department of Energy (2003) DOE Building Technologies Program: Integrated building design for energy efficiency [online]. Health Goods. Available at: <http://www.eere.energy.gov/buildings/design/integratedbuilding/> [14 June 2004].

DOE - U.S. Department of Energy and NREL - National Renewable Energy Laboratory (1993) Advances in glazing materials for windows [online]. Health Goods. Available at: <http://www.healthgoods.com/Education/Healthy_Home_Information/Doors_and_Windows/advances_glazing.htm> [13 October 2000].

Drever, E. (1995) *Using semi-structured interviews in small-scale research: a teacher's guide*. Glasgow: The Scottich Council for Research in Education.

Duffy, F., A. Laing and V. Crisp (1993) *The Responsible workplace: the redesign of work and office.* Oxford: Butterworth Architecture in association with Estates Gazette.

Dul, J. and B. A. Weerdmeester (1991) *Ergonomics for beginners: a quick reference guide.* 9th ed. London: Taylor & Francis.

EDL - Electricite Du Liban Institute (1994) *Electricity in Lebanon: the history of a century (1885-1994).* Beirut: EDL.

Edwards, B. (Ed.) (1998) *Green buildings pay,* London: E & FN Spon.

EIA - Energy Information Administration (1997) World Energy Database - Lebanon [online]. Energy Information Administration. Available at:
<http://www.eia.doe.gov/emeu/international/electric.html> [11 August 2000].

EIA - Energy Information Administration (2004) International electricity Information [online]. Energy Information Administration. Available at:
<http://www.eia.doe.gov/emeu/international/electric.html#IntlConsumption>
[10 July 2004].

Elder, J., G. E. Turner and A. I. Rubin (1979) "Post-occupancy evaluation: a case study of the evaluation process." *NBSIR 79-1780*, Gaithersburg, USA: National Engineering Laboratory, National Bureau of Standards.

El-Fadel, M., R. Chedid, M. Zeinati and W. Hmaidan (2002) Mitigating energy-related GHG emissions through renewable energy, *Renewable Energy,* 28 (2003), 1257-1276.

Elmahdy, A. H. and S. M. Comick (1988) New technology in the window industry [online]. National Research Council of Canada. Available at:
<http://www.nrc.ca/irc/bsi/88-5_E.html> [1 November 2000].

Ely, M., R. Vinz, M. Anzul and M. Downing (1997) *On writing qualitative research: living by words.* London: Falmer.

Embrechts, R. and C. V. Bellegem (1997) Increased energy savings by individual light control, In Right Light 4, Copenhagen, November 18 – 21, 1997. pp. 179-182.

Energy Code (1991) "Energy Edge - Post-occupancy evaluation project." Seattle, USA: University of Washington.

Energy Source Builder (1994) Choose your glazing by the numbers [online]. Oikos. Available at: <http://oikos.com/esb/35/glazing.html> [1 December 2002].

Erhorn, H. and M. Dirksmöller (Eds.) (2000) *SUPERLINK / RADLINK user's manual,* Stuttgart: Fraunhofer-Institut fur Bauphysik.

Erhorn, H. and M. Dirksmöller (Eds.) (2000) *SUPERLITE user's manual,* Stuttgart: Fraunhofer-Institut fur Bauphysik.

Ernest, P. (1994) *Educational research, its philosophy and purpose: an introduction to research methodology and paradigms.* Exeter: University of Exeter.

Errington, A., M. Hastings, L. Norman and R. Soffe (1988) *Benefiting from research: a study guide for those embarking on part-time research for a higher degree.* Reading: Farm Management Unit, University of Reading.

Evan, M. D. V. (1983) *Concepts in architectural lighting.* New York: McGraw-Hill.

Evans, G. W. and J. M. McCoy (1998) When buildings don't work: the role of architecture in human health, *Journal of Environmental Psychology,* 18 85-94.

Fanger, P. O. (1970) *Thermal comfort: analysis and applications in environmental engineering.* Malabar, Florida: Robert E. Krieger Publishing Company.

Fanger, P. O. (2001) Human requirements in future air-conditioned environments, *International Journal of Refrigeration,* 24 (2), 148-153.

Federal Energy Management Program (1998) Spectrally selective glazings: a well proven window technology to reduce energy costs while enhancing daylight and view [online]. The U.S. Department of Energy. Available at: <http://www.eren.doe.gov/femp/prodtech/pdfs/FTA_Glazings.pdf> [1 December 2002].

Federspiel, C., G. Liu, M. Lahiff, D. Faulkner, D. Dibartolomeo, W. Fisk, P. Price and D. Sullivan (2002) "Worker performance and ventilation rate in a call center: analyses of time-series data for a group of workers." *LBNL-45356*, Berkeley, CA: Lawrence Berkeley National Laboratory.

Fellows, R. and A. Liu (1997) *Research methods for construction.* London: Blackwell Science.

Figueiro, M., M. Rea, R. Stevens and A. Rea (2002) Daylight and productivity: a field study, In 2002 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, August 22 - 27, 2002.

Firman, T. (2004) New town development in Jakarta Metropolitan Region: a perspective of spatial segregation, *Habitat International,* 28 (3), 349-368.

Fisekis, K., M. Davies, P. Langford and M. Kolokotroni (2002) Visual quality in a daylit environment: prediction of discomfort glare, In World Renewable Energy Congress VII (WREC 2002), Cologne, June 29 – July 5, 2002. Elsevier Science Ltd., CD Version.

Fletcher, B. (1987) *History of architecture.* 19th ed. London: Butterworths.

Florence, N. (1976) Comparison of the energy effectiveness of office lighting systems, *Lighting Design and Application,* 6 (9), 30-36.

Flynn, E., J. A. Kremers, A. W. Segil and G. R. Steffy (1992) *Architectural interior systems: lighting, acoustics, air-conditioning.* 3rd ed. New York: Van Nostrand Reinhold.

Fontoynont, M. (Ed.) (1999) *Daylight performance of buildings,* London: James & James Science Publishers Ltd.

Fontoynont, M. and V. Berruto (1997) Daylight performance of buildings: monitoring procedure, In Right Light 4, Vol. 2, Copenhagen, Denmark, November 18 - 21, 1997, 1997. pp. 119-127.

Fontoynont, M., P. Laforgue, R. Mitanchey, M. Aizelwood, J. Butt, W. Carroll, R. Hitchcock, H. Erhorn, J. de Boer, M. Dirksmöller, B. Paule, J. L. Scartezzini, M. Bodart and G. Roy (1999) Validation of daylighting simulation programmes within IEA Task 21, In CIE Conference, Warsaw, June 24 - 30, 1999.

Forster, W., S. Greenberg and D. Hawekes (2000) Studies for the sustainable urban office building, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 63-66.

Frankfort-Nachmias, C. and D. Nachmias (1996) *Research methods in the social sciences.* 5th ed. London: Arnold.

Franta, G. and K. Anstead (2000) Daylighting offers great opportunities [online]. Window and Door Manufacturers Association. Available at:
<http://www.nwwda.org/articles/designlab_daylighting.html> [15 July 2001].

Galasiu, A. D. and M. R. Atif (1998) "Applicability of daylighting computer modelling in real case studies: comparison between measured and simulated daylight availability and lighting consumption." *T21/C1-21/CAN/98-11 - NRCC-42862*, Ottawa: National Research Council of Canada.

Galasiu, A. D. and M. R. Atif (2002) Applicability of daylighting computer modelling in real case studies: comparison between measured and simulated daylight availability and lighting consumption, *Building and Environment,* 37 (4), 363-377.

Galliers, R. D. (1992) Choosing information systems research approaches In (Galliers, R. D. (Ed.)) *Information systems research: issues, methods, and practical guidelines.* Oxford: Blackwell Scientific Publications.

Gardner, C. (1998) Introduction to light in the interior environment: a lighting designer's view, In The Importance of Light: Light, Colour and Health - Design for Reduced Stress in the Workplace, The Institution of Civil Engineers, London, October 29, 1998. Clearvision International, pp. 1-8.

General Directorate of Urban Planning (2003) "Lebanese energy standards for new non-residential, high-rise residential and low-rise residential buildings." *LEB/99/G35 - Draft 1B*, Beirut: General Directorate of Urban Planning.

Gephart, R. (1999) Paradigms and research methods [online]. Research Methods Division, Academy of Management. Available at: <http://www.aom.pace.edu/rmd/1999_RMD_Forum_Paradigms_and_Research_Methods.htm> [10 June 2003].

Ghosn, R. S. (1970) *"Beirut Architecture", Beirut crossroads of cultures.* Beirut: Librarie du Liban.

Gittins, R. G. (1999) Qualitative research: an investigation into methods and concepts in qualitative research [online]. Software Engineering Service integration. Available at: <http://www.sesi.informatics.bangor.ac.uk/english/home/research/technical-reports/sesi-020/formats/SESI-020.pdf> [31 July 2002].

Godet, M. (1994) *From anticipation to action: a handbook of strategic prospective (future-oriented studies).* Paris: UNESCO.

Gould, J. G. (1968) Visual factors in the design of computer-controlled CRT displays, *Human Factors,* (10), 359-376.

Goulding, J. R., J. O. Lewis and T. C. Steemers (Eds.) (1992) *Energy conscious design: a primer for architects,* London: B. T. Bastford.

Grandjean, E. (1988) *Fitting the task to the man: a textbook of occupational ergonomics.* 4th ed. London: Taylor & Francis.

Greenfield, T. (1996) Laboratory and industrial experiments In (Greenfield, T. (Ed.)) *Research methods. guidance for postgraduates.* London: Arnold.

Groat, L. N. and D. Wang (2002) *Architectural research methods.* New York: John Wiley & Sons.

Guam Energy Department (1995) Guam building energy code [online]. Eley Associates. Available at: <http://www.eley.com/guam/> [15 June 2004].

Guba, E. G. and Y. S. Lincoln (2000) Paradigmatic controversies, contradictions, and emerging confluences In (Denzin, N. K. and Y. S. Lincoln (Eds.)) *Handbook of qualitative research.* 2nd ed. London: Sage Publications.

Guba, E. G., Y. S. Lincoln and C. Park (1994) Competing paradigms in qualitative research In (Denzin, N. K. and Y. S. Lincoln (Eds.)) *Handbook of qualitative research.* 1st ed. Thousand Oaks: Sage Publications.

Gugliermetti, F. and F. Bisegna (2003) Meteorological days for HVAC system design in Mediterranean climate, *Building and Environment,* 38 (8), 1063-1074.

Guzowski, M. (2000) *Daylighting for sustainable design.* New York: McGraw Hill.

Haddlesey, P. (2001) Guiding light, *Building Services Journal,* (July 2001), 42-43.

Hadi, M. (2001) Personnel space, *Building Services Journal,* (July 2001), 45-47.

Haken, H. and J. Portugali (2003) The face of the city is its information, *Journal of Environmental Psychology,* 23 (4), 385-408.

Hammarberg, E. and A. Roos (2003) Antireflection treatment of low-emitting glazings for energy efficient windows with high visible transmittance, *Thin Solid Films,* 442 (2003), 222 - 2226.

Hanna, G. B. and N. M. Guirgis (2003) Egypt energy code for new residential buildings, In Energy Codes for Buildings, Beirut, Lebanon, December 2 - 4, 2003. Order of Engineers and Architects - Beirut, CD publication.

Harris, J., H. Elkadi and M. Wigginton (1998) The evaluation of the intelligent skin, In World Renewable Energy Congress V, Vol. 3, Florence, Italy, September 20 - 25, 1998. Pergamon, pp. 1336-1340.

Health and Safety Executive (1987) *Lighting at work.* London: Health and Safety Executive.

Heerwagen, J. H. (1998) Design, productivity and well being: what are the links, In Highly Effective Facilities, The American Institute of Architect, Ohio, March 12 - 14, 1998.

Hens, H., G. Verbeeck and B. Verdonck (2001) Impact of energy efficiency measures on the CO2 emissions in the residential sector, a large scale analysis, *Energy and Buildings,* 33 (2001), 275-281.

Heschong, L. and F. Oaks (2003) "Windows and offices: a study of office worker performance and the indoor environment." *P500-03-082-A-9*, California: California Energy Commission.

Hitchcock, R. J. (1995) "Advancing lighting and daylighting simulation: the transition from analysis to design aid tools." *LBL-37285 DA 333*, Berkeley, CA: Building Technology Program, Energy and Environment Division, Laurence Berkeley Laboratory, University of California.

Hopkinson, R. G. (1972) Glare from daylighting in buildings, *Applied Ergonomics,* 3 (4), 206-215.

Hopkinson, R. G. and J. B. Collins (1970) *The ergonomics of lighting.* London: MacDonald Technical and Scientific.

Hopkinson, R. G., P. Petherbridge and J. Longmore (1966) *Daylighting.* London: Heinemann.

Hraska, J. (2000) Right to light versus right to build, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 839-840.

Huang, Y. J., B. Thom and B. Ramadan (1989) A daylighting design tool for Singapore based on DOE-2.1C simulations, In Proceedings of the ASHRAE Far East Conference on Air-conditioning in Hot Climates, Kuala Lumpur, October 25 - 28, 1989. pp. 200–227.

Huizenga, C., Z. Hui and E. Arens (2001) A model of human physiology and comfort for assessing complex thermal environments, *Building and Environment,* 36 691-699.

Huld, T. and M. Suri (2002) Solar irradiation data utility [online]. Institute for Environment and Sustainability (IES). Available at: <http://iamest.jrc.it/pvgis/solradframe.php> [12 January 2004].

Hunt, D. R. G. (1980) Predicting artificial lighting use - a method based upon observed patters and behaviour, *Lighting Research and Technology,* 12 (1), 7-14.

HunterLab, (2001) The basics of colour perception and measurement [online]. HunterLab. Available at: <http://www.hunterlab.com/pdf/color.pdf> [28 June 2004].

Hutchins, M. G. (1997) "Application guidance and technology transfer." *T18/A5B10/FR1/97*, International Energy Agency.

Hutchins, M. G., A. J. Topping, C. Anderson, F. Olive, P. v. Nijnatten, P. Polato, A. Roos and M. Rubin (2000) Angle-dependent optical properties of coated glass products: results of an interlaboratory comparison of spectral transmittance and reflectance, In 3rd International Conference: Coatings on Glass, Maastricht, The Netherlands, October 29 – November 2, 2000. pp. 467-478.

Hygge, S. and H. A. Lofberg (1997) User evaluation of visual comfort in some buildings of the Daylight Europe project, In Right Light 4 - Proceedings of the 4th European Conference on Energy-Efficient Lighting, Vol. 2, Copenhagen, Denmark, November 18 - 21, 1997. International Association for Energy-Efficiency Lighting (IAEEL), pp. 69-74.

Hygge, S. and H. A. Lofberg (1999) "POE Post- occupancy evaluation of daylighting buildings." Galve, Sweden: International Energy Agency, Solar Heating and Cooling Programme.

IESNA - Illuminating Engineering Society of North America (1984) *IES lighting handbook 1984 reference volume.* New York: IESNA.

IESNA - Illuminating Engineering Society of North America (1999) "Recommended practice of daylighting." *IESNA RP-5-99*, New York: IESNA.

Ikeda, K., H. Yamashina and A. Ichihashi (1994) New colour space for evaluation of colour rendering properties of light sources, In CIBSE National Lighting Conference, Robin College, Cambridge, March 27 -30, 1994. CIBSE, pp. 45-60.

Ikeda, K., H. Yamashina and A. Ichihashi (1996) Colour rendering properties of light sources: new colour space for evaluation, *International Journal of Lighting Research and Technology*, 28 (2), 97-112.

ISO - International Organisation for Standardisation (1995) *ISO 7730 - 1995: Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.* Geneva: ISO.

Janda, K. B. and J. F. Busch (1994) Worldwide status of energy standards for buildings, *Energy*, 19 (1), 27-44.

Janesick, V. J. (1998) *"Stretching" exercises for qualitative researchers.* Thousand Oaks: Sage Publications.

Jeffreys, A. (1999) *Emerging Lebanon 2000: the annual business, economic and political review.* London: Oxford Business Group.

Johnsen, K. (1998) Daylight in buildings, collaborative research in the International Energy Agency (IEA Task 21), *Renewable Energy,* 15 (1-4), 142-150.

Johnsen, K. (1999) "Daylight. A basic human need." Washington, D.C.: International Energy Agency, IEA.

Johnson, C. (2001) Workplace productivity, environmental comfort and individual control: a direct relationship [online]. Johnson Controls. Available at: <http://www.jci.com/cg/PersEnv/pe_whitepaper.html> [29 July 2001].

Johnson, R., R. Sullivan, S. Selkowitz, S. N. S. and C. Conner (1984) "Glazing energy performance and design optimization with daylighting." *LBL-15625*, California: Lawrence Berkeley Laboratory, University of California.

Jukes, J. (1998) Light in the workplace: design and application using virtual daylight, In The Importance of Light: Light, Colour and Health - Design for Reduced Stress in the Workplace, The Institution of Civil Engineers, London, October 29, 1998. Clearvision International, pp. 42-46.

Kane, E. and M. O. R.-d. Brún (2001) *Doing your own research.* London: Marion Boyars.

Karasek, R. and T. Theorell (1990) *Healthy work: stress, productivity, and the reconstruction of working life.* New York: BasicBooks.

Keep, P., J. James and M. Inman (1980) Windows in the intensive therapy unit, *Anathesia,* (35), 257-262.

Kenney, P. and J. O. Lewis (Eds.) (1995) *Tools and techniques for the design and evaluation of energy efficient buildings*, Dublin: University College.

Kerlinger, F. N. (1986) *Foundations of behavioural research.* 3rd ed. New York: Holt, Rinehart and Winston.

Khalaf, S. and P. S. Khoury (Eds.) (1993) *Recovering Beirut: urban design and post-war reconstruction*. Leiden: E. J. Brill.

Khalaf, S. and P. Kongstad (1973) *Hamra of Beirut: a case of rapid urbanization.* Leiden: E. J. Brill.

Knight, I. P. (1999) Measured energy savings due to photocell control of individual luminaires. *Lighting Research and Technology,* 31 (1), 19-22.

Koenigsberger, O. H., T. G. Ingersoll, A. Mayhew and S. V. Szokolay (1973) *Manual of tropical housing and building, part 1: climatic design.* London: Longman.

Kokoshka, S. and P. Haubner (1985) Luminance ratios and visual display workstations and visual performance, *Lighting Research and Technology,* (17), 138-144.

Kolb, H., E. Fernandez and R. Nelson (2000) Light and dark adaptation [online]. Webvision. Available at: <http://webvision.med.utah.edu/light_dark.html> [15 July 2001].

Kotani, H., M. Narasaki, R. Sato and T. Yamanaka (2003) Environmental assessment of light well in high-rise apartment building, *Building and Environment,* 38 (2), 283-289.

Kovach-Hebling, A., M. Goller, S. Herkel and J. Wienold (1997) Assessing the energy saving potential of daylighting technologies for non-residential buildings in Germany, In Right Light 4, Vol. 2, Copenhagen, Denmark, November 18 – 21, 1997. IAEEL, pp. 115-118.

Kroemer, K. H. E. and E. Grandjean (1997) *Fitting the task to the man: a textbook of occupational ergonomics.* 5th ed. London: Taylor & Francis.

Kroner, W. and J. Stark-Martin (1994) Environmentally responsive workstations and office-worker productivity, *ASHRAE Transactions,* 100 (2), 750-755.

Krueger, T. (1994) Like a second skin: living machines, *Architectural Design,* 66 (9/10).

Lacy, M. L. (1998) Colour aspects of light in the workplace: how different colours affects human mood and brain activity, In The Importance of Light: Light, Colour and Health -

Design for Reduced Stress in the Workplace, The Institution of Civil Engineers, London, October 29, 1998. Clearvision International, pp. 27-31.

Laforgue, P., B. Souyri, M. Fontoynont and G. Achard (1997) Simulation of visual and thermal comfort related to daylighting and solar radiation In office buildings, In Building Simulation '97, Vol. 2, Prague, Czech Republic, September 8 - 10, 1997. pp. 299-306.

Laine, M. d. (2000) *Fieldwork, participation and practice: ethics and dilemmas in qualitative research.* London: Sage Publications.

Laing, A., F. Duffy, D. Jaunzens and S. Willis (1998) *New environments for working: the re-design of offices and environmental systems for new ways of working.* London: E & FN Spon.

Lam, J. C. and S. C. M. Hui (1996) Sensitivity analysis of energy performance of office buildings, *Building and Environment,* 31 (1), 27-39.

Lam, J. C. and D. H. W. Li (1999) An analysis of daylighting and solar heat for cooling-dominated office building, *Solar Energy,* 65 (4), 251-262.

Langston, C. A. and G. K. C. Ding (Eds.) (2001) *Sustainable practices in the built environment,* Oxford: Butterworth Heinemann.

Larson, M. B. (2004) The Sun in the sky at different times of the year in the Northern hemisphere [online]. Available at: <http://solar.physics.montana.edu/YPOP/Classroom/Lessons/Sundials/skydome.html> [15 June 2004].

Laurentin, C., V. Berruto and M. Fontoynont (2000) Effect of thermal conditions and light source type on visual comfort appraisal, *International Journal of Lighting Research and Technology,* 32 (4), 223-233.

Leaman, A. (1992) "Productivity and efficiency in the workplace." London: Building Uses Studies.

Leaman, A. and B. Bordass (2000) Productivity in buildings: the 'killer' variables In (Clements-Croome, D. (Ed.)) *Creating the productive workplace.* London: E & FN Spon.

Lechner, N. (1991) *Heating, cooling, lighting design methods for architect.* New York: John Wiley & Sons.

Lee, E. S., D. L. DiBartolomeo and S. E. Selkowitz (2000) "Electrochromic windows for commercial buildings: monitored results from a full-scale testbed." *LBNL-45415 DA-414*, Berkeley, CA: Windows and Daylighting Group - University of California.

Leedy, P. D. (1989) *Practical research: planning and design.* 4th ed. New York: Macmillan.

Leslie, R. P. (2003) Capturing the daylight dividend in buildings: why and how?, *Building and Environment,* 38 (2003), 381- 385.

Li, D. H. W. and J. C. Lam (2000) Measurements of solar radiation and illuminance on vertical surfaces and daylighting implications, *Renewable Energy,* 20 (4), 389-404.

Li, D. H. W. and J. C. Lam (2001) Evaluation of lighting performance in office buildings with daylighting controls, *Energy and Buildings,* 33 (8), 793-803.

Li, D. H. W. and J. C. Lam (2003) An investigation of daylighting performance and energy saving in a daylit corridor, *Energy and Buildings,* 35 (2003), 365-373.

Liger-BLair, J. (1966) *L'habitation au Liban.* Beirut: L'Association pour la Protection des Sites et Anciennes Demeures.

Light and Radiation Group (1998) Presentation of Genelux [online]. Département Génie Civil et Bâtiment URA CNRS and Ecole Nationale des Travaux Publics de l'Etat. Available at: <http://genelux.entpe.fr/sommaire.html> [18 August 2002].

Littlefair, P. J. (1988) *Average daylight factor: a simple basis for daylight design.* Watford: Building Research Establishment (BRE).

Littlefair, P. J. (1989) *Solar shading of buildings.* Watford: Building Research Establishment (BRE).

Littlefair, P. J. (1996) *Designing with innovative daylighting.* Watford: Building Research Establishment (BRE).

Littlefair, P. J. (1999) *Solar shading of buildings.* Watford: Building Research Establishment (BRE).

Littler, J. and R. Thomas (1984) *Design with energy: the conservation and use of energy in buildings.* Cambridge: Cambridge University Press.

Loe, D. (1998) Task and building lighting - a design approach, In The Importance of Light: Light, Colour and Health - Design for Reduced Stress in the Workplace, The

Institution of Civil Engineers, London, October 29, 1998. Clearvision International, pp. 20-25.

Loe, D. L. (1996) The art and science of lighting: a strategy for lighting design, *International Journal of Lighting Research and Technology,* 28 (4), 153-164.

Loe, D. L., K. P. Mansfield and E. Rowlands (1994) Appearance of lit environment and its relevance in lighting design: experience study, *Lighting Research and Technology,* (26), 119-133.

Louw, H. (Ed.) (2002) *The place of technology in architectural history: joint symposium 2001,* Newcastle upon Tyne: The Society of Architectural Historians of Great Britain.

Love, J. (1995) The regulation of residential daylighting in responce to new window technologies, In Right Light Three, Newcastle, UK, June 18-21, 1995. pp. 329-335.

Lynes, J. A. (1996) Lighting a language?, In CIBSE National Lighting Conference, University of Bath, Bath, March 31 – April 3, 1996. CIBSE, pp. 67-73.

Lyons, P., D. Arasteh and C. Huizenga (1999) "Window performance and human thermal comfort." *LBNL-44032 / Ta-412*, Dallas Texas: Lawrence Berkeley National Laboratory.

Mahnke, F. H. and R. H. Mahnke (1993) *Colour and light in man-made environments.* New York: Van Nostrand Reinhold.

March, A. (1999) Human eye and sight [online]. The FRIDGE Architectural Science Lab. Available at: <http://fridge.arch.uwa.edu.au/topics/lighting/basics/human_eye.html> [17 July 2001].

Markus, T. A. (1967) The function of windows: a reappraisal, *Building Science,* 2 97-121.

Marmot, A. and J. Eley (2000) *Office space planning. designing for tomorrow's workplace.* New York: McGraw-Hill.

Marshall, C. and G. B. Rossman (1999) *Designing qualitative research.* 3rd ed. Thousand Oaks, California: Sage Publications.

Mason, J. (2002) *Qualitative researching.* 2nd ed. London: Sage Publications.

May, T. (2001) *Social research: issues, methods and process.* 3rd ed. Philadelphia.: Open University.

McCloughan, C. L. B., P. A. Aspinall and R. S. Webb (1996) The effects of lighting upon mood and decision making, In CIBSE National Lighting Conference, University of Bath, Bath, March 31 – April 3, 1996. CIBSE, pp. 237-243.

McCloughan, C. L. B., P. A. Aspinall and R. S. Webb (1999) The impact of lighting on mood, *International Journal of Lighting Research and Technology,* 31 (3), 81-88.

McGowan, T. and N. J. Miller (2000) Lighting quality and its design application, *Light and Lighting,* (18 October 2000), 29-31.

McHugh, J. R. (1995) Daylighting design via Monte Carlo. Degree of Master of Science, Colorado State University, Department of Mechanical Engineering.

McMillan, J. H. and S. Schumacher (1997) *Research in education: a conceptual introduction.* 4th ed. New York: Harlow, Longman.

McMullan, R. (2002) *Environmental science in building.* 5th ed. New York: Palgrave.

McNicholl, A. and J. O. Lewis (Eds.) (1994) *Daylighting in buildings,* Dublin: University College.

Megaw, E. D. and L. J. Bellamy (1983) Illumination at work In (Oborne, D. J. and M. M. Gruneberg (Eds.)) *The Physical Environment at Work.* Chichester: John Wiley & Sons.

Meister, D. (1999) *The History of human factors and ergonomics.* New Jersey: Lawrence Erlbaum Associates.

Michel, P. (2001) Indoor air quality and ventilation in urban environment In (Santamouris, M. (Ed.)) *Energy and climate in the urban built environment.* London: James & James Science Publishers Ltd.

Miller, N. (1994) Pilot studies reveal quality results, *Lighting Design and Application,* 24 (3), 19-21.

Miller, N., H. McKay and P. R. Boyce (1995) An approach to a measurement of lighting quality, In The Annual Conference of the Illuminating Engineering Society of North America, New York, July 29 - 31, 1995. IESNA, pp. 19-21.

Mills, E. (1996) Window as luminaires [online]. Centre for Building Science (CBS). Available at: <http://eande.lbl.gov/CBS/NEWSLETTER/NL10/windows.html>
[2 November 2000].

Milner, P. and B. Sims (2000) Window of opportunity, *Light and Lighting,* (19 November 2000), 15-17.

Milton, D., P. Glencross and M. Walters (2000) Risk of sick leave associated with outdoor ventilation level, humidification, and building related complaints, *Indoor Air,* 10 (4), 212-221.

Minichiello, V. and R. Aroni (1990) *In-depth interviewing: researching people.* South Melbourne: Longman Cheshire.

Ministry of Environment / LEDO (2001) Lebanon state of the environment report [online]. The Lebanese Ministry of Environment. Available at: <http://www.moe.gov.lb/Reports/SOER2001.htm> [10 July 2004].

Ministry of Planning (1969) "Recueil de statistiques Libanaise, No. 5." *No. 5*, Beirut: Ministry of Planning, Lebanese Republic.

Ministry of Public Affairs and Transport (1966) *Climatic atlas of Lebanon (in French).* Beirut: Department of Lebanese Meteorology.

Mitchell, M. L. and J. M. Jolley (1988) *Research design explained.* New York: Holt, Rinehart and Winston.

Moore, F. (1991) *Concepts and practice of architectural daylighting.* 2nd ed. New York: Van Nostrand Reinhold.

Moore, N. (1983) *How to do research.* London: Library Association.

Mudri, L. and J.-D. Lenard (2000) Comfortable and/or pleasant ambience: conflicting issues, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 599-604.

Mueller, H. F. O. (2002) Simultaneous field tests of different facades with combined shading and daylighting systems, In World Renewable Energy Congress VII (WREC 2002), Cologne, 2002, June 29 – July 5, 2002. Elsevier Science Ltd.

Mullins, R., (1998) `Daylighting': Does it improve office productivity? [online]. American City Business Journals Inc. Available at: <http://milwaukee.bizjournals.com/milwaukee/stories/1998/06/01/focus3.html?page=1> [3 June 2004].

Muneer, T., N. Abodahab, G. Weir and J. Kubie (2000) *Windows in buildings: thermal acoustic, visual and solar performance.* Oxford: Architectural Press.

Munton, A. G. (1999) *Attributions in action. a practical approach to coding qualitative data*. Chichester: John Wiley & Sons.

Murdoch, J. B. (1985) *Illumination engineering: from Edison's lamp to the laser.* New York: Macmillan Publications Co.

Myatt , T., J. Staudenmayer, K. Adams, M. Walters, S. Rudnick and D. Milton (2002) A study of indoor carbon dioxide levels and sick leave among office worker, *Environmental Health,* 1 (1), 3.

Ne'eman, E. (1974) Visual aspects of sunlight in buildings, *Lighting Research and Technology*, 6 (3), 159-164.

Nemeskeri, R., J. A. Love, M. Navvab and R. W. Wardell (1995) User assessment of offices with and without windows, In IESNA annual conference, New York, 1995. IESNA.

Newsham, G. R. and J. A. Veitch (1998) Individual control over office lighting: perceptions, choices and energy savings, *Construction Technology Update,* 1998 Collection (No. 21), 1-4.

Ng, E. Y.-Y., L. K. Poh, W. Wei and T. Nagakura (2001) Advanced lighting simulation in architectural design in the tropic, *Automation in Construction,* 10 (3), 365-379.

Norris, D. and L. Tillet (1997) Daylight and productivity: is there a causal link?, In Glass Processing Days Conference, Tampere, Finland, September 13 - 15, 1997. pp. 213-217.

Noyes, J. (2001) *Design for humans.* East Sussex: Psychology Press, Taylor and Fransis Group.

NUTEK - Swedish National Board for Industrial and Technological Development (1994) *Lighting design requirements: office lighting (S-117 86).* Stockholm: NUTEK, Department of Energy Efficiency.

Oborne, D. J. (1995) *Ergonomics at work: human factors in design and development.* 3rd ed. Chichester: John Wiley & Sons.

Oborne, D. J. and M. M. Gruneberg (Eds.) (1983) *The physical environment at work,* Chichester: John Wiley & Sons.

Oikos Green Building Source, (1994) Choose your glazing by the numbers [online]. Oikos Green Building Source. Available at: <http://oikos.com/esb/35/glazing.html> [20 September 2000].

Oklahoma State University (2001) Defining ergonomics [online]. Oklahoma State University. Available at: <http://www.pp.okstate.edu/ehs/training/ergo.htm> [19 June 2004].

Olgyay, V. W. and S. Meder (2000) Daylight design guidelines for Hawaii, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 833-844.

Opdal, K. and B. Brekke (1995) Energy saving in lighting by utilisation of daylight, In Right Light 3, Newcastle upon Tyne, June 18 -21, 1995. pp. 67-74.

Oppenheim, A. N. (1992) *Questionnaire design, interviewing, and attitude measurement.* London: Pinter Publishers.

Order of Architects and Engineers (2004) Building investements from 1993 - 2003 (in Arabic), *Al-Mouhandes,* 6 (2), 5-17.

Order of Engineers & Architects (1995) *Building legislation and codes in Lebanon.* Beirut: Order of Engineers & Architects.

Oseland, N. and P. Barltett (1999) *Improving office productivity: a guide for business and facilities managers.* Harlow: Longman.

Osterhaus, W. K. E. (1993) Office lighting: a review of 80 years of standards and recommendations, In The 1993 IEEE Industry Applications Society Annual Meeting, Toronto, Ontario, Canada, October 2 - 8, 1993. Lawrence Berkeley Laboratory.

Osterhaus, W. K. E. and S. E. Selkowitz (1992) "Background and conceptual plan for conducting post-occupancy evaluations of interior luminous environments." Berkeley, USA: Energy and Environment Division, Laurence Berkeley Laboratory.

Pantry, S. (1996) Ergonomic checkpoint [online]. Health and Safety World Focus. Available at: <http://www.hspublishing.com/hsworld/focus-1996-11.html> [25 July 2001].

Papamichael, K., C. Ehrlich and G. Ward (1996) "Design and evaluation of daylighting applications of holographic glazings." *LBNL-44167 DA-409,* Berkeley, CA: Environmental Energy Technologies Division, University of California.

Parpairi, K., N. Baker and K. Steemers (2000) Daylighting quality through user preferences: investigating libraries, In Architecture, City, Environment, Proceedings of

PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 611-616.

Parry, C. M. (1994) Expression of light: the architecture of Louis Kahn, In CIBSE National Lighting Conference, Robin College, Cambridge, March 27 – 30, 1994. CIBSE, pp. 1-14.

Parsons, K. C. (1995a) Ergonomics and international standards: introduction, brief review of standards for anthropometry and control room design and useful information, *Applied Ergonomics,* 26 (4), 239-247.

Parsons, K. C. (1995b) Ergonomics and the physical environment: international ergonomics standards concerning speech communication, danger signals, lighting, vibration and surface temperatures, *Applied Ergonomics,* 26 (4), 281-292.

Parsons, K. C. (2000) Environmental ergonomics: a review of principles, methods and models, *Applied Ergonomics,* 31 (6), 581-594.

Parsons, K. C. and C. Kenneth (1993) *Human thermal environments.* London: Taylor & Francis.

Parsons, K. C., B. Shackel and B. Metz (1995) Ergonomics and international standards: history, organisational structure and method of development, *Applied Ergonomics,* 26 (4), 249-258.

Payne, R. (1996) Agricultural experiments In (Greenfield, T. (Ed.)) *Research methods. guidance for postgraduates.* London: Arnold.

Pellegrino, A. (1999) Assessment of artificial lighting parameters in a visual comfort perspective, *International Journal of Lighting Research and Technology,* 31 (3), 107-116.

Perry, M. J. (1992) Visual distraction and its role in discomfort glare perception, In CIBSE National Lighting Conference, UMIST, Manchester, April 5 - 8, 1992. CIBSE, pp. 164-177.

Perry, M. J. and I. R. Moorhead (1994) A visual performance model based on human vision, In CIBSE National Lighting Conference, Robin College, Cambridge, March 27 – 30, 1994. CIBSE, pp. 75-90.

PG&E Energy Centre (1997) Energy-efficient window glazing systems for commercial facilities [online]. Pacific Gas and Electric Company. Available at:

<http://www.pge.com/003_save_energy/003c_edu_train/pec/info_resource/pdf/GLAZSYS.PDF> [30 November 2002].

PG&E Energy Centre (1998) Smarter energy, window glazing systems [online]. PG&E Energy Centre. Available at: <http://www.pge.com/customer_services/business/energy/smart/html/ns_windows_guide.html> [2 October 2000].

Pheasant, S. (1987) *Ergonomics: standards and guidelines for designers.* Milton Keynes: British Standards Institution.

Pheasant, S. (1998) *Bodyspace: anthropometry, ergonomics and the design of work.* 2nd ed. London: Taylor & Francis.

Phillips, D. (2002) *The lit environment.* Boston, MA: Architectural Press.

Pickering, M. and R. Orrell (1993) "Daylighting in the building regulations: a feasibility study report." *Report S1353*, Harwel: ETSU.

Powler, D. and D. Kelbaugh (1990) Building envelopes In (Anderson, B. (Ed.)) *Solar building architecture.* Cambridge, Mass: Massachusetts Institute of Technology Press.

Preiser, W. F. E., H. Z. Rabinowitz and E. T. White (1988) *Post-occupancy evaluation.* New York: Van Nostrand Reinhold.

Price, I. (2000) Research methods and statistics [online]. School of Psychology, University of New England. Available at: <http://www.une.edu.au/WebStat> [16 April 2004].

Public Work and Governement Services (2002) "Daylighting guide for Canadian commercial buildings." *Final Report*, Ottawa: Public Work and Governement Services.

QUT - Queensland University of Technology (2000) Laser cut light deflecting panel (LCP) [online]. AD LUX. Available at: <http://www.adlux.fi/fi/tuotteet/valaistus/paivanvalopaneeli/LCP.htm> [15 October 2000].

Ragette, F. (1974) *Architecture in Lebanon: the Lebanese house during the 18th and 19th centuries.* New York: Caravan Books.

Ragette, F. (Ed.) (1983) *Beirut of tomorrow,* Beirut: American University of Beirut.

Randall, T. (Ed.) (1999) *Environmental design: an introduction for architects and engineers,* New York: E & FN Spon.

Rea, M. S. (Ed.) (2000) *The IESNA lighting handbook. reference & application,* New York: Illuminating Engineering Society of North America.

Rea, M. S., M. J. Ouellette and M. E. Kennedy (1990) The effects of luminous surroundings on visual performance, pupil size, and human preference, *Journal of Illuminating Engineering Society,* (19), 45-58.

Rennie, D. and F. Parand (1998) *Environmental design guide for naturally ventilated and daylit office.* Watford: Building Research Establishment (BRE).

Reppel, J. and I. R. Edmonds (1998) Angle selective glazing for radiant heat control in buildings: theory, *Solar Energy,* 62 (3), 245-253.

Riley, T. (1995) *Light construction.* New York: The Museum of Modern Art.

Robbins, C. L. (1986) *Daylighting design and analysis.* New York: Van Nostrand Reinhold.

Roberts, B. (1997) *The quest for comfort.* London: CIBSE.

Robinson, P. C. (Ed.) (1988) *Academic writing: process and product - ELT documents 129,* Hong Kong: English Publication and the British Council.

Roche, L., E. Dewey and P. Littlefair (2000) Occupant reactions to daylight in offices, *International Journal of Lighting Research and Technology,* 32 (3), 119-126.

Rostron, J. (Ed.) (1997) *Sick building syndrome: concepts issues and practice,* London: E & FN Spon.

Roulet, C.A. (2001) Indoor environment quality in buildings and its impact on outdoor environment, *Energy and Buildings,* 33 (3), 183-191.

Routio, P. (2004) Theory of architecture [online]. University of Art and Desgn Helsinki. Available at: <http://www2.uiah.fi/projects/metodi/135.htm#begin> [13 July 2004].

Rouveyran, K.-C. (1989) *Mémoires et thèses: l'art et les méthodes.* Paris: Maisonneuve & Larose.

Rowe, P. and H. Sarkis (1998a) From colonial style to regional revivalism: modern architecture in Lebanon and the problem of cultural identity In (Rowe, P. and H. Sarkis

(Eds.)) *Projecting Beirut: episodes in the construction and reconstruction of a modern city*. Munich: Prestel.

Rowe, P. and H. Sarkis (1998b) *Projecting Beirut: episodes in the construction and reconstruction of a modern city*. Munich: Prestel.

Roy, G. G. (2000) A comparative study of lighting simulation packages suitable for use in architectural design [online]. School of Engineering, Murdoch University. Available at: <http://eng.murdoch.edu.au/FTPsite> [20 December 2001].

Ruck, N. C. (Ed.) (1989) *Building design and human performance,* New York: Van Nostrand Reinhold.

Ruppert, H. (1999) *Beyrouth, une ville d'orient marquee par l'occident.* Beirut: CERMOC.

Rutten, A. J. F. (1991) Daylight-controlled artificial lighting: a potential energy saver right interior light by sky luminance tracking, In Right Light 1, Stockholm, 1991. pp. 47-56.

Ruys, T. (1975) Windowless offices In (Colins, B. (Ed.)) *Windows and people: a literature survey - psychological reaction to environments with and without windows.* Washington DC: Institute of Applied Technology, National Bureau of Standards.

Salam, A. (1972) Town planning problems in Beirut and its outskirts In (Taylor, J. L. (Ed.)) *Planning for urban growth: British perspectives on the planning process.* New York: Praeger Publishers.

Salam, A. (1998) The role of government in shaping the built environment In (Rowe, P. and H. Sarkis (Eds.)) *Projecting Beirut: episodes in the construction and reconstruction of a modern city.* Munich: Prestel.

Saliba, R. (1998) *Beirut 1920-1940: domestic architecture between tradition and modernity.* Beirut: The Orders of Engineers and Architects.

Saliba, R. (2004) *Beirut City Centre recovery: the Foch - Allenby and Etoile conservation area.* Gottingen: Steidl.

Santamouris, M. (Ed.) (2001) *Energy and climate in the urban built environment,* London: James & James Science Publishers Ltd.

Saridar, S. and H. Elkadi (2001) Daylighting and intelligent façade features in office buildings, In Sharjah Solar Energy Conference, Sharjah, UAE, February 19 – 22, 2001. CD Publication.

Sarkis, H. and S. Khalaf (1993) Chronology of Beirut's urban history (1830-present) In (Khalaf, S. and P. S. Khoury (Eds.)) *Recovering Beirut: urban design and post-war reconstruction*. Leiden: E. J. Brill.

Sauter, S. L., M. J. Dainoff and M. J. Smith (Eds.) (1990) *Promoting heath and productivity in the computerized office: models of successful ergonomic intervention,* London: Taylor & Francis.

Schiler, M. E. and S. A. Japee (2000) Interior illuminance, daylight controls and occupant response [online]. School of Architecture, University of Southern California. Available at:
<http://dell2002.cap.utk.edu/ecodesign/546c/ACTIVITIES/DAYLIGHT/dayl-sml.pdf>
[28 July 2002].

Schmidtke, H. (1980) Ergonomic design principles of alphanumeric displays In (Grandjean, E. and E. Vigliani (Eds.)) *Ergonomic aspects of visual display terminals: proceedings of the international workshop.* London: Taylor & Francis.

Schofield, W. (1996) Survey sampling In (Sapsford, R. and V. Jupp (Eds.)) *Data collection and analysis.* London: Sage Publications.

Sehnaoui, N. (1981) L'occidentalisation de la vie quotidienne à Beyrouth: 1860-1914. University of Paris X.

Selkowitz, S. and E. S. Lee (1998) Advanced fenestration systems for improved daylight performance, In Daylighting '98 Conference, Ottawa, Ontario, Canada, May 11-13, 1998. Natural Resources, pp. 341-350.

Serof, G. (1983) Vision of the Beirut of tomorrow In (Ragette, F. (Ed.)) *Beirut of tomorrow.* Beirut: American University of Beirut.

Shaw, I. F. (1999) *Qualitative evaluation.* London: Sage Publications.

Silverman, D. (2001) *Interpreting qualitative data: methods for analyzing talk, text and interaction.* London: Sage Publications.

Simpson, M. and J. Tuson (1995) *Using observations in small-scale research: a beginner's guide.* Glasgow: Scottish Council for Research in Education.

Singleton, W. T. (Ed.) (1982) *The body at work: biological ergonomics,* Cambridge: Cambridge University Press.

Sinno, N. (2000) Active envelope for passive architecture: the making of friendly contemporary constructions, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2- 5, 2000. James & James Science Publishers Ltd., pp. 304-305.

Skelly, M. (2000) Essay competition: the individual and the intelligent façade, *Building Research and Information,* 28 (1), 67-69.

Smeha, G. (1982) *Building Regulation no 59/71 between text and application.* Beirut: Nomnom publication.

Smith, P. F. (2001) *Architecture in a climate of change: a guide to sustainable design.* Oxford: Architectural Press.

Sozer, H. (2000) Effectiveness of the shading factor on PV productivity: a case study, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2 - 5, 2000. James & James Science Publishers Ltd., pp. 843-844.

Stake, R. E. (1995) *The art of case study research.* London: Sage Publications.

Steffy, G. (2002) *Architectural lighting design.* 2nd ed. New York: John Wiley & Sons.

Stein, B. (1992) *Mechanical and electrical equipment for buildings.* 8th ed. New York: John Wiley & Sons.

Stein, B. and J. Reynolds (2000) *Mechanical and electrical equipment for buildings.* 9th Ed. New York: John Wiley & Sons.

Stephenson, J. P. (1998) New technologies in lighting, In The Importance of Light: Light, Colour and Health - Design for Reduced Stress in the Workplace, The Institution of Civil Engineers, London, October 29, 1998. Clearvision International, pp. 33-40.

Steven Winter Associates (1998) "Energy-efficient daylighting of the Burnet park zoo." Norwalk, CT: Steven Winter Associates, Inc.

Stone, P. T. (1999) The effects of environmental illumination on melatonin, bodily rhythms and mood states: a review, *International Journal of Lighting Research and Technology,* 31 (3), 71-80.

Sullivan, R., E. S. Lee and S. Selkowitz (1992) "A method of optimising solar control and daylighting performance in commercial office buildings." *LBL-32931*, California: Lawrence Berkeley Laboratory, University of California.

Sundstrom, E. D. (1986) *Work places: the psychology of the physical environment in offices and factories.* Cambridge: Cambridge University Press.

Sundstrom, E. D. (1987) Work environments: offices and factories In (Stokols, D. and I. Altman (Eds.)) *Handbook of environmental psychology.* Vol. 1. New York: John Wiley & Sons.

Szerman, M. (1993) Superlink: a computer tool to evaluate the impact of daylight-controlled lighting system onto the overall energetic behaviour of buildings, In Right Light 2, Arnhem, Sweden, 1993. pp. 673-685.

Tabet, J. (1998) From colonial style to regional revivalism: modern architecture in Lebanon and the problem of cultural identity In (Rowe, P. and H. Sarkis (Eds.)) *Projecting Beirut: episodes in the construction and reconstruction of a modern city.* Munich: Prestel. pp. 83-105.

Tenner, A. D., S. H. A. Begemann and G. J. v. d. Beld (1997) Acceptance and preference of illuminances in offices, In Lux Europa, Amsterdam, The Netherlands, May 11 – 14, 1997. pp. 130-143.

Terman, M. (1986) The photic environment and physiological timekeeping, In International Daylighting Conference Proceedings, Vol. I, 1986. pp. 356.

Ternoey, S. (1982) Don't trust your instincts: big building design defies intuition, *Solar Age,* April .

Ternoey, S. E. (1999) Daylight every building [online]. Daylighting Collaborative Energy Centre of Wisconsin. Available at: <http://www.daylighting.org/pubs/daylight_every.pdf> [8 June 2004].

The Columbia Electronic Encyclopedia (2000) The scientific method [online]. The Columbia Electronic Encyclopedia. Available at: <http://www.encyclopedia.com/articles/41918TheScientificMethod.html> [24 February 2002].

The European Commission: Directorate General XVII for Energy (1999) *A green Vitruvius: principles and practice of sustainable architectural design.* London: James & James Science Publishers Ltd.

The Levant, (1994) Old Beirut [online]. The Levant. Available at: <http://almashriq.hiof.no/lebanon/700/760/769/old_beirut/fairuz_program.html> [16 May 2004].

Thibon, J. (2003) Background analysis of building energy codes / standards (international and regional), In Energy Codes for Buildings, Beirut, Lebanon, December 2 - 4, 2003. Order of Engineers and Architects - Beirut, CD publication.

Thomas, R. (1996) Surveys In (Greenfield, T. (Ed.)) *Research methods. guidance for postgraduates.* London: Arnold.

Tombazis, A. N. (1996) On skins and other preoccupations of architectural design, *Renewable Energy*, 8 (1), 51-55.

Tombazis, A. N. (1998) Step by step and hand in hand: recollections a pathway into the future. In Environmentally Friendly Cities: Proceedings PLEA 98 Passive and Low Energy Architecture, Lisbon, Portugal, June 1- 3, 1998. MPG Books, pp. 29-32.

Travers, M. (2001) *Qualitative research through case studies.* London: Sage Publications.

Tregenza, P. and D. Loe (1998) *The Design of lighting.* London: E & FN Spon.

Tregenza, P., S. M. Romaya, S. P. Dowe, L. J. Heap and B. Truck (1974) Consistency and variation in preferences for office lighting, *Lighting Research and Technology,* (6), 205-211.

Trochim, W. M. (2000) Research methods knowledge base [online]. Cornell University. Available at: <http://trochim.human.cornell.edu/kb/> [6 June 2003].

Tulloch, S. (Ed.) (1997) *The Oxford dictionary and thesaurus,* Oxford: Oxford University Press.

Turabian, K. L. (1973) *A manual for writers of term papers, theses, and dissertations.* 4th ed. Chicago: The University of Chicago Press.

U.S. EPA Green Lights Program (1995) Lighting Fundamentals [online]. Architectural Lighting Magazine. Available at: <http://www.lightforum.com/library/general/fundamentals1.html> [22 July 2001].

U.S. EPA Green Lights Program (1995) "Lighting upgrade manual." *EPA 430-B-95-003*, US EPA Office of Air and Radiation 6202J.

Usibelli, A., S. Greeberg, M. Meal, A. Mitchell, R. Johnson, G. Switzer, F. Rubinstein and D. Aratesh (1985) "Commercial-sector conservation technologies." *Report LBL-18543*, Berkeley, CA: Lawrence Berkeley Laboratory.

Van Ooyen, M. H. F., J. C. A. Van de Weijgert and S. H. A. Begemann (1986) Luminance distribution as a basis for office lighting design, In The CIBSE National Lighting Conference, Nottingham, UK, 1986. CIBSE, pp. 103-108.

Van Ooyen, M. H. F., J. C. A. Van de Weijgert and S. H. A. Begemann (1987) Preferred luminances in offices, *Journal of the Illuminating Engineering Society,* (16), 152-156.

van den Bogaard, M. A. and R. F. Spekle (2003) Reinventing the hierarchy: strategy and control in the Shell Chemicals carve-out, *Management Accounting Research,* 14 (2), 79-93.

Vanandruel, N. (1997) Daylighting through glass: principle, tools and products, In Glass Proceeding Days, September 13 - 15, 1997. pp. 192-198.

Veitch, J. (1990) Office noise and illumination effects on reading comprehension, *Journal of Environmental Psychology,* (10), 209-217.

Veitch, J. A. (1997) Revisiting the performance and mood effects of information about lighting and fluorescent lamp type, *Journal of Environmental Psychology,* 17 (3), 253-262.

Veitch, J. A. (2000) Creating high-quality workplaces using lighting In (Clements-Croome, D. (Ed.)) *Creating the productive workplace.* London: E & FN Spon.

Veitch, J. A. (2001) Lighting quality contributions from biopsychological process, *Journal of the Illuminating Engineering Society,* 30 (1), 2-16.

Veitch, J. A. and R. Gifford (1996) Choice, perceived control, and performance decrements in the physical environment, *Journal of Environmental Psychology,* 16 (3), 269-276.

Veitch, J. A. and G. R. Newsham (1995) Quantifying lighting quality based on experimental investigations of end user performance and preference, In Right Light 3, The Third European Conference on Energy-Efficient Lighting, Vol. 1, Northern Electric PLC, Newcastle upon Tyne, June 18 - 21, 1995. NE, pp. 119-127.

Veitch, J. A. and G. R. Newsham (1996a) Determinants of lighting quality II: research and recommendations [online]. National Research Council of Canada. Available at: <http://www.nrc.ca/irc> [29 July 2001].

Veitch, J. A. and G. R. Newsham (1996b) Numerical criteria - a help or a hindrance in lighting design: lighting quality research and quality lighting design, In CIBSE National Lighting Conference, University of Bath, Bath, March 31 – April 3, 1996. CIBSE, pp. 65-66.

Veitch, J. A. and G. R. Newsham (1996c) Determinants of lighting quality I: state of the science [online]. National Research Council of Canada. Available at: <http://www.nrc.ca/irc/fulltext/nrcc39866.html> [29 July 2001].

Veitch, J. A. and G. R. Newsham (1997) Office lighting investments: payoffs for people and the environment, *Construction Technology Update,* 1997 Collection (No. 10), 1-4.

Veitch, J. A. and G. R. Newsham (1998) Determinants of lighting quality I: state of the science, *Journal of Illuminating Engineering Society,* 27 (1), 92-106.

Velds, M. (2000) Assessment of lighting quality in office rooms with daylighting systems. PhD thesis, Delft University of Technology, Faculty of Architecture.

Velds, M. and J. Christoffersen (1997) "Monitoring procedures for the assessment of daylighting performance of buildings." Paris: International Energy Agency.

Venning, R. G. (1992) Maintained illuminance: a designer's point of view, In National Lighting Conference, UMIST, Manchester, April 5 - 8, 1992. CIBSE, pp. 85-96.

Viljanen, T., L. Halonen and J. Lehtovaara (1997) Advanced Lighting Control Technologies for User Satisfaction and Energy Efficiency, In Right Light 4, the 4th European Conference on Energy-Efficient Lighting, Vol. 1, Copenhagen, Denmark, November 18 - 21, 1997. pp. 169-174.

Vischer, J. C. (1996) *Workspace strategies: environment as a tool for work.* New York: Chapman & Hall.

Vitruvius (1999) *Vitruvius: ten books of architecture.* Cambridge: Cambridge University Press.

Vose, D. (1996) *Quantitative risk analysis: a guide to Monte Carlo simulation modelling.* Chichester: John Wiley & Sons.

Wa-Gichia, M. (1998) The high-rise opposing facade in clear sky conditions - not always an "obstruction" to daylight, *Solar Energy*, 64 (4-6), 179-188.

Walliman, N. and B. Baiche (2001) *Your research project : a step-by-step guide for the first-time researcher.* London: Sage Publications.

Wan, K. S. Y. and F. W. H. Yik (2004) Building design and energy end-use characteristics of high-rise residential buildings in Hong Kong, *Applied Energy,* 78 (2004), 19-36.

Ward, G. and F. Rubinstein (1988) A new technique for computer simulation of illuminated spaces, *Journal of the Illuminating Engineering Society,* 17 (1).

Wargocki, P., D. Wyon and P. Fanger (2000) Productivity is affected by the air quality in offices, In Healthy Buildings 2000, Vol. 1, Espoo, Finland, August 6 - 10, 2000. pp. 635-640.

Watkinn, D. (1986) *A history of western architecture.* London: Barrie and Jenkins.

Westmarland, N. (2001) The quantitative/qualitative debate and feminist research: a subjective view of objectivity, *Forum: Qualitative Social Research - Theories, Methods, Applications,* 2 (1).

WHO - World Health Organisation (1999) Air quality guidelines [online]. WHO. Available at:
<http://www.who.int/environmental_information/Air/Guidelines/Chapter6.html>
[3 September 2001].

WHO - World Health Organization (2000) Sick building syndrome [online]. Pan American Centre for Sanitary Engineering and Environmental Sciences. Available at: <http://www.cepis.ops-oms.org/muwww/fulltext/toxicolo/sick/sick.html> [11 August 2001].

Wigginton, M. (1996) *Glass in architecture.* London: Phaidon.

Wigginton, M. and J. Harris (2002) *Intelligent skins.* Oxford: Architectural Press.

Wilkinson, W. K. and K. McNeil (1996) *Research for the helping professions.* London: Brooks Cole.

Williams, M. and T. May (1996.) *Introduction to the philosophy of social research.* London: University College London Press.

Wilson, N. and S. McClean (1994) *Questionnaire design: a practical introduction.* Newtownabbey, Northern Ireland: University of Ulster.

Wilson, S. and A. Hedge (1987) "The office environment survey: a study of building sickness." London: Building Use Studies.

Wong, P. (1994) The beneficial effects of light, In CIBSE National Lighting Conference, Robin College, Cambridge, 1994. CIBSE, pp. 21-35.

Wood, D. (1996) The elements of lighting quality In *Lighting Upgrades: a guide for facility managers.* Lilburn: Fairmont Press.

Woodson, W. E., B. Tillman and P. Tillman (1992) *Human factors design handbook: information and guidelines for the design of systems, facilities, equipment, and products for human use.* 2nd ed. New York: McGraw Hill.

Woolf, J. (2003) Renew: a renewable energy design tool for architects, *Renewable Energy*, 28 (10), 1555-1561.

Yacoub, G. (2003) *A dictionary of 20th century architecture in Lebanon.* Beirut: Alphamedia.

Yancey, K. (2000) Building quality lighting specifications [online]. Architectural Lighting Magazine. Available at: <http://www.lightforum.com/library/design/designspec/lightinghumans.html> [2 July 2001].

Yannas, S. (1994) *Solar energy and housing design, volume 1: principles, objectives, guidelines.* London: Architectural association.

Yannas, S. (1994) *Solar energy and housing design, volume 2: examples.* London: Architectural association.

Yener, A. K. (1999) A method of obtaining visual comfort using fixed shading devices in rooms, *Building and Environment,* (34) 285-291.

Zeguers, J. D. M. (1993) Energy saving lighting electronics: a triple win - for the organization, for the human being and for the environment, In Right Light 2, Arnhem, Sweden, 1993. pp. 158-163.

Zilber, S. A., (1993) Review of health effects of indoor lighting [online]. Architronic, 2 (3). Available at: <http://architronic.saed.kent.edu/v2n3/v2n3.06.html> [7 July 2001].

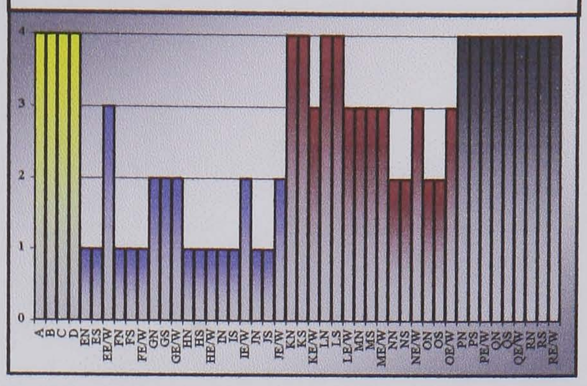
Zouzoulas, T. (2000) Lightweight buildings in hot and dry climates: the potential of lightweight structure in Greece and the optimum amount of thermal mass in a demountable building, In Architecture, City, Environment, Proceedings of PLEA 2000, Cambridge, UK, July 2-5, 2000. James & James Science Publishers Ltd., pp. 71-76.

Zwicky, F. and A. G. Wilson (Eds.) (1967) *New methods of thought and procedure,* New York: Springer Verlag.

Appendix I. Case Studies Data Worksheets

Building ID	1	D.O.C. Start End	 1884	Historical Phase	Architect Name / Interviewed (Yes / No)	Bishara Efendi Dibb & Yussef Efendi Khayyat
				I		No
Building Name	The Petit Serail	Condition	Demolished		POE Questionaire	*Distributed* 0
						Responded 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	477.82
Building Perimeter (m)	198.17
Building Height (m)	11.50
Building Inner Volume (m^3)	5494.93
Compactness Ratio (A)	6.54
Shape coefficient (B)	2.41
Envelope to Floor Area Ratio (C)	1.59
Porosity Ratio (D)	0.24

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	37.13
Sim. Potential Savings (LSOO)	1.32
Sim. Potential Savings (ICD)	3.36

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.21	0.22	0.40	0.30
Aperture Location ($F_{N,S,E/W,Av}$)	Unilat.	Unilat.	Unilat.	Unilat.
Window Shape ($G_{N,S,E/W,Av}$)	0.57	0.57	0.57	0.57
Window Sill Height ($H_{N,S,E/W,Av}$)	0.60	0.60	0.60	0.60
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.12	0.12	0.25	0.18
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.10	0.10	0.21	0.16

WINDOW / OFFICE PARAMETERS

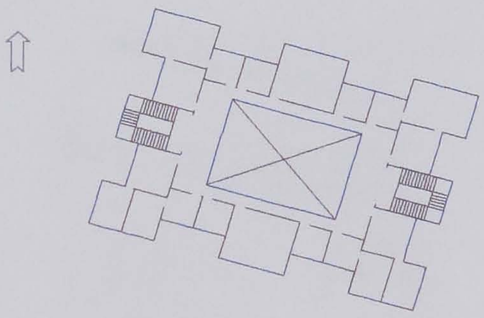
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	3.30	3.30	4.50	3.90
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	1.75	1.75	2.67	2.21
Office Average Area ($M_{N,S,E/W,Av}$)	17.82	17.82	18.00	17.91
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.17	0.17	0.25	0.21
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.15	0.15	0.22	0.18

SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	Hor.	Hor.	Hor.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.74	0.74	0.74	0.74

BUILDING ILLUSTRATIONS

1- Perspective View



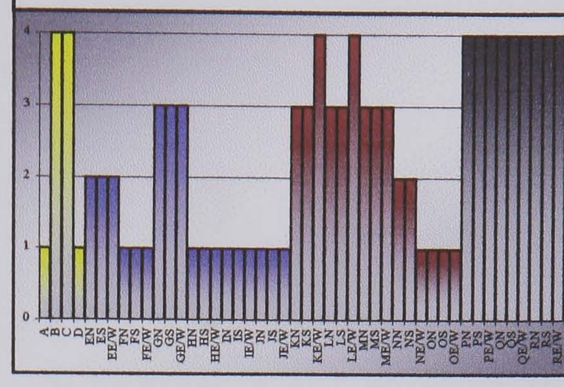
2- Plan Layout

3- North Elevation Detailed View

ILLUSTRATIONS SOURCES	1- image obtained from http://almashriq.hiof.no/lebanon/700/760/769/old_beirut 2- Image obtained from http://www.lib.utexas.edu/maps 3- Scanned from the book of Saliba, R. (1998)	**B 01 - SHEET 01**

Building ID	2	D.O.C. Start End	 1906	Historical Phase	Architect Name / Interviewed (Yes / No)	Antoine Vallaury
				I		-
						No
Building Name	Imperial Ottoman Bank	Condition	Demolished		POE Questionaire	*Distributed*
						0
						Responded
						0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS	
Building Floor Area (m^2)	163.28
Building Perimeter (m)	57.27
Building Height (m)	11.00
Building Inner Volume (m^3)	1796.08
Compactness Ratio (A)	1.60
Shape coefficient (B)	2.85
Envelope to Floor Area Ratio (C)	1.29
Porosity Ratio (D)	0.00

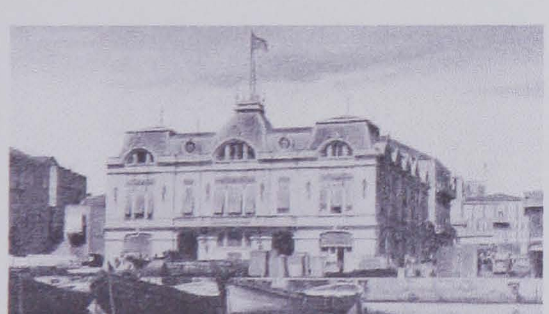
ENERGY DATA (kWh/m²)	
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS		*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio	($E_{N,S,E/W,Av}$)	0.34	0.34	0.25	0.29
Aperture Location	($F_{N,S,E/W,Av}$)	Unilat.	Unilat.	Unilat.	Unilat.
Window Shape	($G_{N,S,E/W,Av}$)	0.33	0.33	0.27	0.30
Window Sill Height	($H_{N,S,E/W,Av}$)	0.60	0.60	0.60	0.60
Window to Wall Ratio	($I_{N,S,E/W,Av}$)	0.16	0.16	0.14	0.15
Daylight Aperture Ratio	($J_{N,S,E/W,Av}$)	0.13	0.13	0.13	0.13

WINDOW / OFFICE PARAMETERS		*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth	($K_{N,S,E/W,Av}$)	4.00	4.00	3.30	3.65
Room Limiting Depth Rule	($L_{N,S,E/W,Av}$)	2.55	2.55	1.93	2.24
Office Average Area	($M_{N,S,E/W,Av}$)	13.20	13.20	13.20	13.2
Fenestration Factor	($N_{N,S,E/W,Av}$)	0.17	0.17	0.20	0.19
Glazing Ratio	($O_{N,S,E/W,Av}$)	0.15	0.15	0.17	0.16

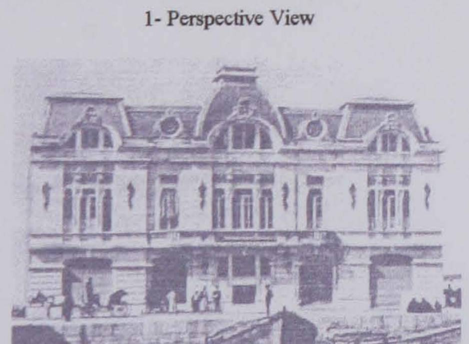
SHADING DEVICES PARAMETERS		*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate		Hor.	Hor.	Hor.	Hor.
Fixed / Movable		Fixed	Fixed	Fixed	Fixed
Projection Ratio	($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor	($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain	($R_{N,S,E/W,Av}$)	0.74	0.74	0.74	0.74

BUILDING ILLUSTRATIONS



1- Perspective View

2- Plan Layout



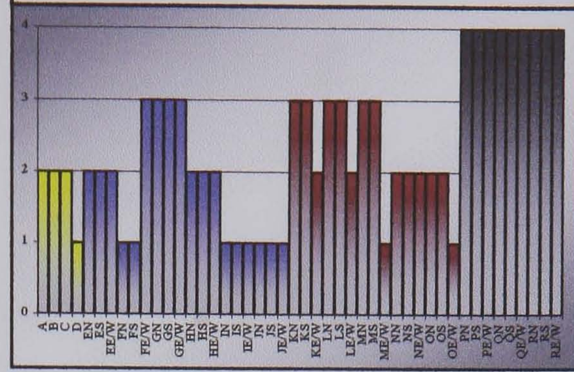
3- East Elevation

ILLUSTRATIONS SOURCES	1and 3- image obtained from http://almashriq.hiof.no/lebanon/700/760/769/old_beirut 2- Image obtained from http://www.lib.utexas.edu/maps	B 02 - SHEET 02

Building ID	3	**D.O.C.** **Start** **End**	1925 1928	**Historical Phase** II	**Architect Name / Interviewed (Yes / No)**	Youssef Aftimus (1866-1952) No
Building Name	Municipality of Beirut	**Condition**		Renovated	**POE Questionaire**	***Distributed*** 27 ***Responded*** 17

Building Typology	***Free-standing / Enclosed***	***Heavy / Light***	***Skin / Core Dependent***	***Open Plan / Cellular offices***	***Classified Type (A/B/C/D/E)***
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	1250.72
Building Perimeter (m)	186.44
Building Height (m)	13.35
Building Inner Volume (m^3)	16697.11
Compactness Ratio (A)	2.21
Shape coefficient (B)	6.71
Envelope to Floor Area Ratio (C)	0.66
Porosity Ratio (D)	0.02

ENERGY DATA (kWh/m^2)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	39.71
Sim. Potential Savings (LSOO)	0.93
Sim. Potential Savings (ICD)	2.74

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.36	0.31	0.32	0.33
Aperture Location ($F_{N,S,E/W,Av}$)	Unilat.	Unilat.	Multil.	Unilat.
Window Shape ($G_{N,S,E/W,Av}$)	0.33	0.33	0.33	0.33
Window Sill Height ($H_{N,S,E/W,Av}$)	0 - 0.9	0 - 0.9	0 - 0.9	0-0.9
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.21	0.20	0.12	0.16
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.19	0.18	0.11	0.14

WINDOW / OFFICE PARAMETERS

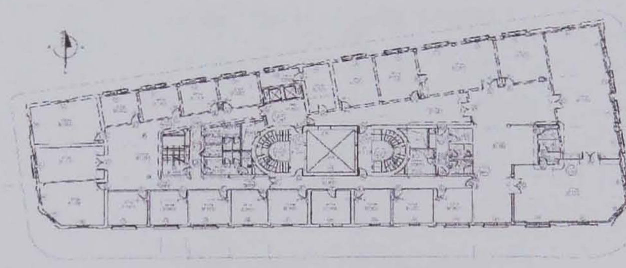
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.75	4.20	7.00	5.74
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.38	2.11	3.19	2.72
Office Average Area ($M_{N,S,E/W,Av}$)	19.95	17.64	36.40	27.60
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.19	0.20	0.15	0.17
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.16	0.17	0.13	0.15

SHADING DEVICES PARAMETERS

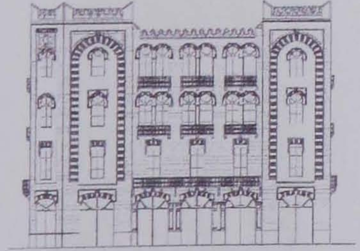
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	Hor.	Hor.	Hor.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.08	0.08	0.08	0.08
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.97	0.91	0.93	0.94
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.72	0.67	0.69	0.69

BUILDING ILLUSTRATIONS

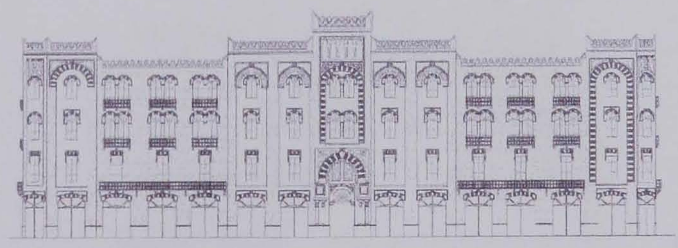
1- Perspective View



2- Typical Floor Plan



3- East Elevation

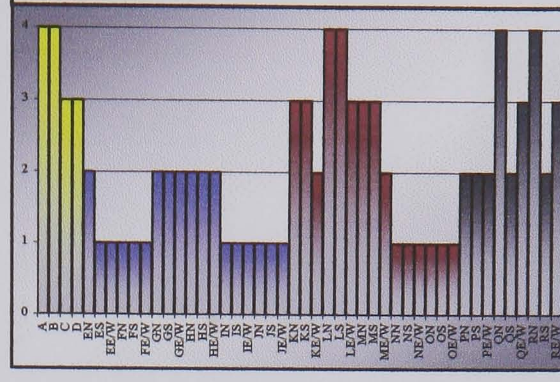


4- South Elevation

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2, 3 and 4 - Architectural CAD drawings obtained from SOLIDERE	**B 03 - SHEET 03**

Building ID	4	D.O.C. Start End	 1925	Historical Phase: II	Architect Name / Interviewed (Yes / No)	Uknown / - / No
Building Name	Fosh 128	Condition	Renovated		POE Questionaire	*Distributed* 0 / *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Open Plan	B

BUILDING SHAPE PARAMETERS

Building Floor Area (m²)	668.56
Building Perimeter (m)	187.73
Building Height (m)	19.30
Building Inner Volume (m³)	12903.21
Compactness Ratio (A)	4.20
Shape coefficient (B)	3.56
Envelope to Floor Area Ratio (C)	1.08
Porosity Ratio (D)	0.10

ENERGY DATA (kWh/m²)

Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.25	0.23	0.16	0.20
Aperture Location ($F_{N,S,E/W,Av}$)	Unilat.	Unilat.	Unilat.	Unilat.
Window Shape ($G_{N,S,E/W,Av}$)	0.51	0.51	0.51	0.51
Window Sill Height ($H_{N,S,E/W,Av}$)	0-0.8	0-0.8	0-0.8	0-0.8
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.10	0.10	0.18	0.14
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.09	0.09	0.15	0.12

WINDOW / OFFICE PARAMETERS

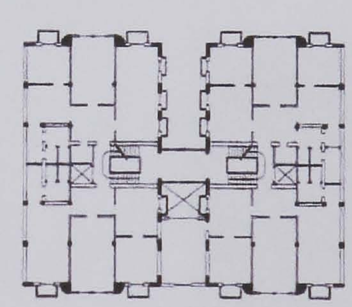
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.20	4.20	6.00	5.10
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	1.66	1.86	2.71	2.24
Office Average Area ($M_{N,S,E/W,Av}$)	16.80	16.80	28.80	22.8
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.10	0.10	0.12	0.11
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.09	0.09	0.10	0.10

SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	Hor.	Hor.	Hor.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.38	0.38	0.38	0.38
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.87	0.63	0.70	0.73
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.65	0.47	0.52	0.54

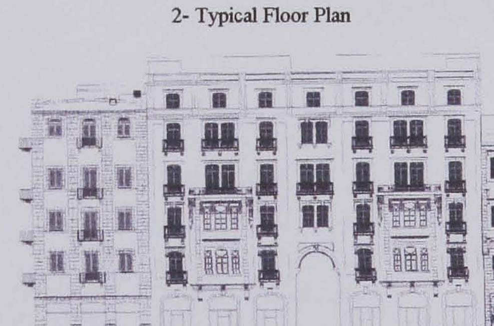
BUILDING ILLUSTRATIONS

1- South Façade View



2- Typical Floor Plan

3- Main Entrance View

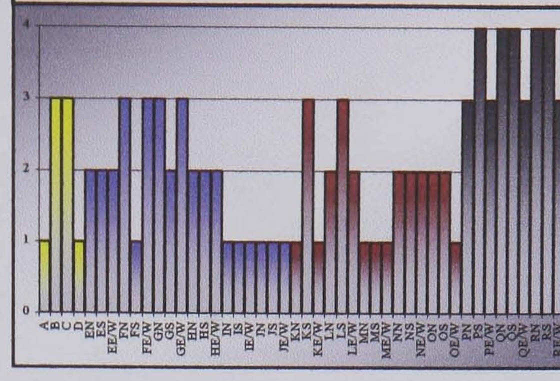


4- South Elevation

ILLUSTRATIONS SOURCES	1and 3- Photographed by Saridar, S. (2003) 2 and 4 - Architectural CAD drawings obtained from SOLIDERE	B 04 - SHEET 04

Building ID	5	D.O.C. Start End	 1932	Historical Phase III	Architect Name / Interviewed (Yes / No)	Uknown / - / No
Building Name	Fosh 1153	Condition		Renovated	POE Questionaire	*Distributed* 0 *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	390.00
Building Perimeter (m)	84.00
Building Height (m)	16.50
Building Inner Volume (m^3)	6435.00
Compactness Ratio (A)	1.44
Shape coefficient (B)	4.64
Envelope to Floor Area Ratio (C)	0.89
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	North	South	E / W	Aver.
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.36	0.31	0.32	0.33
Aperture Location ($F_{N,S,E/W,Av}$)	Multil.	Unilat.	Multil.	Multil.
Window Shape ($G_{N,S,E/W,Av}$)	0.48	0.58	0.48	0.51
Window Sill Height ($H_{N,S,E/W,Av}$)	0-0.8	0.80	0-0.8	0.80
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.13	0.15	0.14	0.14
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.11	0.13	0.12	0.12

WINDOW / OFFICE PARAMETERS

Parameter	North	South	E / W	Aver.
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	8.30	5.75	8.50	7.76
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.48	2.43	3.30	3.13
Office Average Area ($M_{N,S,E/W,Av}$)	62.25	41.98	68.00	60.06
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.16	0.17	0.15	0.16
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.14	0.15	0.13	0.14

SHADING DEVICES PARAMETERS

Parameter	North	South	E / W	Aver.
Vertical / Horizontal/ Egg crate	Hor.	-	Hor.	Hor.
Fixed / Movable	Fixed	-	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.27	0.00	0.27	0.20
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.90	1.00	0.78	0.86
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.67	0.74	0.58	0.64

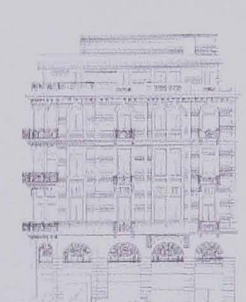
BUILDING ILLUSTRATIONS

1- Perspective View

2- Typical Floor Plan

3- North Elevation View

4- South Elevation



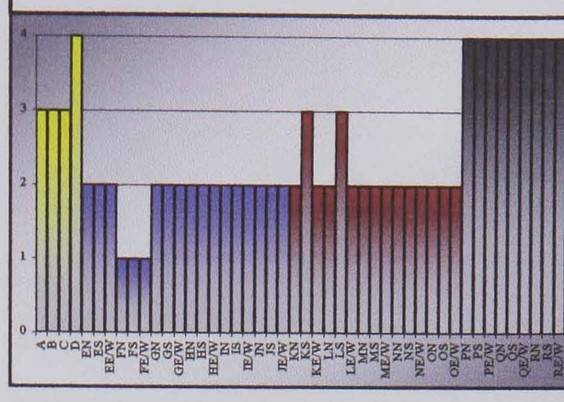
5- East Elevation

ILLUSTRATIONS SOURCES	1and 3- Photographed by Saridar, S. (2003) 2, 4 and 5 - Architectural CAD drawings obtained from SOLIDERE	B 05 - SHEET 05

Building ID	6	D.O.C. Start End	……. 1935	Historical Phase III	Architect Name / Interviewed (Yes / No)	Bahjat Abdulnour (1893-1973) No
Building Name	Ibrahim Sursok Building	Condition	Demolished		POE Questionaire	*Distributed* 0 *Responded* 0

Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular office	C

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS	
Building Floor Area (m²)	964.25
Building Perimeter (m)	190.67
Building Height (m)	17.20
Building Inner Volume (m³)	16585.10
Compactness Ratio (A)	3.00
Shape coefficient (B)	5.06
Envelope to Floor Area Ratio (C)	0.85
Porosity Ratio (D)	0.16

ENERGY DATA (kWh/m²)	
Real Total Consumption	
Simulated Lighting Consumption	38.22
Sim. Potential Savings (LSOO)	0.21
Sim. Potential Savings (ICD)	1.12

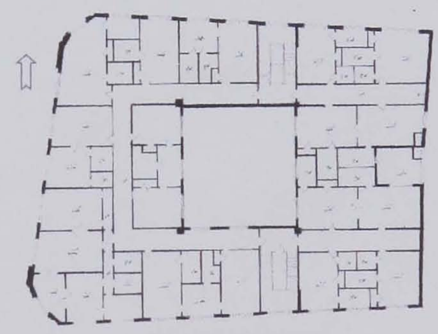
WINDOW / FAÇADE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.33	0.31	0.31	0.31
Aperture Location ($F_{N,S,E/W,Av}$)	Unilat.	Unilat.	Unilat.	Unilat.
Window Shape ($G_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Window Sill Height ($H_{N,S,E/W,Av}$)	0.90	0.90	0.90	0.90
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.30	0.30	0.30	0.30
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.27	0.27	0.27	0.27

WINDOW / OFFICE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	6.00	5.50	6.00	5.88
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.26	2.99	3.26	3.20
Office Average Area ($M_{N,S,E/W,Av}$)	24.00	22.00	24.00	23.5
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.21	0.23	0.21	0.21
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.18	0.20	0.18	0.19

SHADING DEVICES PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	Hor.	Hor.	Hor.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.08	0.08	0.08	0.08
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.97	0.91	0.93	0.93
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.77	0.73	0.74	0.75

BUILDING ILLUSTRATIONS

1- Perspective View

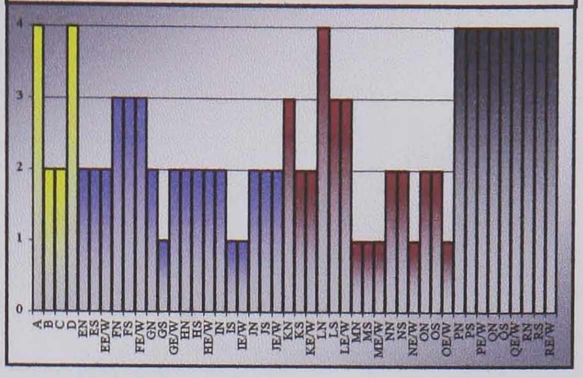


2- Typical Floor Plan

ILLUSTRATIONS SOURCES	1and 2- Images obtaineded from Arbid, G. (2003)	B 06 - SHEET 06

Building ID	7	D.O.C. Start End	1947 1952	Historical Phase	IV	Architect Name / Interviewed (Yes / No)	Georgio Ricci G. Aramane - No
Building Name	Assayli Building	Condition		Renovated		POE Questionaire	*Distributed* 0 *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Core Dependent	Open Plan	A

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	2044.74
Building Perimeter (m)	333.14
Building Height (m)	31.10
Building Inner Volume (m^3)	63591.41
Compactness Ratio (A)	4.32
Shape coefficient (B)	6.14
Envelope to Floor Area Ratio (C)	0.63
Porosity Ratio (D)	0.27

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.27	0.25	0.26	0.26
Aperture Location ($F_{N,S,E/W,Av}$)	Multil.	Multil.	Multil.	Multil.
Window Shape ($G_{N,S,E/W,Av.}$)	1.14	1.11	1.09	1.11
Window Sill Height ($H_{N,S,E/W,Av}$)	0.90	0.90	0.90	0.90
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.27	0.24	0.23	0.24
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.23	0.21	0.20	0.21

WINDOW / OFFICE PARAMETERS

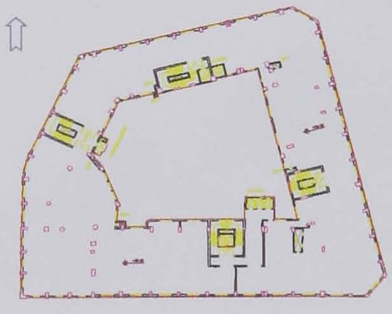
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.70	6.50	6.00	5.80
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	1.63	2.30	2.06	2.01
Office Average Area ($M_{N,S,E/W,Av}$)	398.18	417.69	583.62	495.78
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.20	0.17	0.14	0.16
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.17	0.15	0.12	0.14

SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.80	0.80	0.80	0.80

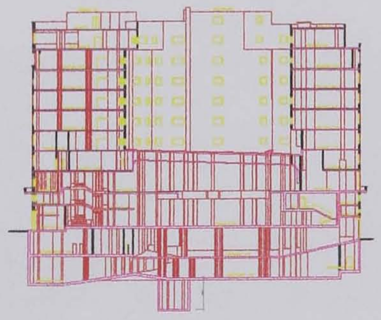
BUILDING ILLUSTRATIONS

1- Perspective View



2- Typical Floor Plan

3- South Elevation



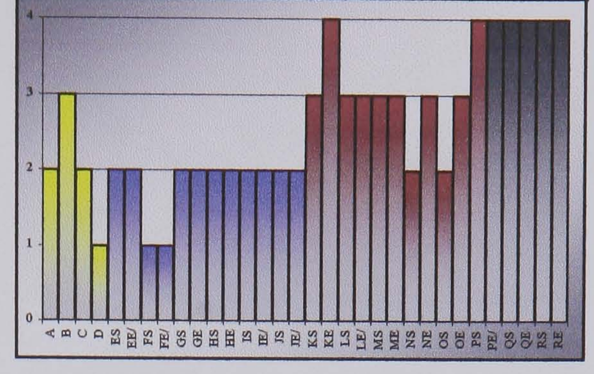
4- Section

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (1999) 2, 3 and 4 - Architectural CAD drawings obtained from SOLIDERE	B 07 - SHEET 07

Building ID	8	D.O.C. Start End	……. 1949	Historical Phase	IV	Architect Name / Interviewed (Yes / No)	Bahjat Abdulnour (1893-1973) No
Building Name	Aboud Abdel Razzak Building	Condition		Renovated		POE Questionaire	*Distributed* 0 *Responded* 0

Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Cellular office	B

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	673.61
Building Perimeter (m)	138.00
Building Height (m)	14.00
Building Inner Volume (m^3)	9430.54
Compactness Ratio (A)	2.25
Shape coefficient (B)	4.88
Envelope to Floor Area Ratio (C)	0.72
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.00	0.34	0.34	0.34
Aperture Location ($F_{N,S,E/W,Av}$)	-	Unilat.	Unilat.	Unilat.
Window Shape ($G_{N,S,E/W,Av}$)	0.00	0.67	0.83	0.33
Window Sill Height ($H_{N,S,E/W,Av}$)	-	0-1.0	0-1.0	0-1.0
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.00	0.31	0.33	0.16
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.00	0.27	0.29	0.14

WINDOW / OFFICE PARAMETERS

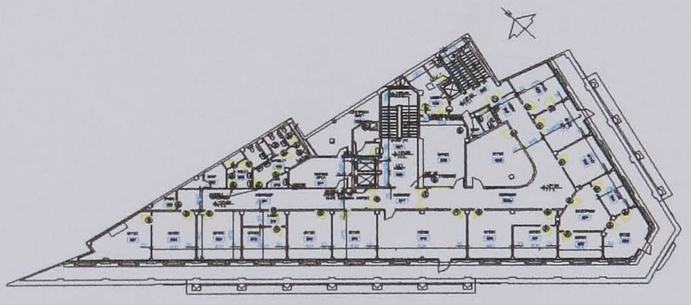
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	0.00	4.75	3.90	4.33
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	0.00	2.77	2.30	2.54
Office Average Area ($M_{N,S,E/W,Av}$)	0.00	19.00	15.41	17.20
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.00	0.21	0.27	0.24
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.00	0.18	0.24	0.21

SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	Hor.	Hor.	Hor.
Fixed / Movable	-	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.10	0.10	0.10
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	0.88	0.91	0.90
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.80	0.71	0.73	0.72

BUILDING ILLUSTRATIONS


1- Perspective View


2- Typical Floor Plan


3- East Elevation View

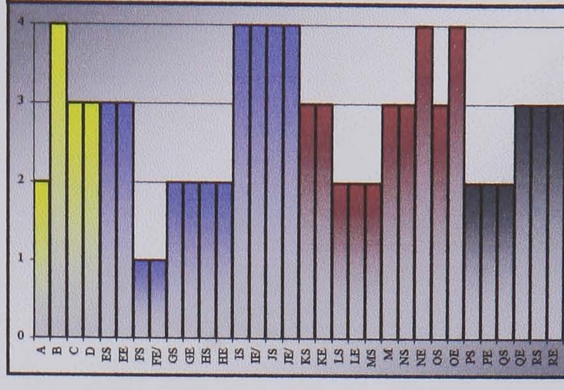

4- South Elevation

ILLUSTRATIONS SOURCES	1and 3- Photographed by Saridar, S. (2003) 2 and 4 - Architectural CAD drawings obtained from Saiidi, M	**B 08 - SHEET 08**

Building ID	9	D.O.C. Start End	1952 1953	Historical Phase	IV	Architect Name / Interviewed (Yes / No)	Georges Rais Theo Kanan (1915-2001) No
Building Name	Pan American Building	Condition		Renovated		POE Questionnaire	*Distributed* 0 *Responded* 0

Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Cellular office	B

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS	
Building Floor Area (m²)	305.56
Building Perimeter (m)	87.88
Building Height (m)	16.50
Building Inner Volume (m³)	5041.74
Compactness Ratio (A)	2.01
Shape coefficient (B)	3.48
Envelope to Floor Area Ratio (C)	0.95
Porosity Ratio (D)	0.11

ENERGY DATA (kWh/m²)	
Real Total Consumption	
Simulated Lighting Consumption	40.35
Sim. Potential Savings (LSOO)	1.07
Sim. Potential Savings (ICD)	2.36

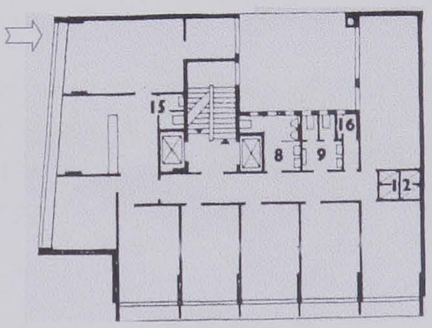
WINDOW / FAÇADE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.00	0.49	0.47	0.48
Aperture Location ($F_{N,S,E/W,Av}$)	-	Unilat.	Unilat.	Unilat.
Window Shape ($G_{N,S,E/W,Av}$)	0.00	1.73	1.50	0.86
Window Sill Height ($H_{N,S,E/W,Av}$)	-	0.80	0.80	0.80
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.00	0.59	0.59	0.29
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.00	0.51	0.51	0.26

WINDOW / OFFICE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	0.00	5.80	4.85	5.33
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	0.00	3.46	3.09	3.27
Office Average Area ($M_{N,S,E/W,Av}$)	0.00	22.04	16.01	19.02
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.00	0.30	0.36	0.33
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.00	0.26	0.32	0.29

SHADING DEVICES PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	Hor.	E.C.	H/E.C
Fixed / Movable	-	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.36	0.30	0.33
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	0.64	0.75	0.70
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.80	0.51	0.60	0.56

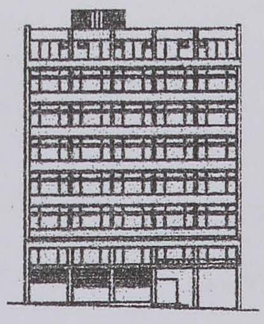
BUILDING ILLUSTRATIONS

1- Perspective View



2- Typical Floor Plan

3- South Elevation View

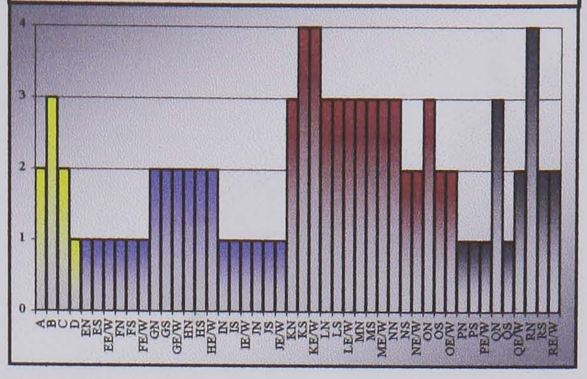


4- East Elevation

ILLUSTRATIONS SOURCES	1and 3- Photographed by Saridar, S. (1999) 2 and 4 - Images obtained from Arbid, G.	**B 09 - SHEET 09**

Building ID	10	D.O.C. Start End	 1955	Historical Phase	IV	Architect Name / Interviewed (Yes / No)	Unknown / - / No
Building Name	Azarieh Building	Condition		Renovated		POE Questionaire	*Distributed* 0 / *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	936.41
Building Perimeter (m)	161.95
Building Height (m)	21.70
Building Inner Volume (m^3)	17851.42
Compactness Ratio (A)	2.23
Shape coefficient (B)	5.08
Envelope to Floor Area Ratio (C)	0.68
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.23	0.22	0.20	0.22
Aperture Location ($F_{N,S,E/W,Av}$)	Unilat.	Unilat.	Unilat.	Unilat.
Window Shape ($G_{N,S,E/W,Av.}$)	1.25	1.25	1.25	1.25
Window Sill Height ($H_{N,S,E/W,Av}$)	0.90	0.90	0.90	0.90
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.20	0.19	0.22	0.20
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.17	0.16	0.19	0.17

WINDOW / OFFICE PARAMETERS

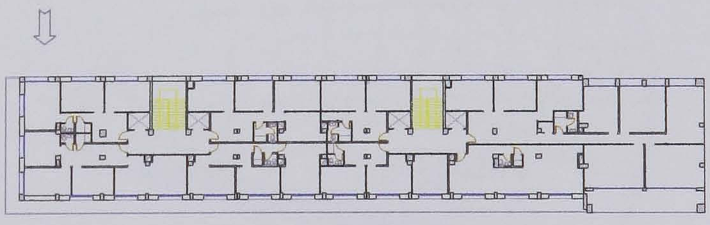
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.00	3.10	3.35	3.48
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.32	2.00	2.27	2.20
Office Average Area ($M_{N,S,E/W,Av}$)	17.97	12.81	12.06	14.28
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.25	0.20	0.21	0.22
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.22	0.17	0.18	0.19

SHADING DEVICES PARAMETERS

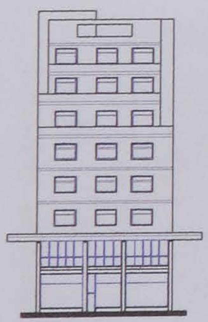
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	Hor.	Hor.	Hor.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.55	0.55	0.55	0.55
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.84	0.53	0.60	0.66
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.67	0.42	0.48	0.53

BUILDING ILLUSTRATIONS

1- Perspective View

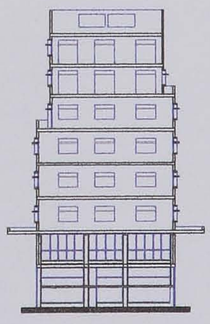


2- Typical Floor Plan



3- East Elevation

4- East Elevation

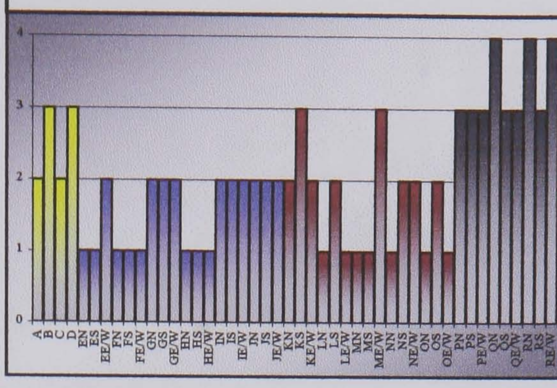


5- Section

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (1999) 2, 3, 4 and 5 - Architectural CAD drawings obtained from SOLIDERE	**B 10 - SHEET 10**

Building ID	11	D.O.C. Start End	……. 1956	Historical Phase	IV	Architect Name / Interviewed (Yes / No)	Unknown / - / No
Building Name	Riad Elsolh 1374 Building	Condition		Renovated		POE Questionaire	*Distributed* 0 / *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Cellular office	B

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	683.99
Building Perimeter (m)	136.09
Building Height (m)	21.14
Building Inner Volume (m^3)	14459.55
Compactness Ratio (A)	2.16
Shape coefficient (B)	5.03
Envelope to Floor Area Ratio (C)	0.70
Porosity Ratio (D)	0.10

ENERGY DATA (kWh/m^2)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.22	0.20	0.25	0.22
Aperture Location ($F_{N,S,E/W,Av}$)	Unilat.	Unilat.	Unilat.	Unilat.
Window Shape ($G_{N,S,E/W,Av.}$)	1.40	1.65	1.10	1.38
Window Sill Height ($H_{N,S,E/W,Av}$)	0.70	0.70	0.70	0.70
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.28	0.28	0.34	0.30
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.24	0.24	0.29	0.26

WINDOW / OFFICE PARAMETERS

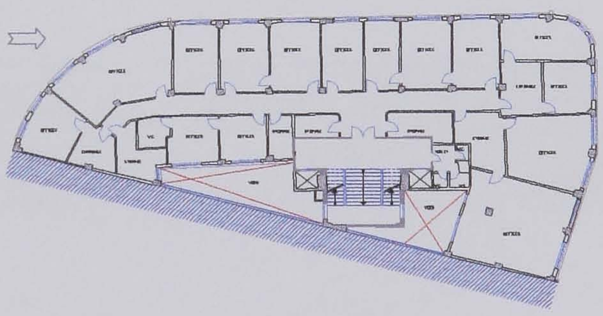
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	7.00	4.90	6.00	5.97
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	4.40	3.18	4.72	4.10
Office Average Area ($M_{N,S,E/W,Av}$)	39.66	40.11	19.70	33.15
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.13	0.17	0.15	0.15
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.11	0.14	0.13	0.13

SHADING DEVICES PARAMETERS

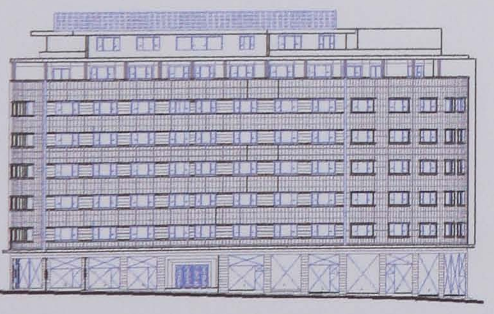
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	Hor.	Hor.	Hor.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.21	0.21	0.21	0.21
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.92	0.77	0.82	0.84
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.74	0.62	0.66	0.67

BUILDING ILLUSTRATIONS

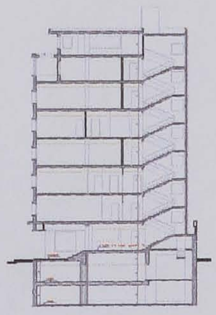
1- Perspective View



2- Typical Floor Plan



3- West Elevation

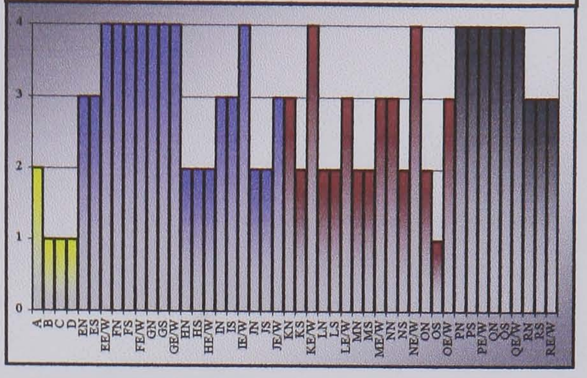


5- Section

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (1999) 2, 3, and 4 - Architectural CAD drawings obtained from SOLIDERE	B 11 - SHEET 11

Building ID	12	**D.O.C. Start End**	1956 1961	**Historical Phase** IV	**Architect Name / Interviewed (Yes / No)**	Addor & Julliard	- / No
Building Name	Starco Building (Northern Block)	**Condition**		Renovated	**POE Questionaire**	***Distributed*** 0	***Responded*** 0

DIAGRAMATIC DESCRIPTION



Building Typology	***Free-standing / Enclosed***	***Heavy / Light***	***Skin / Core Dependent***	***Open Plan / Cellular offices***	***Classified Type (A/B/C/D/E)***
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m²)	1492.47
Building Perimeter (m)	195.48
Building Height (m)	28.13
Building Inner Volume (m³)	41983.18
Compactness Ratio (A)	2.04
Shape coefficient (B)	7.63
Envelope to Floor Area Ratio (C)	0.41
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	North	South	E / W	Aver.
Wall to Aperture Ratio (E N,S,E/W, Av)	0.53	0.53	0.61	0.57
Aperture Location (F N,S,E/W, Av)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape (G N,S,E/W, Av)	2.12	1.77	2.42	2.18
Window Sill Height (H N,S,E/W, Av)	0.90	0.90	0.90	0.90
Window to Wall Ratio (I N,S,E/W, Av)	0.47	0.46	0.60	0.53
Daylight Aperture Ratio (J N,S,E/W, Av)	0.26	0.26	0.33	0.29

WINDOW / OFFICE PARAMETERS

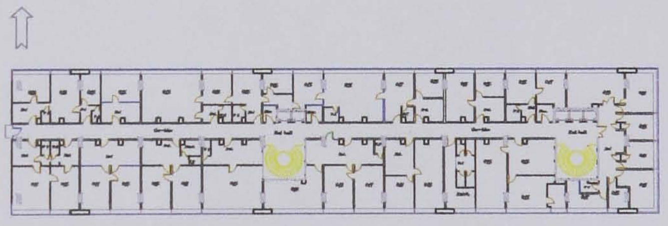
Parameter	North	South	E / W	Aver.
Buffer Zone Depth (K N,S,E/W, Av)	5.70	6.27	3.95	4.97
Room Limiting Depth Rule (L N,S,E/W, Av)	3.45	3.90	2.32	3.00
Office Average Area (M N,S,E/W, Av)	26.86	26.72	18.16	22.47
Fenestration Factor (N N,S,E/W, Av)	0.26	0.22	0.43	0.33
Glazing Ratio (O N,S,E/W, Av)	0.14	0.12	0.24	0.18

SHADING DEVICES PARAMETERS

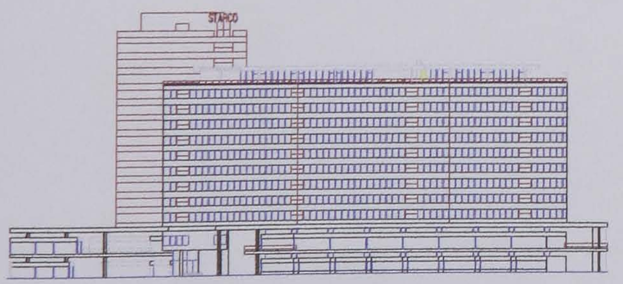
Parameter	North	South	E / W	Aver.
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio (P N,S,E/W, Av)	0.00	0.00	0.00	0.00
Overhang Factor (Q N,S,E/W, Av)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain (R N,S,E/W, Av)	0.53	0.53	0.53	0.53

BUILDING ILLUSTRATIONS

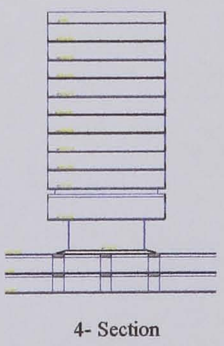
1- Perspective View



2- Typical Floor Plan



3- North Elevation

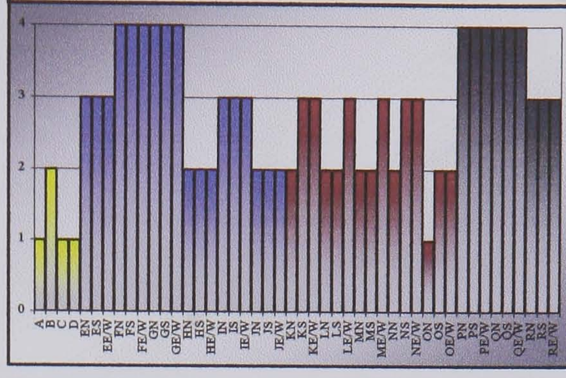


4- Section

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2, 3 and 4 - Architectural CAD drawings obtained from SOLIDERE	**B 12 - SHEET 12**

Building ID	13	D.O.C. Start End	1956 1961	Historical Phase	Architect Name / Interviewed (Yes / No)	Addor & Julliard
				IV		-
						No
Building Name	Starco Building (Southern Block)	Condition		Renovated	POE Questionaire	*Distributed* 0
						Responded 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	627.50
Building Perimeter (m)	100.20
Building Height (m)	39.00
Building Inner Volume (m^3)	24472.50
Compactness Ratio (A)	1.27
Shape coefficient (B)	6.26
Envelope to Floor Area Ratio (C)	0.52
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.50	0.50	0.50	0.50
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	2.20	2.11	1.81	1.99
Window Sill Height ($H_{N,S,E/W,Av}$)	0.90	0.90	0.90	0.90
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.50	0.49	0.52	0.51
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.28	0.27	0.28	0.28

WINDOW / OFFICE PARAMETERS

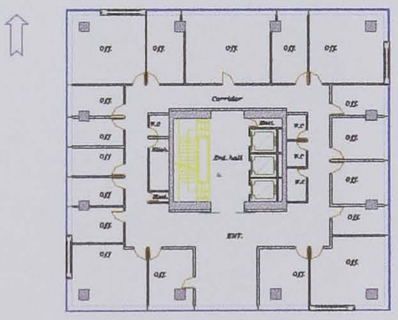
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	6.08	5.50	4.40	5.10
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.61	3.17	2.83	3.11
Office Average Area ($M_{N,S,E/W,Av}$)	29.73	26.80	17.67	22.97
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.24	0.26	0.33	0.29
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.13	0.14	0.18	0.16

SHADING DEVICES PARAMETERS

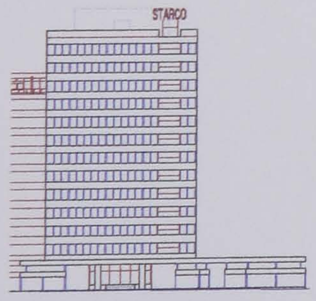
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.53	0.53	0.53	0.53

BUILDING ILLUSTRATIONS

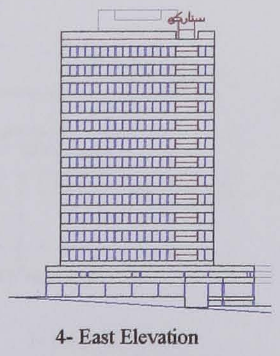
1- Perspective View



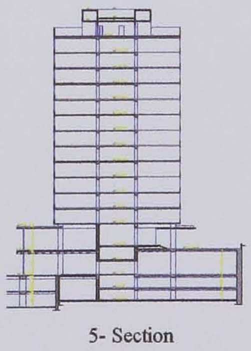
2- Typical Floor Plan



3- South Elevation



4- East Elevation

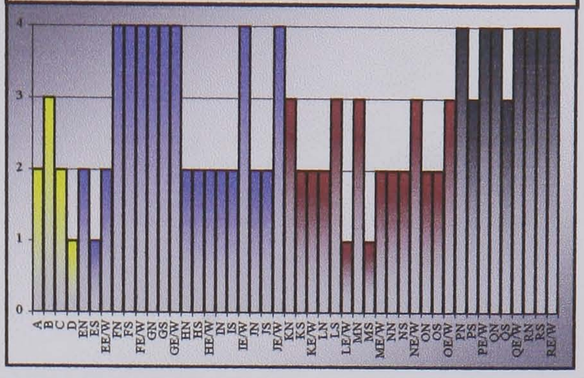


5- Section

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2, 3, 4 and 5 - Architectural CAD drawings obtained from SOLIDERE	**B 13 - SHEET 13**

Building ID	14	**D.O.C. Start End**	1957 1960	**Historical Phase** IV	**Architect Name / Interviewed (Yes / No)**	Wafik Ouwayni - No
Building Name	Building Shaker-Ouwayni	**Condition**	Renovated		**POE Questionaire**	***Distributed*** 0 ***Responded*** 0

DIAGRAMATIC DESCRIPTION



Building Typology	***Free-standing / Enclosed***	***Heavy / Light***	***Skin / Core Dependent***	***Open Plan / Cellular offices***	***Classified Type (A/B/C/D/E)***
	Enclosed	Heavy	Skin Dependent	Cellular office	B

BUILDING SHAPE PARAMETERS

Building Floor Area (m^2)	806.23
Building Perimeter (m)	158.26
Building Height (m)	23.80
Building Inner Volume (m^3)	19188.27
Compactness Ratio (A)	2.47
Shape coefficient (B)	5.09
Envelope to Floor Area Ratio (C)	0.67
Porosity Ratio (D)	0.04

ENERGY DATA (kWh/m²)

Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.30	0.21	0.39	0.30
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	1.66	1.66	1.88	1.73
Window Sill Height ($H_{N,S,E/W,Av}$)	0.90	0.90	0.90	0.90
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.31	0.30	0.61	0.41
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.27	0.26	0.53	0.35

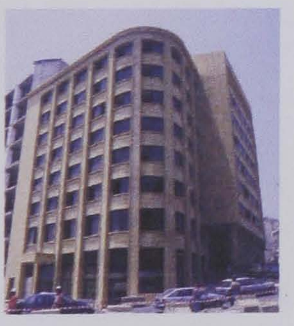
WINDOW / OFFICE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.50	6.00	7.00	5.83
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.21	2.70	4.95	3.62
Office Average Area ($M_{N,S,E/W,Av}$)	14.40	39.90	22.75	25.68
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.24	0.17	0.29	0.23
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.20	0.15	0.25	0.20

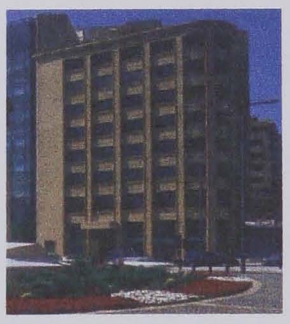
SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	Ver.	-	H / V
Fixed / Movable	Fixed	Fixed	-	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.08	0.17	0.00	0.08
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.97	0.81	1.00	0.93
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.77	0.65	0.80	0.74

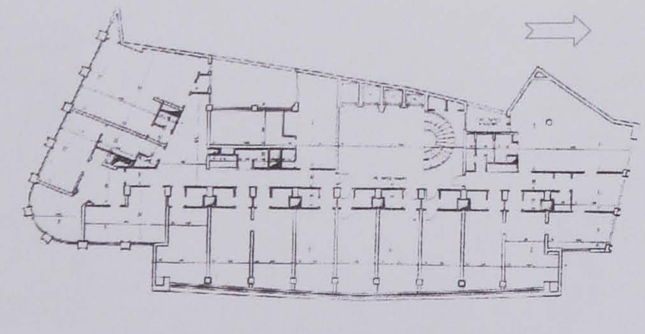
BUILDING ILLUSTRATIONS



1- Perspective View



2- East Elevation View



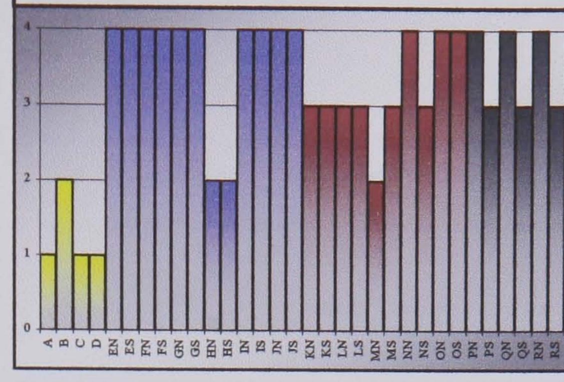
3- Typical Floor Plan

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (1999) 2- Image scanned from the book of Brakhya, J. (2000) 3- Image obtained from George Arbid	**B 14 - SHEET 14**

Building ID	15	D.O.C. Start / End	1956 / 1957	Historical Phase	Architect Name / Interviewed (Yes / No)	Georges Rais (1915-2002)
				IV		Yes (Partner)
Building Name	Cinema Hamra Building	Condition	As Built	POE Questionaire	*Distributed*	0
					Responded	0

Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Cellular Office	B

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	807.15
Building Perimeter (m)	132.95
Building Height (m)	18.10
Building Inner Volume (m^3)	14609.42
Compactness Ratio (A)	1.74
Shape coefficient (B)	6.07
Envelope to Floor Area Ratio (C)	0.50
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m^2)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.75	0.58	0.00	0.66
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	-	C.Glaz.
Window Shape ($G_{N,S,E/W,Av.}$)	1.83	2.28	0.00	2.05
Window Sill Height ($H_{N,S,E/W,Av}$)	0-0.77	0.85	-	0.81
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.76	0.58	0.00	0.67
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.66	0.50	0.00	0.58

WINDOW / OFFICE PARAMETERS

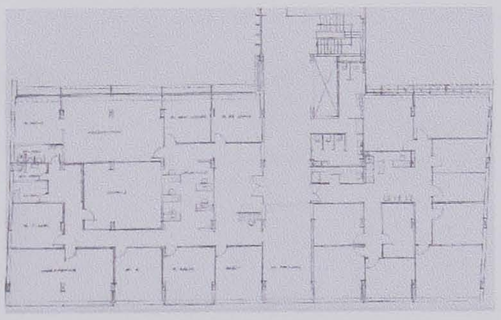
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.80	4.10	0.00	4.45
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.86	2.46	0.00	2.66
Office Average Area ($M_{N,S,E/W,Av}$)	20.16	18.41	0.00	19.28
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.40	0.32	0.00	0.36
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.34	0.28	0.00	0.31

SHADING DEVICES PARAMETERS

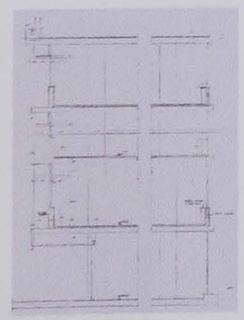
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	E.C.	-	E.C.
Fixed / Movable	-	Fixed	-	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.28	0.00	0.14
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	0.71	1.00	0.86
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.80	0.57	0.80	0.68

BUILDING ILLUSTRATIONS

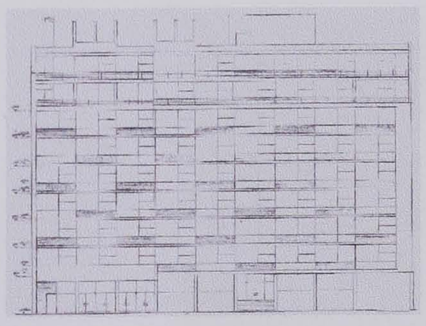
1- Perspective View



2- Typical Floor Plan



3- Section

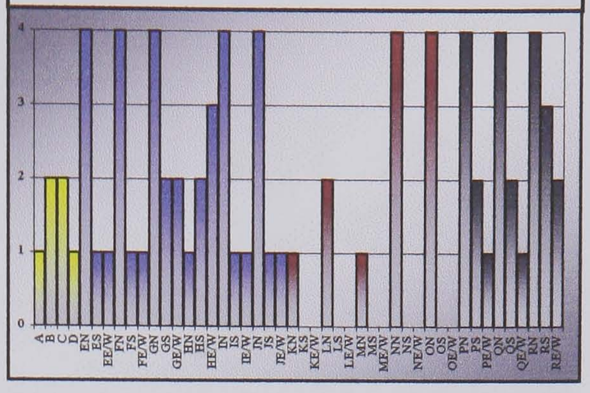


4- North Elevation

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2, 3, and 4- Images obtained from George Arbid	B 15 - SHEET 15

Building ID	16	D.O.C. Start End	1957 1958	Historical Phase	Architect Name / Interviewed (Yes / No)	Karl Schayer Wassek Adib
				IV		-
						Yes
Building Name	Horseshoe Building	Condition		As Built	POE Questionaire	*Distributed*
						10
						Responded
						0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Open Plan	B

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	510.75
Building Perimeter (m)	112.00
Building Height (m)	19.80
Building Inner Volume (m^3)	10112.85
Compactness Ratio (A)	1.96
Shape coefficient (B)	4.56
Envelope to Floor Area Ratio (C)	0.72
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	90.15
Simulated Lighting Consumption	39.10
Sim. Potential Savings (LSOO)	0.00
Sim. Potential Savings (ICD)	1.07

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.94	0.15	0.03	0.37
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	Unilat.	Unilat.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	18.25	1.24	0.67	6.72
Window Sill Height ($H_{N,S,E/W,Av}$)	0.70	1.00	1.80	1.17
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.64	0.22	0.15	0.34
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.42	0.15	0.10	0.22

WINDOW / OFFICE PARAMETERS

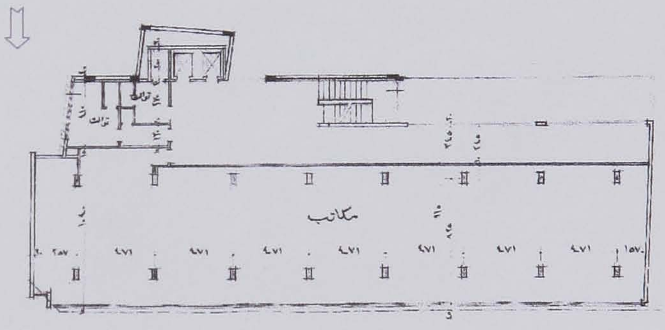
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	9.15	0.00	0.00	9.15
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.64	0.00	0.00	3.64
Office Average Area ($M_{N,S,E/W,Av}$)	83.72	0.00	0.00	83.72
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.78	0.00	0.00	0.78
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.52	0.00	0.00	0.52

SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	Hor.	Hor.	Hor.
Fixed / Movable	-	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.35	0.67	0.34
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	0.65	0.54	0.73
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.67	0.44	0.36	0.49

BUILDING ILLUSTRATIONS

1- Perspective View



2- Typical Floor Plan

3- North East View

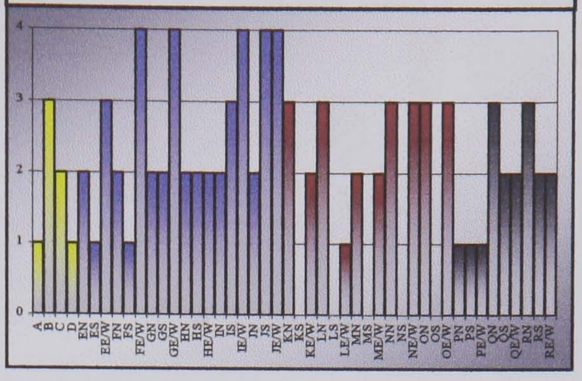
4- South Façade View

5- Closer View of North Façade

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2- Image obtained from George Arbid 3, 4 and 5- Photographed by Saridar, S. (1999)	B 16 - SHEET 16

Building ID	17	D.O.C. Start End	Late 1950s	Historical Phase	Architect Name / Interviewed (Yes / No)	Unknown
				IV		-
						No
Building Name	Riad Solh 1216	Condition		Renovated	POE Questionaire	*Distributed*
						0
						Responded
						0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Cellular office	B

BUILDING SHAPE PARAMETERS

Building Floor Area (m²)	517.44
Building Perimeter (m)	97.78
Building Height (m)	19.74
Building Inner Volume (m³)	10214.27
Compactness Ratio (A)	1.47
Shape coefficient (B)	5.29
Envelope to Floor Area Ratio (C)	0.62
Porosity Ratio (D)	0.02

ENERGY DATA (kWh/m²)

Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.38	0.09	0.46	0.35
Aperture Location ($F_{N,S,E/W,Av}$)	Bilat.	Unilat.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	0.50	0.54	1.94	1.23
Window Sill Height ($H_{N,S,E/W,Av}$)	0.80	0.80	0.80	0.80
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.30	0.49	0.58	0.49
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.26	0.43	0.50	0.42

WINDOW / OFFICE PARAMETERS

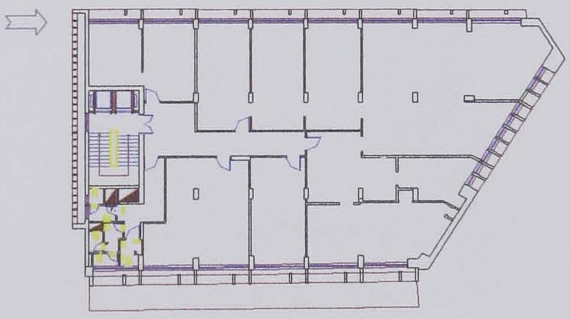
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.60	0.00	7.80	6.73
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.22	0.00	5.64	4.83
Office Average Area ($M_{N,S,E/W,Av}$)	20.88	0.00	26.52	24.64
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.30	0.00	0.30	0.30
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.26	0.00	0.26	0.26

SHADING DEVICES PARAMETERS

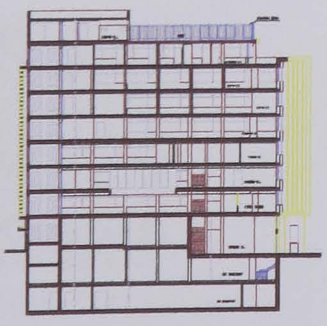
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Ver.	E.C.	E.C.	E.C.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.76	0.47	0.66	0.64
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.80	0.57	0.55	0.62
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.64	0.46	0.44	0.49

BUILDING ILLUSTRATIONS

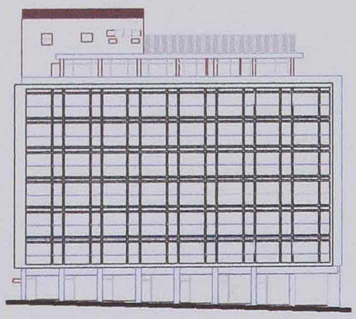
1- Perspective View



2- Typical Floor Plan



3- Section

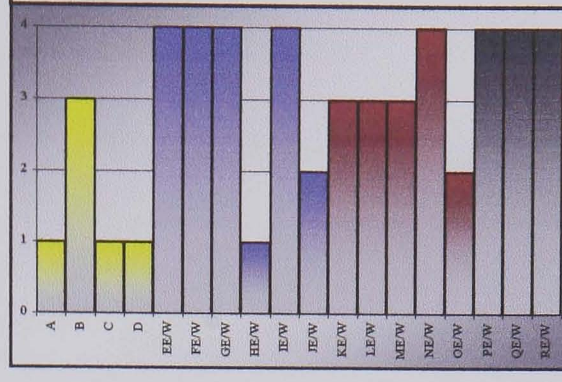


4- West Elevation

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2, 3 and 4 - Architectural CAD drawings obtained from SOLIDERE	B 17 - SHEET 17

Building ID	18	D.O.C. Start / End	1960 / 1962	Historical Phase: V	Architect Name / Interviewed (Yes / No)	Henry Eddeh (1925-Now)	No
Building Name	Industry and Work Bank	Condition	As Built	POE Questionaire	Distributed: 0	Responded: 0	

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Open Plan	B

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	433.00
Building Perimeter (m)	83.86
Building Height (m)	21.35
Building Inner Volume (m^3)	9244.55
Compactness Ratio (A)	1.29
Shape coefficient (B)	5.16
Envelope to Floor Area Ratio (C)	0.59
Porosity Ratio (D)	0.02

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.00	0.00	0.68	0.68
Aperture Location ($F_{N,S,E/W,Av}$)	-	-	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	0.00	0.00	1.72	1.72
Window Sill Height ($H_{N,S,E/W,Av}$)	-	-	0.66	0.66
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.00	0.00	0.66	0.66
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.00	0.00	0.26	0.26

WINDOW / OFFICE PARAMETERS

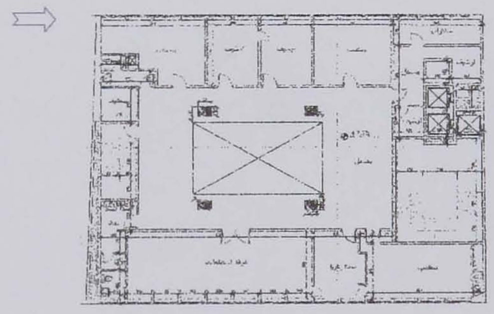
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	0.00	0.00	4.40	4.40
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	0.00	0.00	2.93	2.93
Office Average Area ($M_{N,S,E/W,Av}$)	0.00	0.00	17.38	17.38
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.00	0.00	0.45	0.45
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.00	0.00	0.18	0.18

SHADING DEVICES PARAMETERS

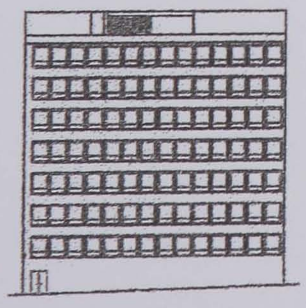
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.67	0.67	0.67	0.67

BUILDING ILLUSTRATIONS

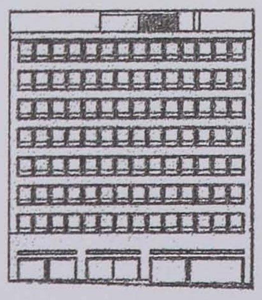
1- Perspective View



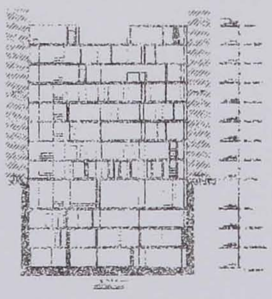
2- Typical Floor Plan



3- West Elevation



4- East Elevation



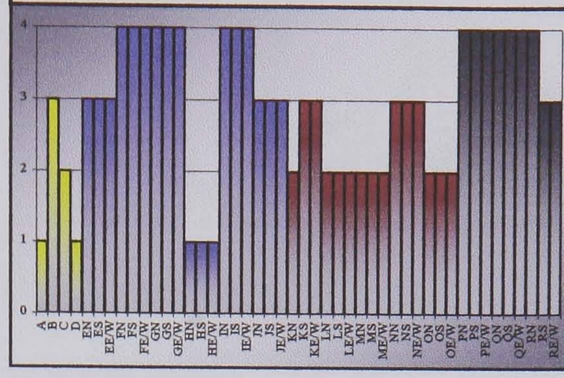
5- Section

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (1999) 2, 3, 4 and 5 - Images obtained from SOLIDERE	B 18 - SHEET 18

Building ID	19	D.O.C. Start End	1961 1963	Historical Phase	Architect Name / Interviewed (Yes / No)	Karl Schayer Wassek Adib
				V		-
						Yes
Building Name	Olivetti Building	Condition		Damaged	POE Questionaire	*Distributed*
						0
						Responded
						0

Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m²)	388.44
Building Perimeter (m)	93.85
Building Height (m)	18.90
Building Inner Volume (m³)	7341.52
Compactness Ratio (A)	1.81
Shape coefficient (B)	4.14
Envelope to Floor Area Ratio (C)	0.76
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.43	0.51	0.49	0.48
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	0.57	0.57	0.57	0.57
Window Sill Height ($H_{N,S,E/W,Av}$)	0.70	0.70	0.70	0.70
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.64	0.64	0.64	0.64
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.32	0.32	0.32	0.32

WINDOW / OFFICE PARAMETERS

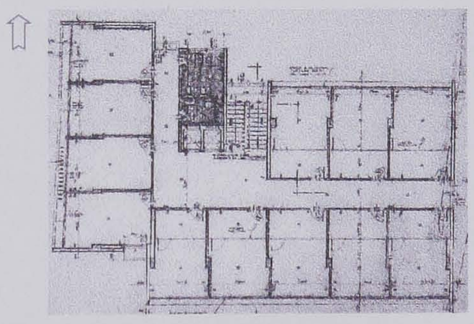
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	6.15	5.90	5.50	5.85
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.81	3.66	3.41	3.63
Office Average Area ($M_{N,S,E/W,Av}$)	23.37	22.42	20.90	22.23
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.29	0.30	0.33	0.31
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.15	0.15	0.16	0.15

SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Ver.	Ver.	Ver.	Ver.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.08	0.08	0.08	0.08
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.97	0.90	0.93	0.93
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.66	0.61	0.63	0.63

BUILDING ILLUSTRATIONS

1- Perspective View

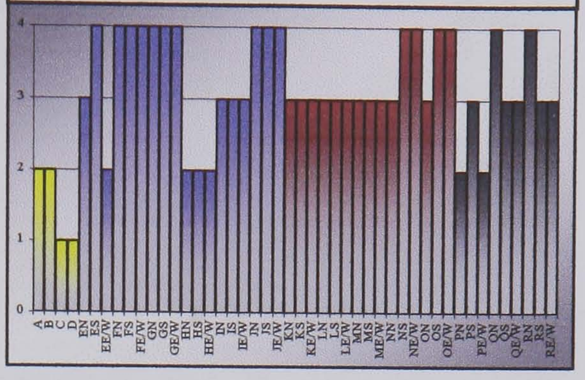


2- Typical Floor Plan

ILLUSTRATIONS SOURCES	1and 2- Images obtained from Georges Arbid	B 19 - SHEET 19

Building ID	20	D.O.C. Start End	1964 1970	Historical Phase	Architect Name / Interviewed (Yes / No)	Alvar Aalto Alfred Roth
				V		-
						No
Building Name	Sabbagh Center	Condition		As Built	POE Questionaire	*Distributed*
						0
						Responded
						0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS		
Building Floor Area (m^2)	987.48
Building Perimeter (m)	168.30
Building Height (m)	38.50
Building Inner Volume (m^3)	35372.44
Compactness Ratio (A)	2.28
Shape coefficient (B)	5.46
Envelope to Floor Area Ratio (C)	0.53
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)	
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

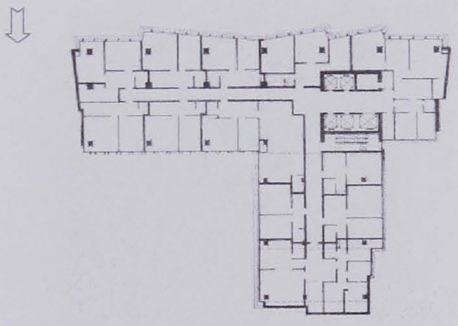
WINDOW / FAÇADE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.51	0.55	0.30	0.42
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	1.88	1.88	1.88	1.88
Window Sill Height ($H_{N,S,E/W,Av}$)	0.80	0.80	0.80	0.80
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.52	0.52	0.52	0.52
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.42	0.43	0.43	0.43

WINDOW / OFFICE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.50	4.50	4.10	4.30
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.73	2.86	2.49	2.64
Office Average Area ($M_{N,S,E/W,Av}$)	18.00	16.20	16.40	16.75
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.33	0.38	0.41	0.38
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.27	0.31	0.33	0.31

SHADING DEVICES PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Ver.	Hor.	Ver.	H / V
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.30	0.26	0.30	0.29
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.90	0.73	0.76	0.78
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.65	0.53	0.55	0.57

BUILDING ILLUSTRATIONS

1- Perspective View



2- Typical Floor Plan

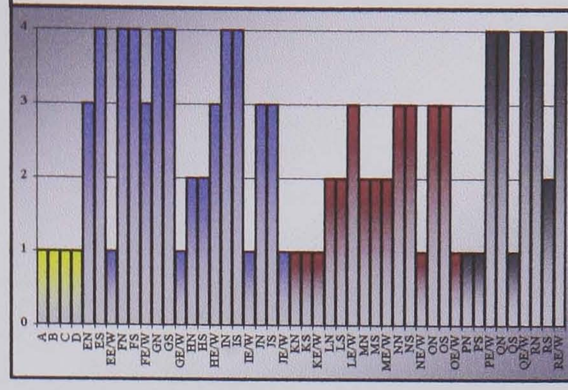
3- North East View

4- Closer View of the South Elevation

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2, 3 and 4 - Images obtained from Georges Arbid	B 20 - SHEET 20

Building ID	21	D.O.C. Start / End	1965 / 1972	Historical Phase	V	Architect Name / Interviewed (Yes / No)	J. Aractingi, J. Nassar and P. Nehmeh / Yes
Building Name	Electricity of Lebanon Headquarters	Condition	As Built			POE Questionaire	*Distributed* 0 / *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular Offices	B

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	1464.00
Building Perimeter (m)	175.00
Building Height (m)	39.60
Building Inner Volume (m^3)	57974.40
Compactness Ratio (A)	1.67
Shape coefficient (B)	8.37
Envelope to Floor Area Ratio (C)	0.39
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m^2)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	41.74
Sim. Potential Savings (LSOO)	0.34
Sim. Potential Savings (ICD)	2.15

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.54	0.55	0.23	0.39
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	Multil.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	0.50	0.50	2.18	1.34
Window Sill Height ($H_{N,S,E/W,Av}$)	0.80	0.80	1.90	1.35
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.62	0.62	0.03	0.32
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.54	0.54	0.03	0.28

WINDOW / OFFICE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	6.25	6.25	4.50	5.38
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.69	3.41	2.22	2.88
Office Average Area ($M_{N,S,E/W,Av}$)	24.38	29.38	28.13	27.50
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.30	0.30	0.02	0.16
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.26	0.26	0.02	0.14

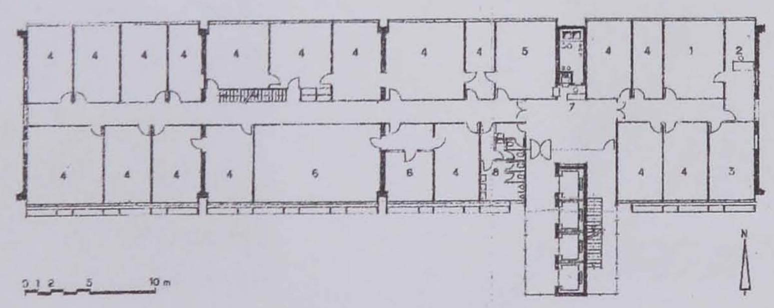
SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	E.C.	-	E.C.
Fixed / Movable	-	Fixed	-	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.55	0.00	0.14
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	0.53	1.00	0.88
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.80	0.42	0.80	0.71

BUILDING ILLUSTRATIONS

1- Perspective View

2- Closer View of the South Façade

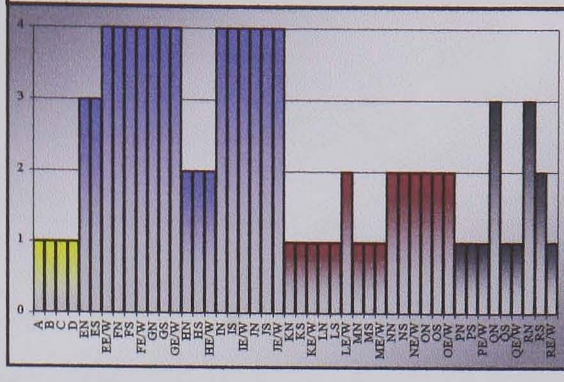


3- Typical Floor Plan

ILLUSTRATIONS SOURCES	1- Image scanned from the edited book of Row, P. and H. Sarkis (1998) 2- Photographed by Saridar, S. (1999) 3 - Image obtained from the building architect P. Nehmeh	B 21 - SHEET 21

Building ID	22	D.O.C. Start / End	.... / 1967	Historical Phase	Architect Name / Interviewed (Yes / No)	Anthony Irving / - / No
				V		
Building Name	American Life Insurance Building	Condition	As Built		POE Questionaire	*Distributed* 0 / *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Open Plan	C

BUILDING SHAPE PARAMETERS

Building Floor Area (m²)	1464.00
Building Perimeter (m)	175.00
Building Height (m)	13.60
Building Inner Volume (m³)	19910.40
Compactness Ratio (A)	1.67
Shape coefficient (B)	8.37
Envelope to Floor Area Ratio (C)	0.41
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter		
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	*North*	0.54
	South	0.55
	E / W	0.23
	Aver.	0.39
Aperture Location ($F_{N,S,E/W,Av}$)	*North*	C.Glaz.
	South	C.Glaz.
	E / W	C.Glaz.
	Aver.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	*North*	5.05
	South	5.05
	E / W	15.79
	Aver.	10.42
Window Sill Height ($H_{N,S,E/W,Av}$)	*North*	0.90
	South	0.90
	E / W	0.90
	Aver.	0.90
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	*North*	0.55
	South	0.55
	E / W	0.54
	Aver.	0.55
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	*North*	0.48
	South	0.48
	E / W	0.47
	Aver.	0.48

WINDOW / OFFICE PARAMETERS

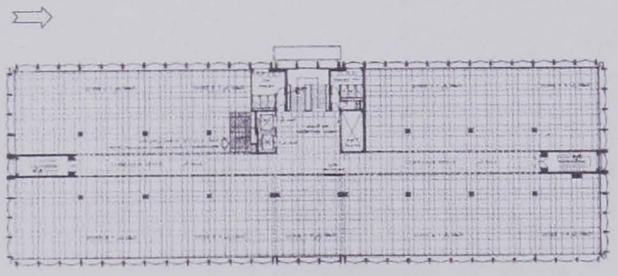
Parameter		
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	*North*	32.50
	South	32.50
	E / W	9.60
	Aver.	21.05
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	*North*	14.99
	South	14.99
	E / W	3.58
	Aver.	9.28
Office Average Area ($M_{N,S,E/W,Av}$)	*North*	312.00
	South	312.00
	E / W	624.00
	Aver.	468.00
Fenestration Factor ($N_{N,S,E/W,Av}$)	*North*	0.23
	South	0.23
	E / W	0.23
	Aver.	0.23
Glazing Ratio ($O_{N,S,E/W,Av}$)	*North*	0.20
	South	0.20
	E / W	0.20
	Aver.	0.20

SHADING DEVICES PARAMETERS

Parameter		
Vertical / Horizontal/ Egg crate	*North*	Ver.
	South	Ver.
	E / W	Ver.
	Aver.	Ver.
Fixed / Movable	*North*	Fixed
	South	Fixed
	E / W	Fixed
	Aver.	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	*North*	1.00
	South	1.00
	E / W	1.00
	Aver.	1.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	*North*	0.79
	South	0.44
	E / W	0.43
	Aver.	0.52
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	*North*	0.63
	South	0.35
	E / W	0.34
	Aver.	0.42

BUILDING ILLUSTRATIONS

1- Perspective View



2- Typical Floor Plan

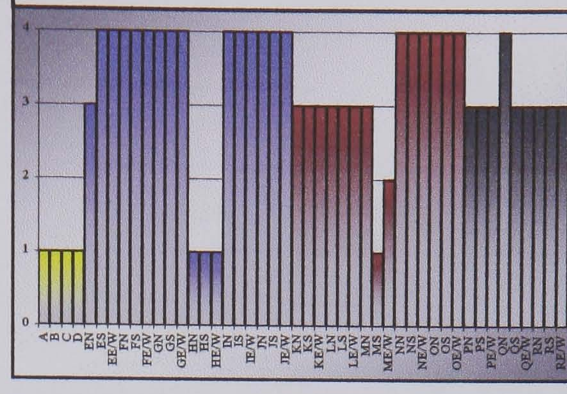
3- East Façade

4- Closer View of the Façade

ILLUSTRATIONS SOURCES	1 and 4- Photographed by Saridar, S. (1999) 2 and 3- Image Obtained from Georges Arbid	B 22 - SHEET 22

Building ID	23	D.O.C. Start End	1968 1970	Historical Phase	V	Architect Name / Interviewed (Yes / No)	G Klink R. Wakim; -; No
Building Name	Arab Bank Building (BCD)	Condition		Renovated		POE Questionaire	*Distributed* 30; *Responded* 17

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m²)	1660.00
Building Perimeter (m)	178.12
Building Height (m)	19.62
Building Inner Volume (m³)	32569.20
Compactness Ratio (A)	1.52
Shape coefficient (B)	9.32
Envelope to Floor Area Ratio (C)	0.35
Porosity Ratio (D)	0.03

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	93.53
Simulated Lighting Consumption	42.24
Sim. Potential Savings (LSOO)	0.48
Sim. Potential Savings (ICD)	2.16

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.54	0.57	0.57	0.56
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	1.21	4.85	1.52	2.27
Window Sill Height ($H_{N,S,E/W,Av}$)	0.45	0.45	0.45	0.45
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.57	0.59	0.57	0.58
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.43	0.44	0.43	0.43

WINDOW / OFFICE PARAMETERS

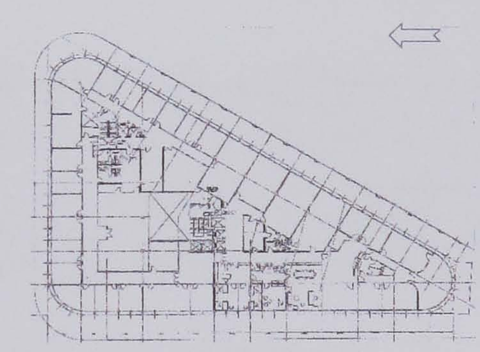
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.50	4.80	4.50	4.58
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.87	2.24	2.67	2.61
Office Average Area ($M_{N,S,E/W,Av}$)	16.20	40.47	20.25	24.29
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.38	0.61	0.38	0.43
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.28	0.45	0.28	0.33

SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	E.C.	E.C.	E.C.	E.C.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.27	0.27	0.27	0.27
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.90	0.72	0.78	0.79
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.63	0.50	0.54	0.55

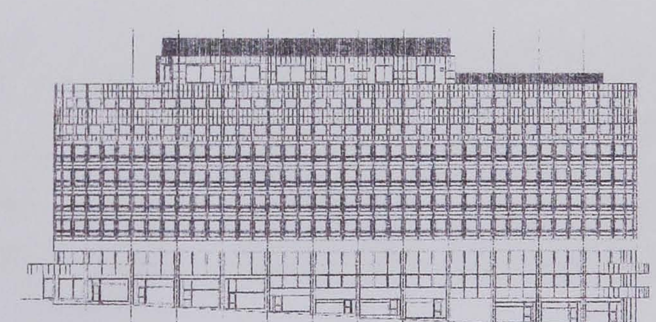
BUILDING ILLUSTRATIONS

1- Perspective View



2- Typical Floor Plan

3- South East Façades View

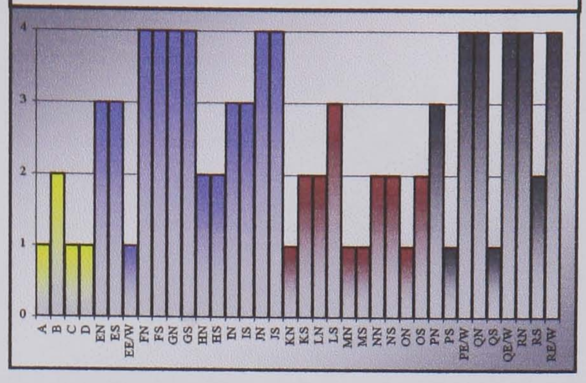


4- West Elevation

ILLUSTRATIONS SOURCES	1 and 3- Photographed by Saridar, S. (2003) 2 and 4- Architectural CAD drawings obtained from SOLIDERE	**B 23 - SHEET 23**

Building ID	24	D.O.C. Start End	 1970	Historical Phase V	Architect Name / Interviewed (Yes / No)	Pierre Nehmeh - Yes
Building Name	Verdun Center	Condition	As Built	POE Questionaire		*Distributed* 40 *Responded* 6

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Open Plan	D

BUILDING SHAPE PARAMETERS

Building Floor Area (m²)	1102.22
Building Perimeter (m)	156.36
Building Height (m)	62.75
Building Inner Volume (m³)	49032.85
Compactness Ratio (A)	1.77
Shape coefficient (B)	5.00
Envelope to Floor Area Ratio (C)	0.48
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.40	0.44	0.03	0.29
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	-	C.Glaz.
Window Shape ($G_{N,S,E/W,Av.}$)	29.16	32.08	0.00	30.62
Window Sill Height ($H_{N,S,E/W,Av}$)	0.90	0.90	-	0.90
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.47	0.52	0.00	0.49
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.41	0.45	0.00	0.43

WINDOW / OFFICE PARAMETERS

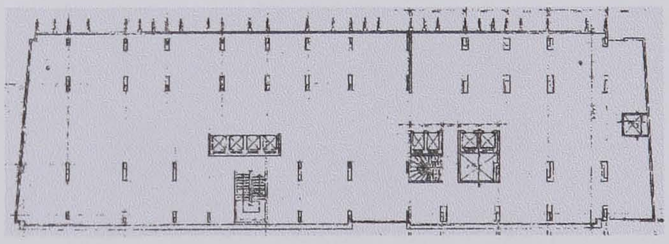
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	9.00	7.90	0.00	8.45
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.37	2.96	0.00	3.16
Office Average Area ($M_{N,S,E/W,Av}$)	504.45	448.96	0.00	476.70
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.15	0.19	0.00	0.17
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.13	0.16	0.00	0.15

SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	E.C.	-	H/E.C.
Fixed / Movable	Fixed	Fixed	-	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.25	0.87	0.00	0.37
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.91	0.44	1.00	0.78
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.73	0.35	0.80	0.63

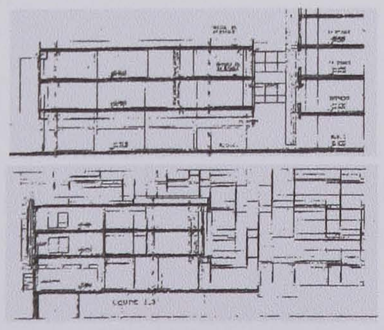
BUILDING ILLUSTRATIONS

1- Perspective View



2- Typical Floor Plan

3- South Façade View



4- Section

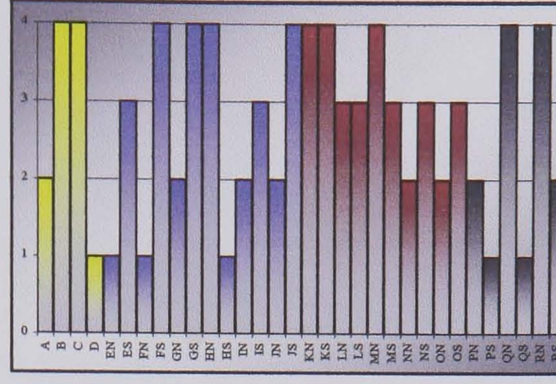
5- Closer Views of the South Façade

ILLUSTRATIONS SOURCES	1- Image obtained from Georges Arbid 2 and 4- Images obtained from the building architect P.Nehmeh 3 and 5- Photographed by Saridar, S. (1999)

B 24 - SHEET 24

Building ID	25	D.O.C. Start End	 1978	Historical Phase	Architect Name / Interviewed (Yes / No)	Saiid Jazaiiri
				VI		-
						Yes
Building Name	Koussa Building	Condition		As Built	POE Questionaire	Distributed: 0
						Responded: 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Cellular offices	B

BUILDING SHAPE PARAMETERS	
Building Floor Area (m^2)	164.40
Building Perimeter (m)	64.90
Building Height (m)	27.70
Building Inner Volume (m^3)	4553.88
Compactness Ratio (A)	2.04
Shape coefficient (B)	2.53
Envelope to Floor Area Ratio (C)	1.22
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m^2)	
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

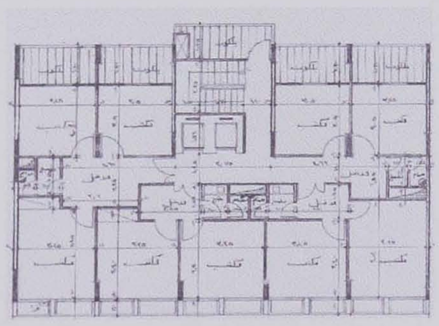
WINDOW / FAÇADE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.23	0.52	0.00	0.37
Aperture Location ($F_{N,S,E/W,Av}$)	Unilat.	C.Glaz.	-	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	0.50	0.68	0.00	0.59
Window Sill Height ($H_{N,S,E/W,Av}$)	0.00	0.40	0.00	0.20
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.25	0.53	0.00	0.39
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.22	0.46	0.00	0.34

WINDOW / OFFICE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	3.05	3.65	0.00	3.35
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.36	2.78	0.00	2.57
Office Average Area ($M_{N,S,E/W,Av}$)	9.61	11.86	0.00	10.74
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.23	0.25	0.00	0.24
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.20	0.22	0.00	0.21

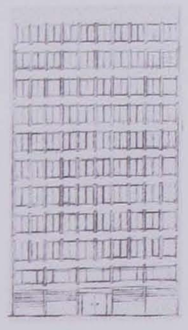
SHADING DEVICES PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	E.C.	-	H/E.C.
Fixed / Movable	Fixed	Fixed	-	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.33	0.82	0.00	0.58
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.89	0.44	1.00	0.66
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.71	0.35	0.80	0.53

BUILDING ILLUSTRATIONS

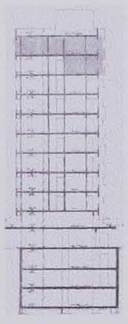
1- Perspective View



2- Typical Floor Plan



3- North Elevation



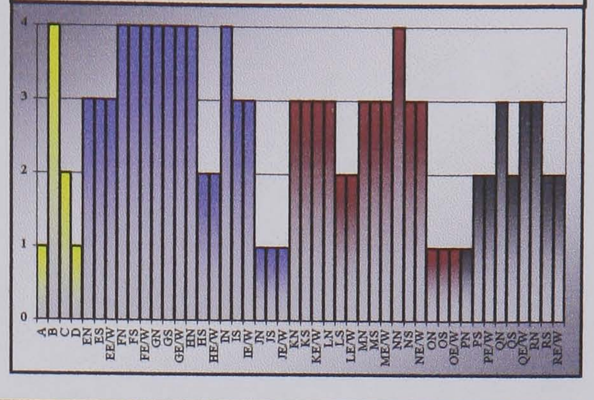
4- Section

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2, 3 and 4- Imagess obtained from the building Architect S. Jazaiiri.	**B 25 - SHEET 25**

Building ID	26	**D.O.C. Start End**	 1982	**Historical Phase**	VI	**Architect Name / Interviewed (Yes / No)**	Saiid Jazaiiiry / - / Yes
Building Name	Arab Bank Building (Mazraa)	**Condition**	As Built			**POE Questionaire**	***Distributed*** 0 / ***Responded*** 0

Building Typology	***Free-standing / Enclosed***	***Heavy / Light***	***Skin / Core Dependent***	***Open Plan / Cellular offices***	***Classified Type (A/B/C/D/E)***
	Enclosed	Heavy	Skin Dependent	Cellular offices	B

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m²)	360.00
Building Perimeter (m)	91.80
Building Height (m)	31.00
Building Inner Volume (m³)	11160.00
Compactness Ratio (A)	1.86
Shape coefficient (B)	3.92
Envelope to Floor Area Ratio (C)	0.79
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	73.66
Simulated Lighting Consumption	39.14
Sim. Potential Savings (LSOO)	0.00
Sim. Potential Savings (ICD)	0.94

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.43	0.54	0.54	0.50
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	1.16	0.54	0.54	0.75
Window Sill Height ($H_{N,S,E/W,Av}$)	0.00	0.90	0.90	0.60
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.85	0.52	0.52	0.63
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.15	0.09	0.09	0.11

WINDOW / OFFICE PARAMETERS

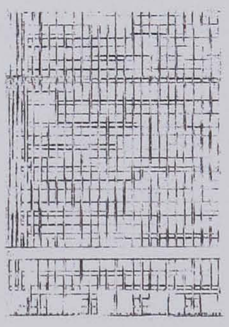
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.20	4.60	4.50	4.43
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.84	3.07	3.00	2.97
Office Average Area ($M_{N,S,E/W,Av}$)	13.44	15.18	14.85	14.49
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.59	0.33	0.34	0.42
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.11	0.06	0.06	0.08

SHADING DEVICES PARAMETERS

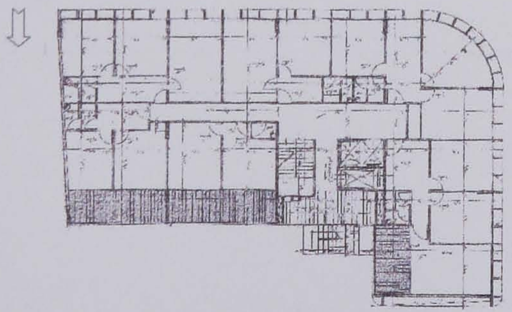
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Hor.	E.C.	E.C.	H/E.C.
Fixed / Movable	Fixed	Fixed	Fixed	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.80	0.32	0.32	0.48
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.80	0.67	0.74	0.74
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.54	0.45	0.49	0.49

BUILDING ILLUSTRATIONS

1- Perspective View



2- South Elevation

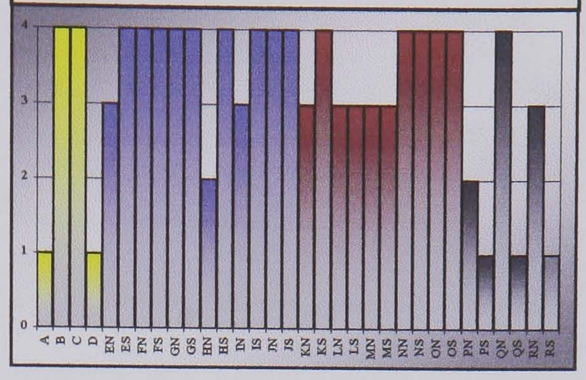


3- Typical Floor Plan

ILLUSTRATIONS SOURCES	1- Photgraphed by Saridar, S. (2003) 2 and 3- Images obtained from the building architect S. Jazaiiri	**B 26 - SHEET 26**

Building ID	27	D.O.C. Start End	 1982	Historical Phase: VI	Architect Name / Interviewed (Yes / No)	Saiid Jazaiiri / - / Yes
Building Name	El-Jazira Center	Condition	As Built		POE Questionaire	*Distributed* 0 / *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Cellular offices	B

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m²)	172.53
Building Perimeter (m)	64.84
Building Height (m)	27.60
Building Inner Volume (m³)	4761.83
Compactness Ratio (A)	1.94
Shape coefficient (B)	2.66
Envelope to Floor Area Ratio (C)	1.15
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.51	0.62	0.00	0.57
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	-	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	0.71	1.18	-	0.94
Window Sill Height ($H_{N,S,E/W,Av}$)	0.90	0.00	-	0.00
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.54	0.90	0.00	0.72
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.41	0.68	0.00	0.54

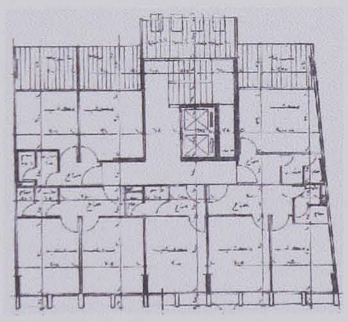
WINDOW / OFFICE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.00	3.30	0.00	3.65
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.74	2.17	0.00	2.45
Office Average Area ($M_{N,S,E/W,Av}$)	12.20	11.17	0.00	11.68
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.38	0.74	0.00	0.56
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.28	0.56	0.00	0.42

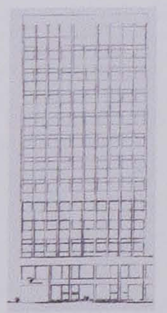
SHADING DEVICES PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	E.C.	Hor.	-	H/E.C.
Fixed / Movable	Fixed	Fixed	-	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.32	0.82	0.00	0.57
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.89	0.44	1.00	0.67
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.62	0.31	0.70	0.47

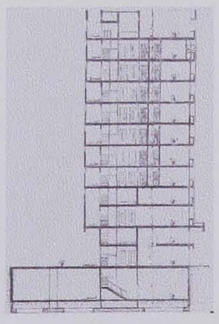
BUILDING ILLUSTRATIONS



1- Typical Floor Plan



2- South Elevation

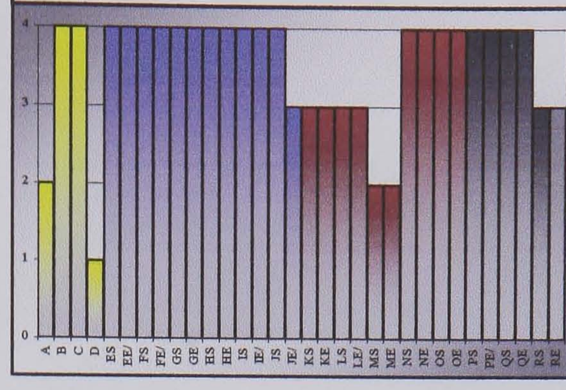


3- Section

ILLUSTRATIONS SOURCES	1, 2, and 3- Imagess obtained from the building Architect S. Jazaiiri.	**B 27 - SHEET 27**

Building ID	28	D.O.C. Start End	 1982	Historical Phase	VI	Architect Name / Interviewed (Yes / No)	Saiid Jazaiiri / - / Yes
Building Name	Unesco Center	Condition	As Built			POE Questionaire	*Distributed* 10 / *Responded* 5

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Cellular offices	B

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	241.00
Building Perimeter (m)	88.73
Building Height (m)	28.30
Building Inner Volume (m^3)	6820.30
Compactness Ratio (A)	2.60
Shape coefficient (B)	2.72
Envelope to Floor Area Ratio (C)	1.04
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	38.91
Sim. Potential Savings (LSOO)	1.68
Sim. Potential Savings (ICD)	3.78

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.00	0.89	0.89	0.89
Aperture Location ($F_{N,S,E/W,Av}$)	-	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	-	1.09	1.16	1.13
Window Sill Height ($H_{N,S,E/W,Av}$)	-	0.00	0.00	0.00
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.00	0.87	0.85	0.86
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.00	0.40	0.39	0.40

WINDOW / OFFICE PARAMETERS

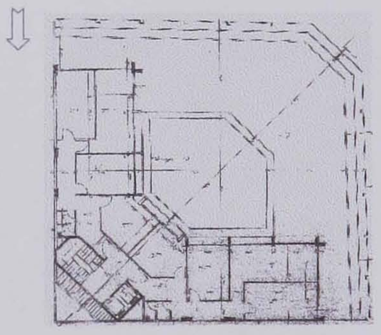
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	0.00	4.50	4.50	4.50
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	0.00	2.62	2.18	2.40
Office Average Area ($M_{N,S,E/W,Av}$)	0.00	20.00	20.00	20.00
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.00	0.63	0.66	0.65
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.00	0.29	0.30	0.30

SHADING DEVICES PARAMETERS

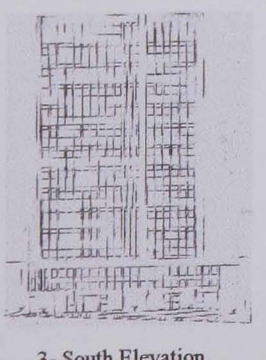
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.60	0.60	0.60	0.60

BUILDING ILLUSTRATIONS

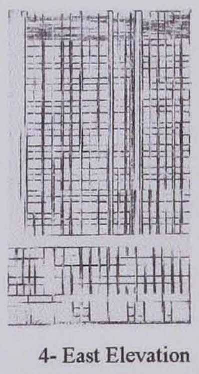
1- Perspective View



2- Typical Floor Plan



3- South Elevation

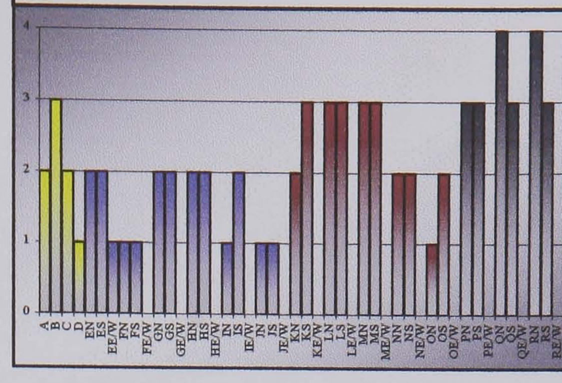


4- East Elevation

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2, 3 and 4 - Images obtained from the building architect S. Jazaiiri	**B 28 - SHEET 28**

Building ID	29	D.O.C. Start / End	..... / 1983	Historical Phase / VI	Architect Name / Interviewed (Yes / No)	Pierre Khoury / - / Yes
Building Name	El-Ghazal Tower	Condition	As Built		POE Questionaire	*Distributed* 50 / *Responded* 9

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices	C

BUILDING SHAPE PARAMETERS

Building Floor Area (m^2)	747.26
Building Perimeter (m)	136.50
Building Height (m)	40.00
Building Inner Volume (m^3)	29890.40
Compactness Ratio (A)	1.99
Shape coefficient (B)	5.47
Envelope to Floor Area Ratio (C)	0.61
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Real Total Consumption	146.34
Simulated Lighting Consumption	39.36
Sim. Potential Savings (LSOO)	0.08
Sim. Potential Savings (ICD)	2.98

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.25	0.27	0.05	0.16
Aperture Location ($F_{N,S,E/W,Av}$)	Unilat.	Unilat.	-	Unilat.
Window Shape ($G_{N,S,E/W,Av.}$)	1.18	1.18	-	1.18
Window Sill Height ($H_{N,S,E/W,Av}$)	0.80	0.80	-	0.80
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.23	0.25	0.00	0.24
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.17	0.18	0.00	0.18

WINDOW / OFFICE PARAMETERS

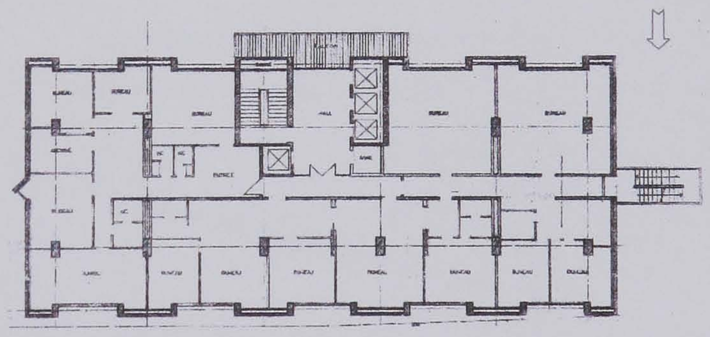
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	4.00	4.00	0.00	4.00
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.39	2.49	0.00	2.44
Office Average Area ($M_{N,S,E/W,Av}$)	18.06	16.60	0.00	17.33
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.17	0.18	0.00	0.18
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.13	0.14	0.00	0.13

SHADING DEVICES PARAMETERS

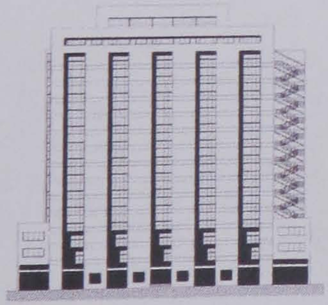
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Ver.	Ver.	-	Ver.
Fixed / Movable	Fixed	Fixed	-	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.19	0.19	0.00	0.09
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.93	0.79	1.00	0.93
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.65	0.56	0.70	0.65

BUILDING ILLUSTRATIONS

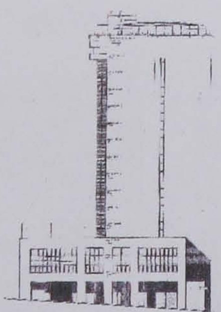

1- Perspective Views



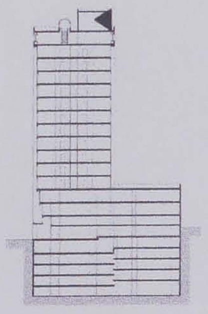
2- Typical Floor Plan



3- North Elevation



4- East Elevation



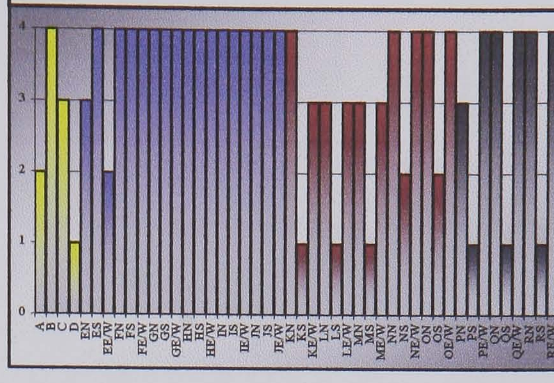
5- Section

ILLUSTRATIONS SOURCES	1, 2, 3, 4 and 5- Images scanned from the book of Brakhya, J. (2000)	B 29 - SHEET 29

Building ID	30	D.O.C. Start End	 1984	Historical Phase	Architect Name / Interviewed (Yes / No)	Louis Tabet & B. Muller (Renov.)
				VI		Yes
Building Name	Inter-continental Bank Headquarters	Condition	Renovated	POE Questionaire	*Distributed*	40
					Responded	15

Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Heavy	Skin Dependent	Cellular offices / Open Plan	C

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	445.23
Building Perimeter (m)	116.35
Building Height (m)	23.60
Building Inner Volume (m^3)	10507.43
Compactness Ratio (A)	2.42
Shape coefficient (B)	3.83
Envelope to Floor Area Ratio (C)	0.88
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.46	0.55	0.28	0.43
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	1.52	1.57	1.41	1.50
Window Sill Height ($H_{N,S,E/W,Av}$)	0.20	0.20	0.20	0.20
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.66	0.67	0.74	0.69
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.58	0.58	0.64	0.60

WINDOW / OFFICE PARAMETERS

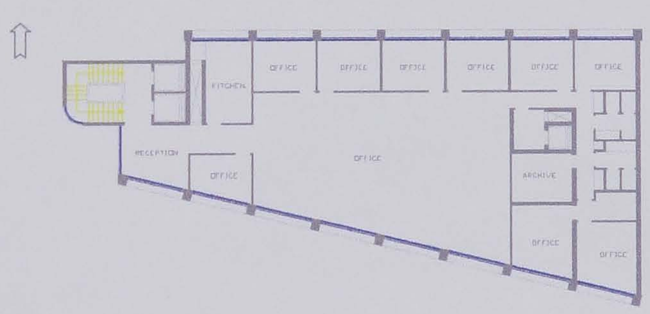
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	3.35	9.50	4.15	5.67
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	2.20	4.38	2.94	3.17
Office Average Area ($M_{N,S,E/W,Av}$)	13.07	156.75	13.49	61.10
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.55	0.19	0.50	0.41
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.48	0.17	0.43	0.36

SHADING DEVICES PARAMETERS

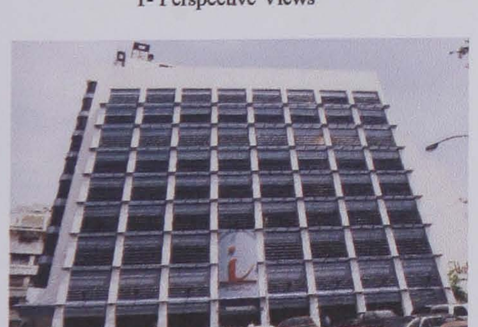
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	Ver.	Ver.	-	Ver.
Fixed / Movable	Fixed	Fixed	-	Fixed
Projection Ratio ($P_{N,S,E/W,Av}$)	0.17	1.00	0.00	0.39
Overhang Factor ($Q_{N,S,E/W,Av}$)	0.94	0.44	1.00	0.79
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.65	0.31	0.70	0.55

BUILDING ILLUSTRATIONS

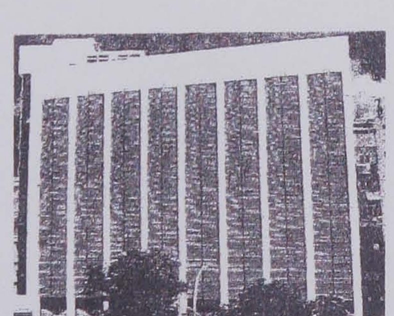
1- Perspective Views



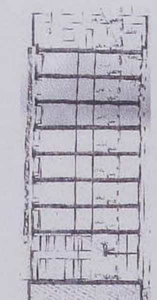
2- Typical Floor Plan



3- Renovated South Façade



4- Old South Façade

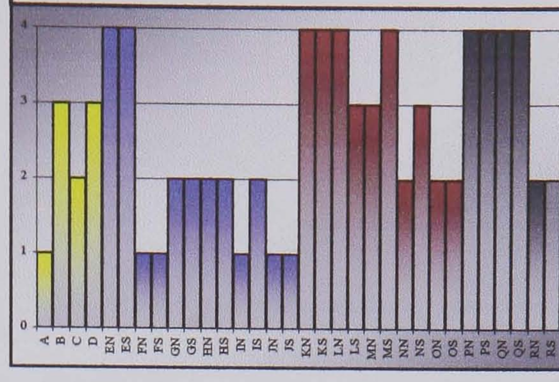


5- Section

ILLUSTRATIONS SOURCES	1 and 3- Photographed by Saridar, S. (2003) 2, 4, and 5 - Images obtained from B. Muller	B 30 - SHEET 30

Building ID	31	D.O.C. Start End	1993 1995	Historical Phase	Architect Name / Interviewed (Yes / No)	Pierre Khoury
				VII		-
						Yes
Building Name	BLOM (Block A)	Condition		As Built	POE Questionaire	*Distributed*
						0
						Responded
						0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Light	Skin Dependent	Cellular offices	E

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	494.93
Building Perimeter (m)	107.04
Building Height (m)	24.10
Building Inner Volume (m^3)	11927.81
Compactness Ratio (A)	1.84
Shape coefficient (B)	4.62
Envelope to Floor Area Ratio (C)	0.65
Porosity Ratio (D)	0.14

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	194.95
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter		Value
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	*North*	0.59
	South	0.58
	E / W	0.00
	Aver.	0.59
Aperture Location ($F_{N,S,E/W,Av}$)	*North*	Unilat.
	South	Unilat.
	E / W	-
	Aver.	Unilat.
Window Shape ($G_{N,S,E/W,Av}$)	*North*	0.50
	South	0.50
	E / W	-
	Aver.	0.50
Window Sill Height ($H_{N,S,E/W,Av}$)	*North*	0.80
	South	0.80
	E / W	-
	Aver.	0.80
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	*North*	0.20
	South	0.26
	E / W	0.00
	Aver.	0.23
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	*North*	0.13
	South	0.17
	E / W	0.00
	Aver.	0.15

WINDOW / OFFICE PARAMETERS

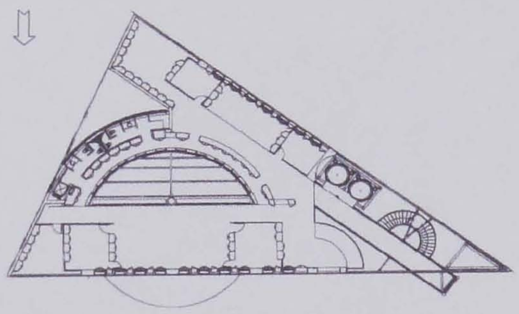
Parameter		Value
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	*North*	3.00
	South	3.00
	E / W	0.00
	Aver.	3.00
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	*North*	1.91
	South	2.14
	E / W	0.00
	Aver.	2.03
Office Average Area ($M_{N,S,E/W,Av}$)	*North*	12.60
	South	9.60
	E / W	0.00
	Aver.	11.10
Fenestration Factor ($N_{N,S,E/W,Av}$)	*North*	0.21
	South	0.27
	E / W	0.00
	Aver.	0.24
Glazing Ratio ($O_{N,S,E/W,Av}$)	*North*	0.14
	South	0.18
	E / W	0.00
	Aver.	0.16

SHADING DEVICES PARAMETERS

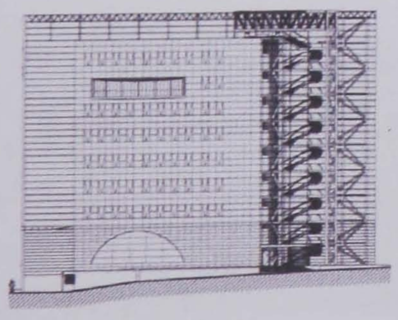
Parameter		Value
Vertical / Horizontal/ Egg crate	*North*	-
	South	-
	E / W	-
	Aver.	-
Fixed / Movable	*North*	-
	South	-
	E / W	-
	Aver.	-
Projection Ratio ($P_{N,S,E/W,Av}$)	*North*	0.00
	South	0.00
	E / W	0.00
	Aver.	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	*North*	1.00
	South	1.00
	E / W	1.00
	Aver.	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	*North*	0.39
	South	0.39
	E / W	0.39
	Aver.	0.39

BUILDING ILLUSTRATIONS

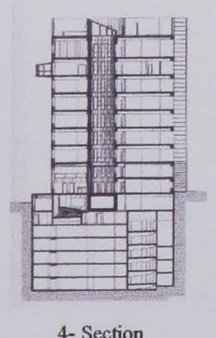
1- Perspective View



2- Typical Floor Plan



3- North Elevation



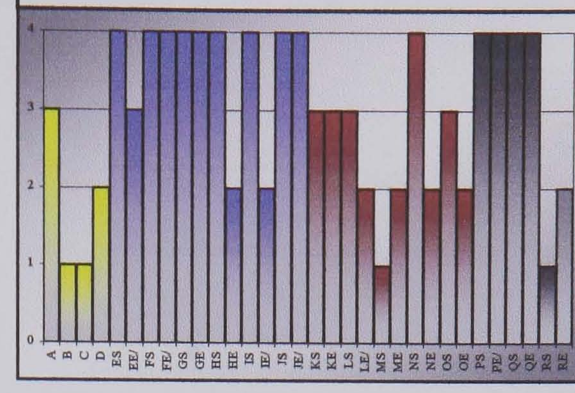
4- Section

5- Internal View

ILLUSTRATIONS SOURCES	1, 2, 3, 4 and 5- Imagess Scanned from the book of Brakhya, J. (2000)	B 31 - SHEET 31

Building ID	32	D.O.C. Start End	1995 1996	Historical Phase	Architect Name / Interviewed (Yes / No)	Pierre Khoury
				VII		-
						Yes
Building Name	ESCWA Headquarters	Condition		As Built	POE Questionaire	*Distributed* 0 *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Light	Skin Dependent	Cellular offices	E

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m²)	2184.72
Building Perimeter (m)	289.52
Building Height (m)	25.60
Building Inner Volume (m³)	56566.50
Compactness Ratio (A)	3.05
Shape coefficient (B)	7.63
Envelope to Floor Area Ratio (C)	0.48
Porosity Ratio (D)	0.05

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	175.03
Simulated Lighting Consumption	41.32
Sim. Potential Savings (LSOO)	1.67
Sim. Potential Savings (ICD)	3.22

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.00	0.84	0.42	0.56
Aperture Location ($F_{N,S,E/W,Av}$)	-	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	-	2.23	1.06	1.45
Window Sill Height ($H_{N,S,E/W,Av}$)	-	0.00	0.90	0.60
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.00	0.90	0.38	0.55
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.00	0.48	0.25	0.33

WINDOW / OFFICE PARAMETERS

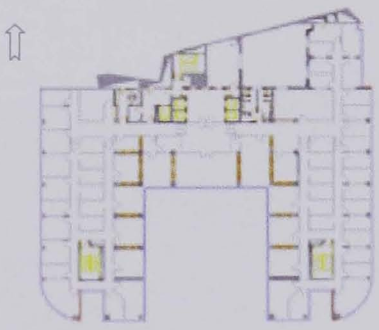
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	0.00	5.70	5.00	5.23
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	0.00	2.91	3.17	3.08
Office Average Area ($M_{N,S,E/W,Av}$)	0.00	40.76	21.38	27.84
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.00	0.51	0.24	0.33
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.00	0.27	0.16	0.20

SHADING DEVICES PARAMETERS

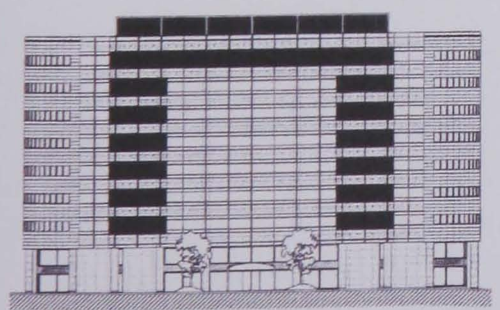
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.74	0.32	0.39	0.37

BUILDING ILLUSTRATIONS

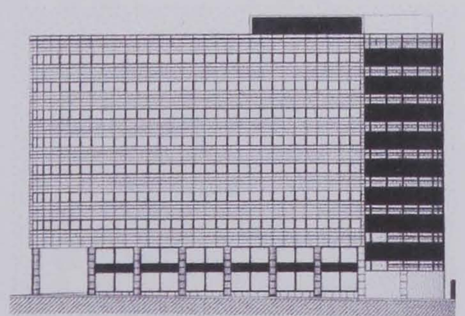
1- Perspective View



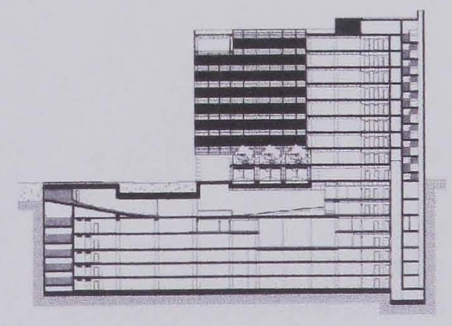
2- Typical Floor Plan



3- South Elevation



4- East Elevation



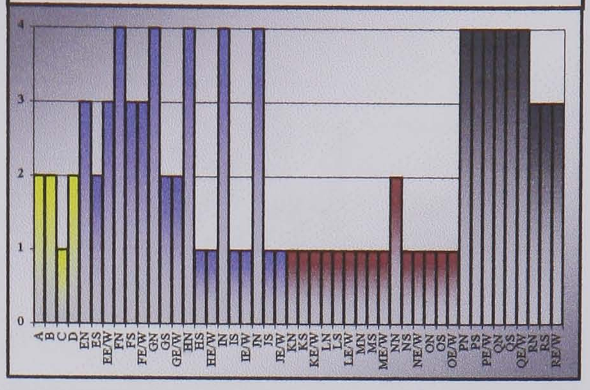
5- Section

ILLUSTRATIONS SOURCES	1- Image scanned from the book of Brakhya, J. (2000) 2, 3 4 and 5 - Architectural CAD drawings obtained from SOLIDERE	B 32 - SHEET 32

Building ID	33	D.O.C. Start End	1996 1998	Historical Phase	Architect Name / Interviewed (Yes / No)	Nabil Azar (1866-1952)
				VII		No
Building Name	The Atrium' Office Building	Condition		As Built	POE Questionaire	*Distributed* 0 *Responded* 0

Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Open Plan	B

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS	
Building Floor Area (m^2)	1734.39
Building Perimeter (m)	239.66
Building Height (m)	18.30
Building Inner Volume (m^3)	31739.34
Compactness Ratio (A)	2.64
Shape coefficient (B)	7.24
Envelope to Floor Area Ratio (C)	0.51
Porosity Ratio (D)	0.09

ENERGY DATA (kWh/m^2)	
Real Total Consumption	
Simulated Lighting Consumption	42.34
Sim. Potential Savings (LSOO)	0.59
Sim. Potential Savings (ICD)	2.20

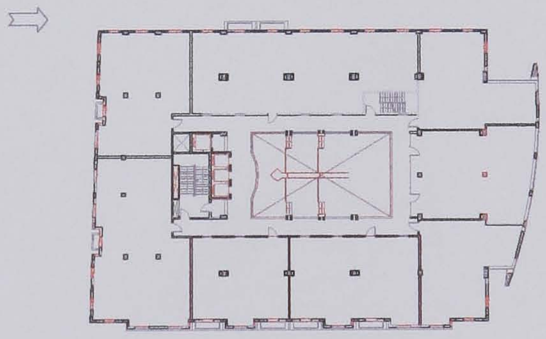
WINDOW / FAÇADE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.45	0.27	0.40	0.38
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	Multil.	Multil.	Multil.
Window Shape ($G_{N,S,E/W,Av.}$)	3.70	0.64	0.64	1.40
Window Sill Height ($H_{N,S,E/W,Av}$)	0.00	0-0.9	0-0.9	0-0.9
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.90	0.20	0.21	0.38
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.50	0.11	0.12	0.21

WINDOW / OFFICE PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	12.00	10.00	10.00	10.50
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	4.76	4.30	4.51	4.52
Office Average Area ($M_{N,S,E/W,Av}$)	142.20	171.50	149.50	153.18
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.24	0.07	0.07	0.12
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.13	0.04	0.04	0.06

SHADING DEVICES PARAMETERS	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.53	0.53	0.53	0.53

BUILDING ILLUSTRATIONS

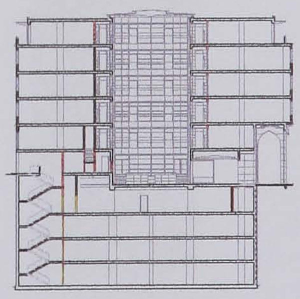
1- Perspective View



2- Typical Floor Plan

3- North Elevation

4- South Elevation



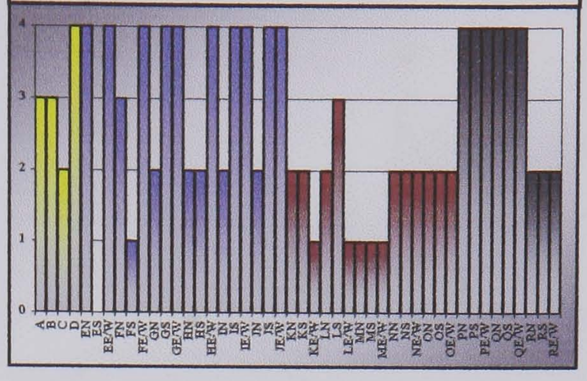
5- Section

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2,3, 4 and 5- Architectural CAD drawings obtained from SOLIDERE	B 33 - SHEET 33

Building ID	34	D.O.C. Start End	1999 2001	Historical Phase: VII	Architect Name / Interviewed (Yes / No)	Pierre Khoury / - / Yes
Building Name	BLOM (Block B)	Condition	As Built		POE Questionaire	*Distributed*: 0 / *Responded*: 0

Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Light	Skin Dependent	Cellular offices	E

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m²)	838.00
Building Perimeter (m)	189.79
Building Height (m)	24.10
Building Inner Volume (m³)	20195.80
Compactness Ratio (A)	3.42
Shape coefficient (B)	4.42
Envelope to Floor Area Ratio (C)	0.68
Porosity Ratio (D)	0.19

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	North	South	E / W	Aver.
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.59	0.00	0.80	0.69
Aperture Location ($F_{N,S,E/W,Av}$)	Multil.	Unilat.	C.Glaz.	Multil.
Window Shape ($G_{N,S,E/W,Av}$)	0.50	8.64	4.58	4.57
Window Sill Height ($H_{N,S,E/W,Av}$)	0.80	0.90	0.00	0.43
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.33	0.71	0.90	0.65
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.22	0.47	0.59	0.43

WINDOW / OFFICE PARAMETERS

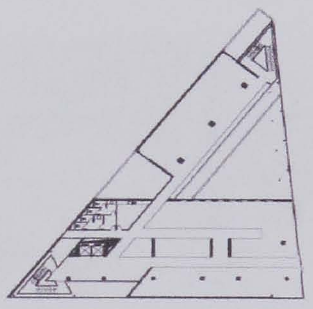
Parameter	North	South	E / W	Aver.
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	7.20	7.85	12.00	9.02
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	3.61	2.95	5.47	4.01
Office Average Area ($M_{N,S,E/W,Av}$)	345.60	149.15	345.60	280.12
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.22	0.25	0.22	0.23
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.15	0.17	0.15	0.23

SHADING DEVICES PARAMETERS

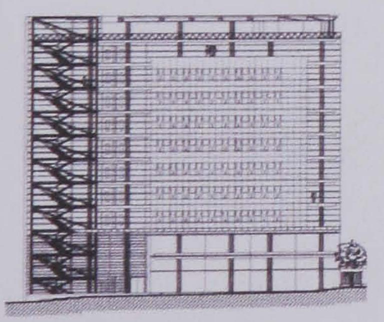
Parameter	North	South	E / W	Aver.
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.39	0.00	0.39	0.59

BUILDING ILLUSTRATIONS

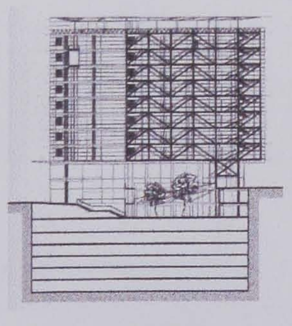
1- Perspective Views



2- Typical Floor Plan



3- North Elevation



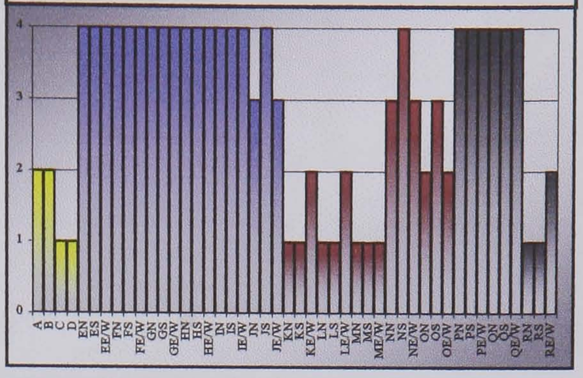
4- Section

5- Internal View

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S (2003) 2, 3, 4 and 5- Imagess scanned from the book of Brakhya, J. (2000)	B 34 - SHEET 34

Building ID	35	D.O.C. Start End	1999 2003	Historical Phase VII	Architect Name / Interviewed (Yes / No)	Pierre Khoury / - / Yes
Building Name	El-Nahar Office Building	Condition	As Built		POE Questionaire	*Distributed* 0 / *Responded* 0

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Free-standing	Light	Skin Dependent	Open Plan	D

BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m²)	1338.22
Building Perimeter (m)	201.41
Building Height (m)	24.10
Building Inner Volume (m³)	31850.09
Compactness Ratio (A)	2.41
Shape coefficient (B)	6.56
Envelope to Floor Area Ratio (C)	0.45
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	
Sim. Potential Savings (LSOO)	
Sim. Potential Savings (ICD)	

WINDOW / FAÇADE PARAMETERS

Parameter	*North*	*South*	*E / W*	*Aver.*
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	0.84	0.84	0.75	0.80
Aperture Location ($F_{N,S,E/W,Av}$)	C.Glaz.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	2.27	4.00	1.07	2.10
Window Sill Height ($H_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	0.71	0.90	0.72	0.76
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	0.37	0.48	0.38	0.40

WINDOW / OFFICE PARAMETERS

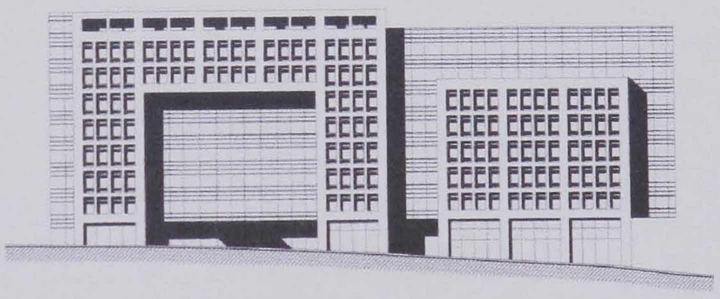
Parameter	*North*	*South*	*E / W*	*Aver.*
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	19.00	22.70	7.80	14.33
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	7.22	9.46	3.03	5.68
Office Average Area ($M_{N,S,E/W,Av}$)	406.98	272.40	231.82	285.75
Fenestration Factor ($N_{N,S,E/W,Av}$)	0.31	0.39	0.32	0.34
Glazing Ratio ($O_{N,S,E/W,Av}$)	0.17	0.21	0.17	0.18

SHADING DEVICES PARAMETERS

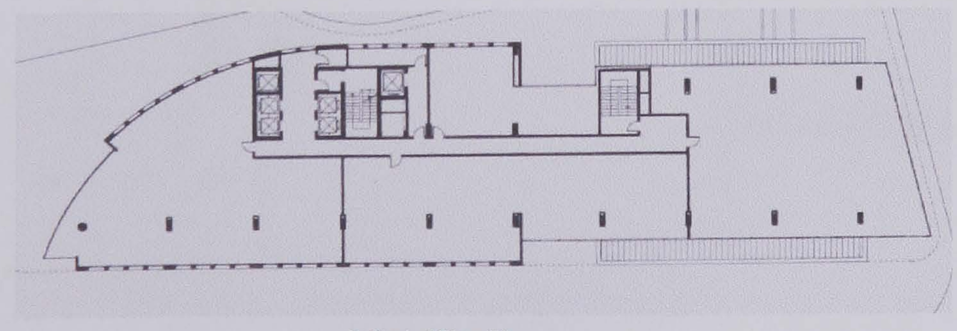
Parameter	*North*	*South*	*E / W*	*Aver.*
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio ($P_{N,S,E/W,Av}$)	0.00	0.00	0.00	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	0.32	0.32	0.39	0.36

BUILDING ILLUSTRATIONS

1- Perspective View



2- East Elevation

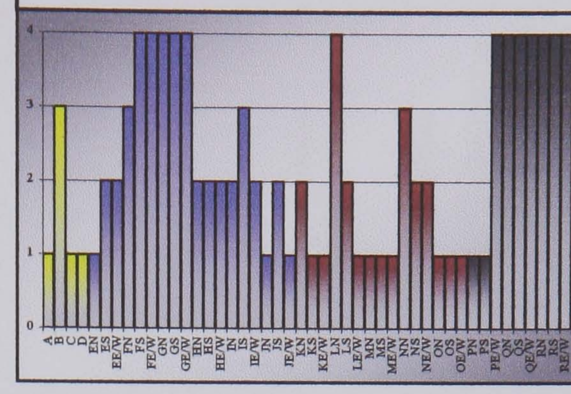


3- Typical Floor Plan

ILLUSTRATIONS SOURCES	1- Photographed by Saridar, S. (2003) 2 and 3- Images scanned from the book of Brakhya, J. (2000)	**B 35 - SHEET 35**

Building ID	36	D.O.C. Start End	....	Historical Phase	-	Architect Name / Interviewed (Yes / No)	- - -
Building Name	Base Case A1-OL	Condition	-	POE Questionaire			*Distributed* - *Responded* -

DIAGRAMATIC DESCRIPTION



Building Typology	*Free-standing / Enclosed*	*Heavy / Light*	*Skin / Core Dependent*	*Open Plan / Cellular offices*	*Classified Type (A/B/C/D/E)*
	Enclosed	Heavy	Skin Dependent	Celluar Offices	B

BUILDING SHAPE PARAMETERS

Building Floor Area (m²)	550.00
Building Perimeter (m)	96.00
Building Height (m)	39.60
Building Inner Volume (m³)	21780.00
Compactness Ratio (A)	1.33
Shape coefficient (B)	5.73
Envelope to Floor Area Ratio (C)	0.58
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Real Total Consumption	
Simulated Lighting Consumption	42.74
Sim. Potential Savings (LSOO)	0.81
Sim. Potential Savings (ICD)	2.98

WINDOW / FAÇADE PARAMETERS

Parameter	North	South	E / W	Aver.
Wall to Aperture Ratio (E N,S,E/W, Av)	0.11	0.39	0.39	0.32
Aperture Location (F N,S,E/W, Av)	Multil.	C.Glaz.	C.Glaz.	C.Glaz.
Window Shape (G N,S,E/W, Av)	1.54	1.54	1.54	1.54
Window Sill Height (H N,S,E/W, Av)	0.90	0.90	0.90	0.90
Window to Wall Ratio (I N,S,E/W, Av)	0.27	0.40	0.35	0.34
Daylight Aperture Ratio (J N,S,E/W, Av)	0.13	0.20	0.17	0.17

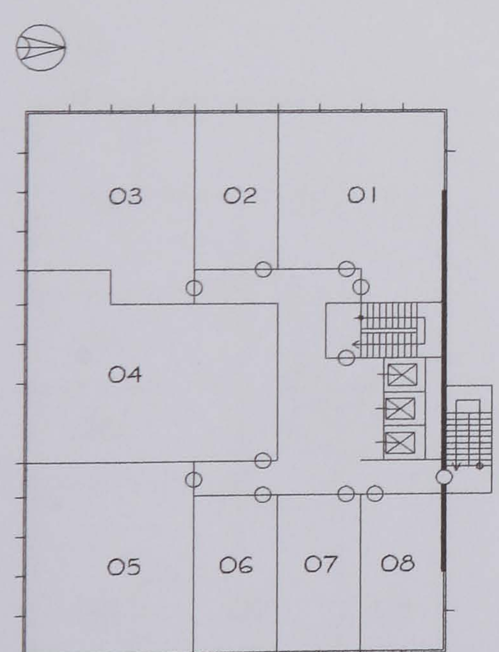
WINDOW / OFFICE PARAMETERS

Parameter	North	South	E / W	Aver.
Buffer Zone Depth (K N,S,E/W, Av)	6.00	10.00	8.00	8.00
Room Limiting Depth Rule (L N,S,E/W, Av)	1.74	3.73	4.39	3.56
Office Average Area (M N,S,E/W, Av)	48.00	80.00	32.00	48.00
Fenestration Factor (N N,S,E/W, Av)	0.26	0.23	0.24	0.24
Glazing Ratio (O N,S,E/W, Av)	0.13	0.11	0.12	0.12

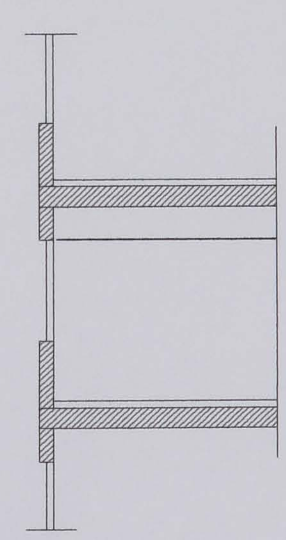
SHADING DEVICES PARAMETERS

Parameter	North	South	E / W	Aver.
Vertical / Horizontal/ Egg crate	-	-	-	-
Fixed / Movable	-	-	-	-
Projection Ratio (P N,S,E/W, Av)	0.00	0.00	0.00	0.00
Overhang Factor (Q N,S,E/W, Av)	1.00	1.00	1.00	1.00
Relative Solar Heat Gain (R N,S,E/W, Av)	0.67	0.67	0.67	0.67

BUILDING ILLUSTRATIONS



1- Typical Floor Plan



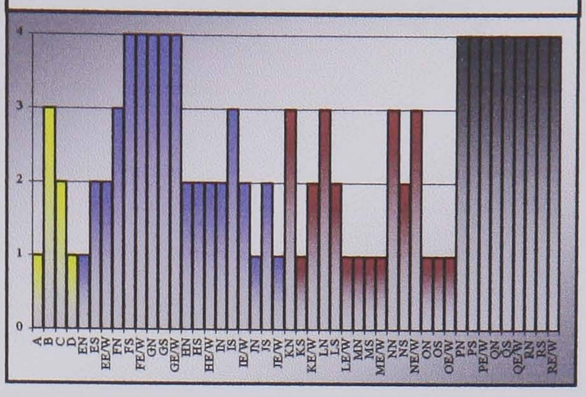
2- Typical Floor Section

ILLUSTRATIONS SOURCES	1and 2- Architectural CAD drawings obtained from Sarah Kouzi (LEB/99/G35 Project Assistant)	**B 36 - SHEET 36**

Building ID	37	**D.O.C. Start End**	....	**Historical Phase**	-	**Architect Name / Interviewed (Yes / No)**	- - -
Building Name	Base Case A1-O	**Condition**	-	-		**POE Questionaire**	***Distributed*** - ***Responded*** -

Building Typology	***Free-standing / Enclosed***	***Heavy / Light***	***Skin / Core Dependent***	***Open Plan / Cellular offices***	***Classified Type (A/B/C/D/E)***
	Enclosed	Heavy	Skin Dependent	Celluar Offices	B

DIAGRAMATIC DESCRIPTION



BUILDING SHAPE PARAMETERS

Parameter	Value
Building Floor Area (m^2)	380.00
Building Perimeter (m)	80.00
Building Height (m)	23.10
Building Inner Volume (m^3)	8778.00
Compactness Ratio (A)	1.34
Shape coefficient (B)	4.75
Envelope to Floor Area Ratio (C)	0.69
Porosity Ratio (D)	0.00

ENERGY DATA (kWh/m²)

Parameter	Value
Real Total Consumption	
Simulated Lighting Consumption	42.17
Sim. Potential Savings (LSOO)	0.93
Sim. Potential Savings (ICD)	3.33

WINDOW / FAÇADE PARAMETERS

Parameter		Value
Wall to Aperture Ratio ($E_{N,S,E/W,Av}$)	***North***	0.13
	South	0.39
	E / W	0.39
	Aver.	0.33
Aperture Location ($F_{N,S,E/W,Av}$)	***North***	Multil.
	South	C.Glaz.
	E / W	C.Glaz.
	Aver.	C.Glaz.
Window Shape ($G_{N,S,E/W,Av}$)	***North***	1.54
	South	1.54
	E / W	1.54
	Aver.	1.54
Window Sill Height ($H_{N,S,E/W,Av}$)	***North***	0.90
	South	0.90
	E / W	0.90
	Aver.	0.90
Window to Wall Ratio ($I_{N,S,E/W,Av}$)	***North***	0.25
	South	0.40
	E / W	0.29
	Aver.	0.31
Daylight Aperture Ratio ($J_{N,S,E/W,Av}$)	***North***	0.12
	South	0.20
	E / W	0.15
	Aver.	0.15

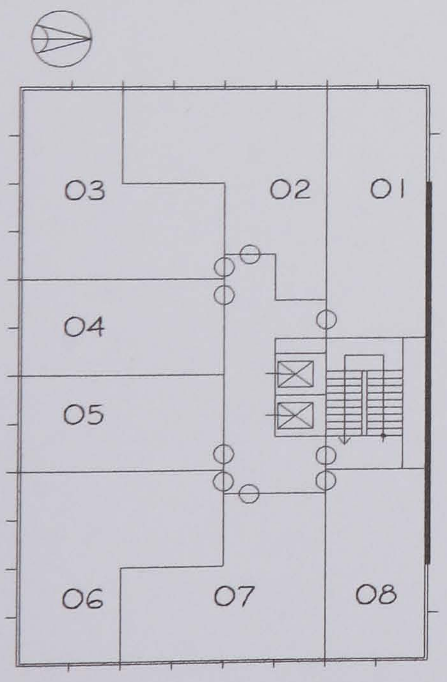
WINDOW / OFFICE PARAMETERS

Parameter		Value
Buffer Zone Depth ($K_{N,S,E/W,Av}$)	***North***	4.00
	South	8.00
	E / W	7.00
	Aver.	6.50
Room Limiting Depth Rule ($L_{N,S,E/W,Av}$)	***North***	2.27
	South	3.98
	E / W	5.77
	Aver.	4.45
Office Average Area ($M_{N,S,E/W,Av}$)	***North***	36.00
	South	40.00
	E / W	40.00
	Aver.	39.00
Fenestration Factor ($N_{N,S,E/W,Av}$)	***North***	0.25
	South	0.21
	E / W	0.25
	Aver.	0.24
Glazing Ratio ($O_{N,S,E/W,Av}$)	***North***	0.12
	South	0.11
	E / W	0.12
	Aver.	0.12

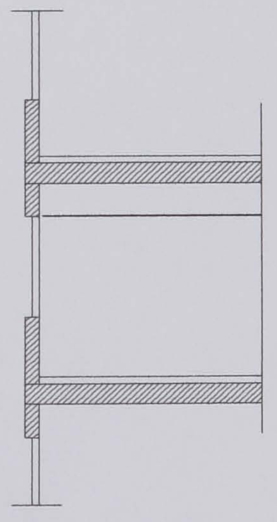
SHADING DEVICES PARAMETERS

Parameter		Value
Vertical / Horizontal/ Egg crate	***North***	-
	South	-
	E / W	-
	Aver.	-
Fixed / Movable	***North***	-
	South	-
	E / W	-
	Aver.	-
Projection Ratio ($P_{N,S,E/W,Av}$)	***North***	0.00
	South	0.00
	E / W	0.00
	Aver.	0.00
Overhang Factor ($Q_{N,S,E/W,Av}$)	***North***	1.00
	South	1.00
	E / W	1.00
	Aver.	1.00
Relative Solar Heat Gain ($R_{N,S,E/W,Av}$)	***North***	0.67
	South	0.67
	E / W	0.67
	Aver.	0.67

BUILDING ILLUSTRATIONS



1- Typical Floor Plan



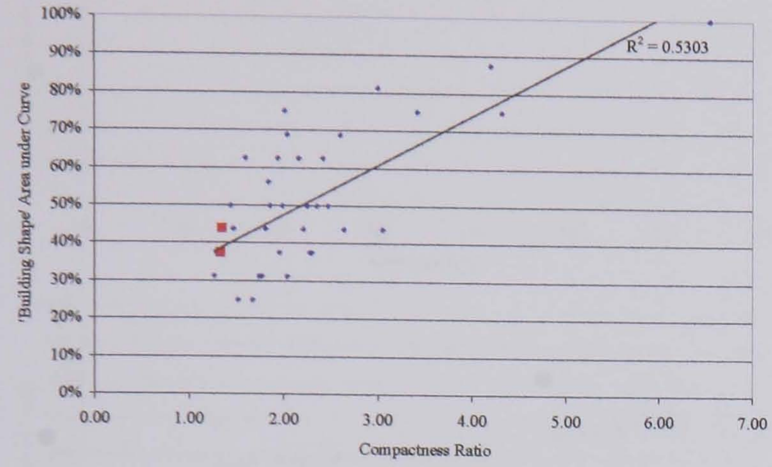
2- Typical Floor Section

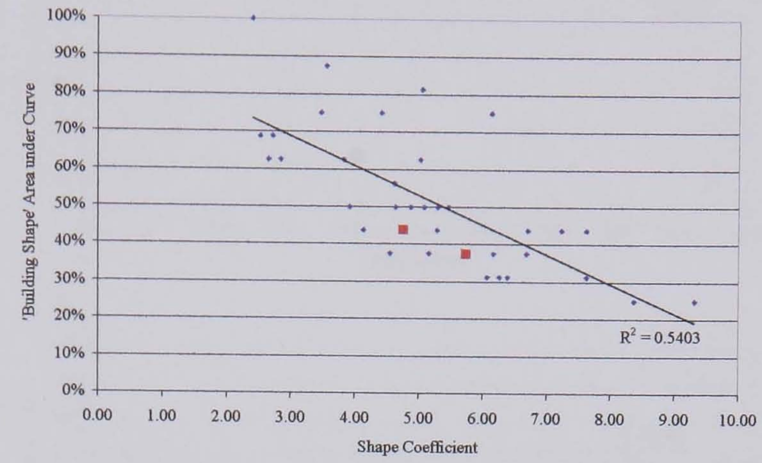
ILLUSTRATIONS SOURCES	1and 2- Architectural CAD drawings obtained from Sarah Kouzi (LEB/99/G35 Project Assistant)	**B 37 - SHEET 37**

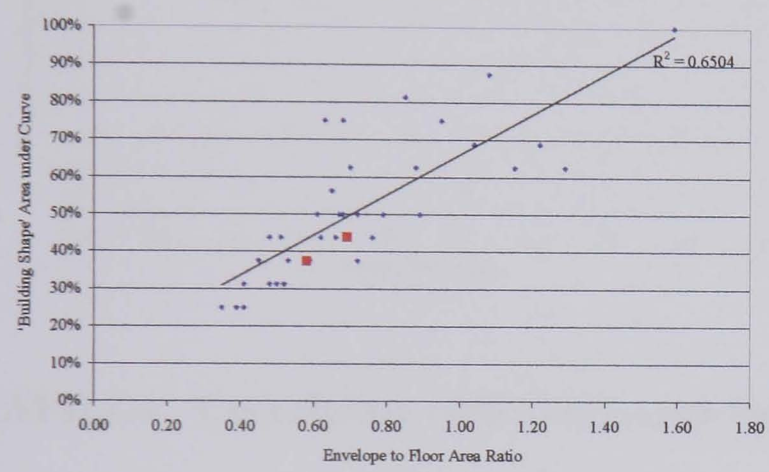
Appendix II. Correlational Analysis of Daylighting Design Variables with Performance Evaluation Values

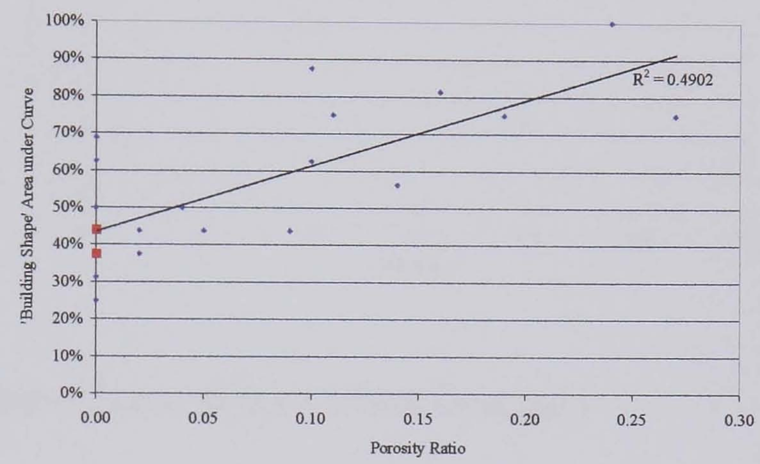
APII.1 'Building Shape' Parametric Level

APII.1.1 Correlation with 'Building Shape' Area under Curve

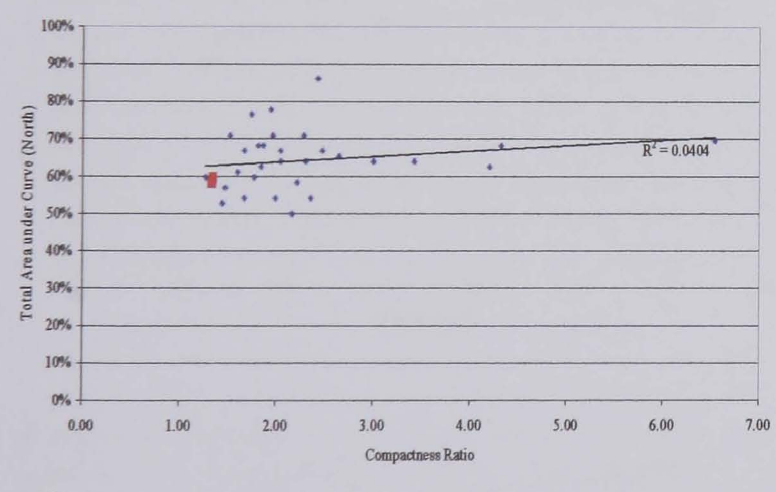


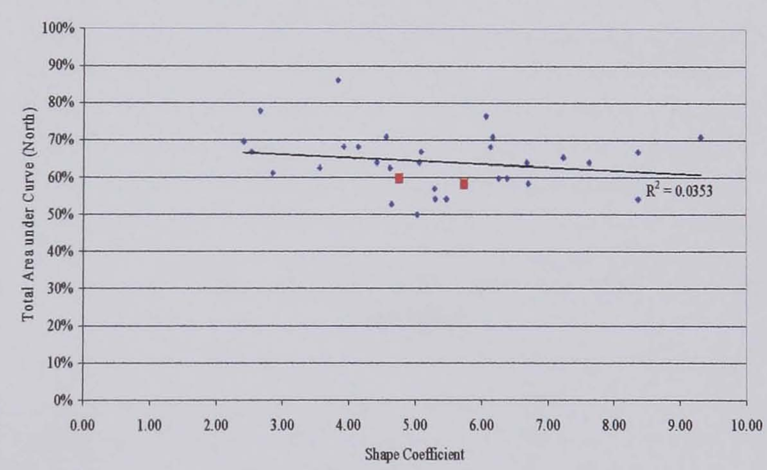


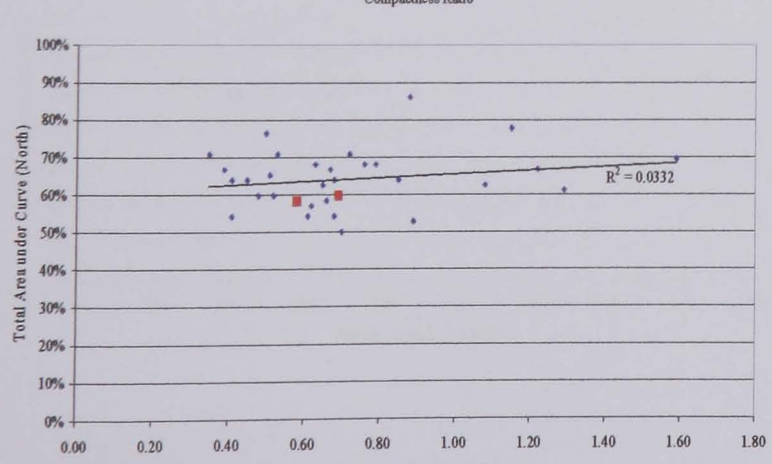




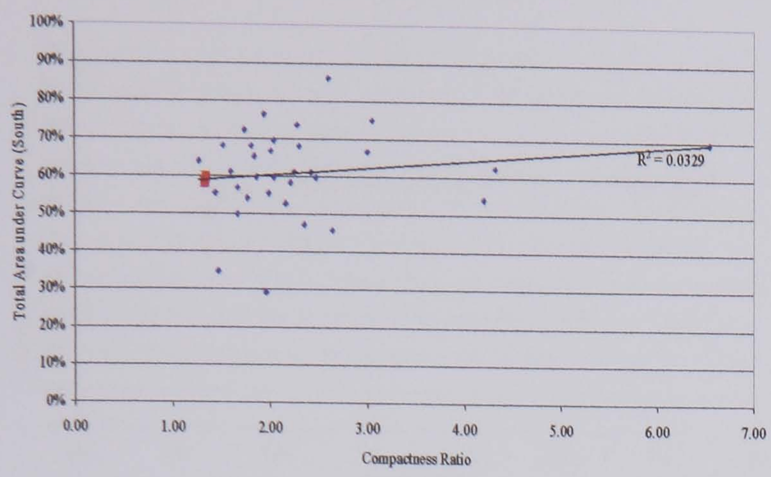
APII.1.2 Correlation with Total Area under Curve (North Average)

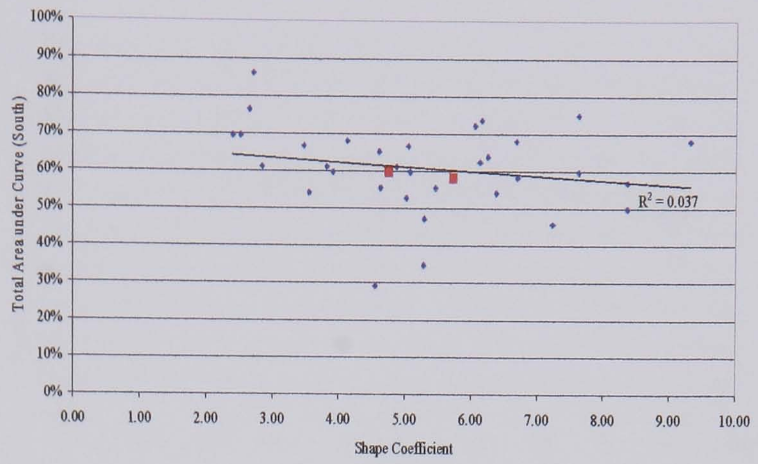


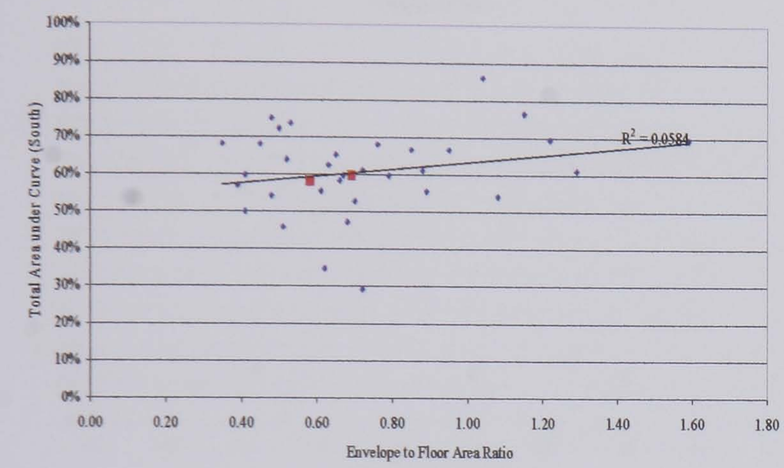


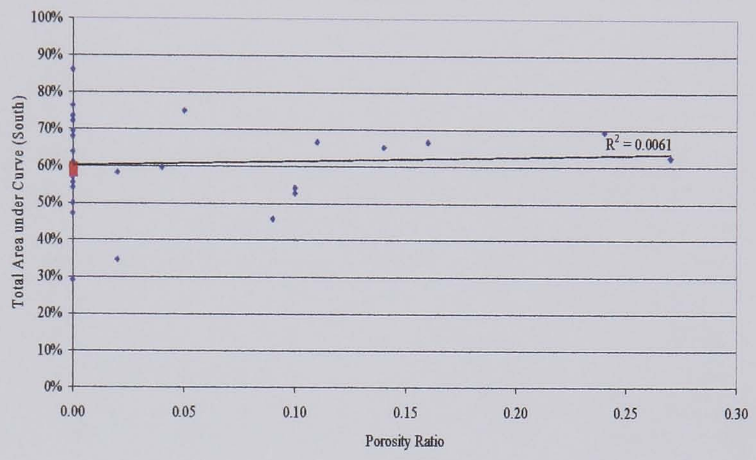


APII.1.3 Correlation with Total Area under Curve (South Average)

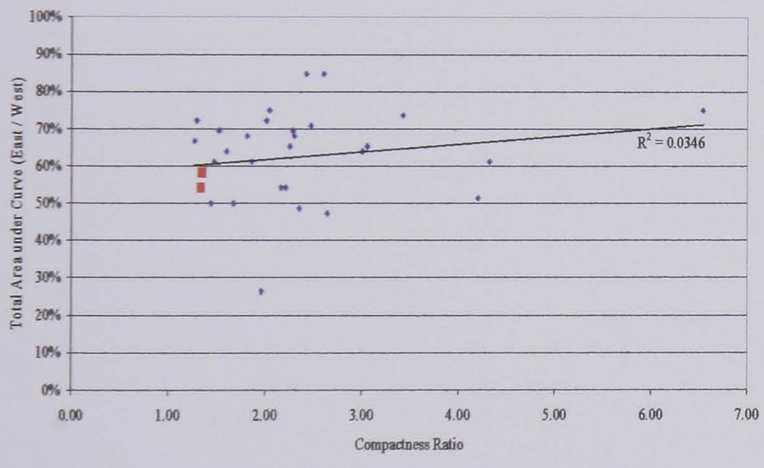


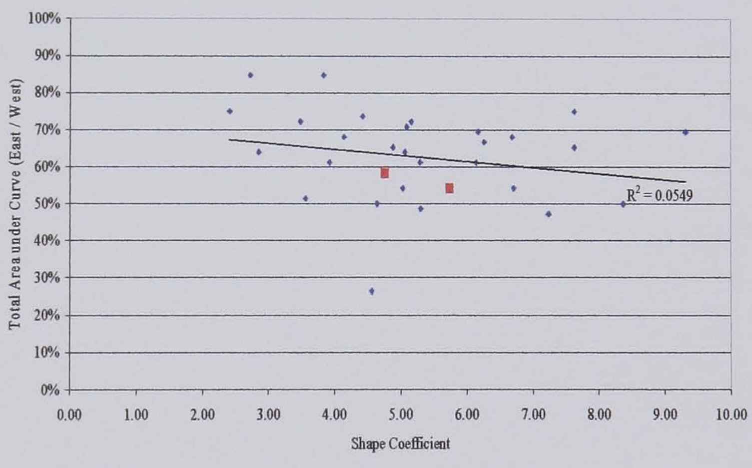


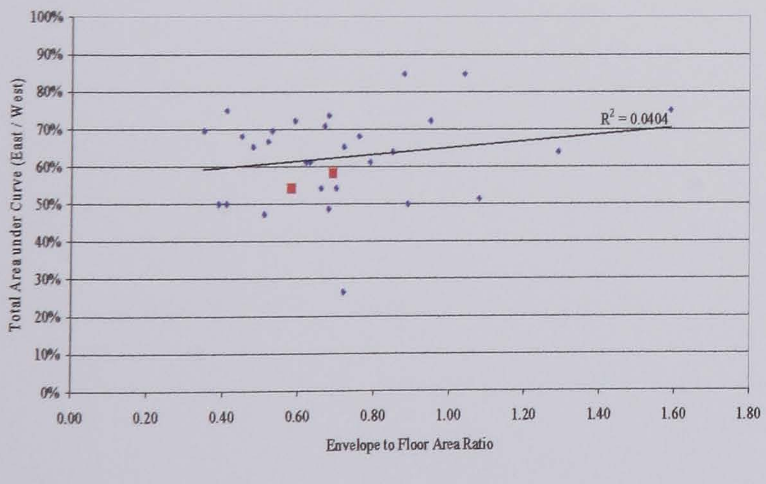


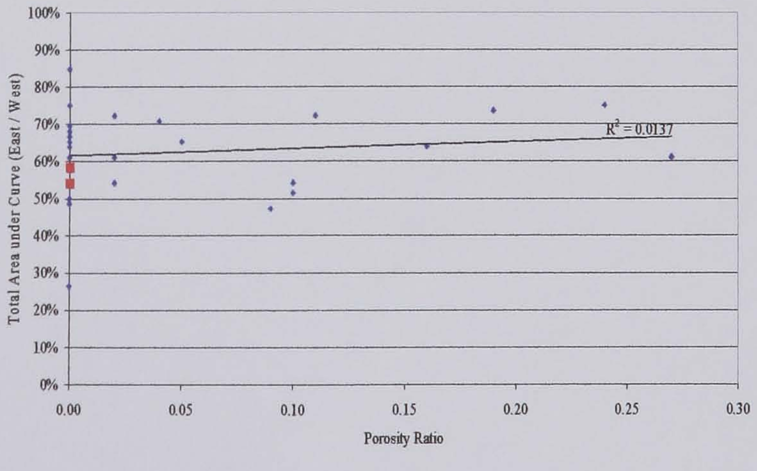


APII.1.4 Correlation with Total Area under Curve (East / West Average)

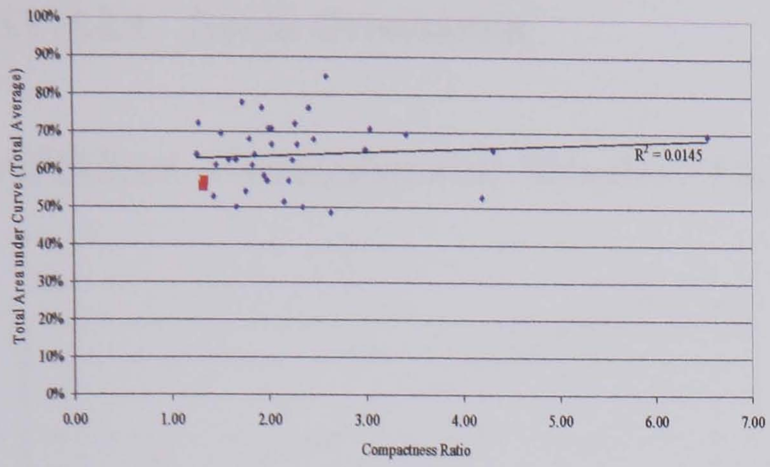


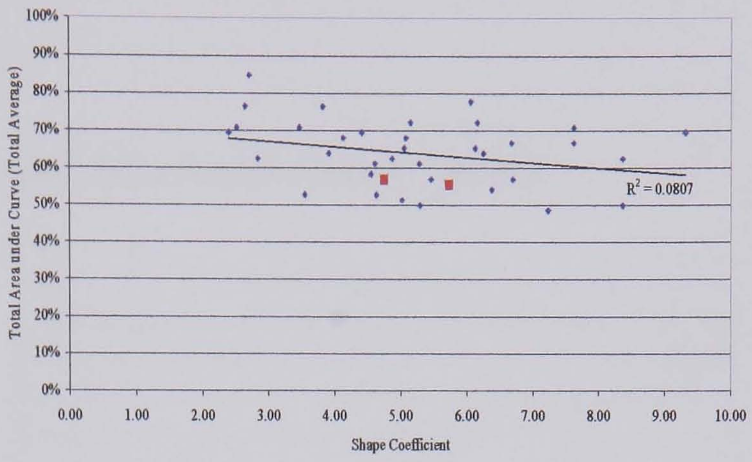


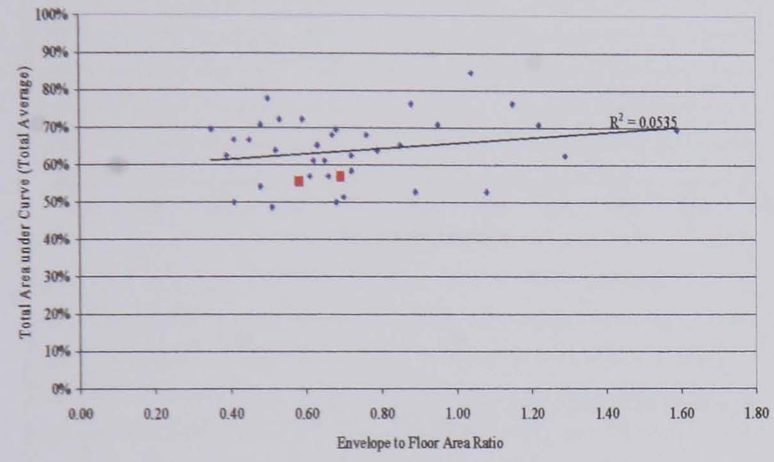


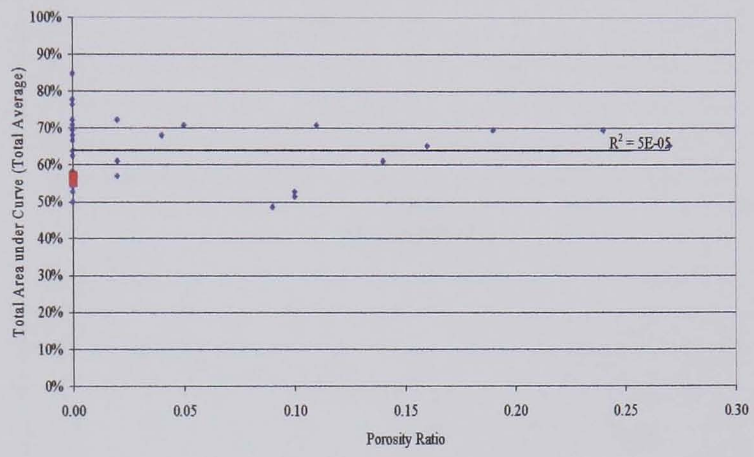


APII.1.5 Correlation with Total Area under Curve (Total Building Average)





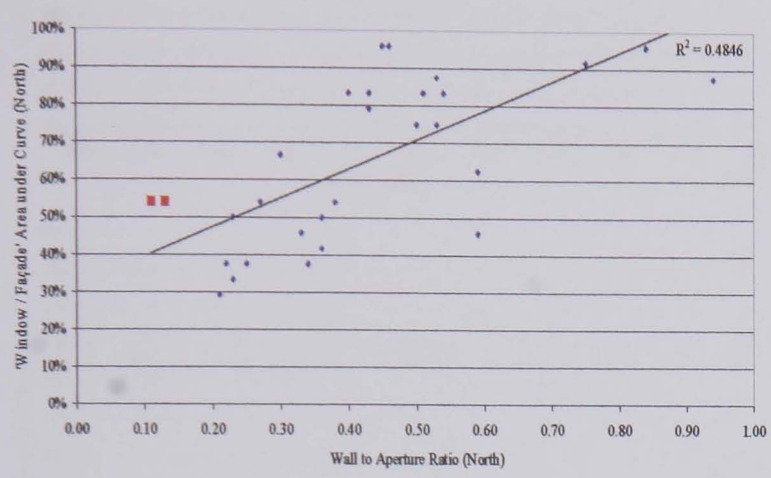


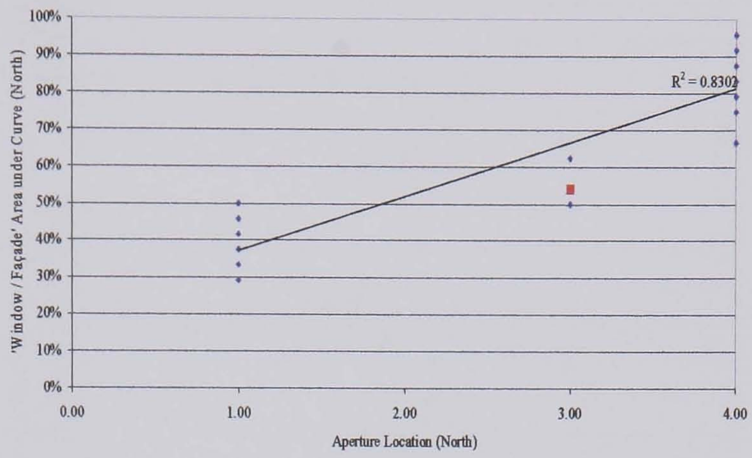


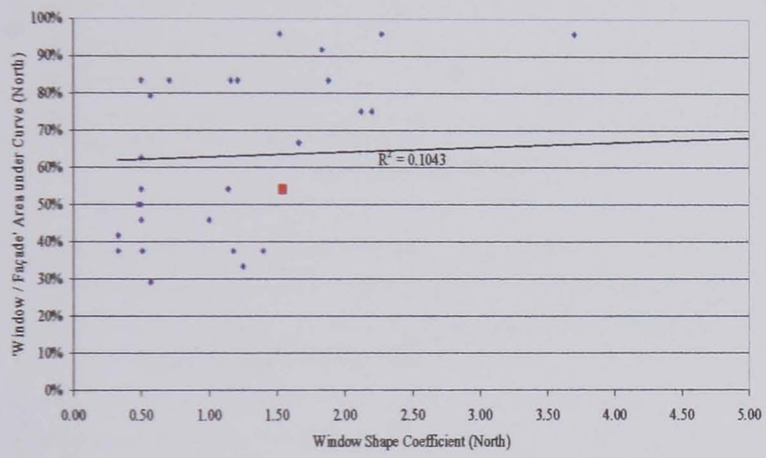
APII.2 'Window / Façade' Parametric Level

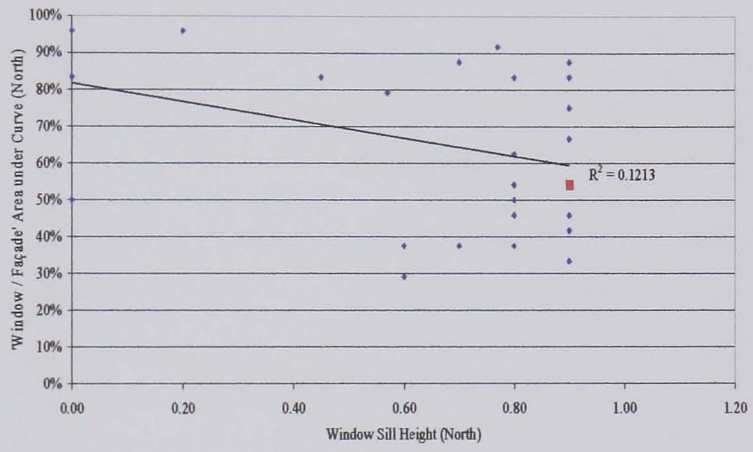
APII.2.1 North Orientation

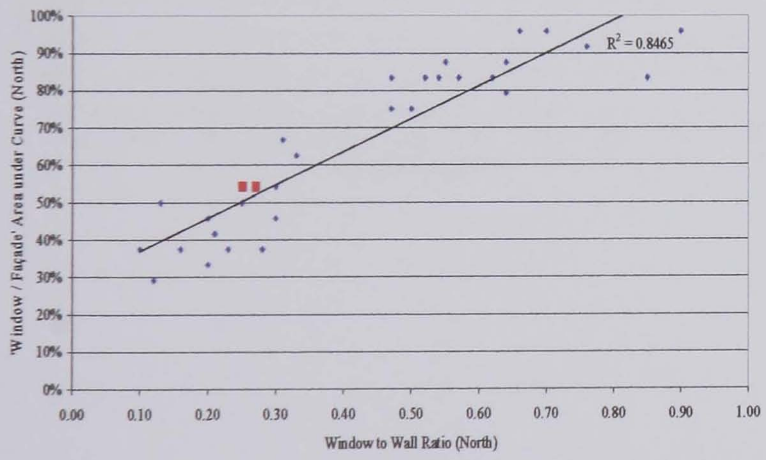
APII.2.1.1 *Correlation with 'Window / Façade' Area under Curve (North)*

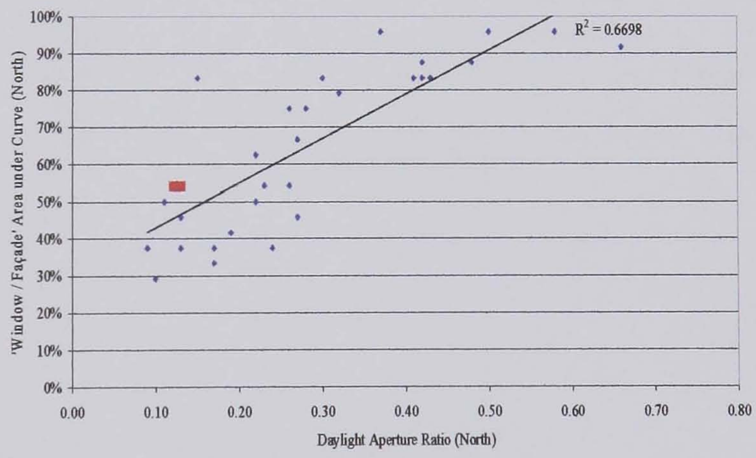




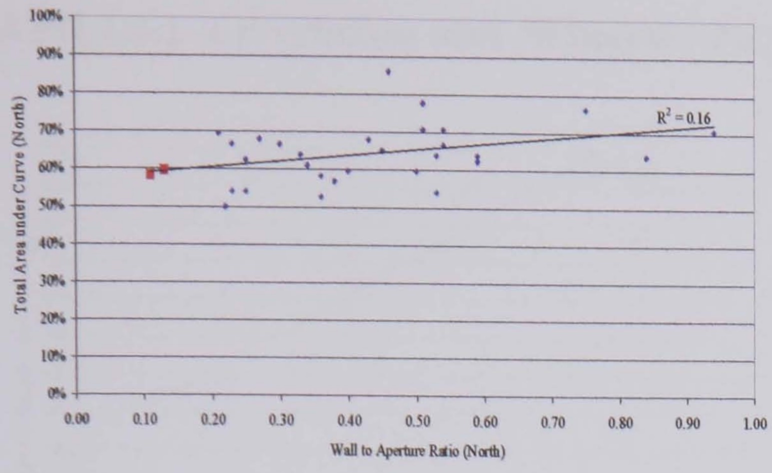


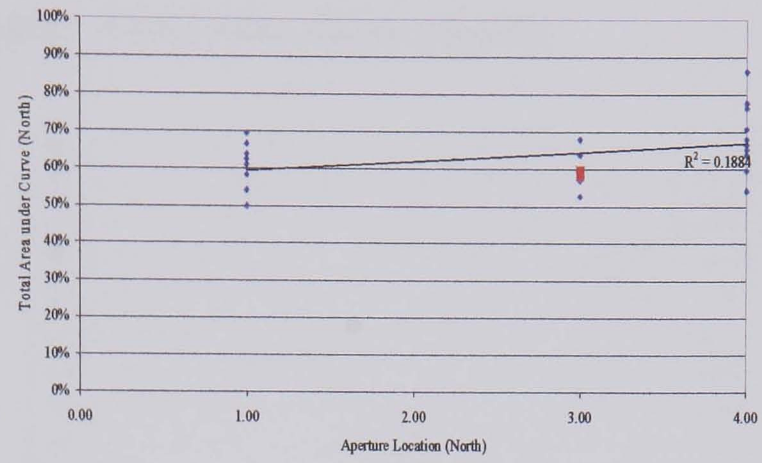


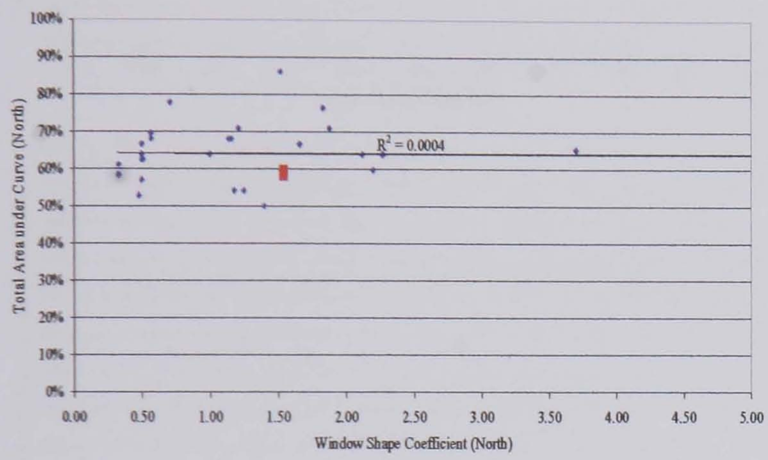


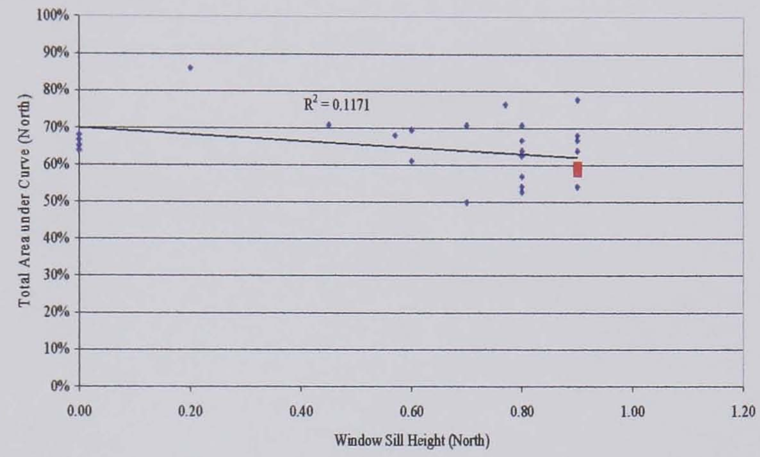


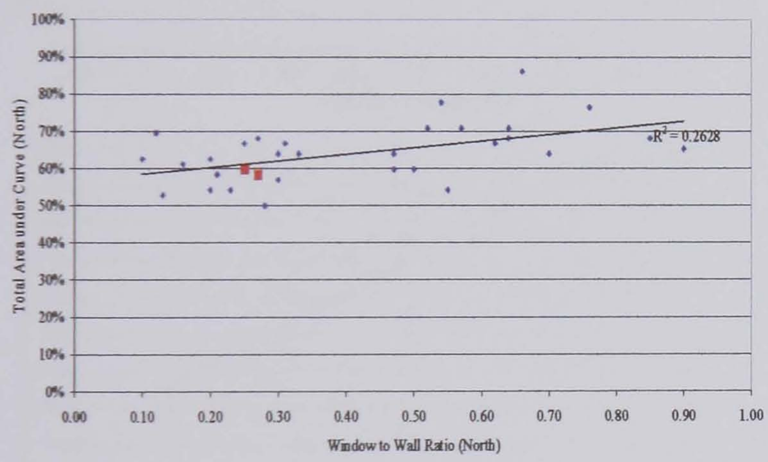
APII.2.1.2 *Correlation with Total Area under Curve (North)*

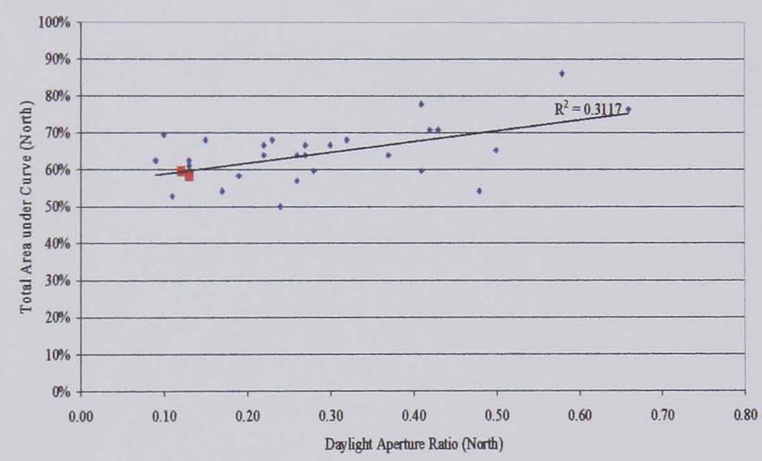






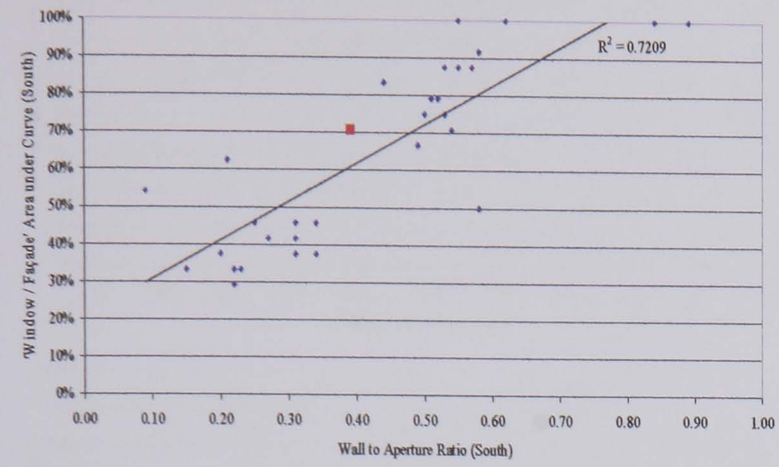


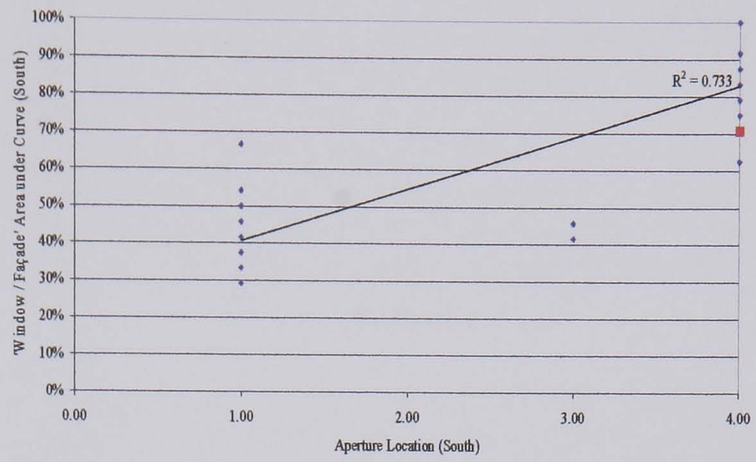


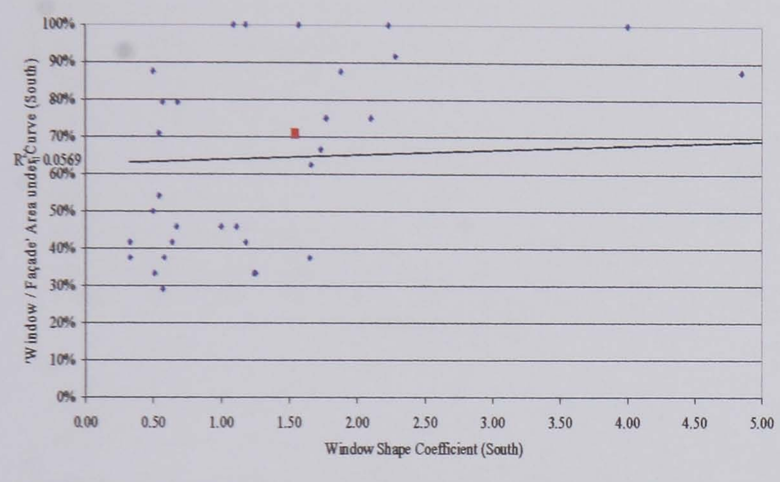


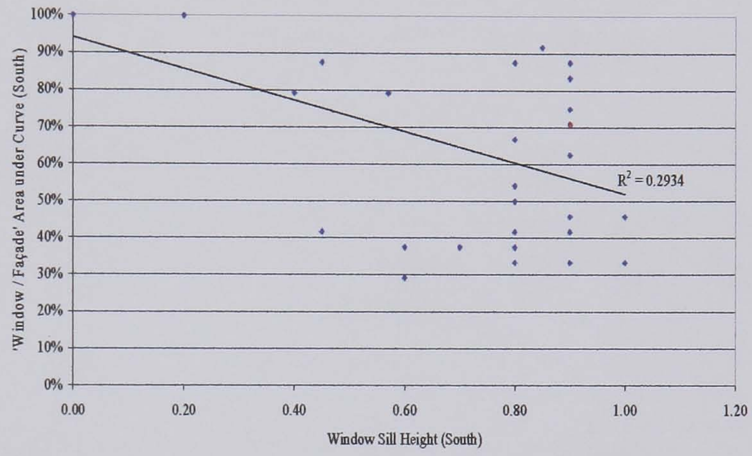
APII.2.2 South Orientation

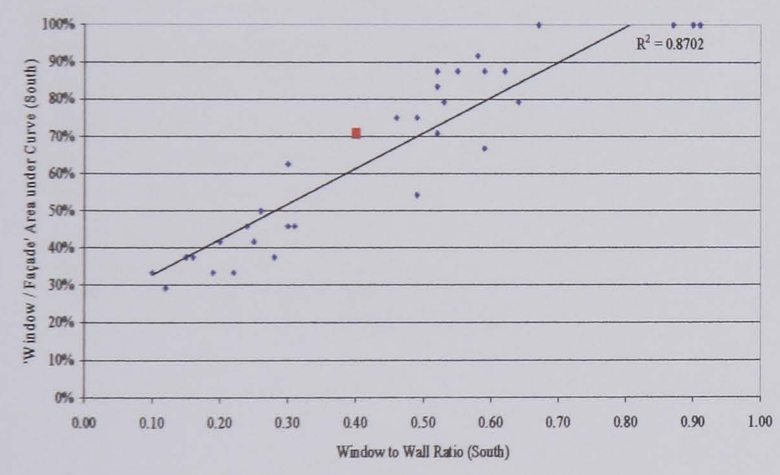
APII.2.2.1 *Correlation with 'Window / Façade' Area under Curve (South)*

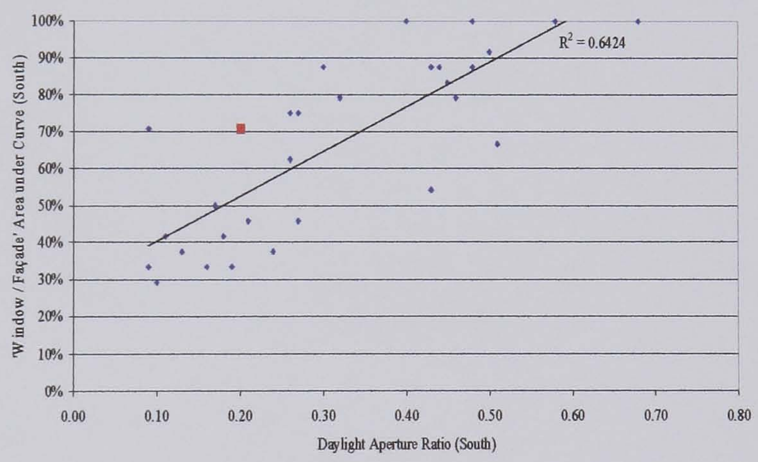




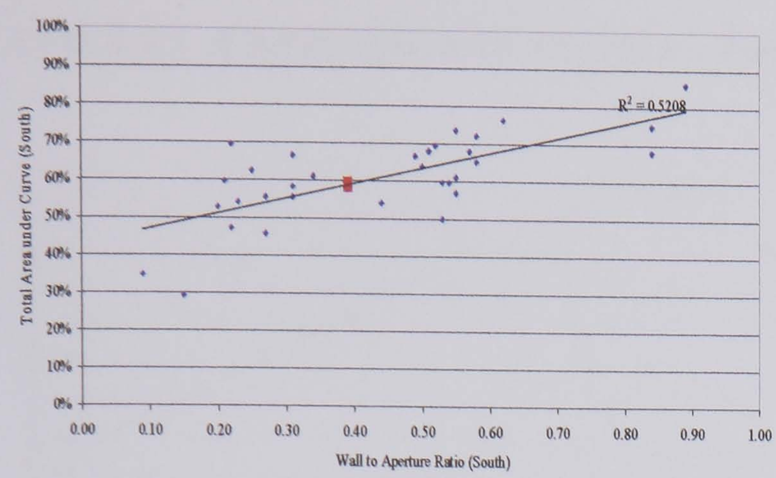


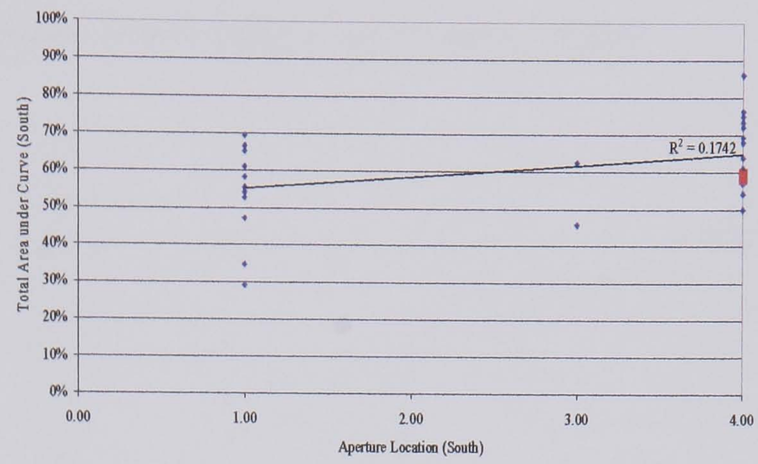


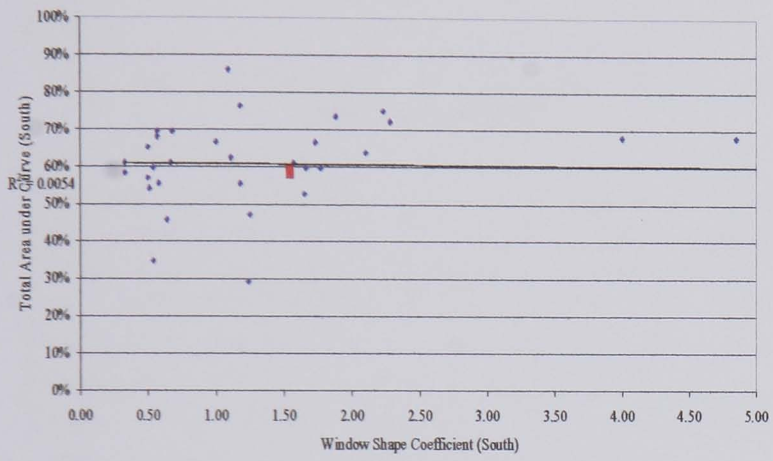


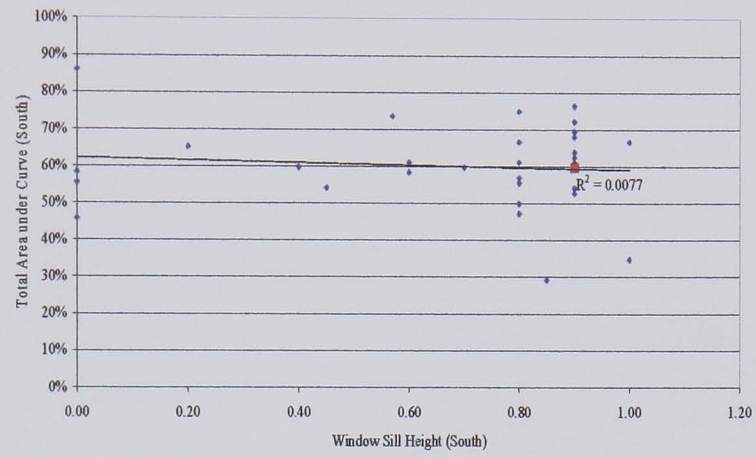


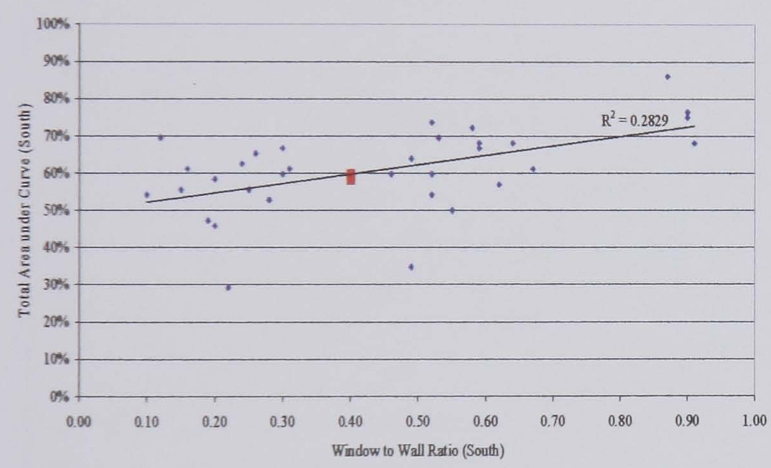
APII.2.2.2 *Correlation with Total Area under Curve (South)*

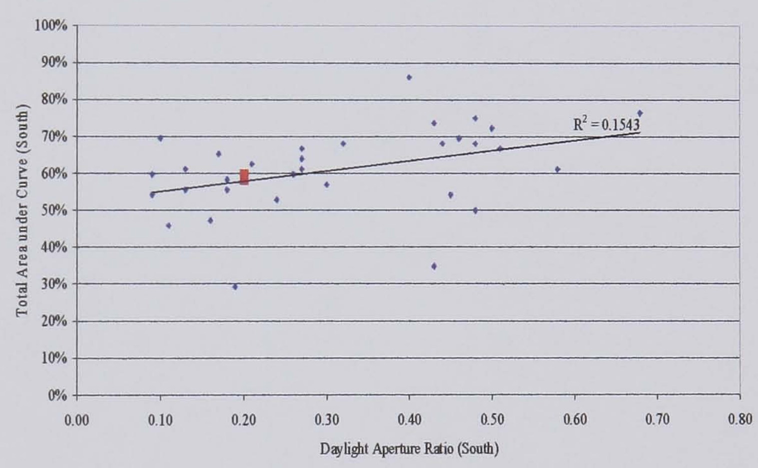






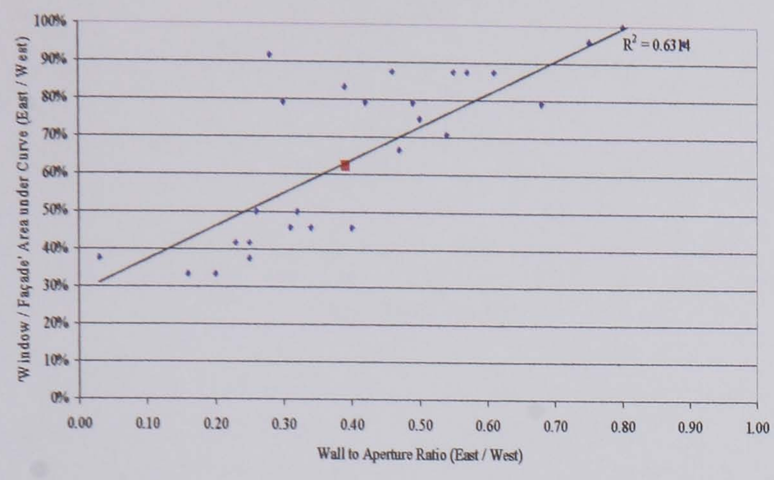


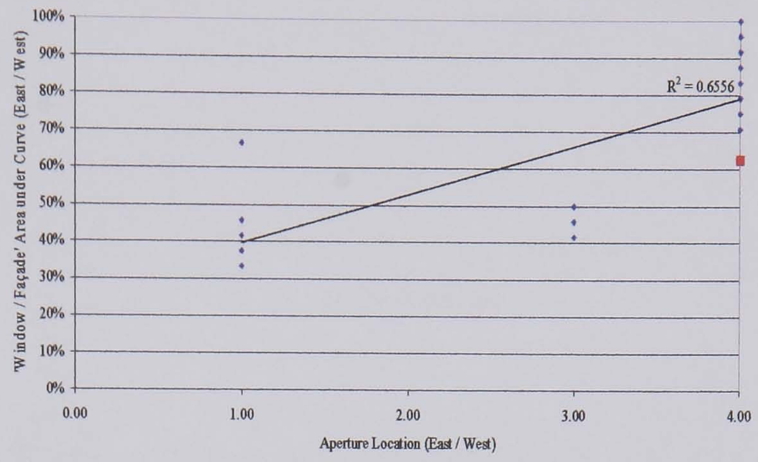


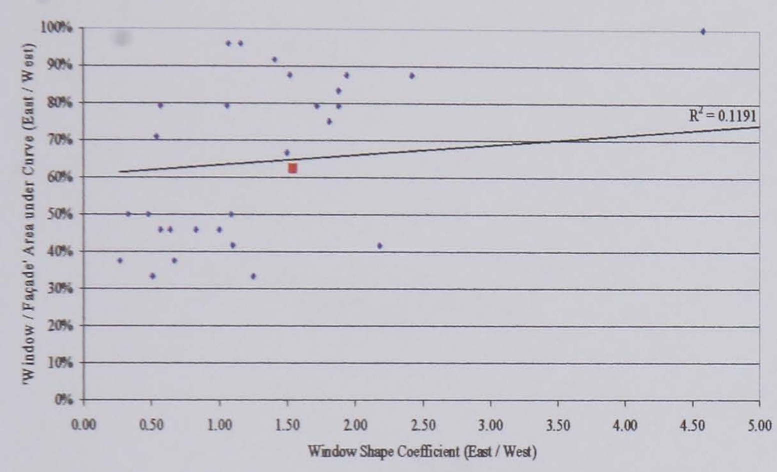


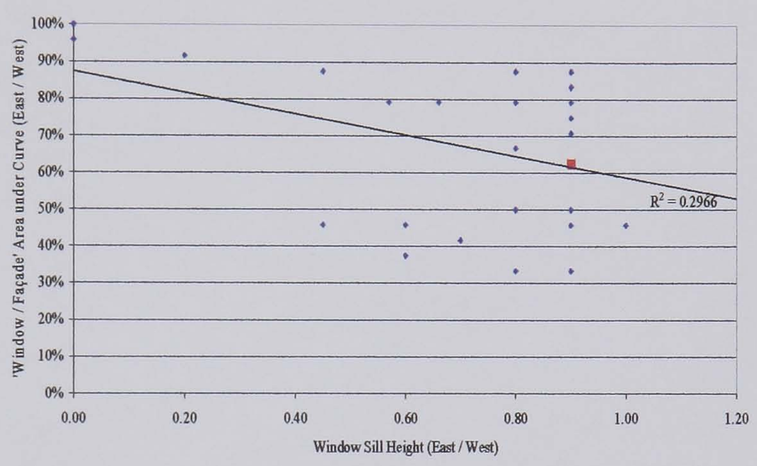
APII.2.3 East / West Orientation

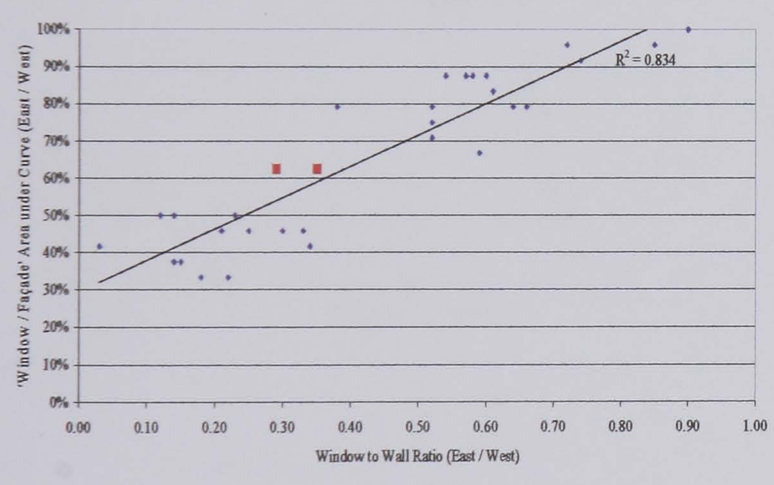
APII.2.3.1 *Correlation with 'Window / Façade' Area under Curve (East / West)*

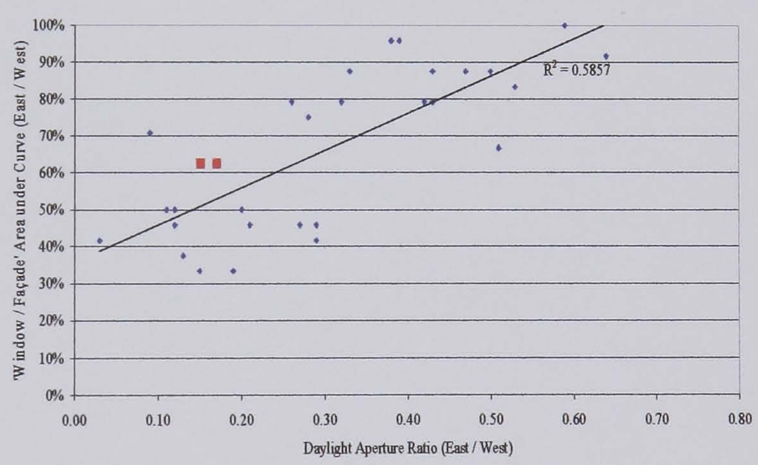




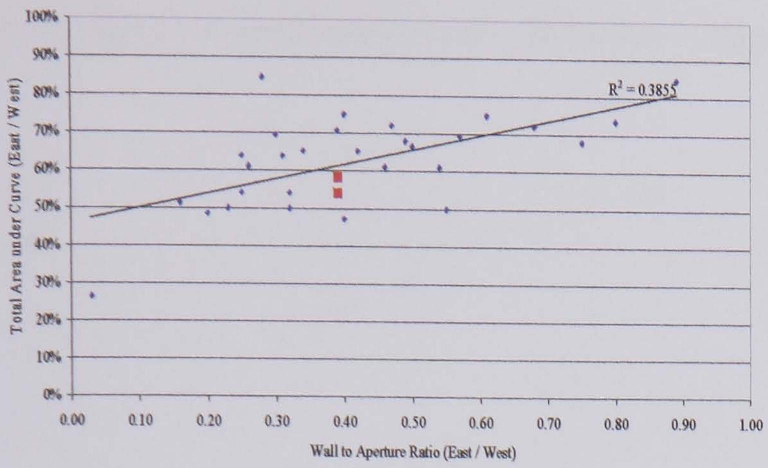


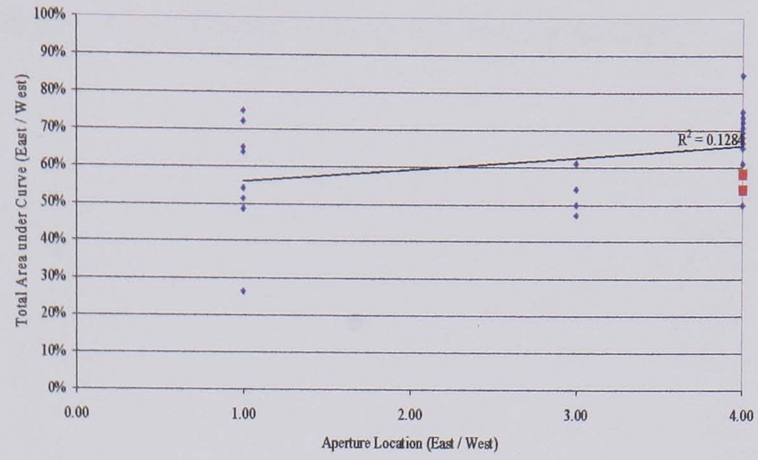


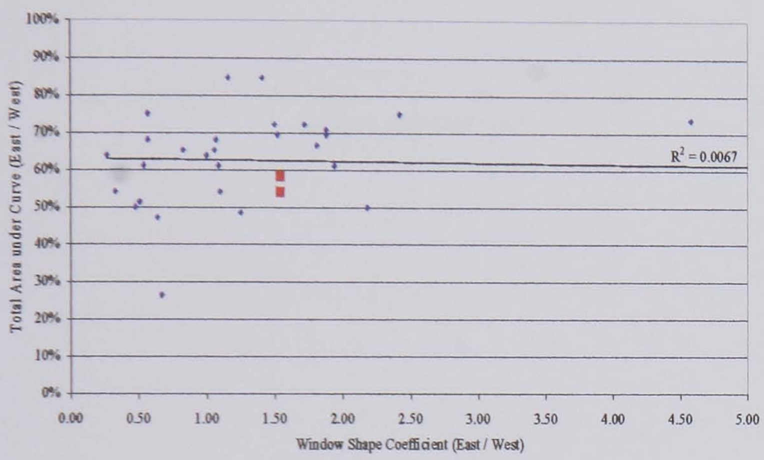


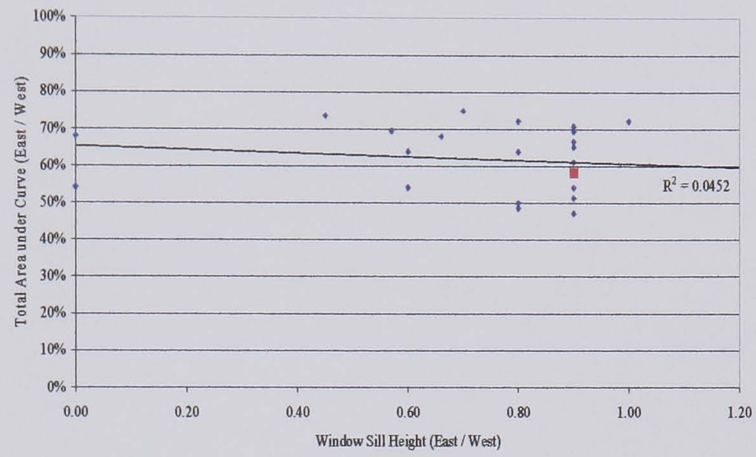


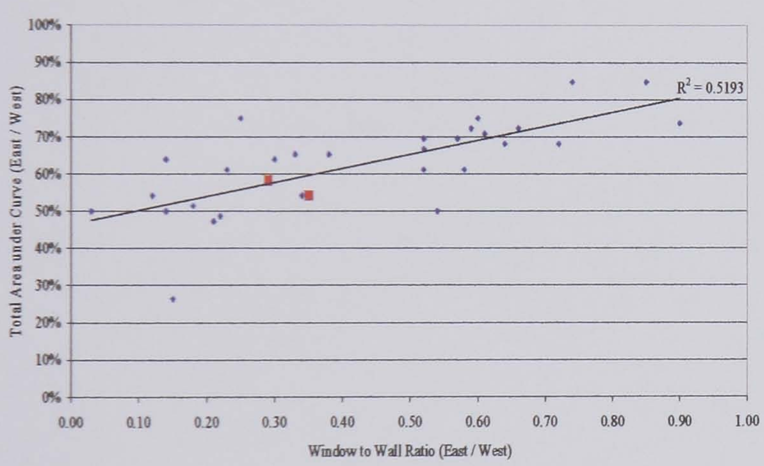
APII.2.3.2 *Correlation with Total Area under Curve (East / West)*

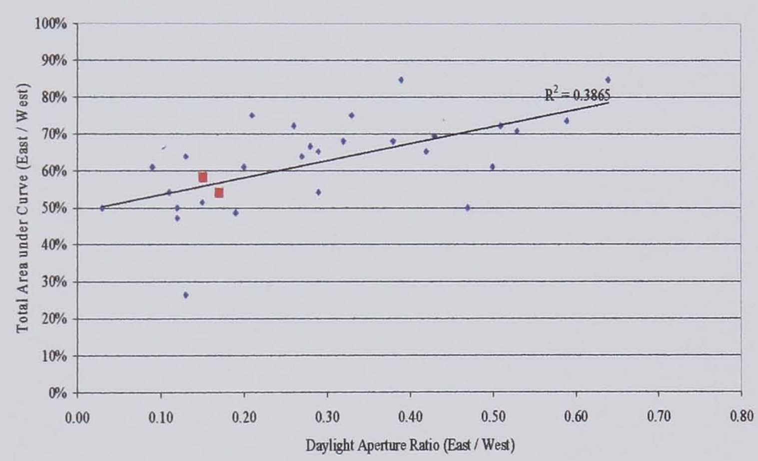






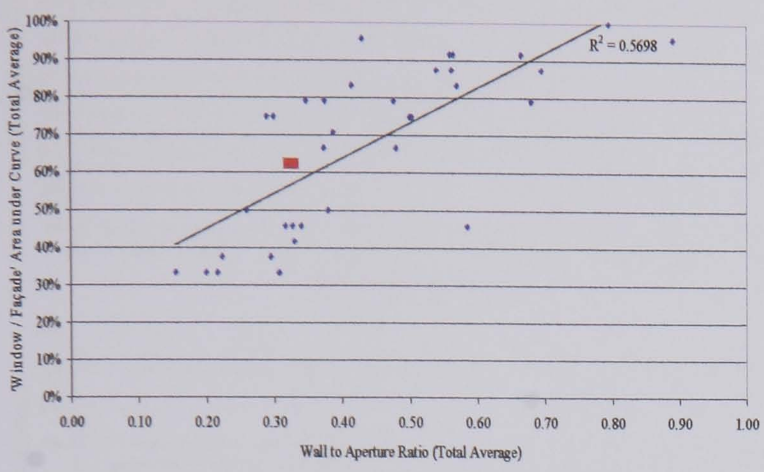


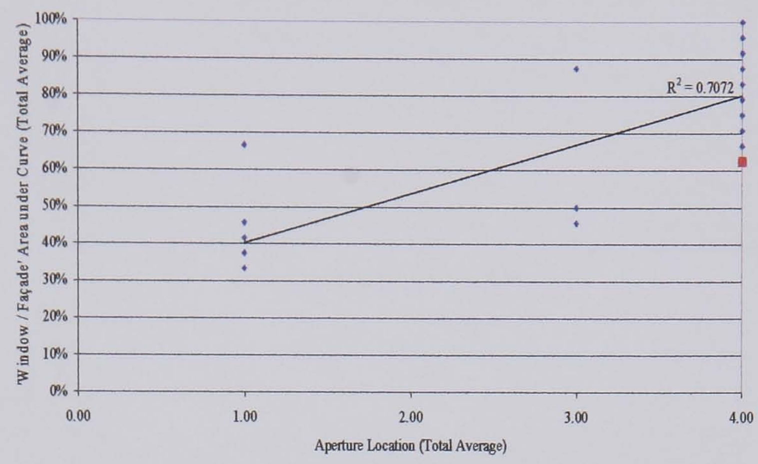


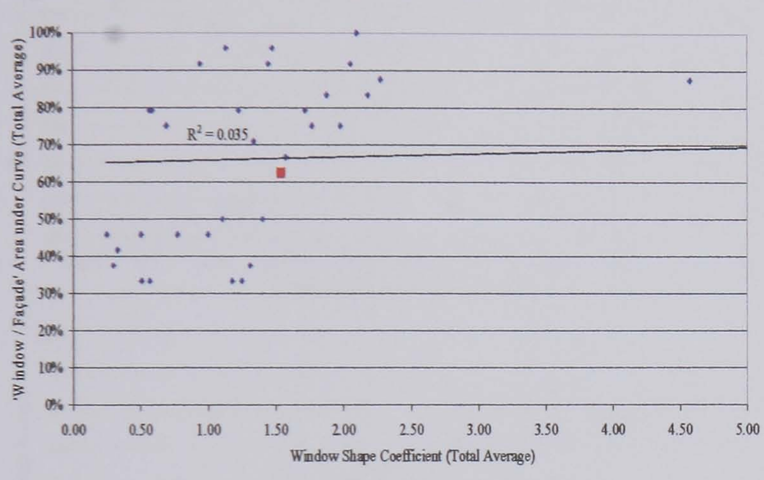


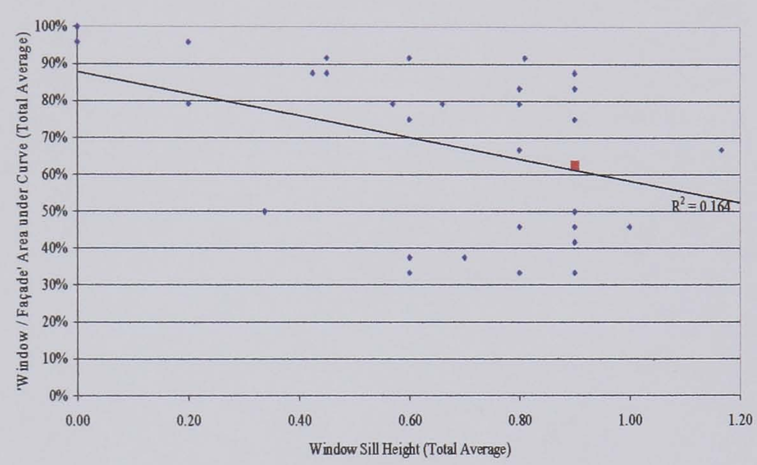
APII.2.4 Total Building Average

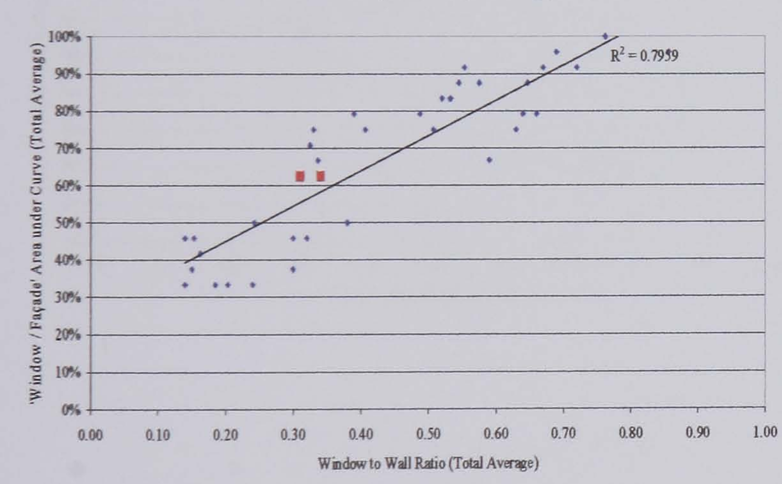
APII.2.4.1 *Correlation with 'Window / Façade' Area under Curve (Total Average)*

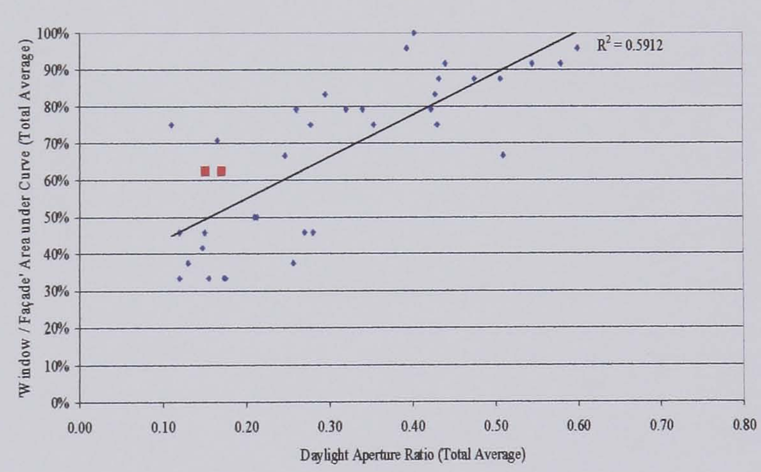




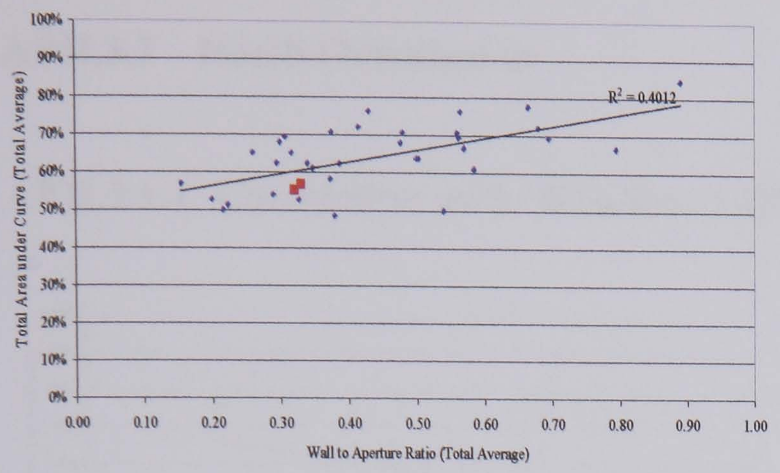


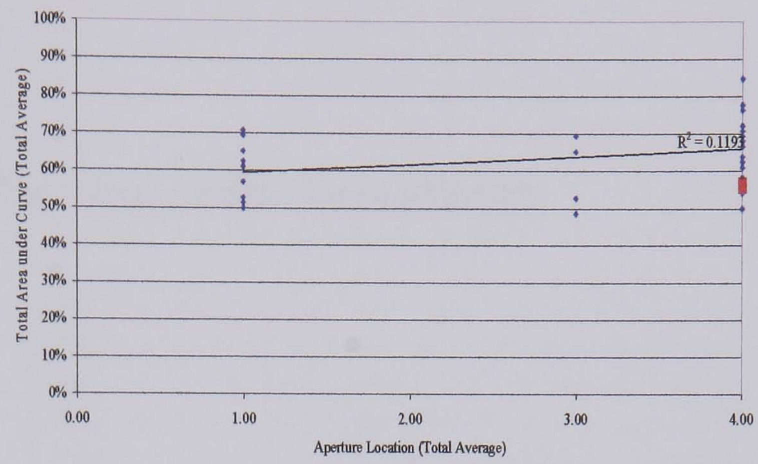


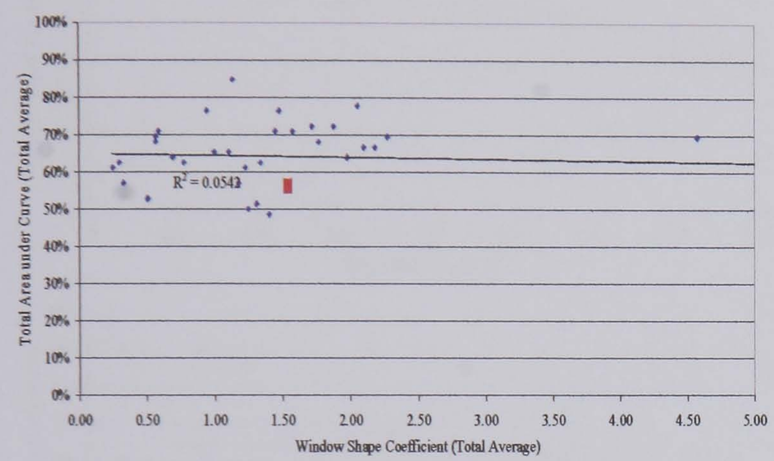


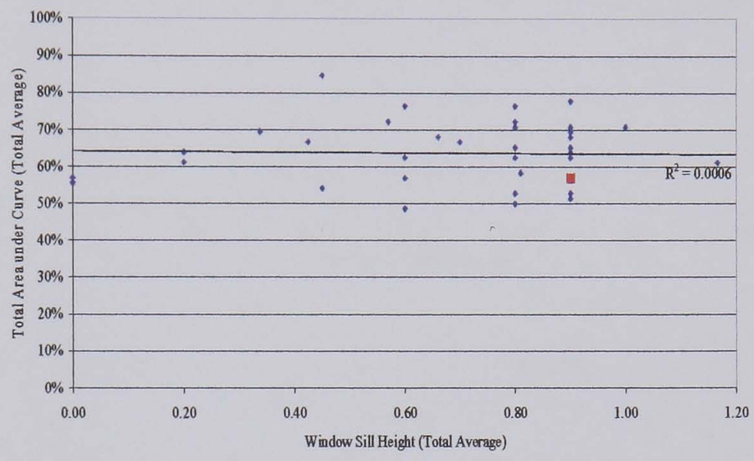


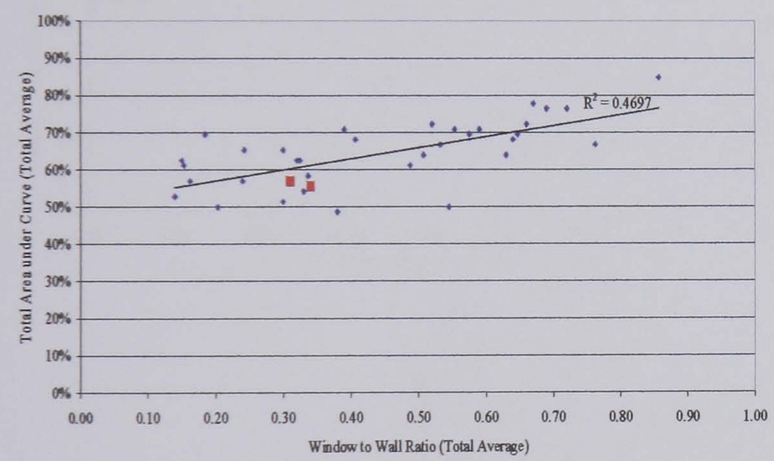
APII.2.4.2 *Correlation with Total Area under Curve (Total Average)*

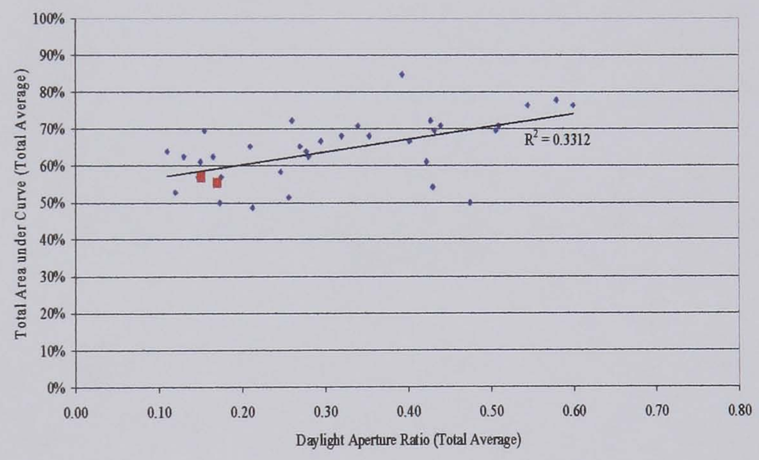








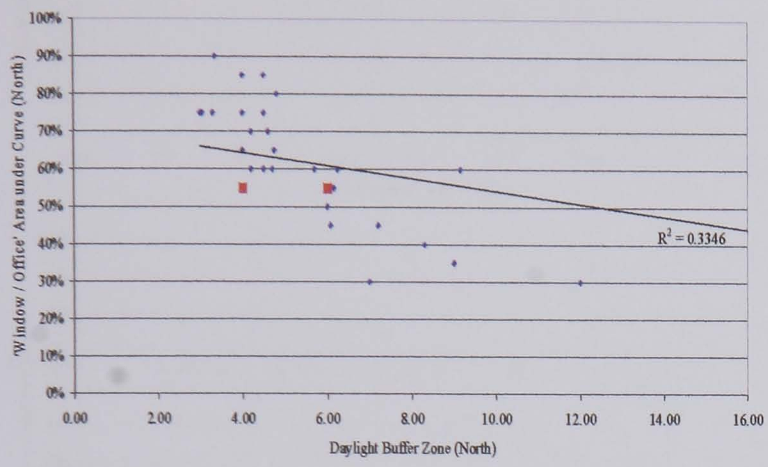


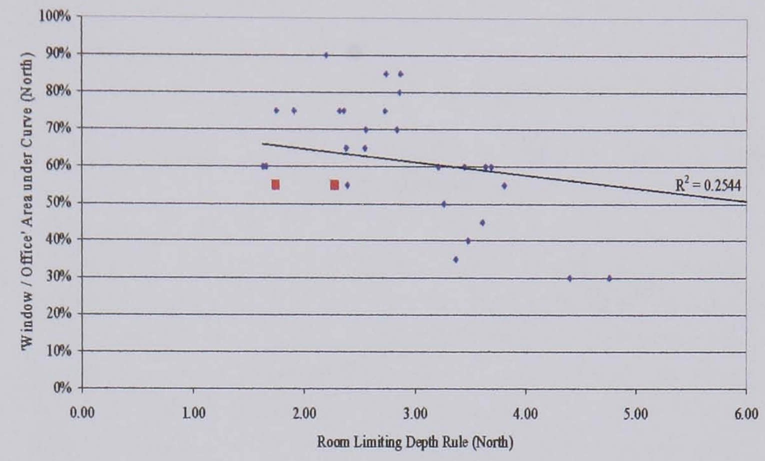


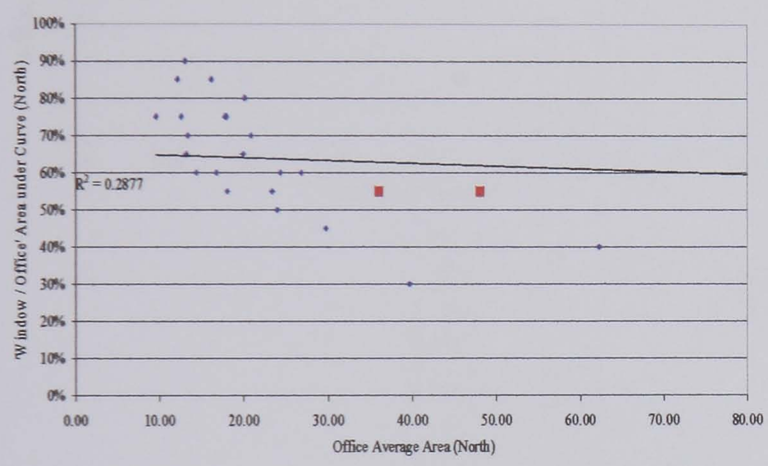
APII.3 'Window / Office' Parametric Level

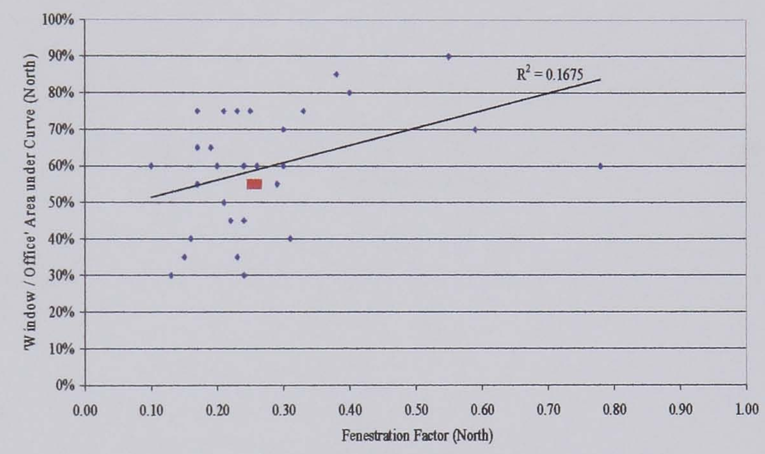
APII.3.1 North Orientation

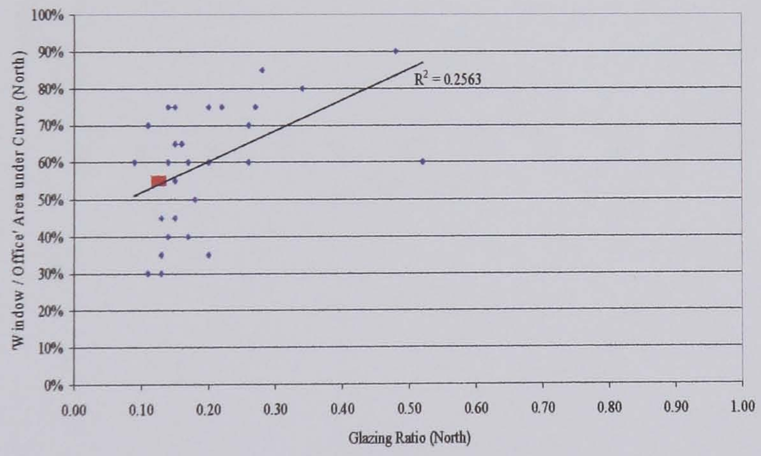
APII.3.1.1 *Correlation with 'Window / Office' Area under Curve (North)*



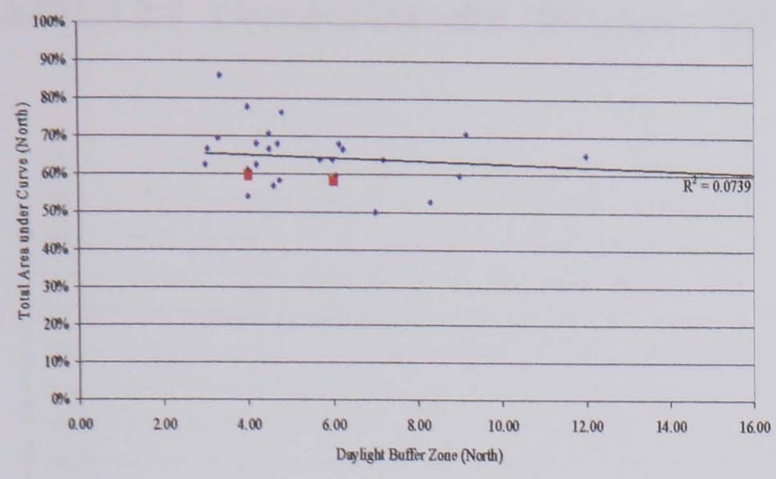


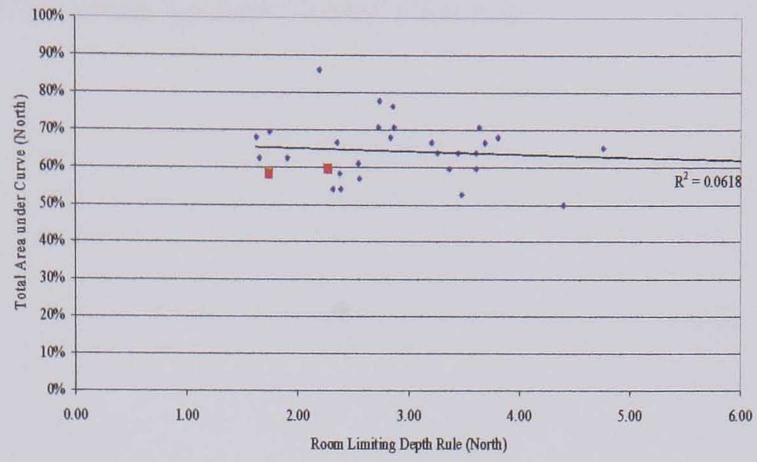


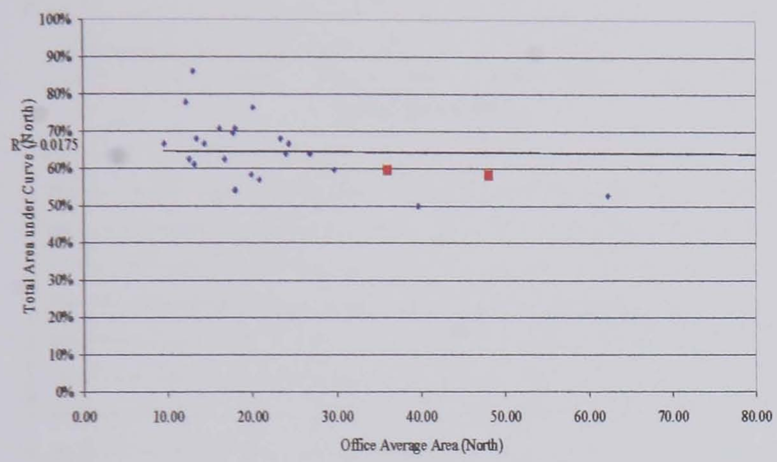


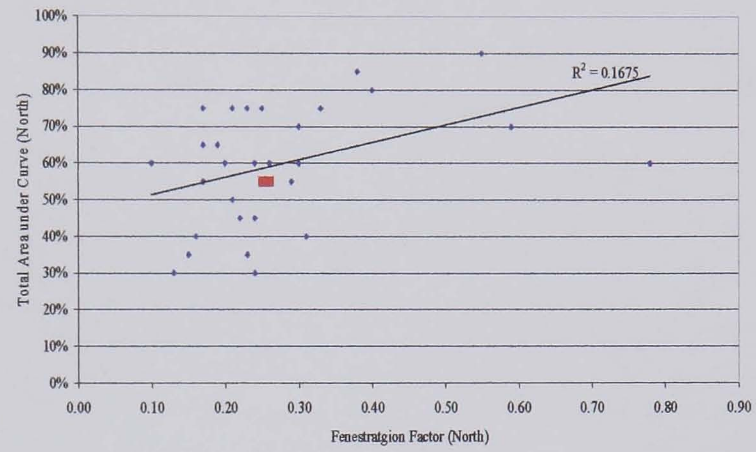


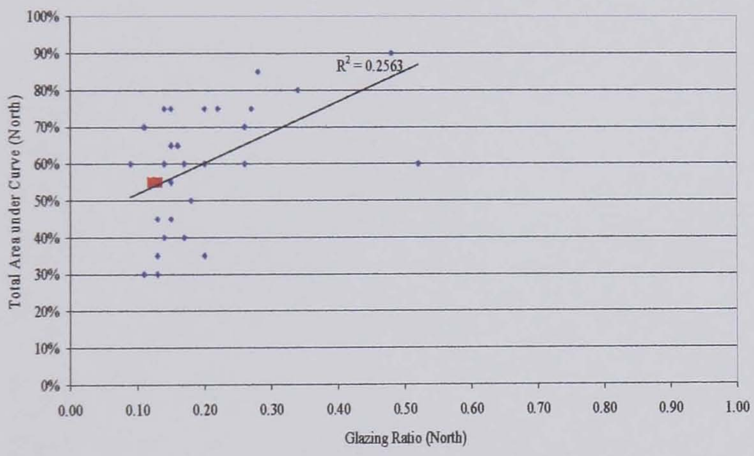
APII.3.1.2 *Correlation with Total Area under Curve (North)*





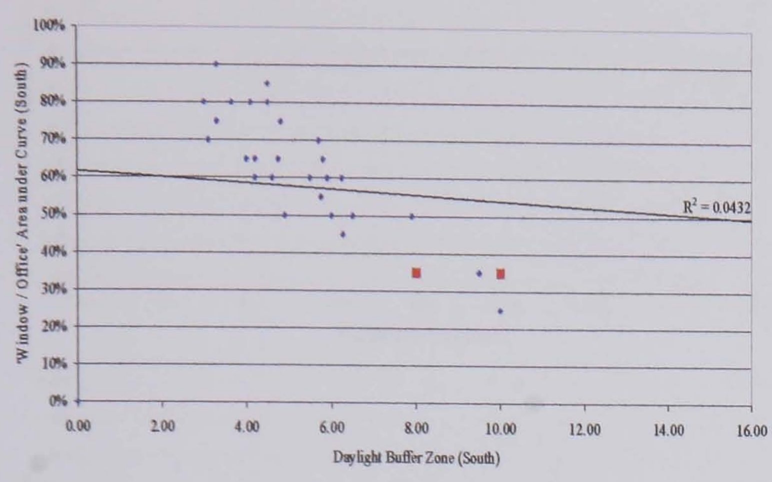


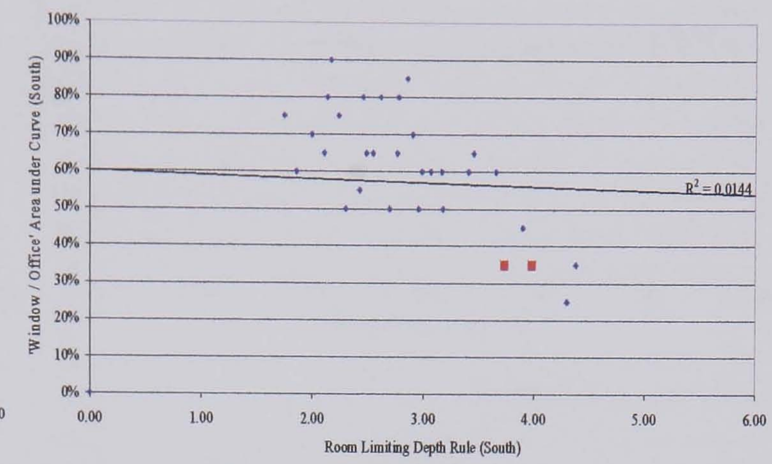


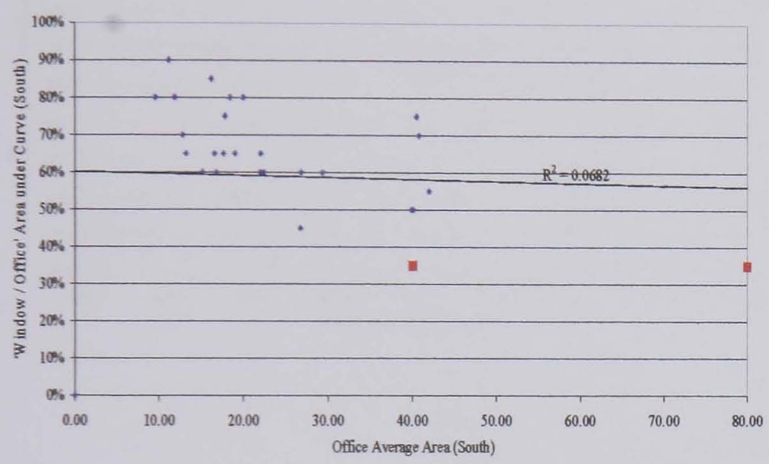


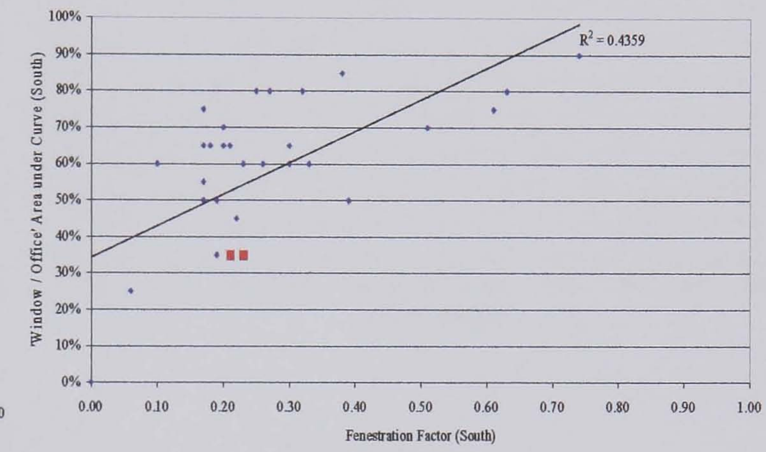
APII.3.2 South Orientation

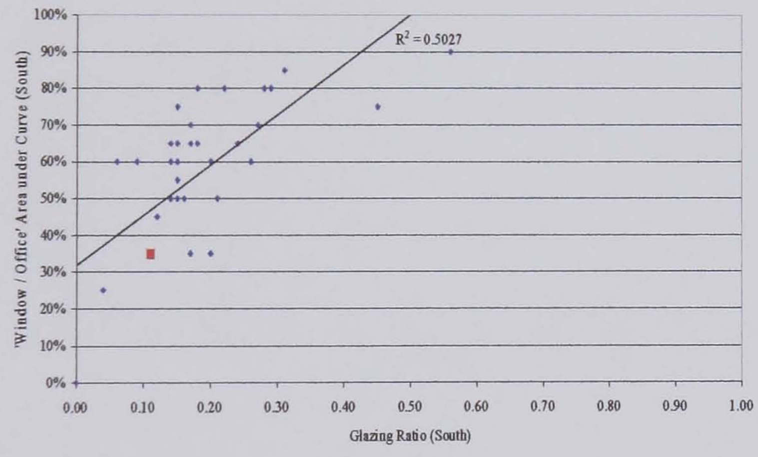
APII.3.2.1 *Correlation with 'Window / Office' Area under Curve (South)*



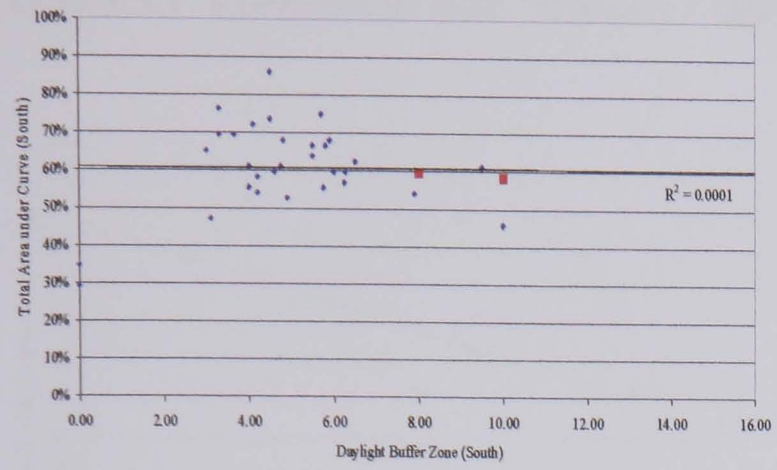


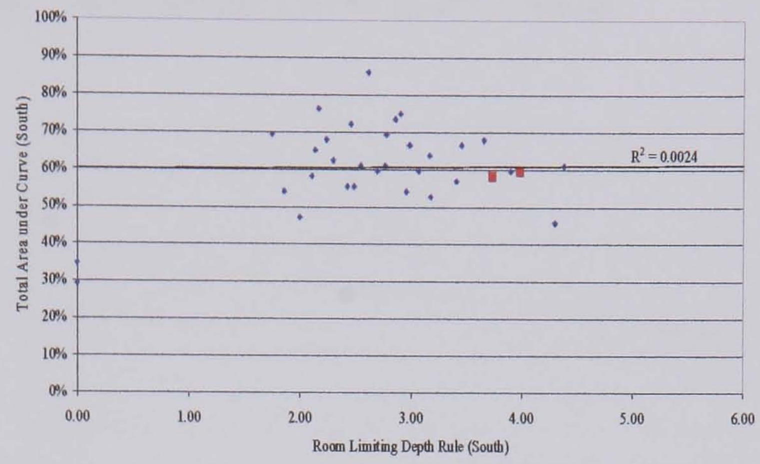


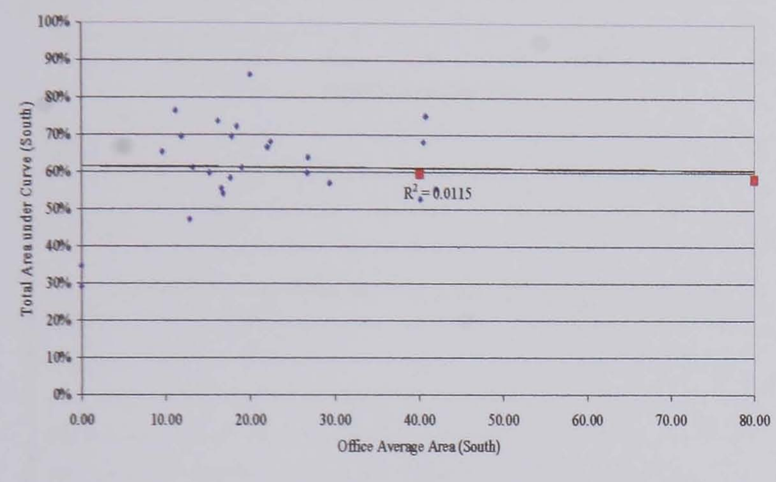


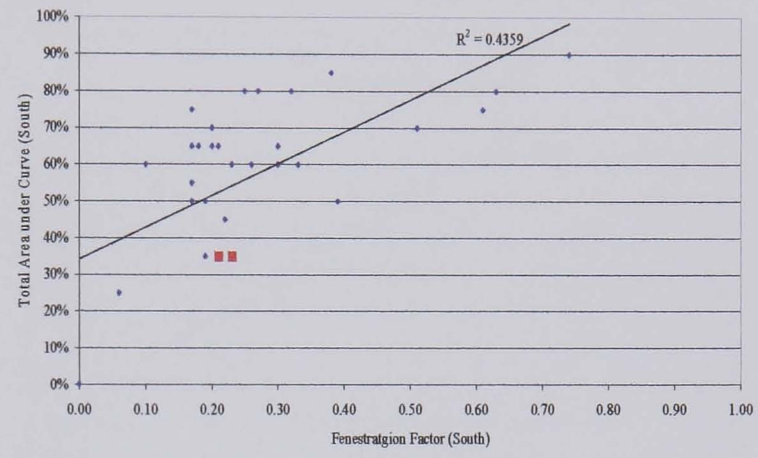


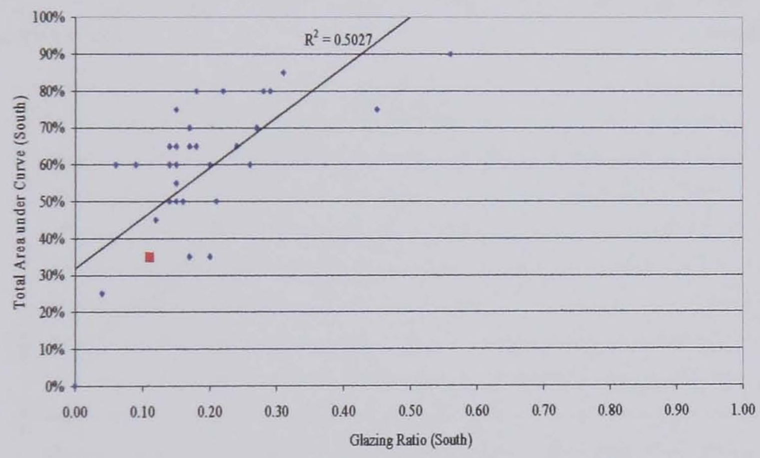
APII.3.2.2 *Correlation with Total Area under Curve (South)*





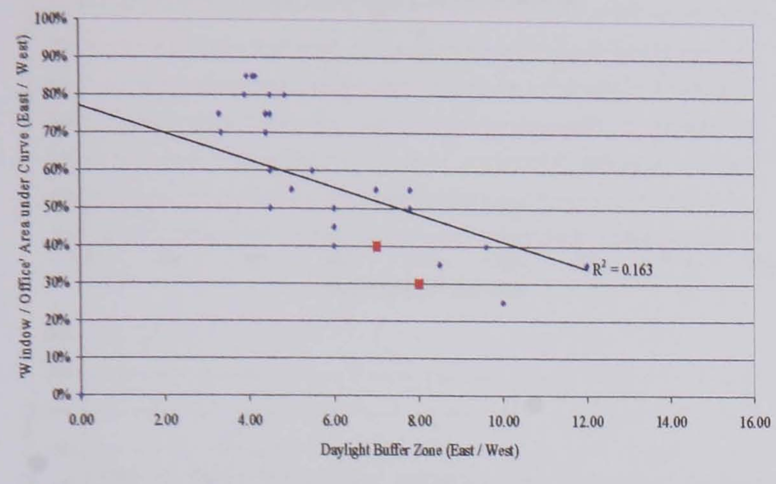


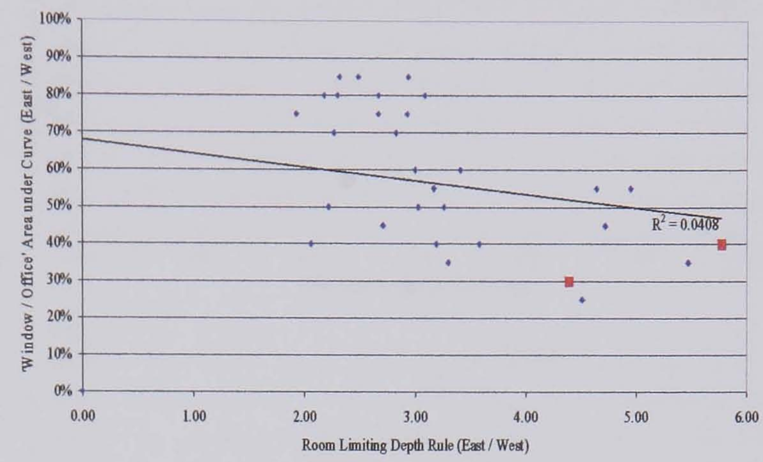


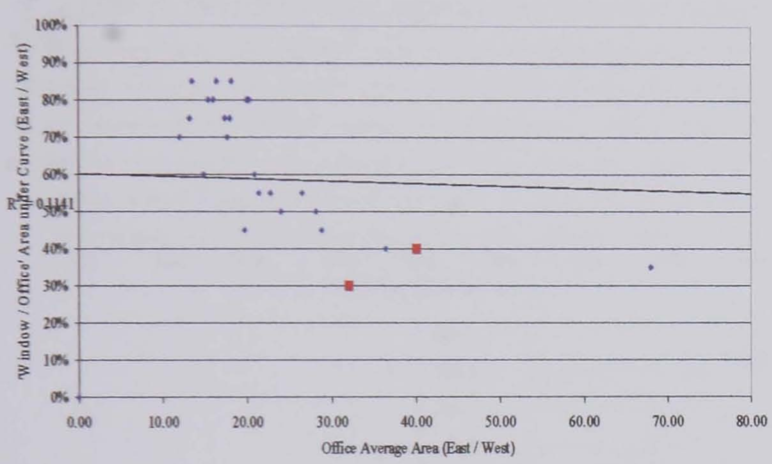


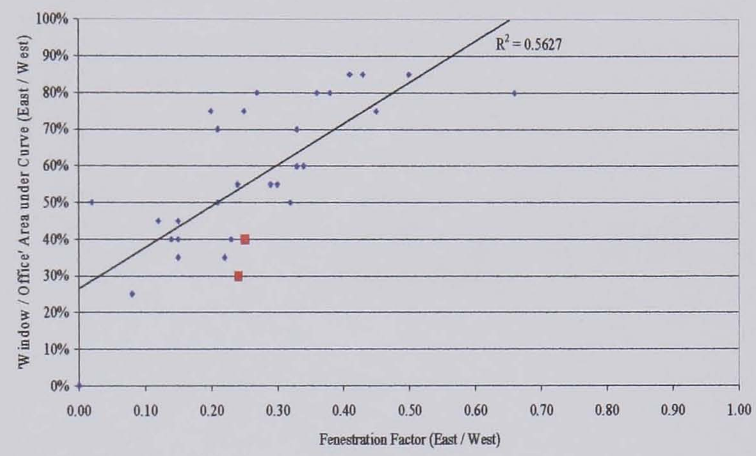
APII.3.3 East / West Orientation

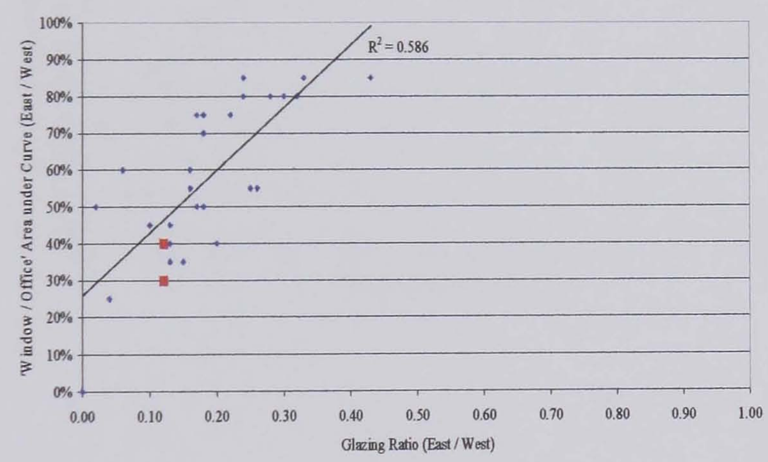
APII.3.3.1 *Correlation with 'Window / Office' Area under Curve (East / West)*



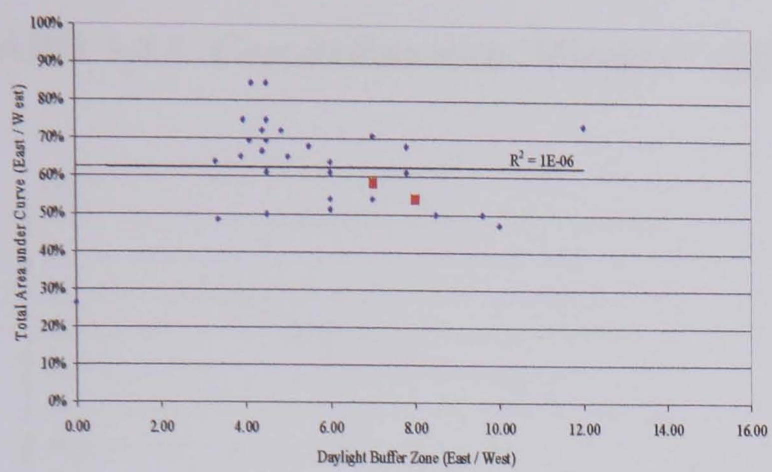


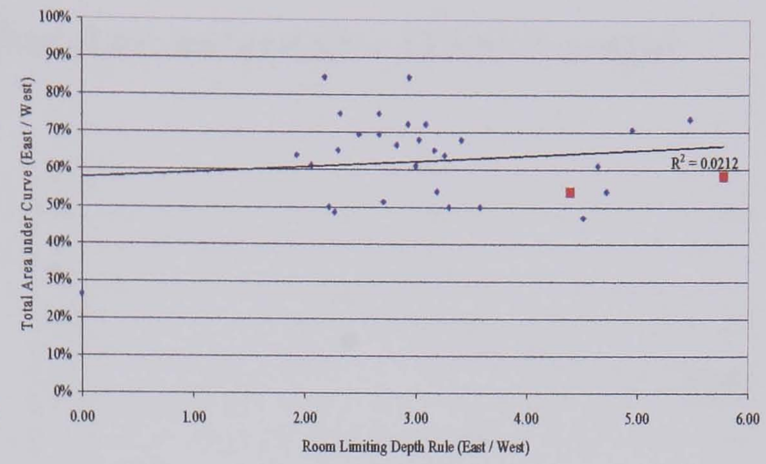


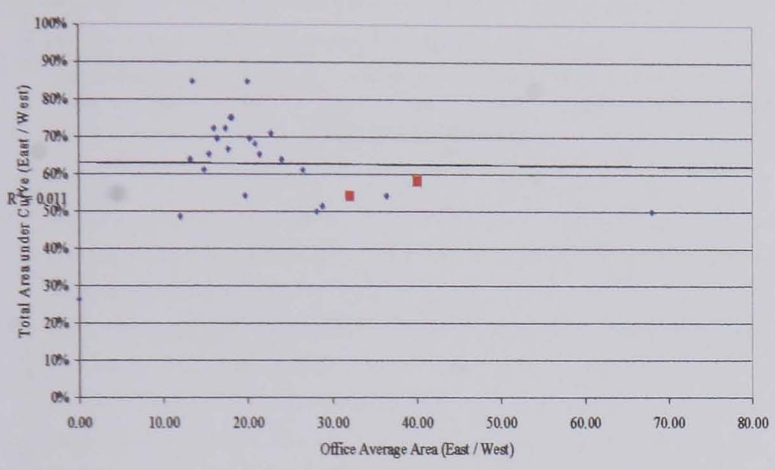


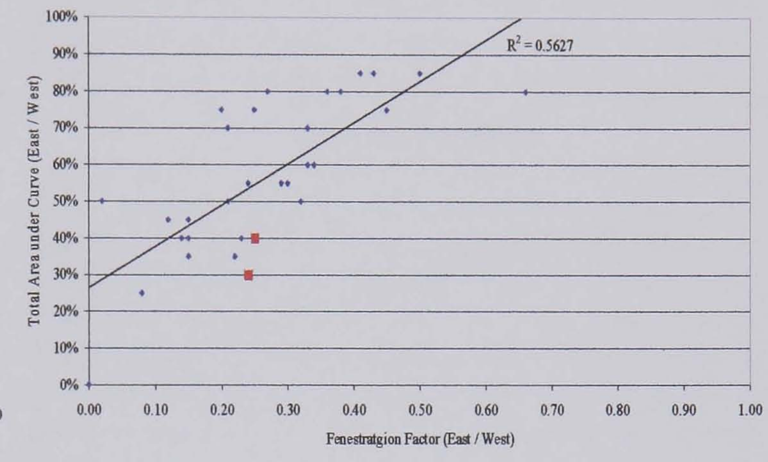


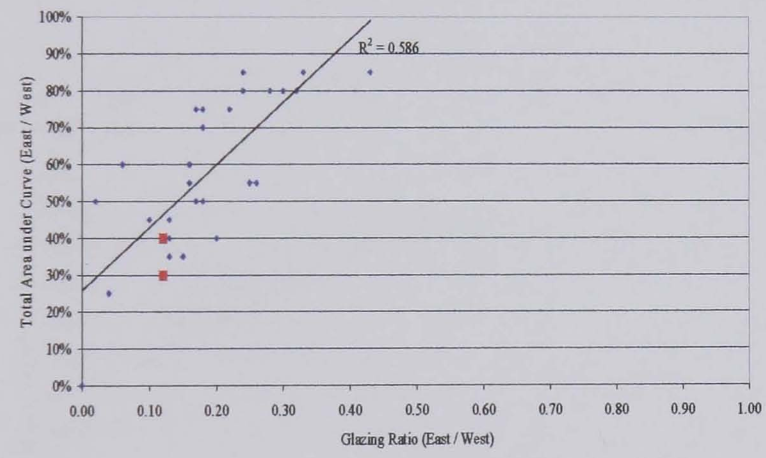
APII.3.3.2 *Correlation with Total Area under Curve (East / West)*





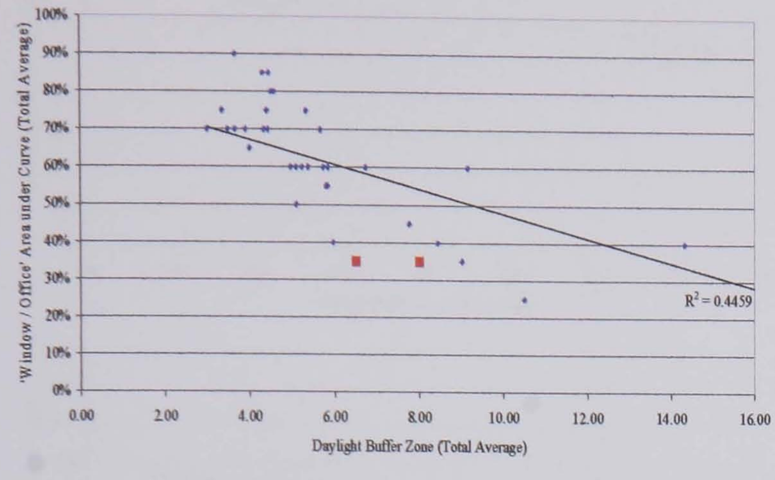


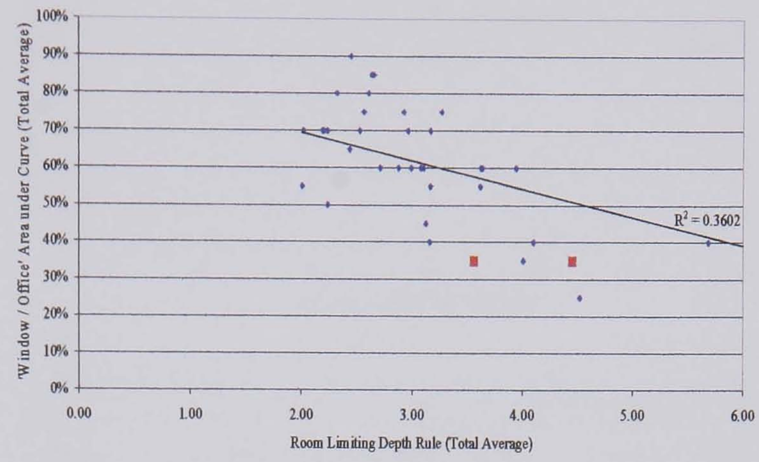


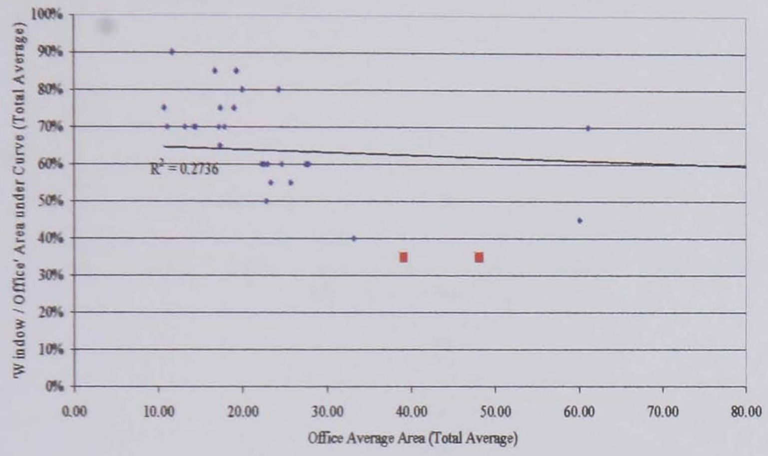


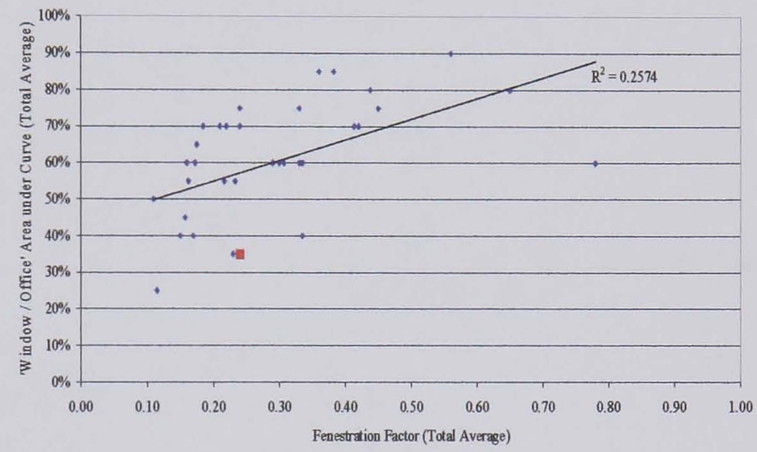
APII.3.4 Total Building Average

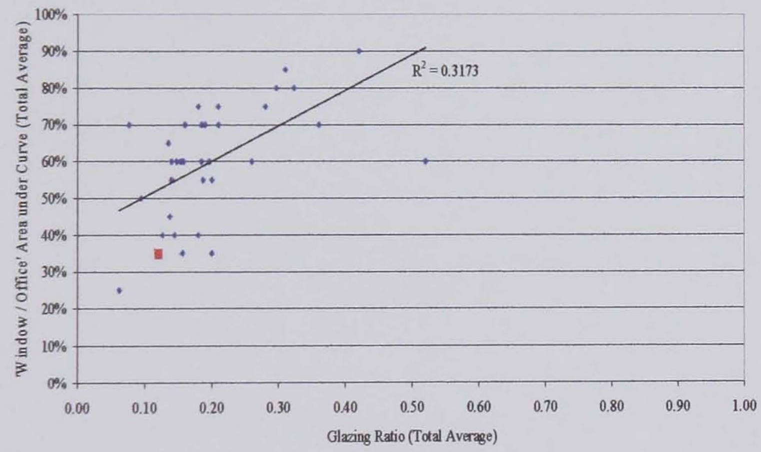
APII.3.4.1 *Correlation with 'Window / Office' Area under Curve (Total Average)*



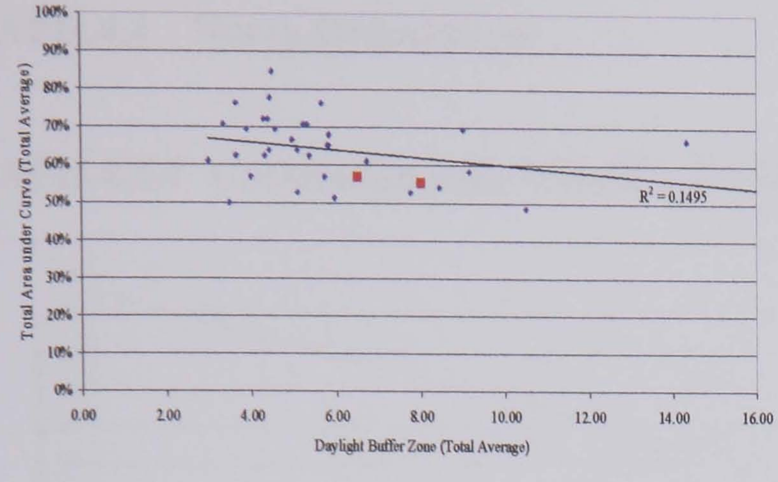


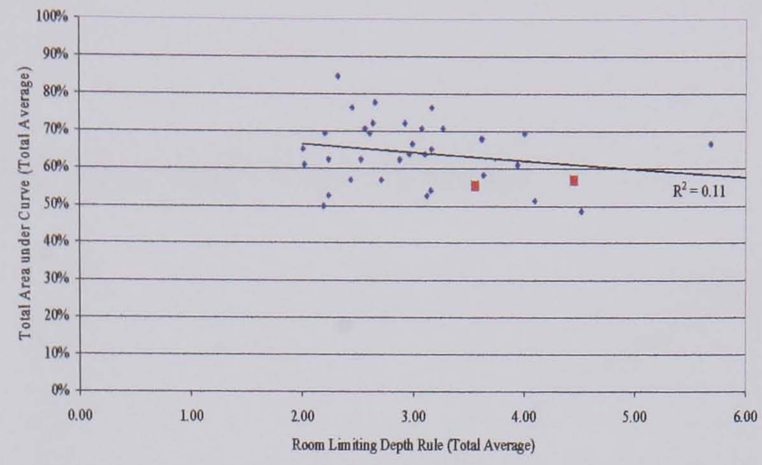


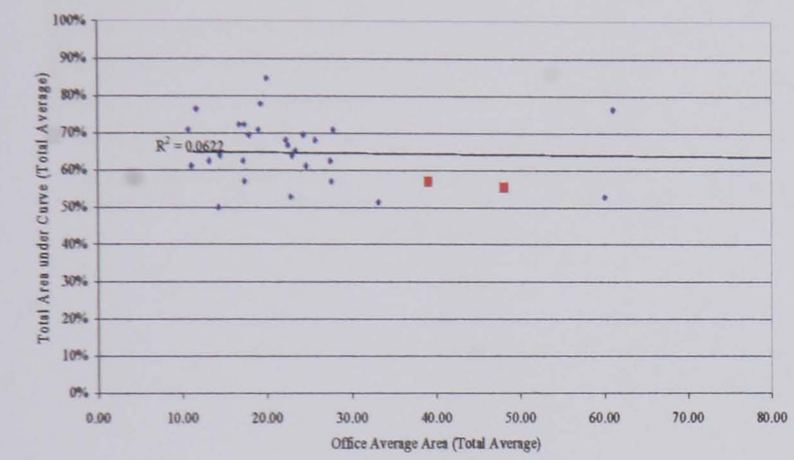


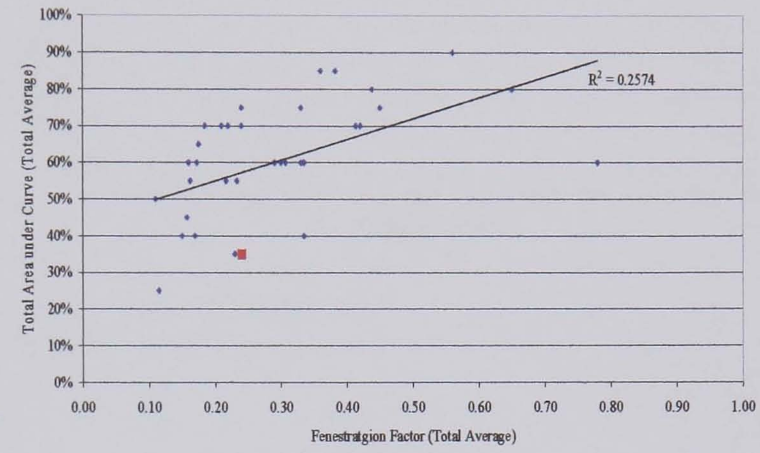


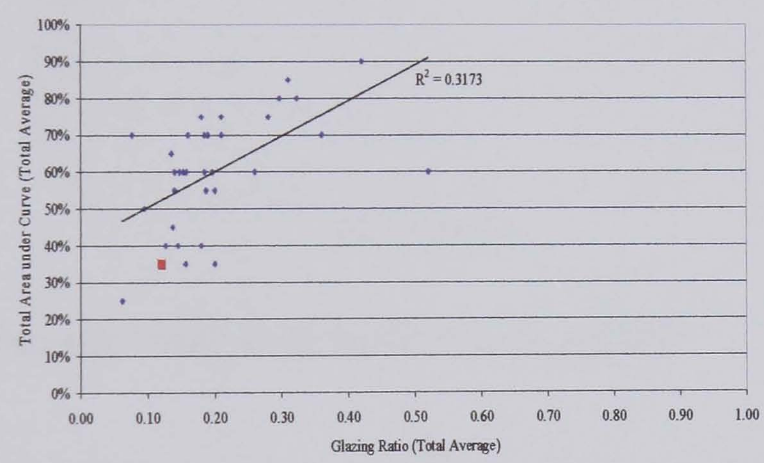
APII.3.4.2 *Correlation with Total Area under Curve (Total Average)*







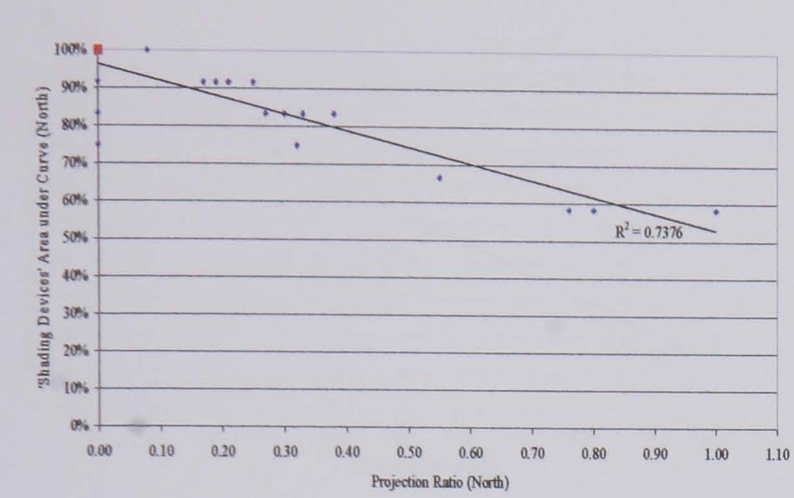


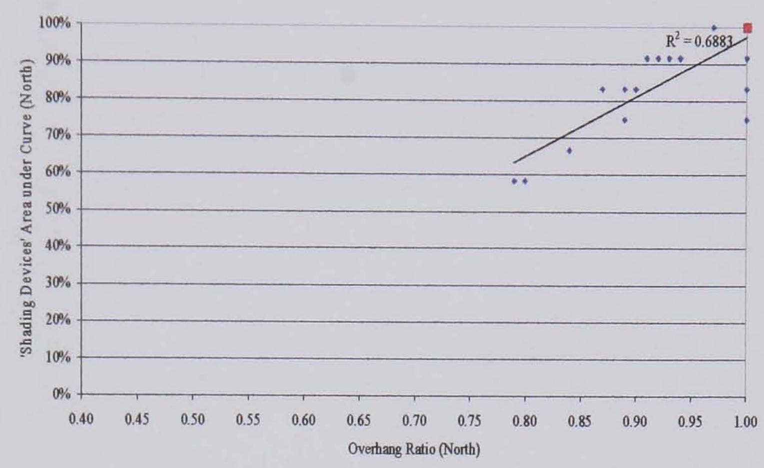


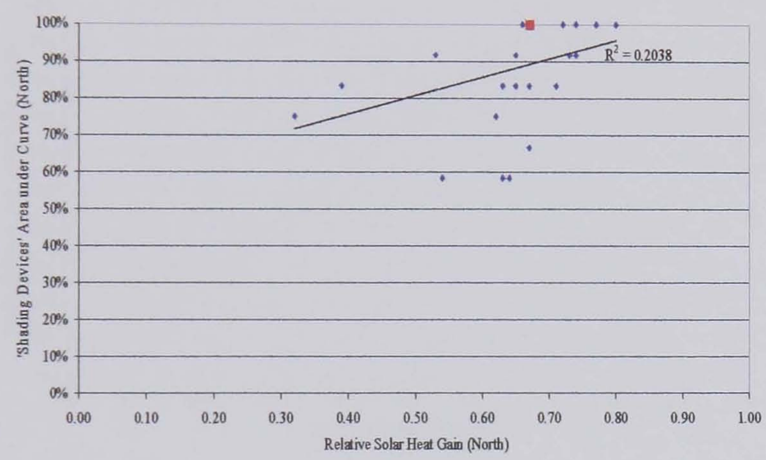
APII.4 'Shading Devices' Parametric Level

APII.4.1 North Orientation

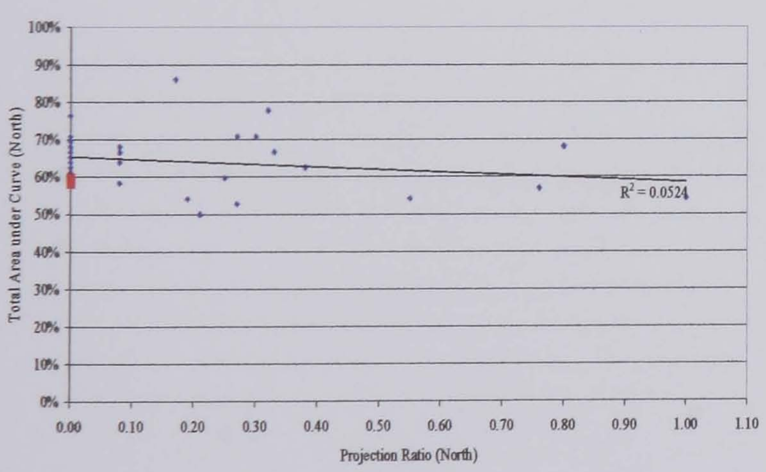
APII.4.1.1 *Correlation with 'Shading Devices' Area under Curve (North)*

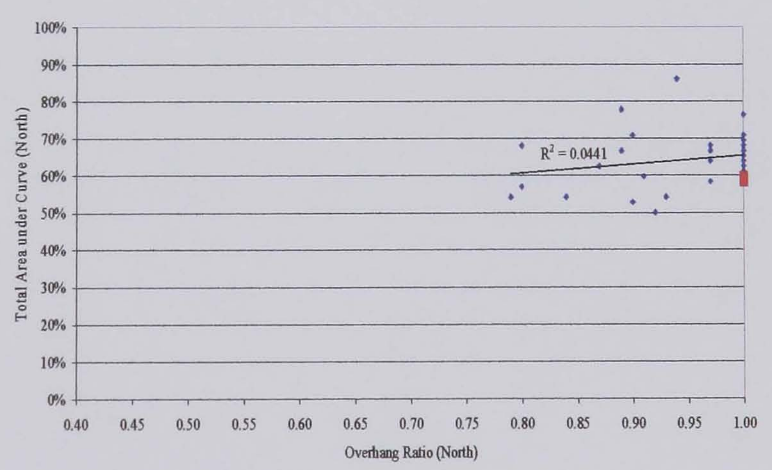


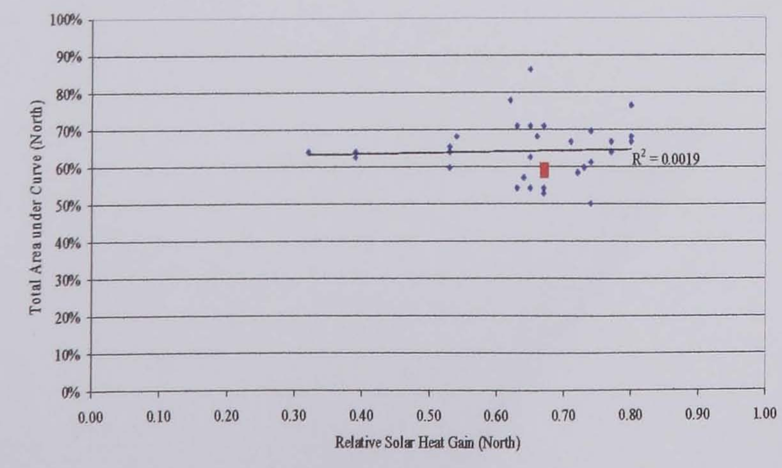




APII.4.1.2 *Correlation with Total Area under Curve (North)*

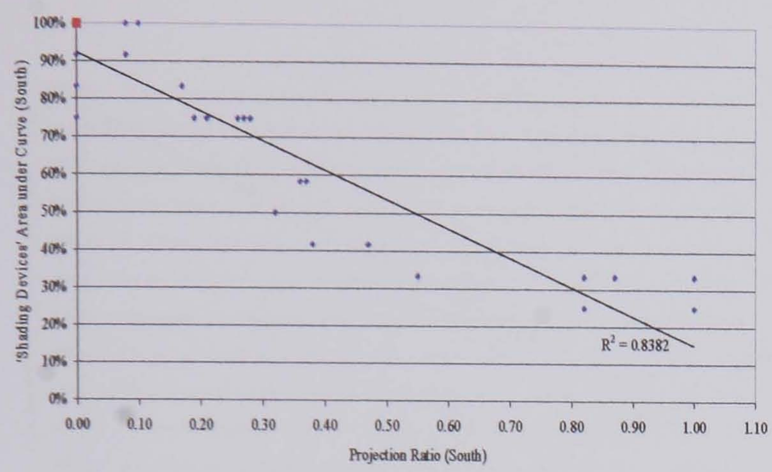


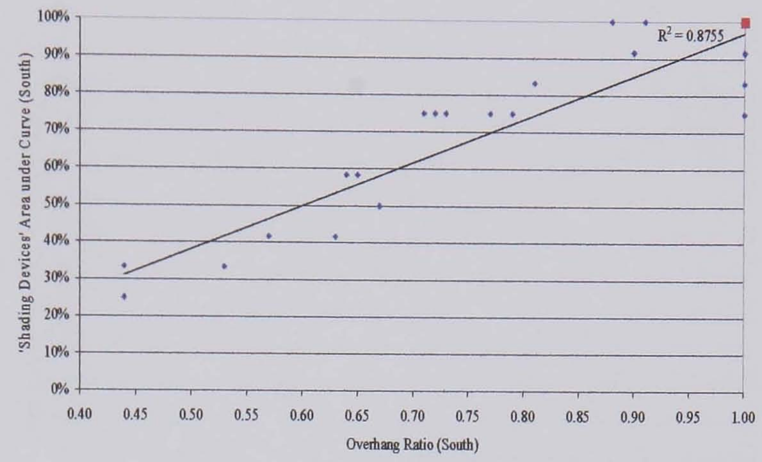


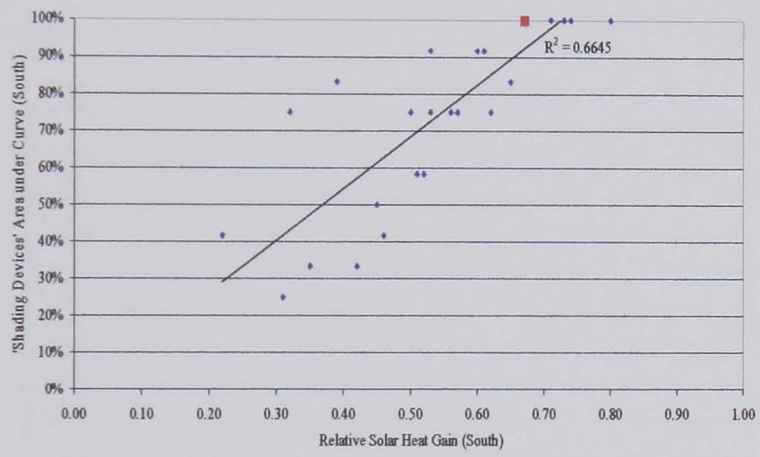


APII.4.2 South Orientation

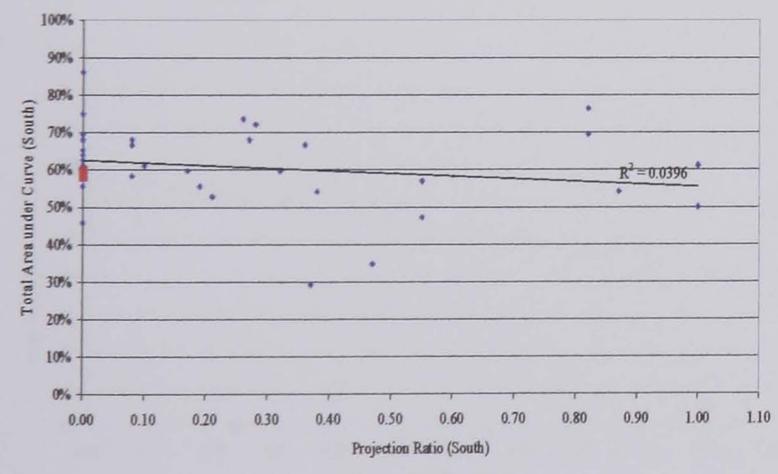
APII.4.2.1 *Correlation with 'Shading Devices' Area under Curve (South)*

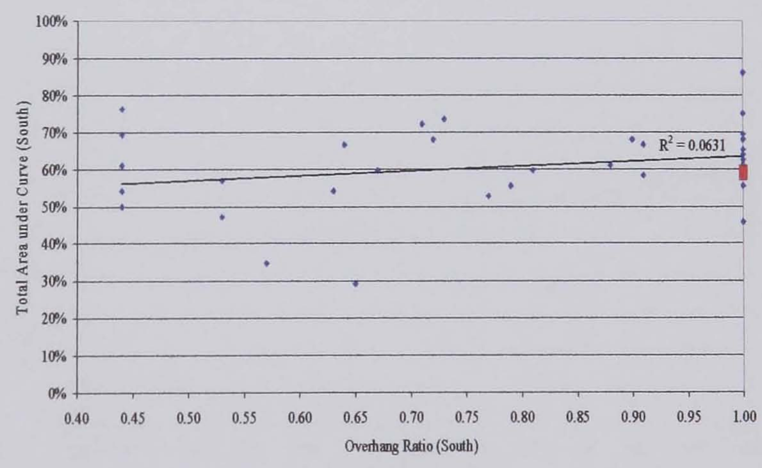


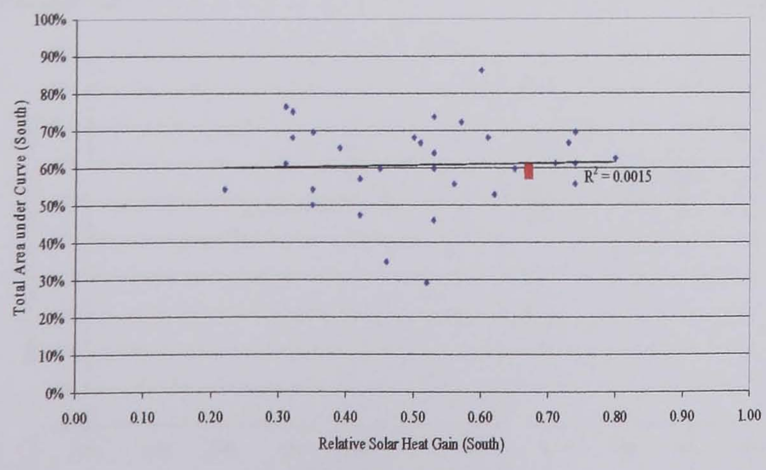




APII.4.2.2 *Correlation with Total Area under Curve (South)*

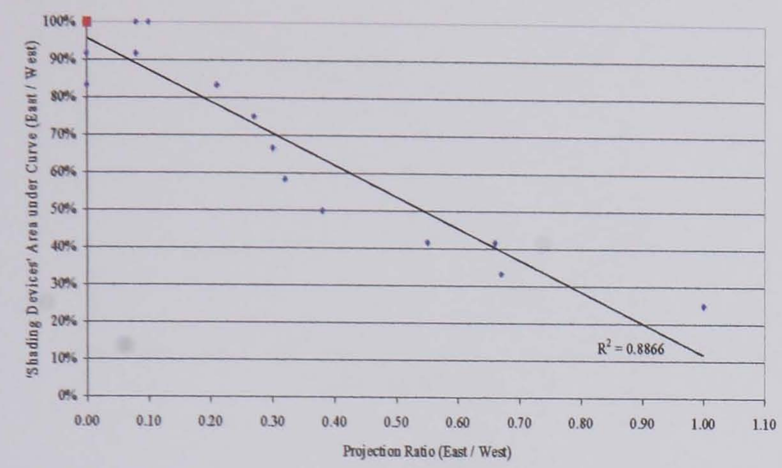


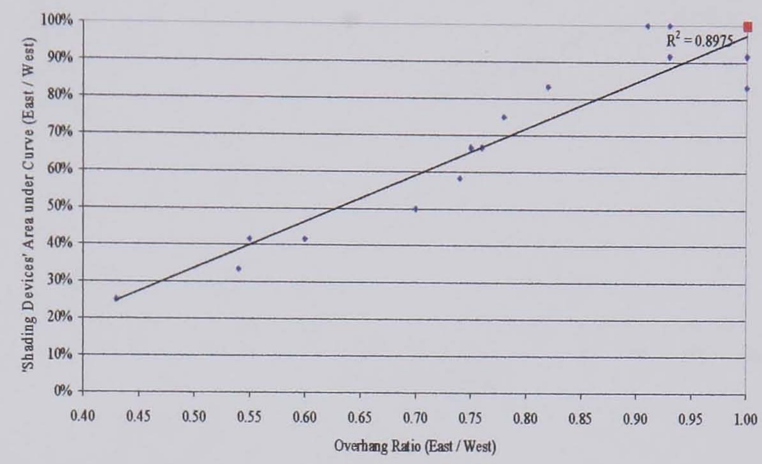


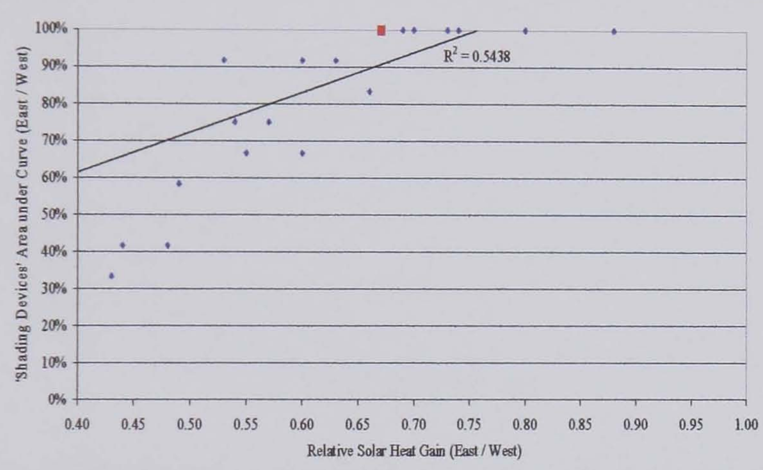


APII.4.3 East / West Orientation

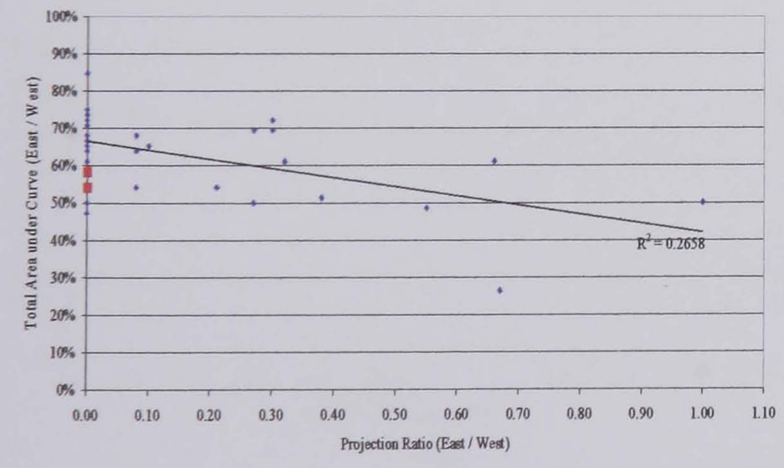
APII.4.3.1 *Correlation with 'Shading Devices' Area under Curve (East / West)*

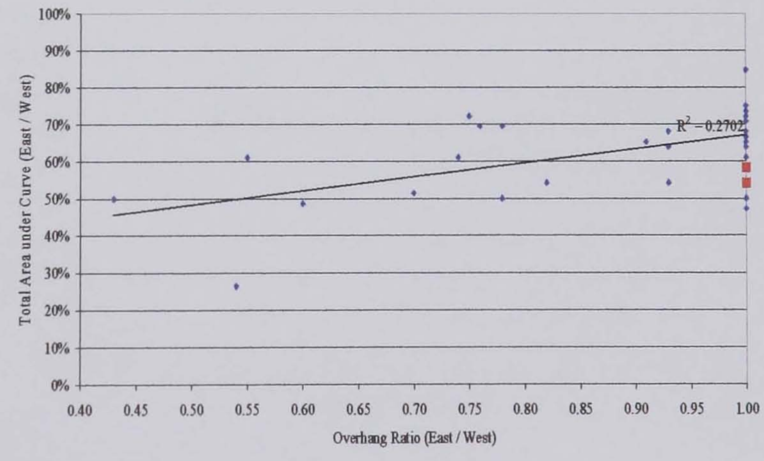


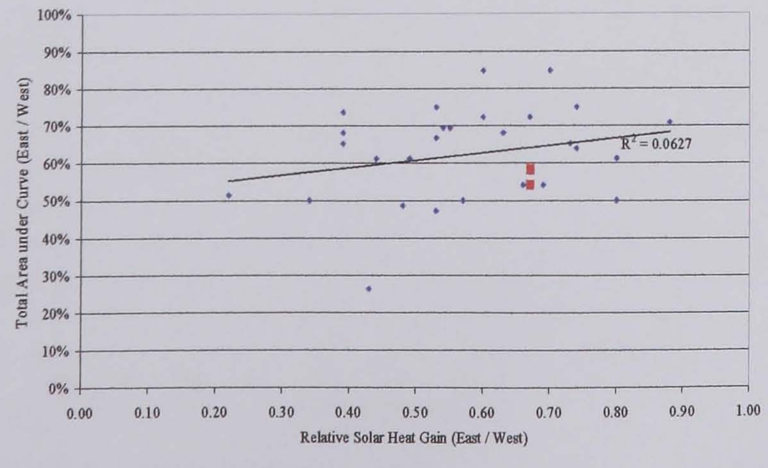




APII.4.3.2 *Correlation with Total Area under Curve (East / West)*

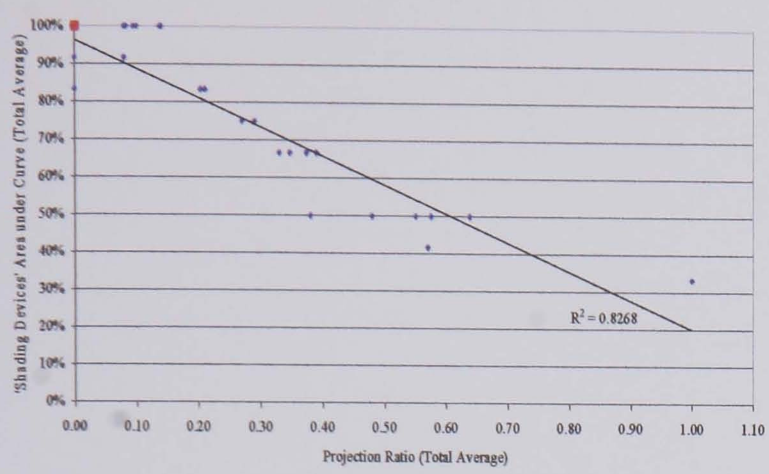


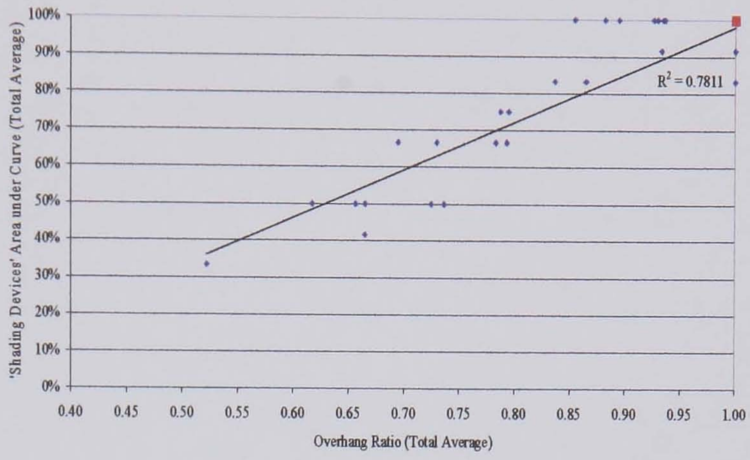


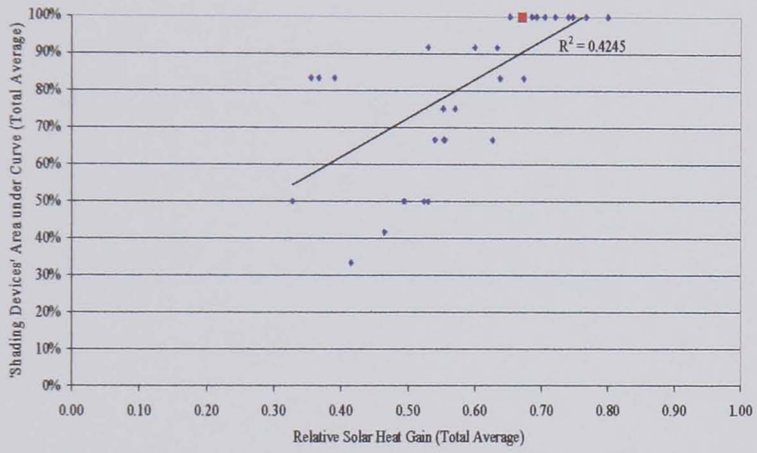


APII.4.4 Total Building Average

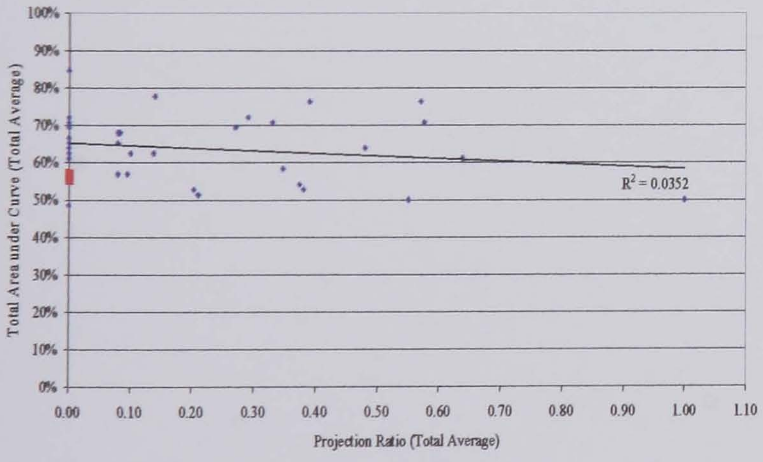
APII.4.4.1 *Correlation with 'Shading Devices' Area under Curve (Total Average)*

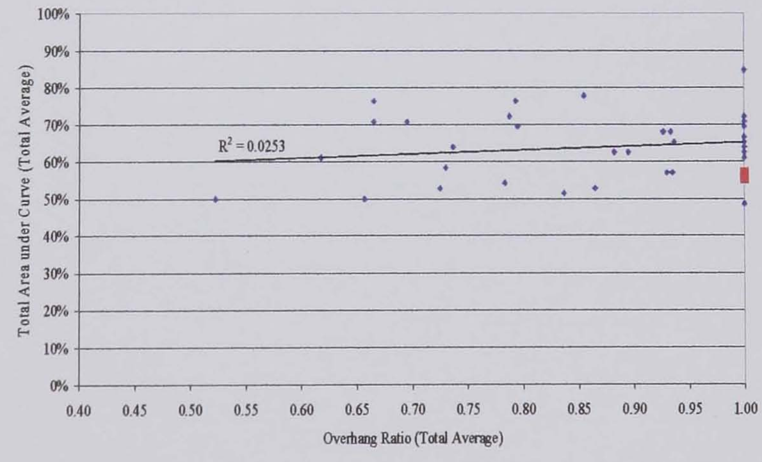


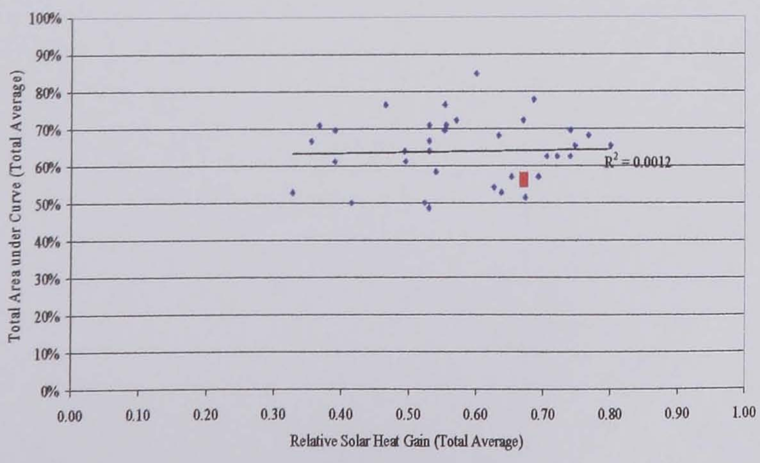




APII.4.4.2 *Correlation with Total Area under Curve (Total Average)*

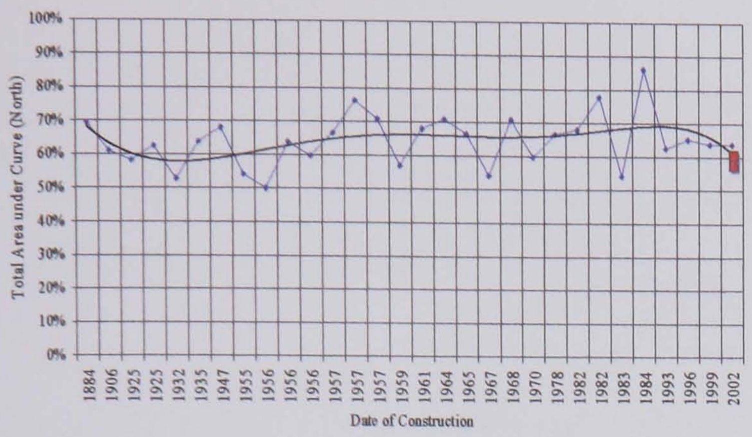




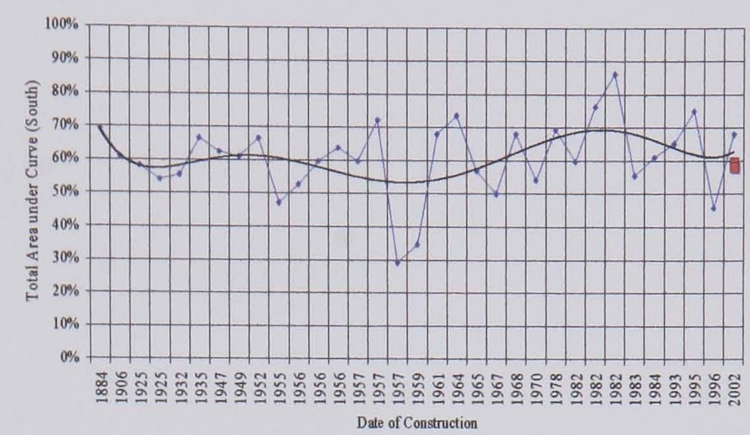


Appendix III. Development of Daylight Design Variables and Parametric Level Performance Evaluation in Beirut

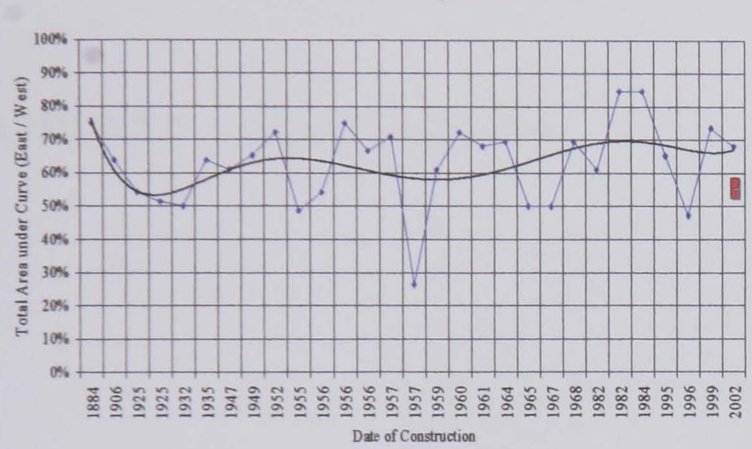
APIII.1 Development of all Daylight Design Parametric Levels



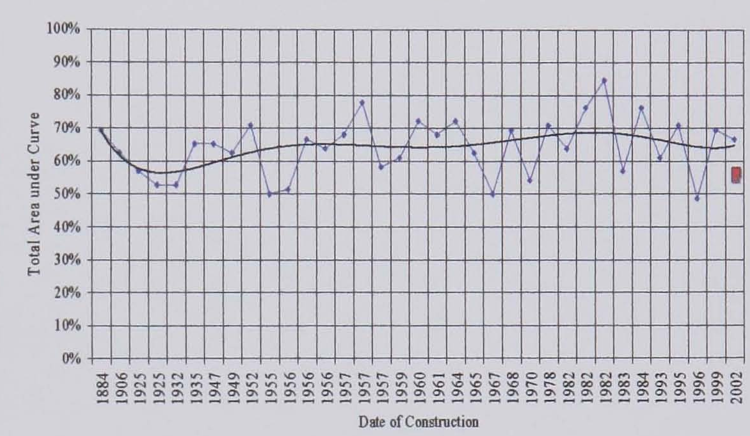
North Façades



South Façades



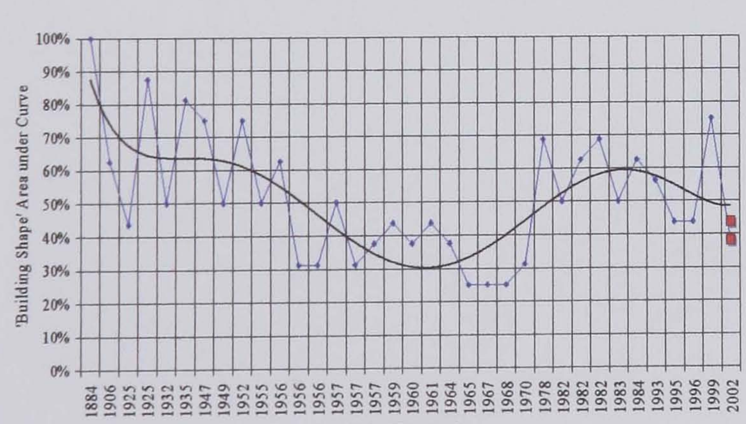
East / West Façades



Total Building Average

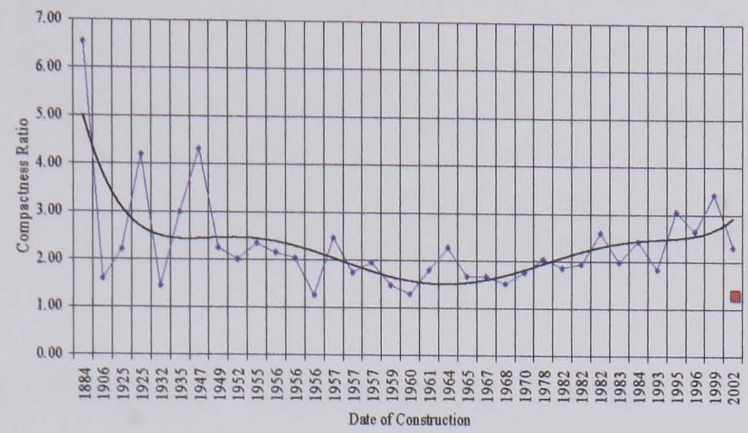
APIII.2 'Building Shape' Parametric Level

APIII.2.1 Development of 'Building Shape' Performance Evaluation

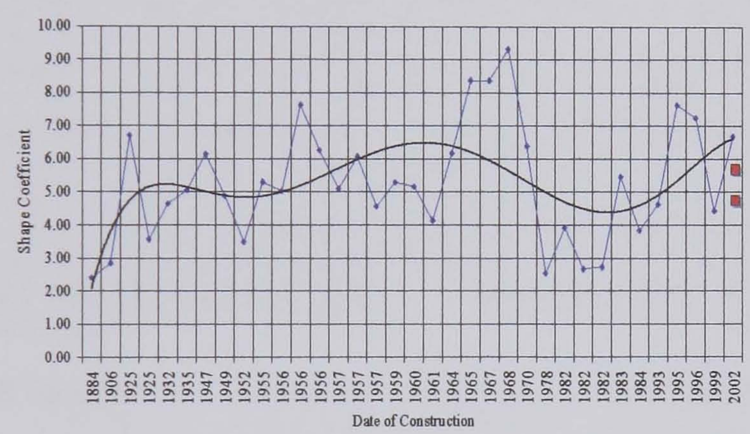


APIII.2.2 Development of 'Building Shape' Variables

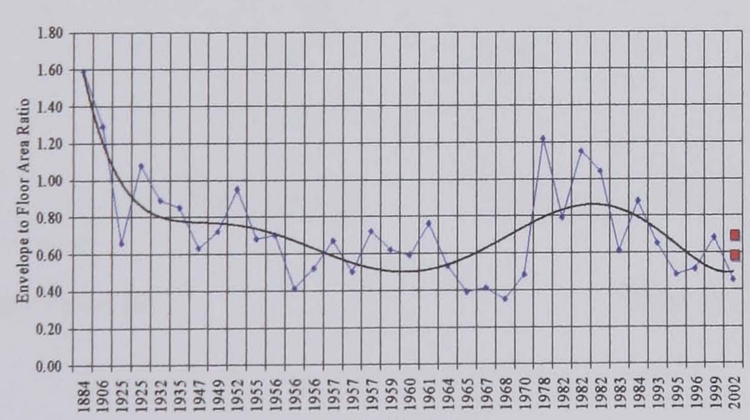
APIII.2.2.1 *Compactness Ratio*



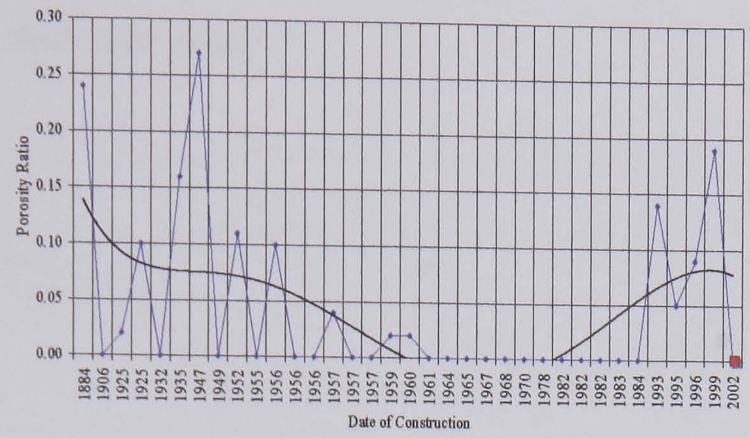
APIII.2.2.2 *Shape Coefficient*



APIII.2.2.3 *Envelope to Floor Area Ratio*

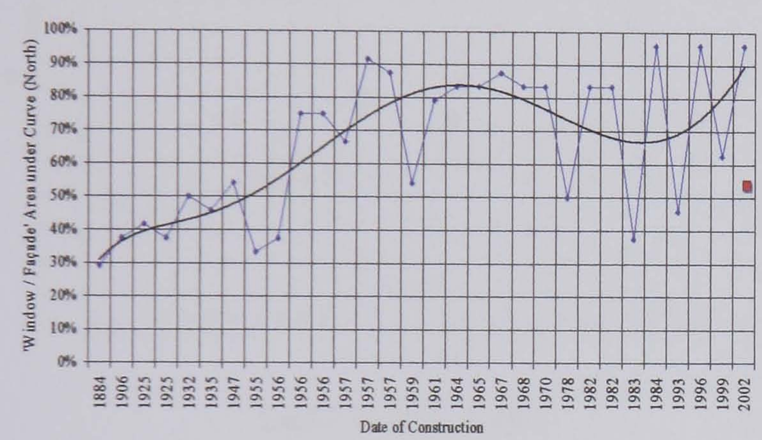


APIII.2.2.4 *Porosity Ratio*

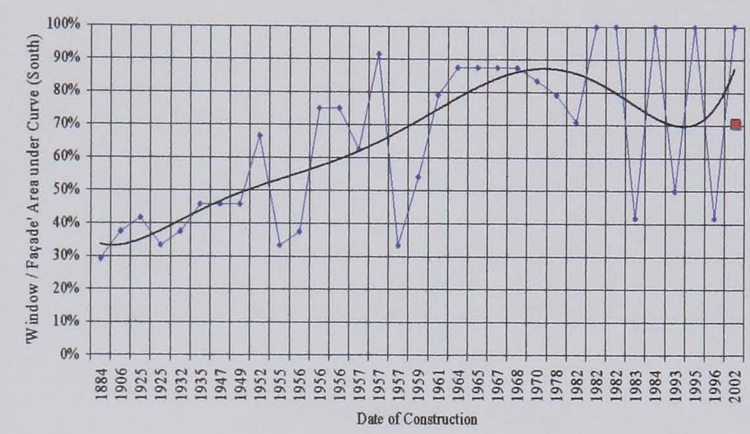


APIII.3 'Window / Façade' Parametric Level

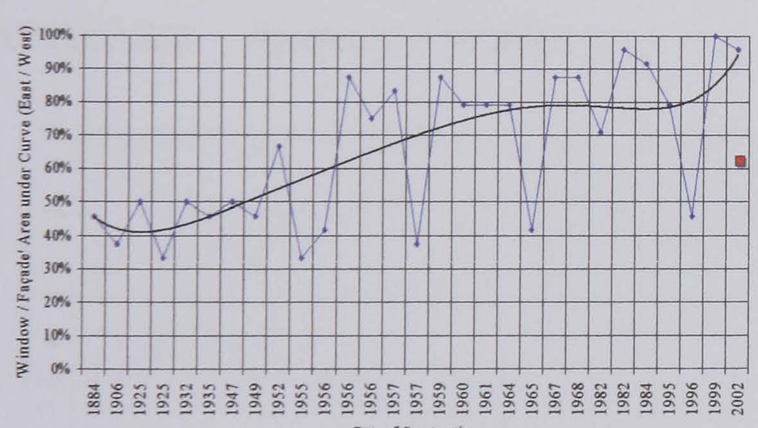
APIII.3.1 Development of 'Window / Façade' Performance Evaluation



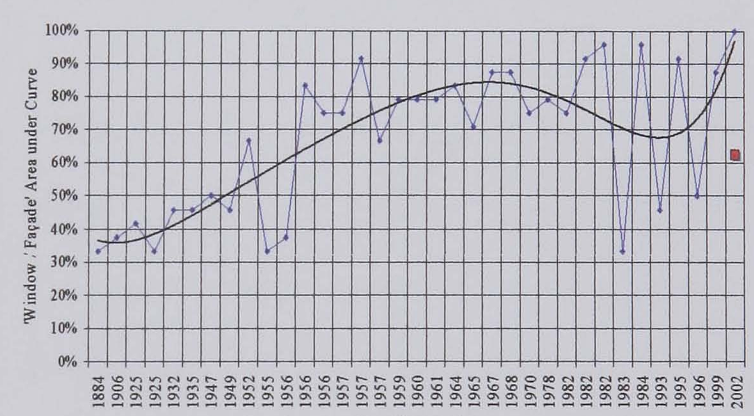
North Façades



South Façades



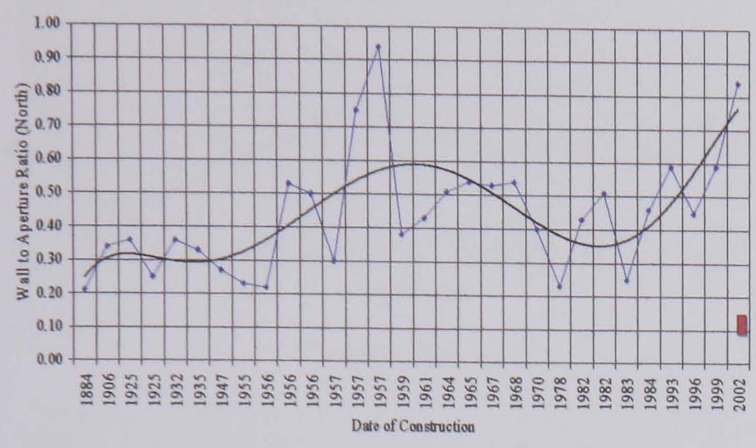
East / West Façades



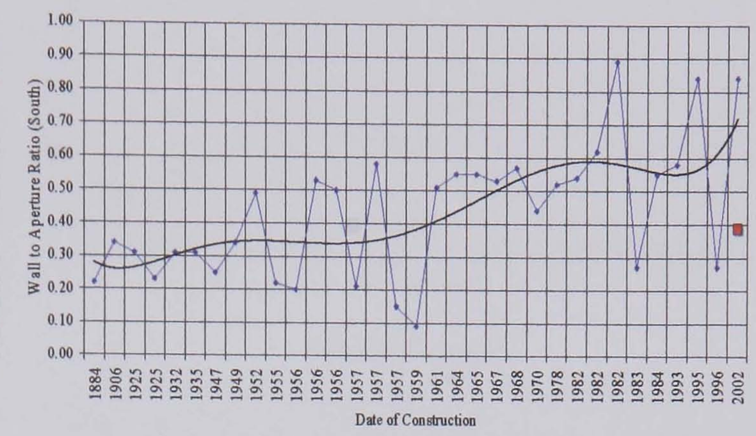
Total Building Average

APIII.3.2 Development of 'Window / Façade' Variables

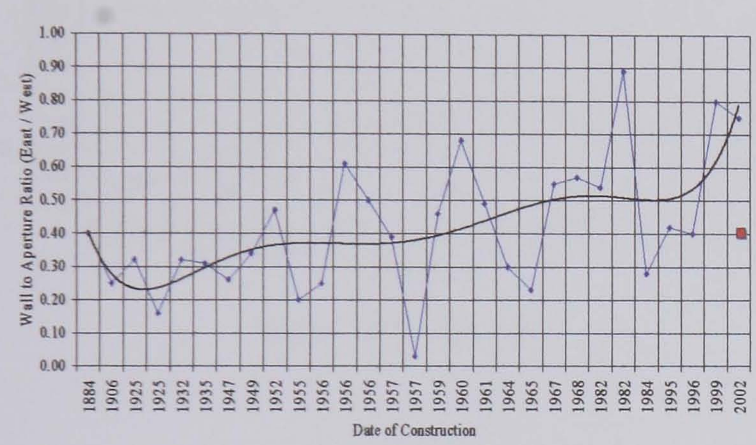
APIII.3.2.1 *Wall to Aperture Ratio*



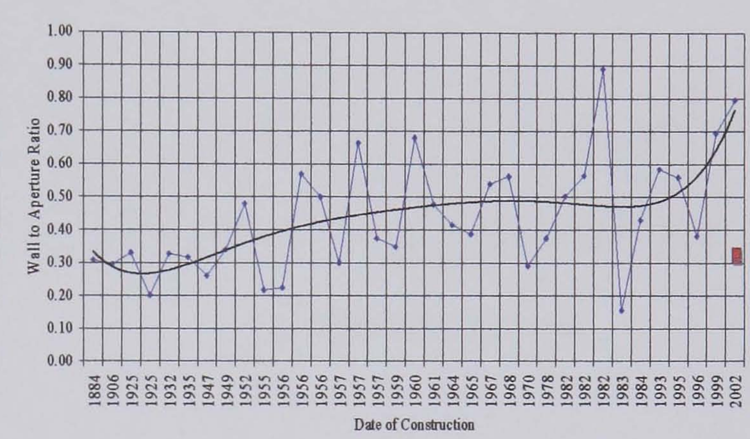
North Façades



South Façades

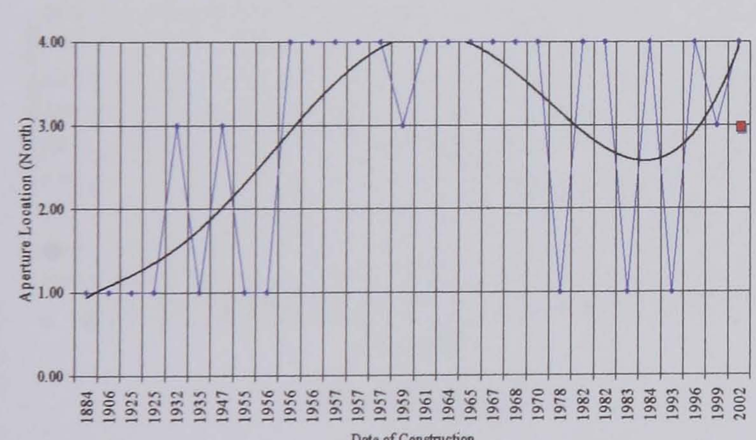


East / West Façades



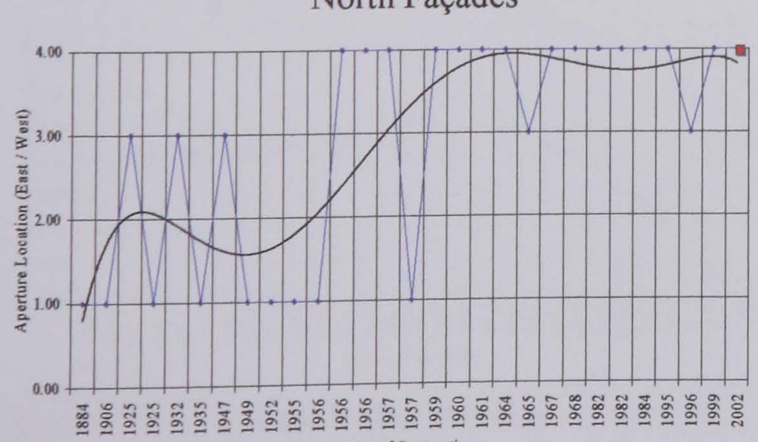
Total Building Average

APIII.3.2.2 *Aperture Location*

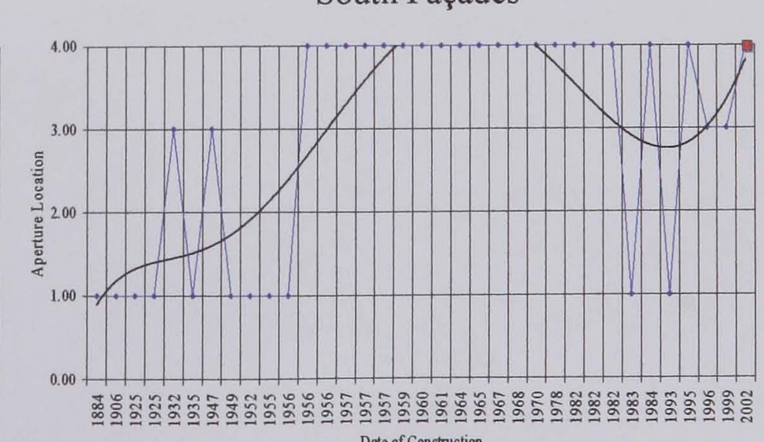


North Façades

South Façades

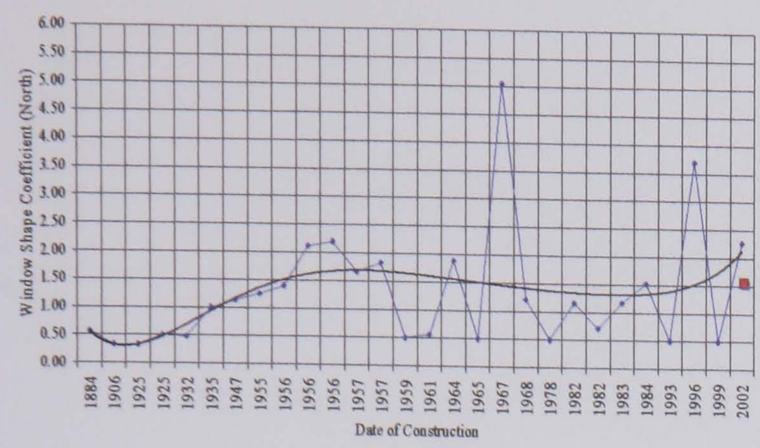


East / West Façades

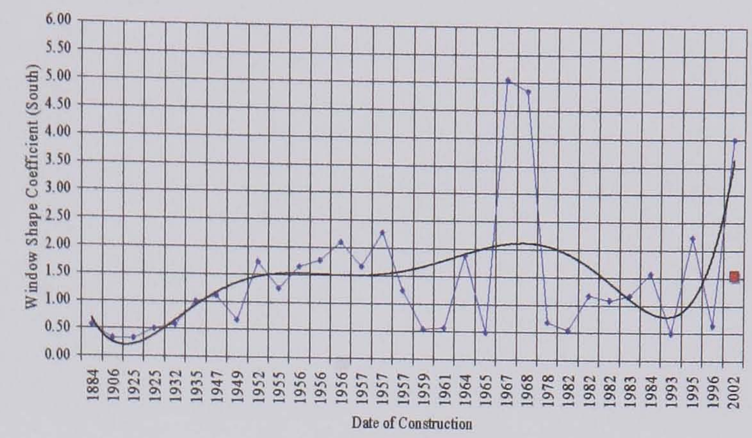


Total Building Average

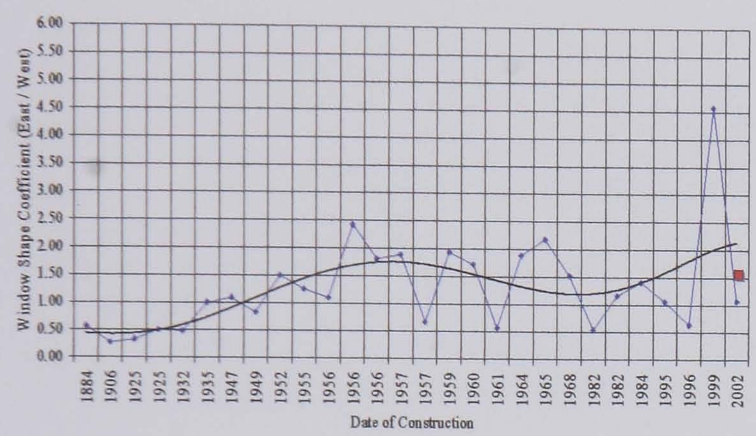
APIII.3.2.3 *Window Shape Coefficient*



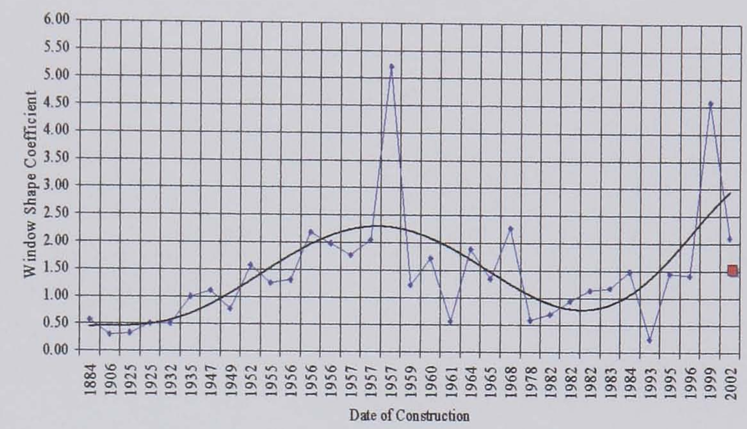
North Façades



South Façades

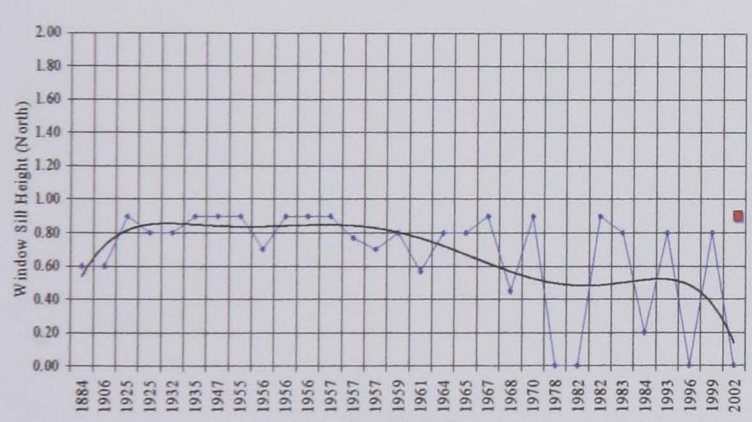


East / West Façades

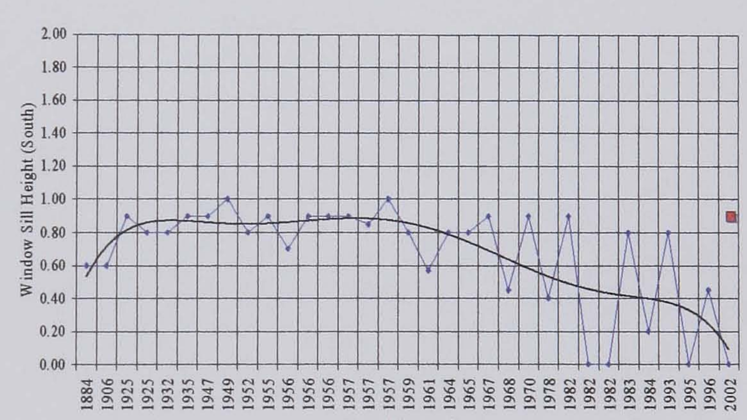


Total Building Average

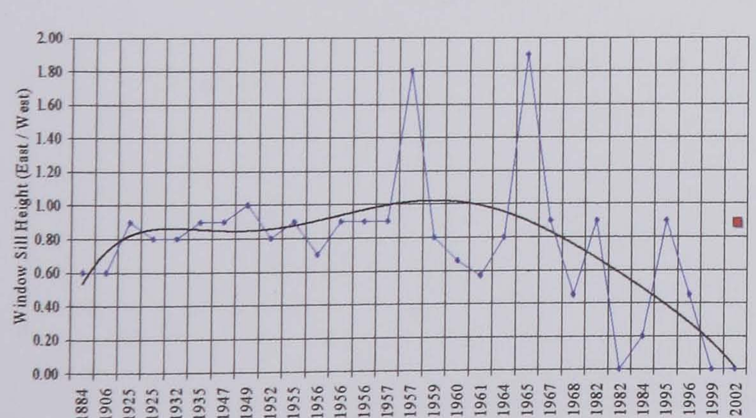
APIII.3.2.4 *Window Sill Height*



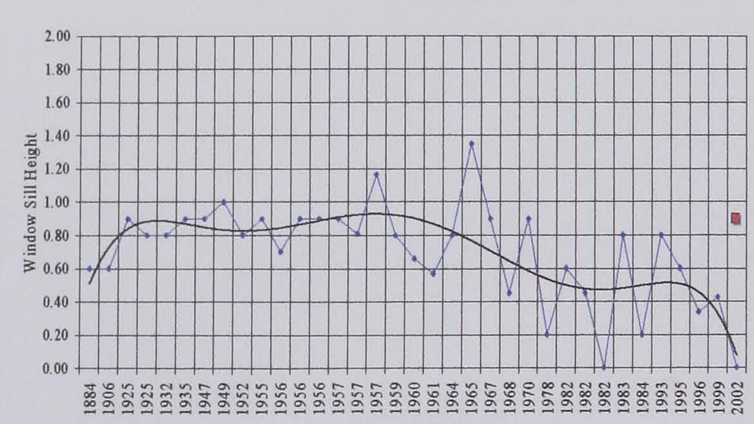
North Façades



South Façades

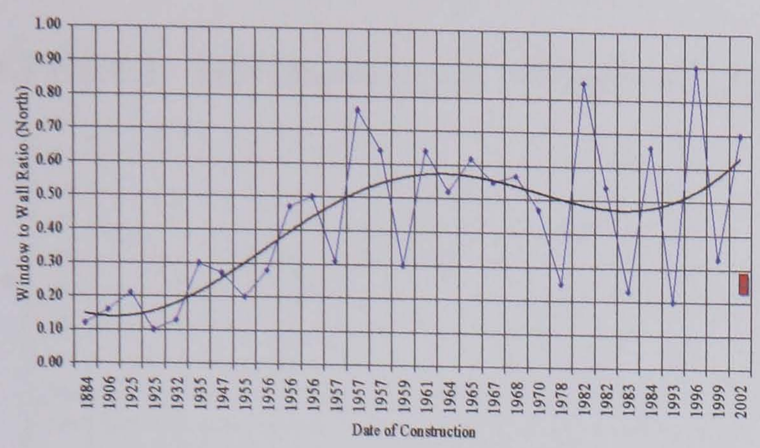


East / West Façades

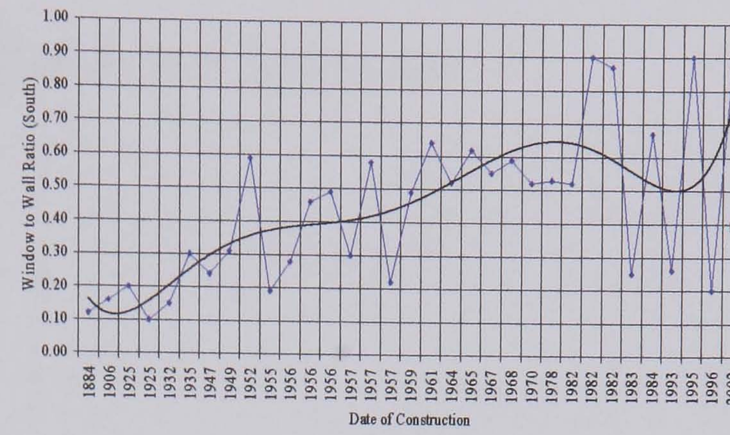


Total Building Average

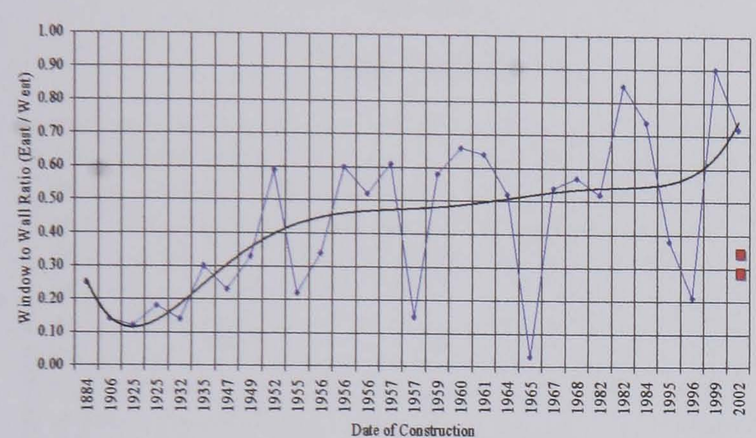
APIII.3.2.5 *Window to Wall Ratio*



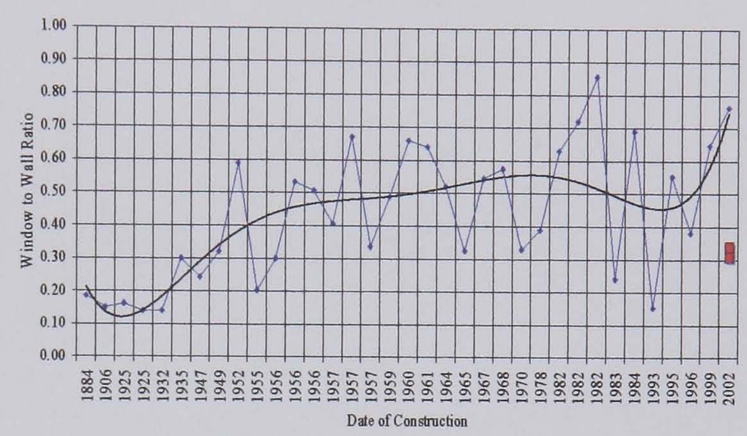
North Façades



South Façades

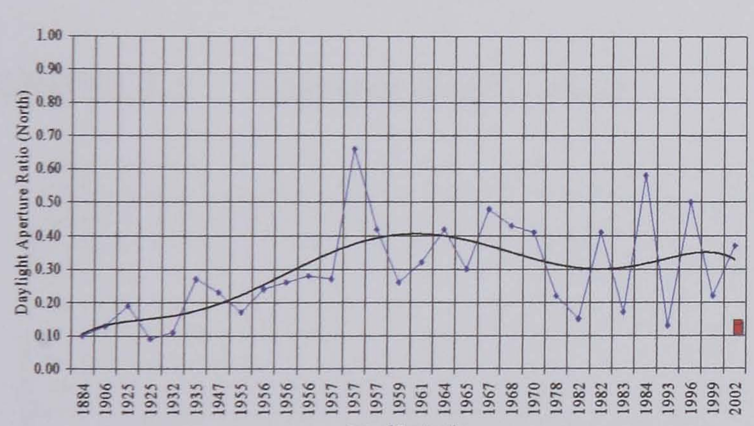


East / West Façades

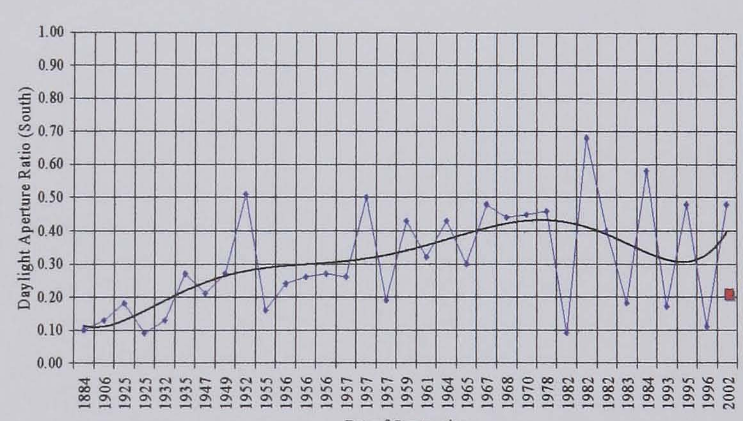


Total Building Average

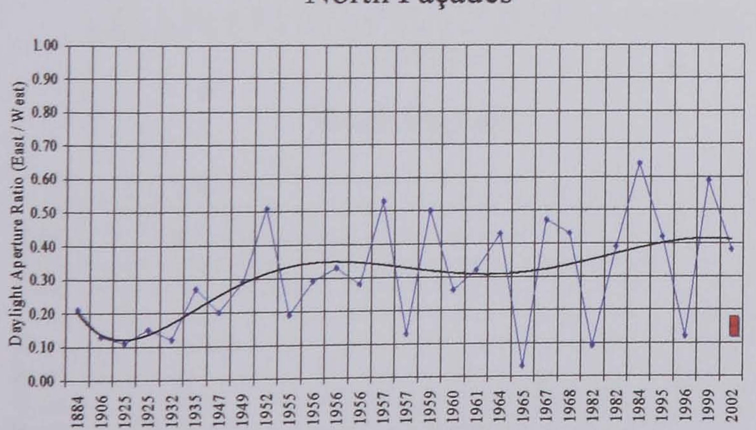
APIII.3.2.6 *Daylight Aperture Ratio*



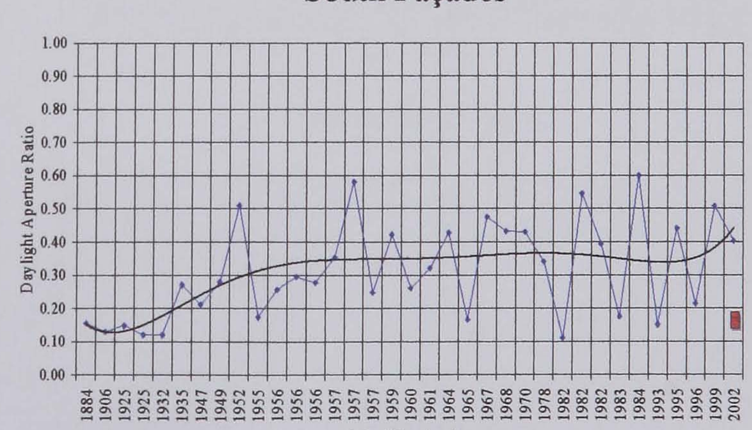
North Façades



South Façades



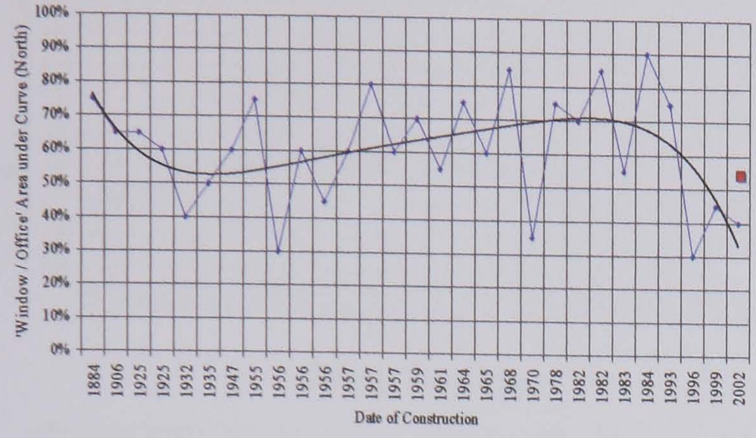
East / West Façades



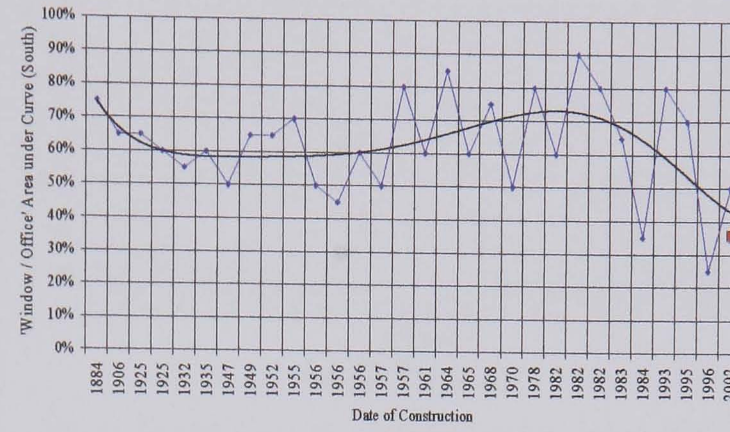
Total Building Average

APIII.4 'Window / Office' Parametric Level

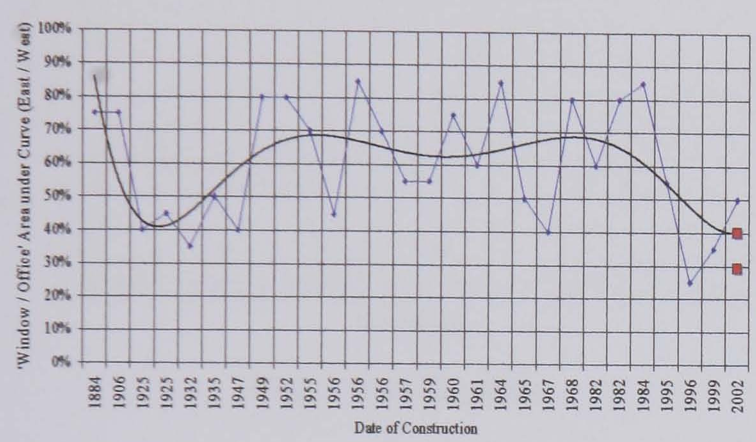
APIII.4.1 Development of 'Window / Office' Performance Evaluation



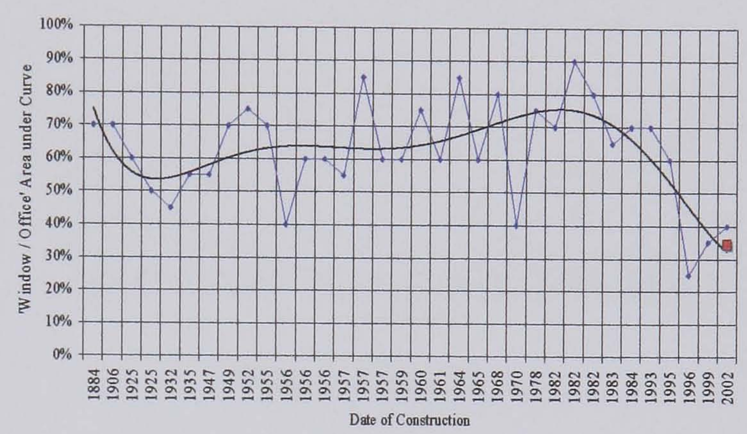
North Façades



South Façades



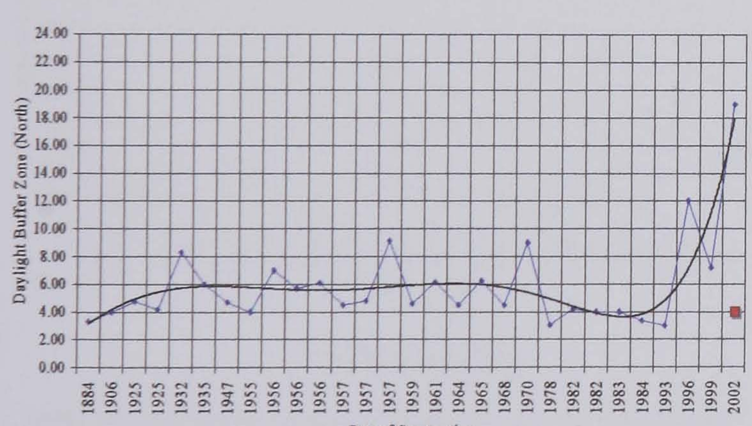
East / West Façades



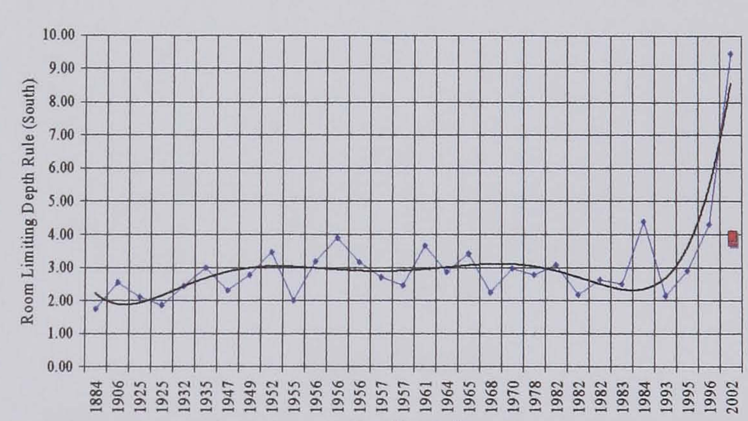
Total Building Average

APIII.4.2 Development of 'Window / Office' Variables

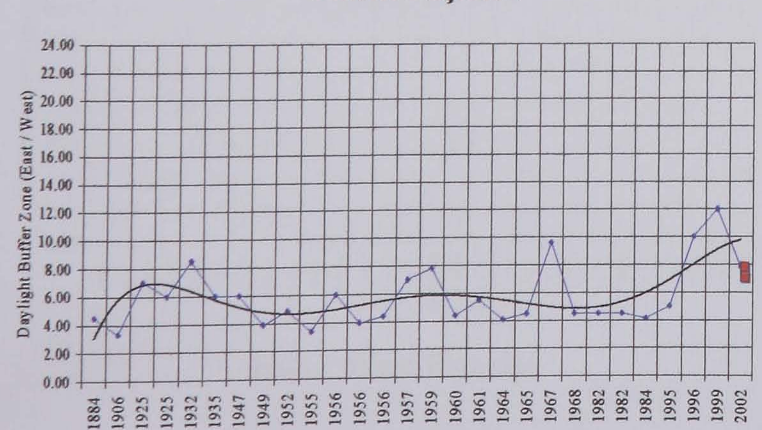
APIII.4.2.1 *Daylight Buffer Zone*



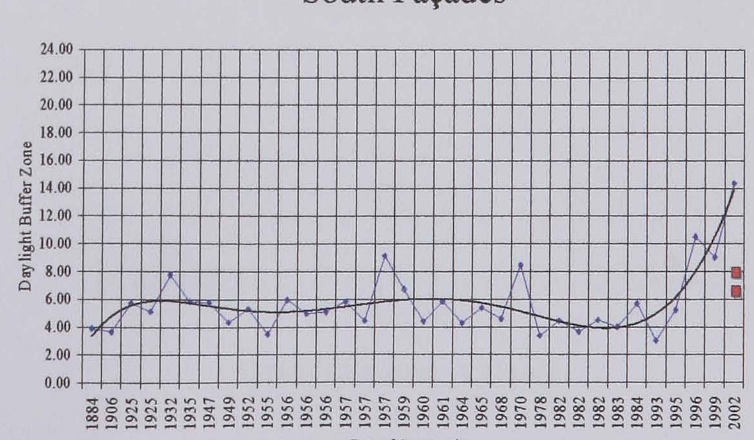
North Façades



South Façades

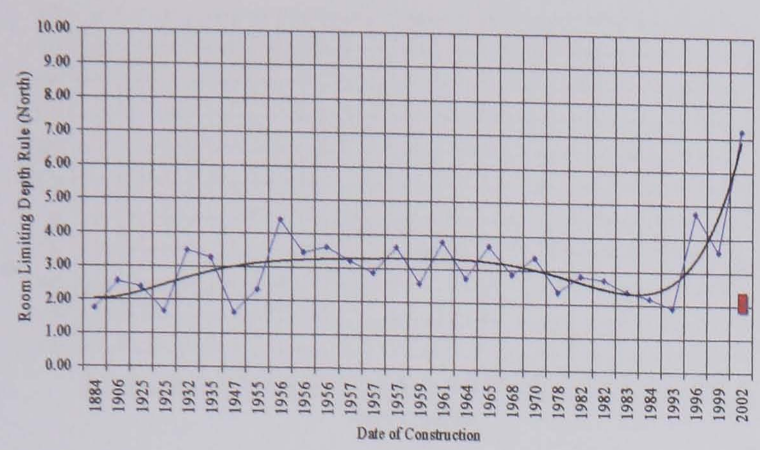


East / West Façades

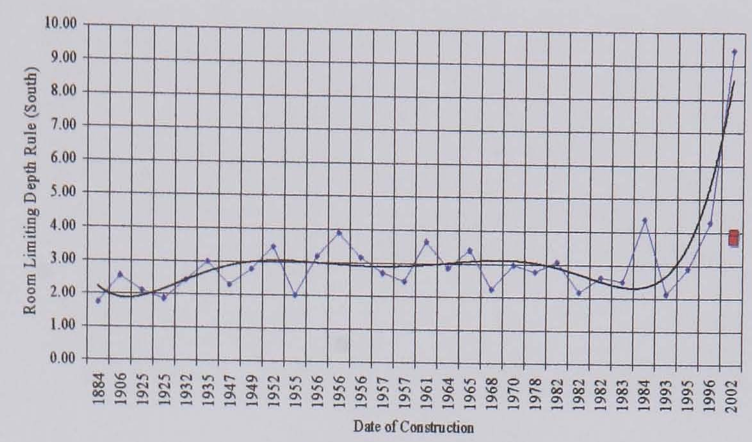


Total Building Average

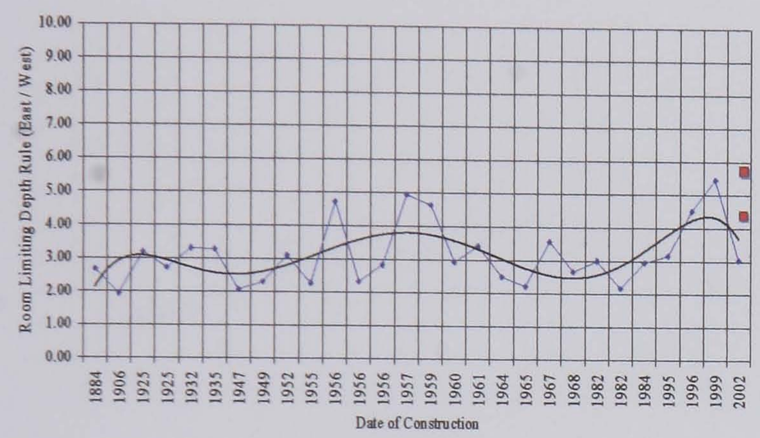
APIII.4.2.2 *Room Limiting Depth Rule*



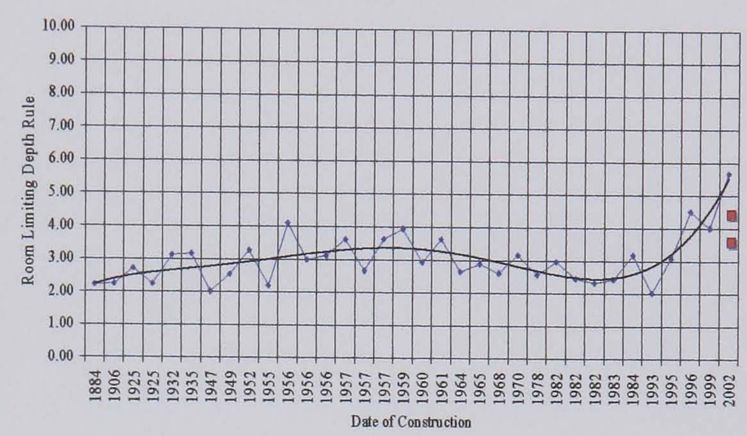
North Façades



South Façades

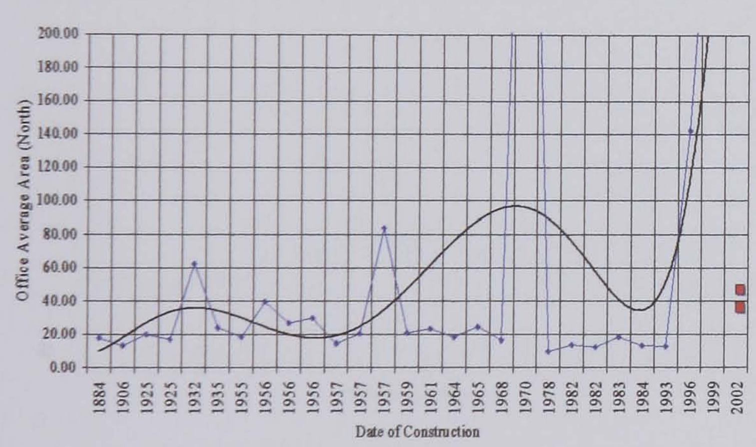


East / West Façades

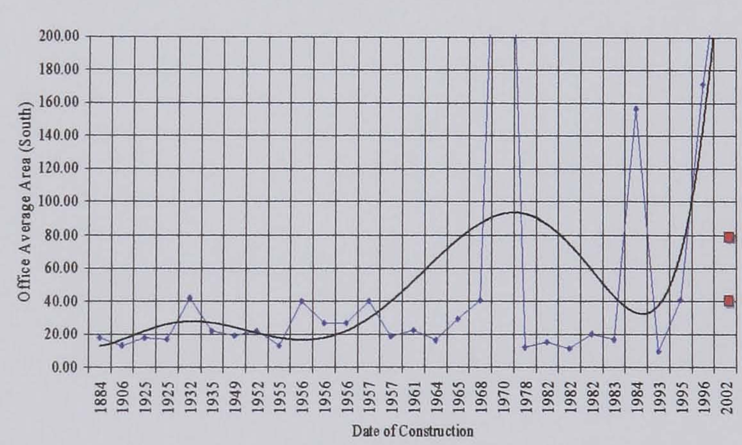


Total Building Average

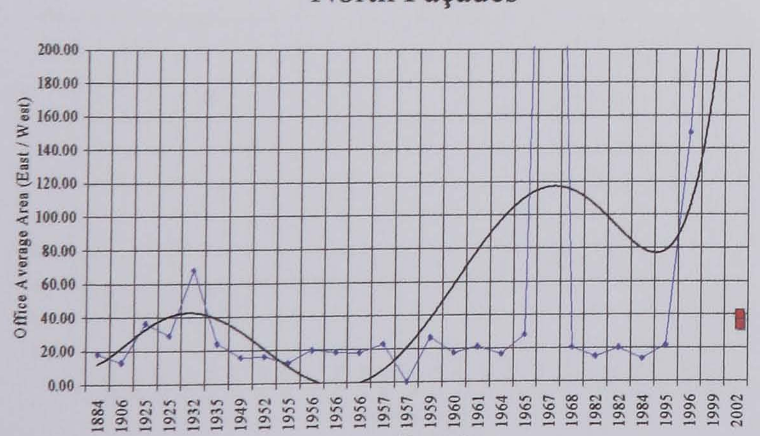
APIII.4.2.3 *Office Average Area*



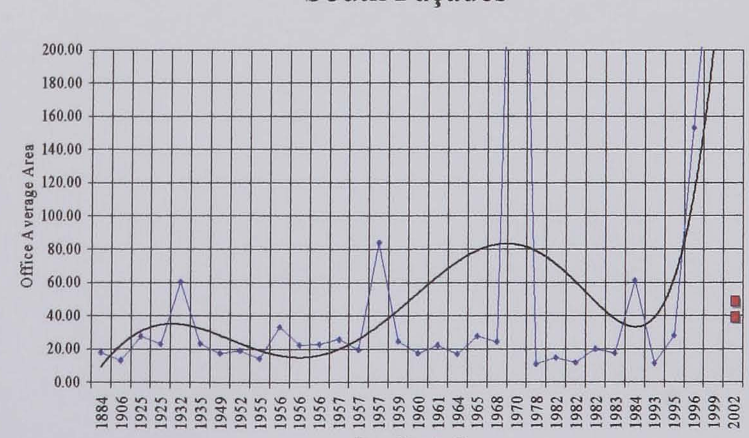
North Façades



South Façades

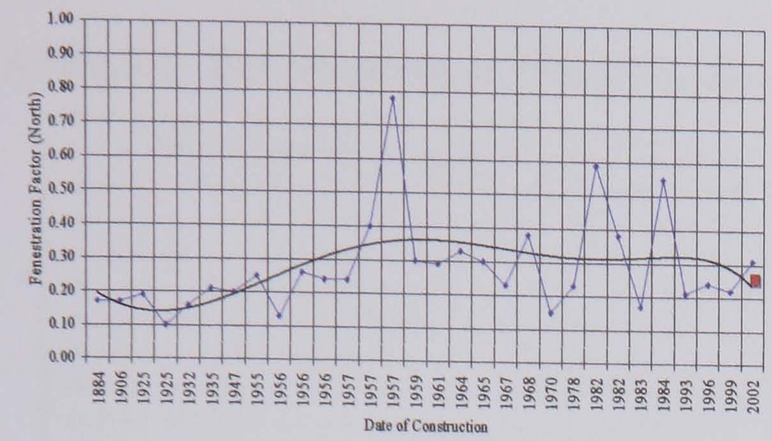


East / West Façades

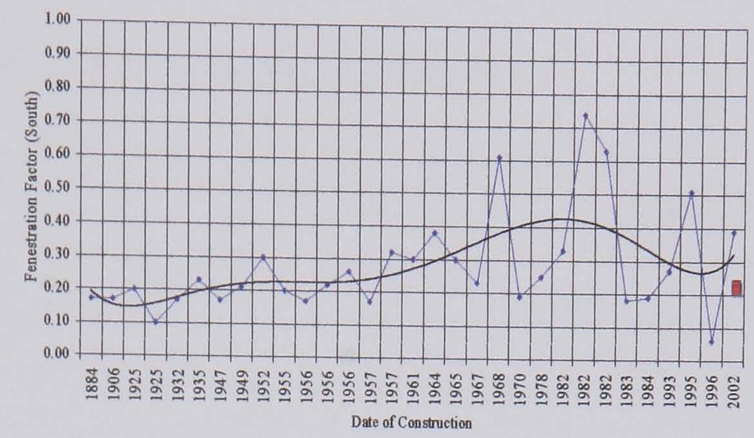


Total Building Average

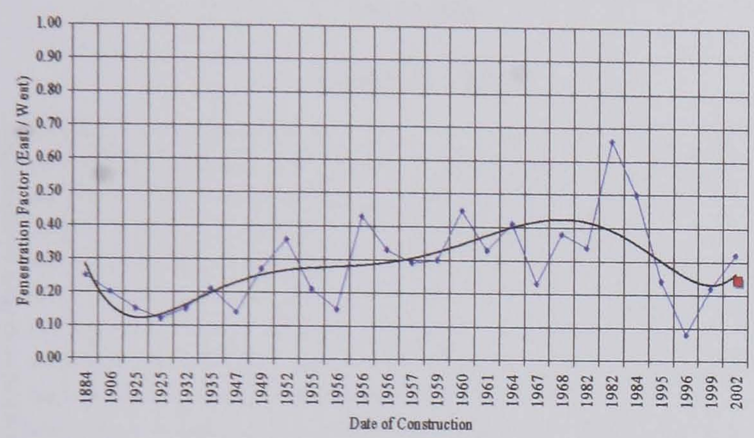
APIII.4.2.4 *Fenestration Factor*



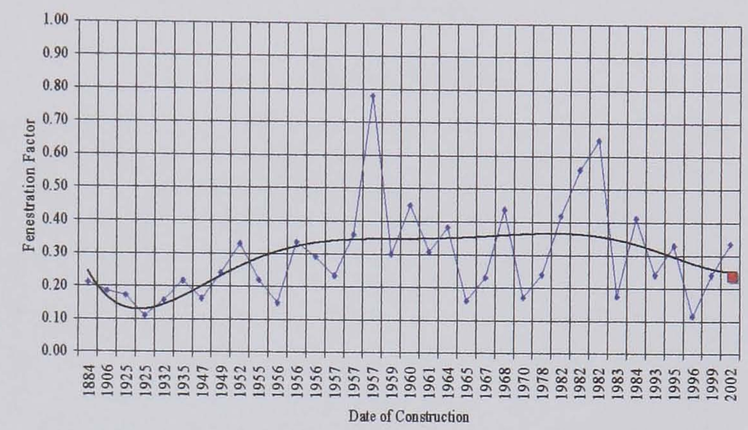
North Façades



South Façades

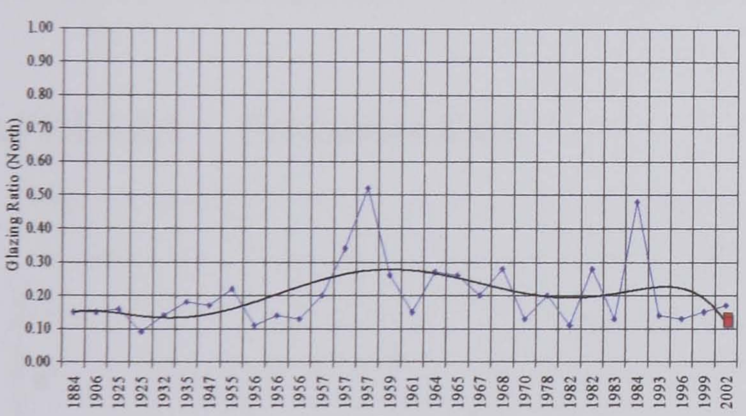


East / West Façades

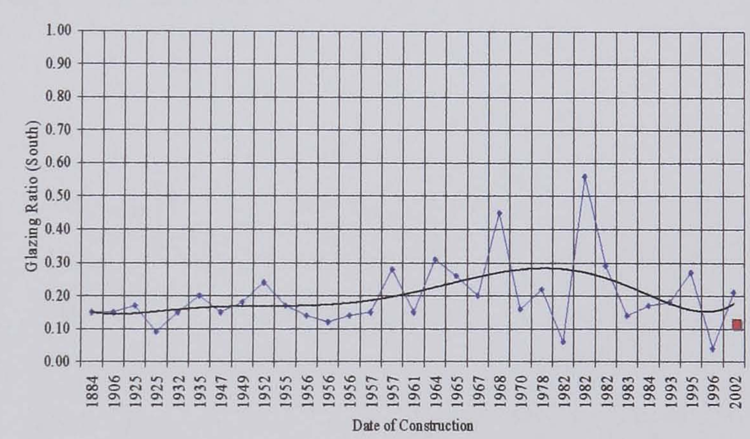


Total Building Average

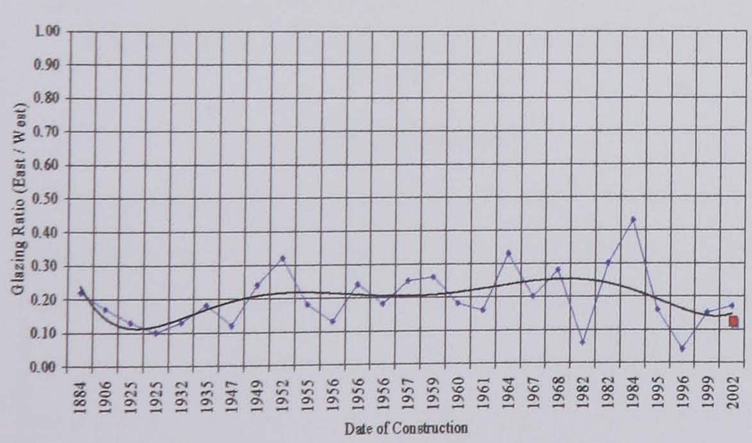
APIII.4.2.5 *Glazing Ratio*



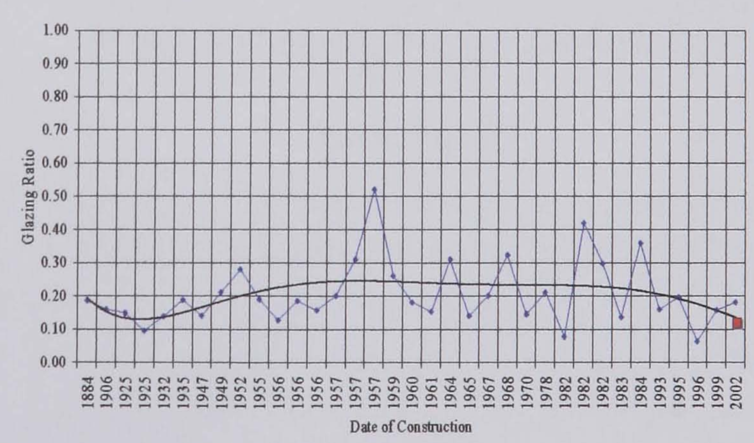
North Façades



South Façades



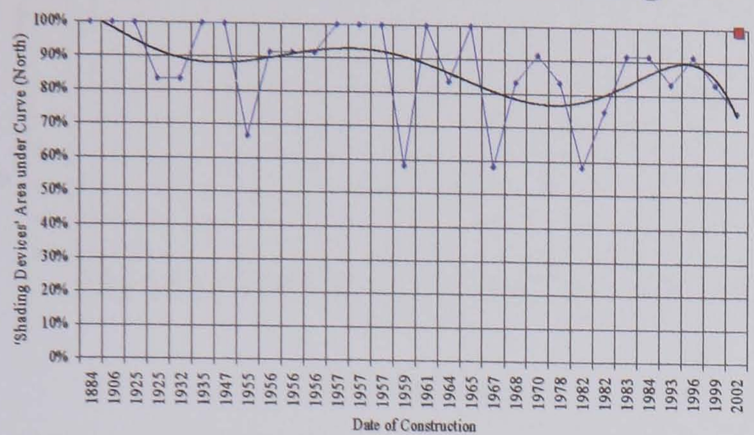
East / West Façades



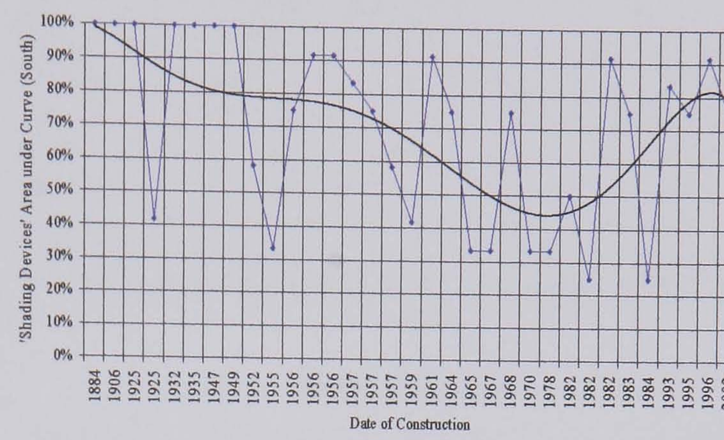
Total Building Average

APIII.5 ‘Shading Devices’ Parametric Level

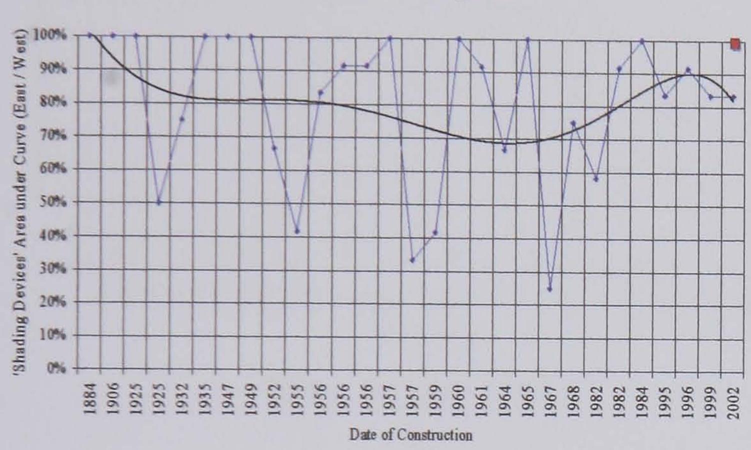
APIII.5.1 Development of ‘Shading Devices’ Performance Evaluation



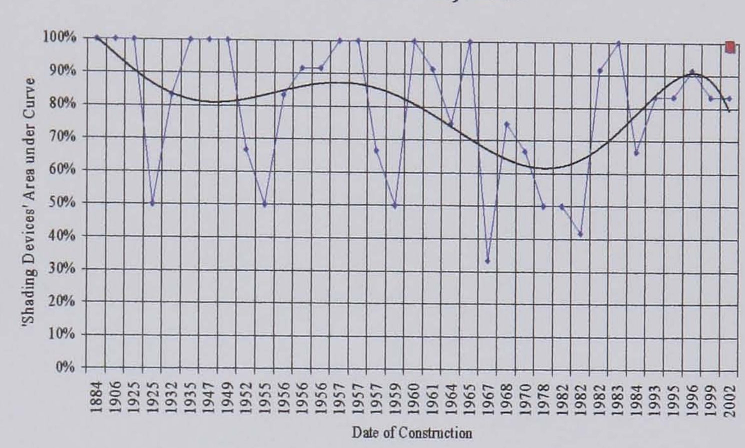
North Façades



South Façades



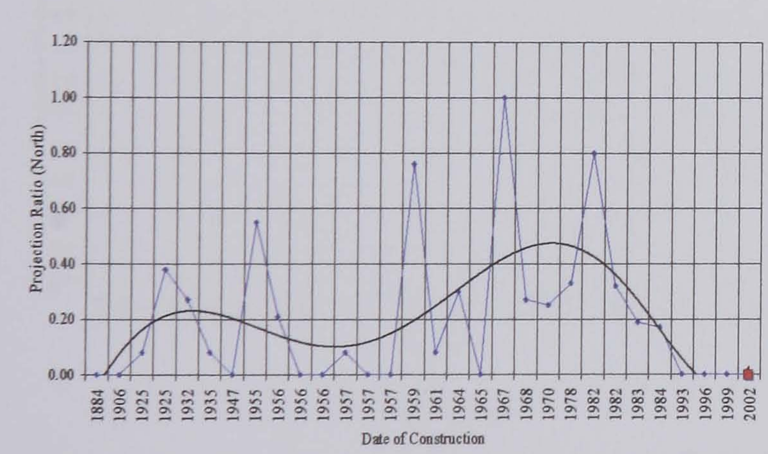
East / West Façades



Total Building Average

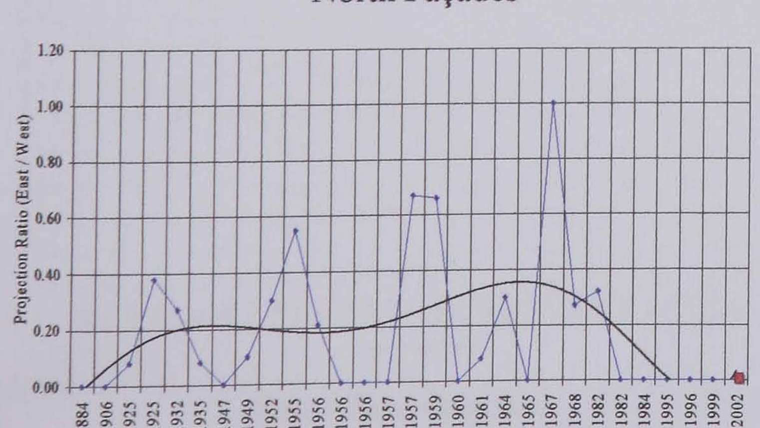
APIII.5.2 Development of ‘Shading Devices’ Variables

APIII.5.2.1 *Projection Ratio*

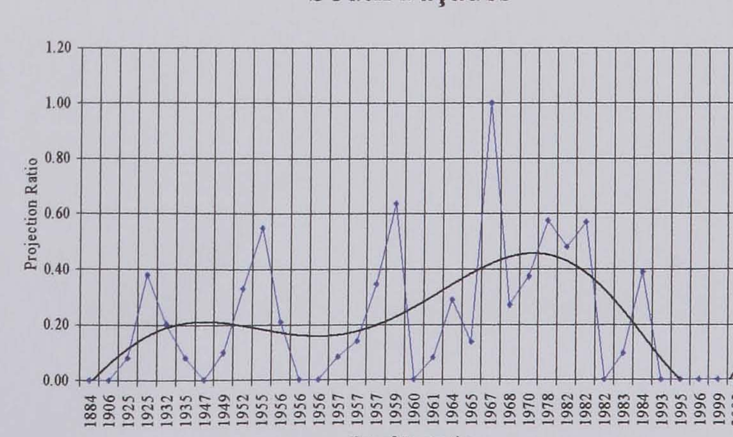


North Façades

South Façades

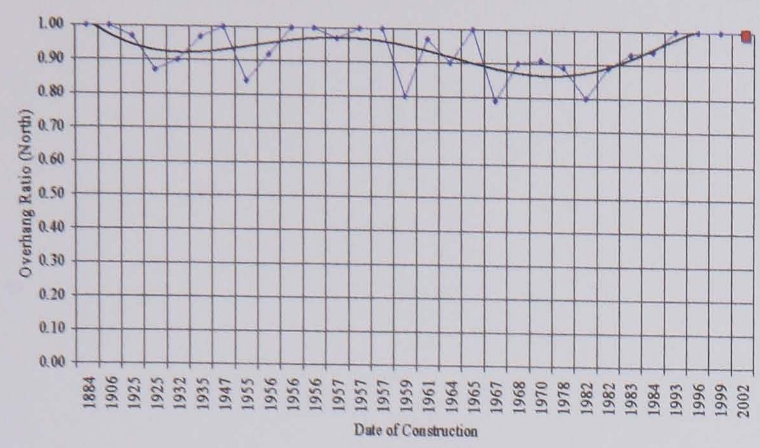


East / West Façades

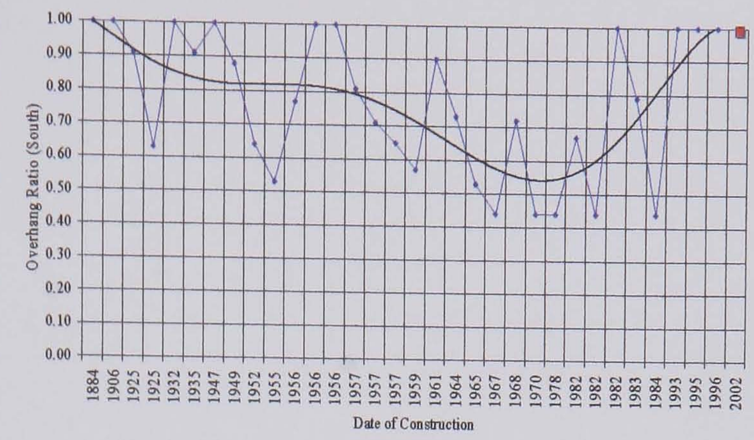


Total Building Average

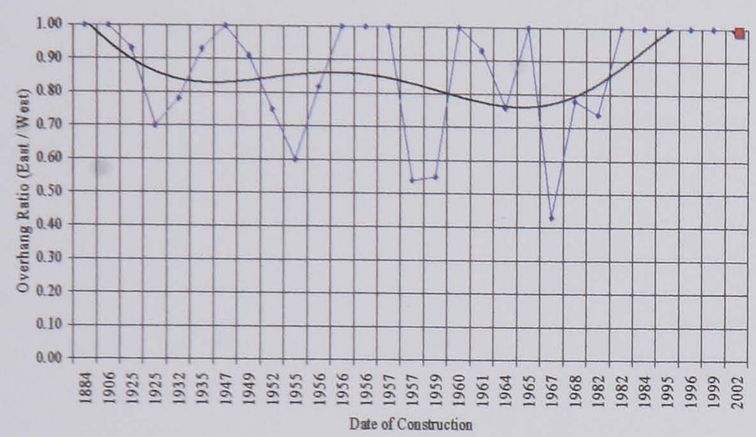
APIII.5.2.2 *Overhang Ratio*



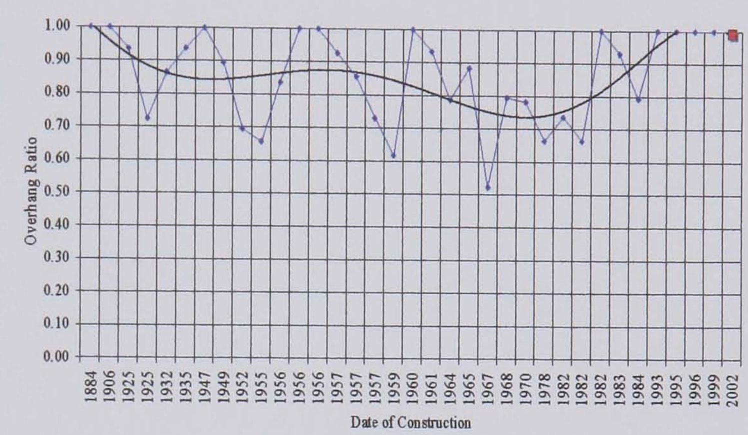
North Façades



South Façades

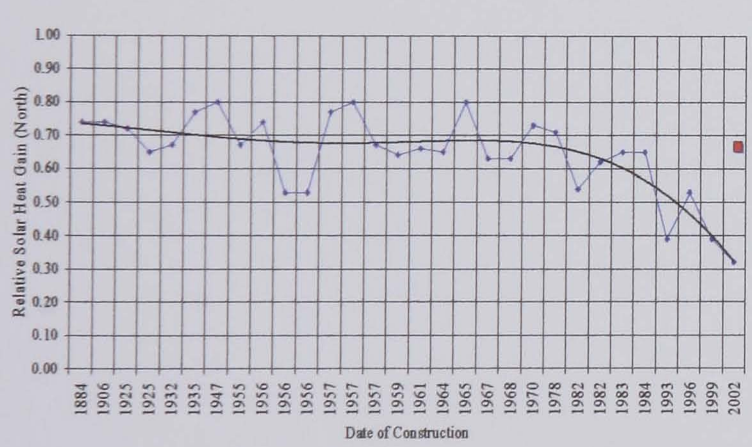


East / West Façades

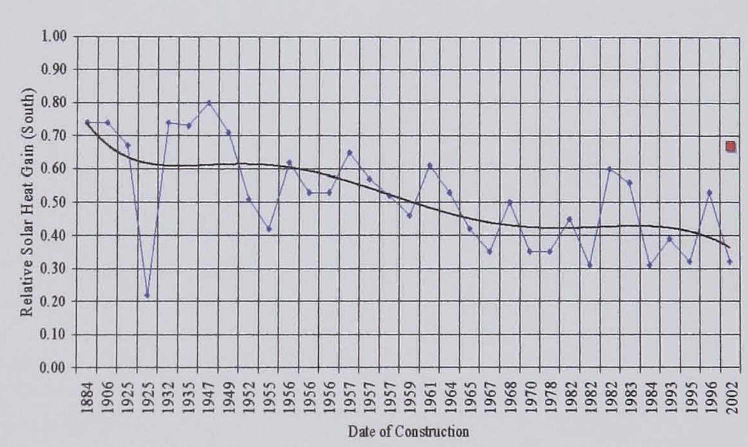


Total Building Average

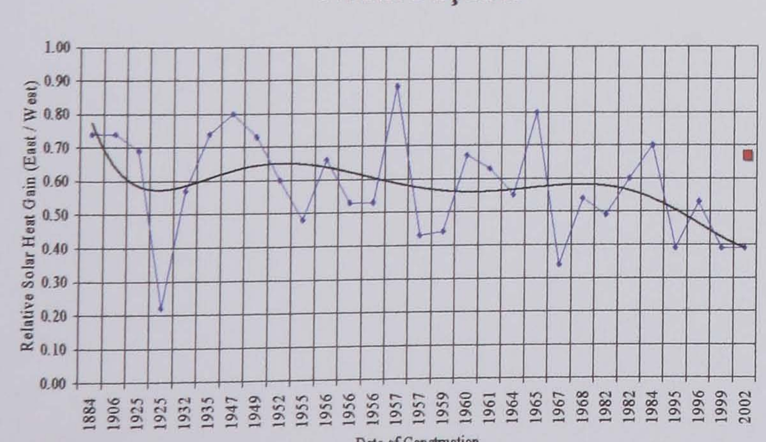
APIII.5.2.3 *Relative Solar Heat Gain*



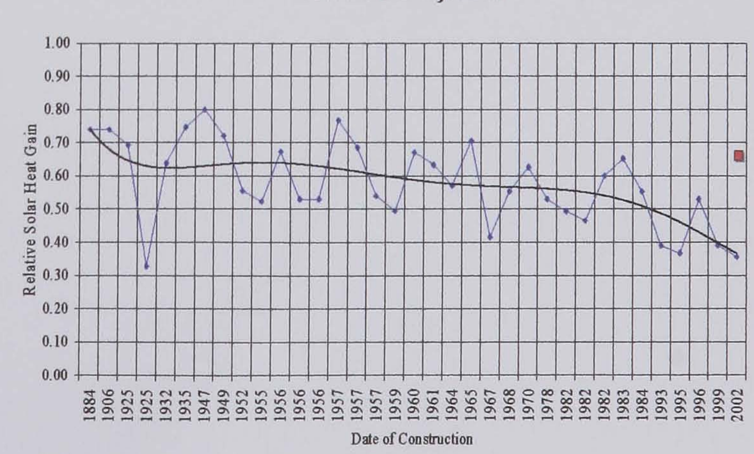
North Façades



South Façades



East / West Façades



Total Building Average

Appendix IV. Parameters Definition File (*.def)

APIV.1 Content of Building _ID.def (i.e. B03.def)

```
DEFAULTS_DATA 2 2 5 2 1 200 0.50 1 3
WINDOWS_DEFDATA   0.20   0.50
GEOGRAPHIC_DATA  33.81  -35.48 -2  15.0   0.40 Beirut
TIME_LOOP_DATA 3 3 1 21 12 12 1
ATMOSPHERIC_DATA   2.22   0.18
   1.44   0.12
   1.39   0.13
   1.64   0.15
   1.67   0.26
   1.97   0.18
   2.61   0.18
   3.03   0.25
   3.25   0.23
   3.20   0.23
   2.63   0.17
   2.00   0.14
   1.88   0.14
SOLAR_DATA  56.26   0.00 682.00 110.00 214.00 110.00
OVERHANG_DEFDATA 1 0   0.80   0.10   0.40   0.00
SUNSHINE_PROBABILITY c:\Adeline3\examples\sswsol.ssp
LIGHTING_SYSTEM 1 500.00 350.00  35.71   1.40
SHADING_SYSTEM 0 1   1.00
OCCUPANCY 1 6 5 1 8 17
HOLIDAY_PERIODS 0 unnamed
LINKE_TURBIDITY   3.20
   3.30
   3.60
   5.20
   4.00
   4.10
   5.00
   4.80
   4.70
   3.90
   3.50
   3.50
```

APIV.2 Description of Data Entries

Lines 1 to 19 contain SUPERLITE specific data. This data is relevant for RADLINK also. Lines 20 to 24 contain SUPERLINK/RADLINK specific data. Lines 25 to 36 contain RADLINK specific data. The following table describes the content of the parameter definition file (*.def) in details.

General Parameters for Superlite / Superlink - Radlink (Line 1)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Weather Model	Selects the input requirements for the weather algorithms to be used in the calculation.	1 = irradiance, ground and sky model data (own measured data of daylight availability) 2 = geographic, sky model and ground reflectance data 3 = sun position, sky model and ground reflectance data	2
Sky Model	Selects the sky condition for the daylighting analysis. Sky luminance distributions are modeled according to the CIE standard sky luminance distributions.	1 = no direct sun, overcast sky 2 = direct sun with clear sky 3 = no direct sun, uniform sky 4 = no direct sun, clear sky	2
Number of Iterations	Defines the number of iterations to be performed by the program in the calculation of indoor surface luminances. The more iterations, the longer the runtime of the program.	3 to 5 iterations will be satisfactory for most normal surface reflectances. Highly reflective surfaces require more iterations, such as 10.	5
Tabular Output	Selects the program output for either work surfaces only, or for all surfaces of the room.	0 = no output 1 = illuminance values and daylight factors for work surfaces only 2 = luminance values for room surfaces as well as illuminance values and daylight factors for work surfaces	2
Plot Output	Graphical output (plot) of illuminances on work surfaces, or no graphical output.	0 = no plot 1 = plot	1
Number of Nodes	Switch to control the number of nodes generated for each surface. This value is only used by the user interface program and is dependent on simulation accuracy switch. It may be overridden by the setting of mode density.	any positive integer below the program limit which is 400.	200 (average)
Node Density	Distance between two adjacent nodes on a surface measured in meter.	any positive real number	0.5 (default)
Visualization Output	Enables generation of additional data files for the visualization of luminances with RADIANCE rview program. Data is only generated for last calculated hour.	0 = no visualization data 1 = generate visualization data	1
Accuracy Mode	Switch to control the accuracy of the simulation (number of iterations and mesh size). This value is only used by the user interface program.	0 = low 1 = medium 2 = high 3 = user defined	3 (default)

Window Data (Line 2)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Glass Recess	Refers to the distance that the window glass is recessed with respect to the exterior wall surface.	If the window glass is flush with the exterior wall surface, glass recess = 0.	0.20
Maintenance Factor	Refers to the window cleaning and repair frequency.	0 < maintenance factor < 1 If a window is cleaned and repaired frequently, the maintenance factor = 1, if the window is never cleaned, the maintenance factor = 0.	0.5 (average value)

Geographic Data (Line 3)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Latitude	Site location latitude in degrees	Positive north of the equator	33.81
Longitude	Site location longitude in degrees	Positive west of Greenwich	-35.48
Time Zone	Time zone in hours behind Greenwich time.	European time zones: 0 = Great Britain -1 = Central Europe -2 = Eastern Europe U. S. time zones: 5 = Eastern Standard Time	-2
Altitude	Site altitude above sea level	Altitude in meters	15
Ground Reflectance	Average ground reflectance	Any number from 0 to 1	0.4
Name of Site	Identifier for the location	Any string. Maximum length is 40 characters	Beirut

Time Loop Data (Line 4)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
First Month	Specify the first month to be calculated. This allows multiple calculations for various runs with one input file.	Any whole number from 1 to 12	3
Last Month	Specify the last month to be calculated. This allows multiple calculations for various runs with one input file.	Any whole number from 1 to 12	3
Step	Month increment between calculations	Any whole number from 1 to 12	1
Day	Day within each month to be calculated	Any possible day in a particular month	21
First Hour	First hour to be calculated. Uses 24-hour clock. Calculates runs at various times for the particular day selected for each month.	Any whole number from 1 to 24	12
Last Hour	Last hour to be calculated Uses 24-hour clock. Calculates runs at various times for the particular day selected for each month.	Any whole number from 1 to 24	12
Step	Hour increment between calculations	Any whole number from 1 to 24	1

Atmospheric Data (Line 5 - 17)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Water Vapor	Thickness , measured in cm, of the condensable water in the atmosphere for the month to be analyzed. This data is obtained from the database of the Atmospheric Sciences Data Center at NASA Langley Research Center (Barkstrom, 2000).		2.22 1.44 1.39 1.64 1.67 1.97 2.61 3.03 3.25 3.2 2.63 2.00 1.88
Turbidity	Turbidity coefficient as Ångström Turbidity. Coefficient for the month to be analyzed. Ångström turbidity has been converted from Linke turbidity using the conversion graph showed at the end of this Appendix.		0.18 0.12 0.13 0.15 0.16 0.18 0.18 0.25 0.23 0.23 0.17 0.14 0.14

Solar Data (Line 18)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Sun Altitude	Sun altitude angle in degrees		56.26
Sun Azimuth	Azimuth in degrees off south.	Positive towards east or counterclockwise.	0.00
Direct Solar Irradiance	Direct solar irradiance on a horizontal plane measured in watts per square meter (W/m^2).	Any positive number	482.00
Luminance Efficacy of Direct Solar Irradiance	Luminance efficacy of direct solar irradiance on a horizontal plane measured in lumens per watt (lm/W).	Any positive number	110
Diffuse Solar Irradiance	Diffuse solar irradiance on a horizontal plane measured in watts per square meter (W/m^2).	Any positive number	214.00
Luminance Efficacy of Direct Solar Irradiance	Luminance efficacy of diffuse solar irradiance on a horizontal plane measured in lumens per watt (lm/W).	Any positive number	110

Overhang Data (Line 19)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Type	Defines the location of devices used to shade the window glass, e.g. overhang, side fins, or extended window sills. An overhang that shades two adjacent windows must be specified separately for each window.	0 = no overhang 1 = top overhang 2 = fins on both sides 3 = bottom overhang 4 = top overhang and side fins 5 = overhang all around 6 = bottom overhang and side fins	1
Property	Defines the opaqueness of the overhang material.	0 = opaque 1 = semitransparent 2 = translucent	0
Depth	Depth of the overhang, measured from the exterior edge of the overhang to the exterior window surface.	The depth must be constant, i.e. the overhang must be of rectangular shape.	0.80
Distance from Window Edge	Distance of the overhang surface facing the window from the exterior edge of the window.		0.10
Reflectance	Reflectance of the overhang surface that faces the window.	Any number from 0 to 1 Concrete = 0.4 Marble = 0.45	0.40
Transmittance	Ratio of the amount of visible light received on the overhang surface facing the window opening (transmitted flux) to that falling onto the overhang surface facing away from the window opening (incident flux).	Any number from 0 to 1	0.00

Sunshine Probability File Name (Line 20)		
Input Name	**Description**	**Use Input**
File Name	The Sunshine Probability Model (SSP) is the ratio of sunshine during on hour, from sunrise to sunset, to the maximum possible time of sunlight that may occur during the defined period (Erhorn, 2000): $SSP = S_{met} / S_{max}$ and $0 \leq SSP \leq 1$, where S_{met} is the direct normal radiation and S_{max} is the maximum normal radiation that may occur. A sunshine probability equal to zero means that the sky was overcast during the whole hour. To obtain this ratio, measured values of direct normal radiation has been used. This data has been obtained from the meteorological centre at the American University of Beirut.	Sswsol.ssp

Lighting System Data (Line 21)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Control Type	Defines the lighting control type	1 = light switch on / off 2 = ideal continuous dimming 3 = Continuous dimming at reference point 4 = 2 steps on / off 5 = 3 steps on / off 6 = 4 steps on / off 7 = manual on / off probability	1

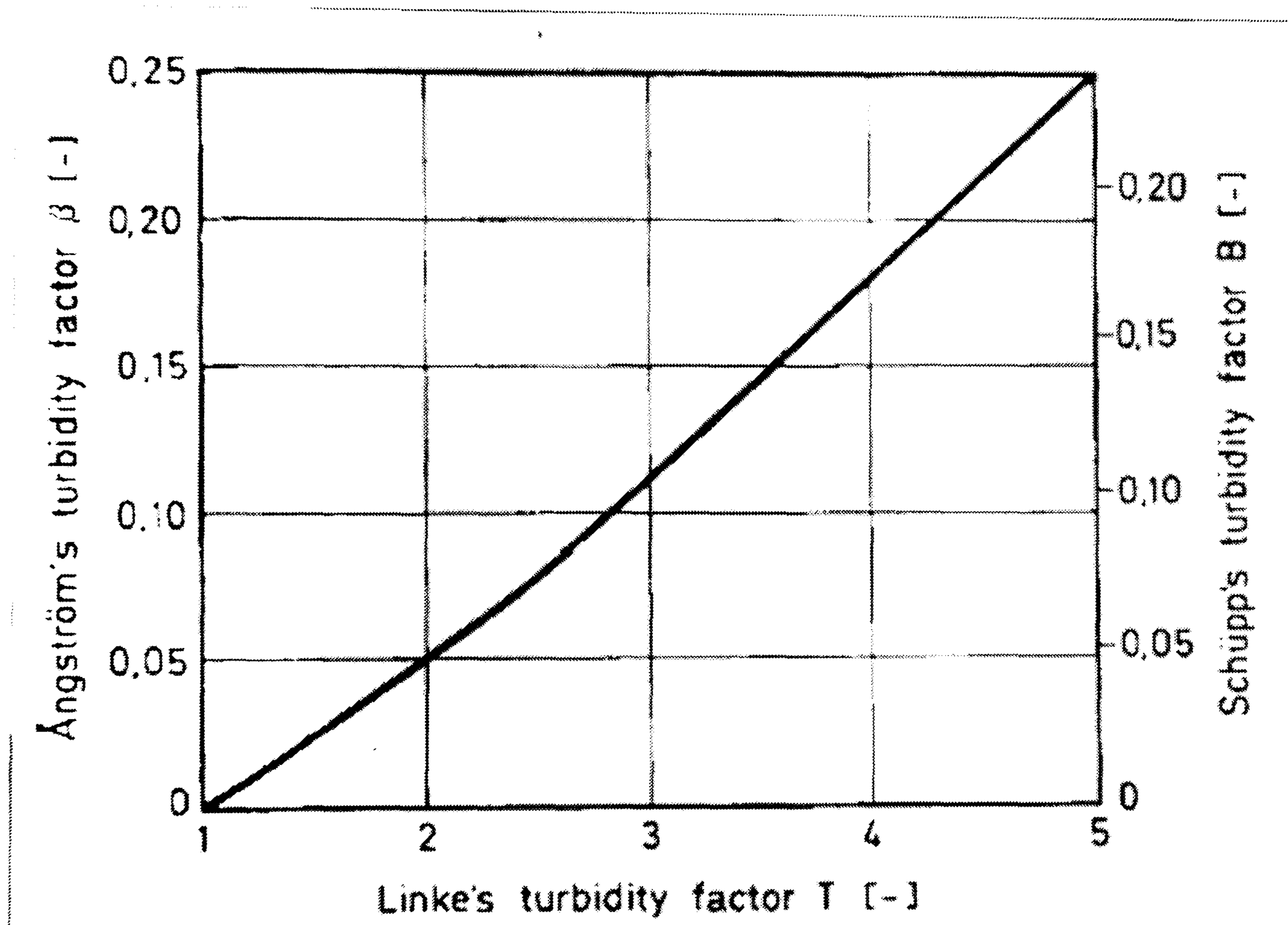
Task Illuminance	Defines the required task illuminance in lux. It is normally based on recommendations for daylight and artificial lighting in working spaces.	A typical office will have a desired work surface illuminance from 200 lux to 500 lux depending on type of activities	500.00
Total Power of System	Defines the power output in Watt of the lighting system for the selected artificial lighting system in the room.	Any positive value	350.00
Luminous Efficacy	Refers to the efficacy of the selected lighting system in lm/W	Any positive value	43.00
Base Load of Dimming System	Defines the minimum fraction (%) of power the lighting system can be reduced to.	Conventional ballast = 15% - 25% Electronic ballast = 0%	1.40

Shading System Data (Line 22)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Shading System Usage	Defines whether a shading system is used or not.	0 = no 1 = yes	0
Type	Defines whether the shading system used is fixed or daylight optimized.	0 = fixed system 1= daylight optimized	0
Shading Coefficient	Defines the shading coefficient of the shading system	Any positive value between 0 and 1	1.00

Occupancy Data (Line 23)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Type of Weekly Schedule	Defines the weekly utilization periods	1 = working the whole week 2 = weekends in a calendary sequence 3 = percentage consideration of weekends	1
First day of Weekend	Defines the first day of the weekend.	Any value between 1 and 7.	6
Number of Working Days per Week	Defines the number of working days per week where the space is utilized.	Any positive value between 1 and 7	5
First of Year	Defines the first day of the year when 'weekends in a calendary sequence' is used	Any positive value between 1 and 7	1
Start of Working Time	Defines the start of working time	Any positive value between 1 and 24	8:00
End of Working Time	Defines the end of working time	Any positive value between 1 and 24	17:00

Holiday Data (Line 24)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Holiday Period Usage	Defines whether a holiday periods are specified	0 = no 1 = yes	0
File Name	Defines the name of holiday period file (*.hol)	Any string of 40 characters maximum	unnamed

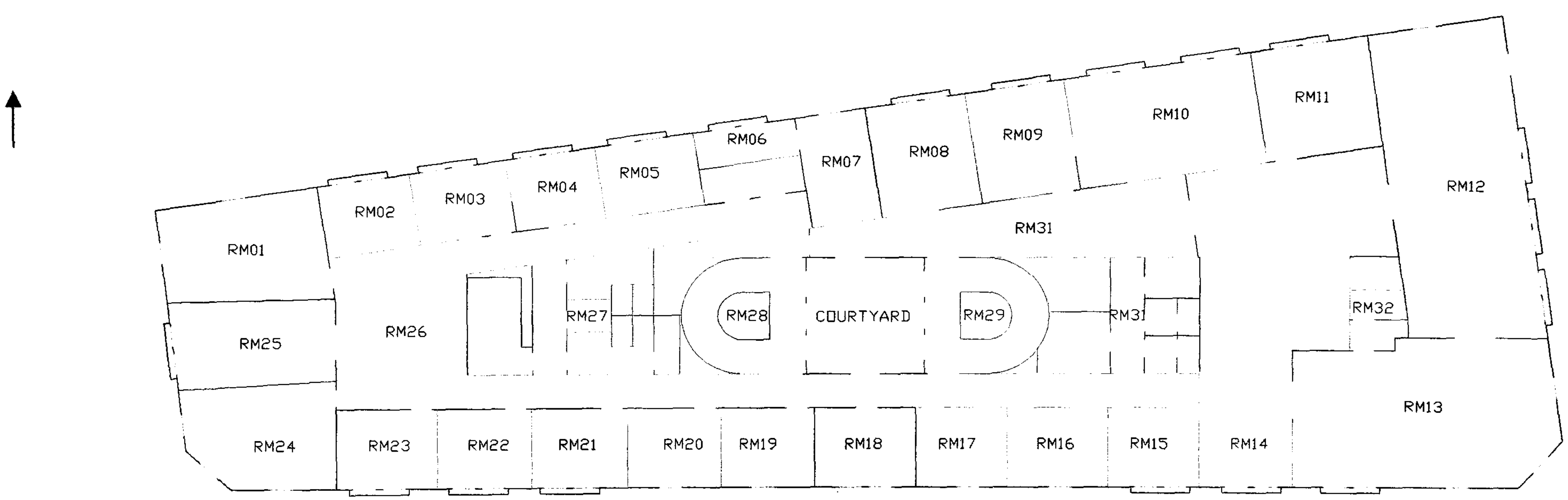
Turbidity Data (Line 25-36)			
Input Name	**Description**	**Input Option, Recommended Values**	**Use Input**
Linke Turbidity	Defines monthly values of Linke turbidity. This data is not within the recorded weather data of Beirut. It has been obtained from the online solar database developed by the Institute of Environment and Sustainability (Huld and Suri, 2002).		3.20 3.30 3.60 5.20 4.00 4.10 5.00 4.80 4.70 3.90 3.50 3.50



Conversion between different turbidity units (Erhorn and Dirksmöller, 2000)

Appendix V. Example of Building Simulation Outputs

B03 - BEIRUT MUNICIPALITY (1925 - 1928)												
CAD Layer Name	DxfConv Layer Code	Scribe Modeller Layer Code	Base	Height	Type	Material						
						Name	Description	Reflectance	Transmittance	Chromacity Values	
										x	y
0 / RAD. VIEW	70	2000	1.7	0	-	-	-	-	-	-	-
N-90WIN	81	20	0.90	2.80	window_b	clear_glass_4	-	-	93.4	0.340	0.342
N-CEILING	78	90	4.00	0.00	surface	2K205	off-white paint	67.50	-	0.330	0.347
N-DOOR	76	30	0.00	2.50	partition	2K219	ivory	64.40	-	0.335	0.359
N-FLOOR	79	95	0.00	0.00	surface	%G45.0	white marble	45.00	-	-	-
N-FWIN	77	25	0.00	3.70	window_a	clear_glass_4	-	-	93.4	0.340	0.342
N-OVERHANG	82	85	4.20	0.00	enclosure_a	%G45.0	white marble	45.00	-	-	-
N-PART	74	40	0.00	4.00	partition	2K205	off-white paint	67.50	-	0.330	0.347
N-PART2	75	45	2.50	1.50	partition	2K205	off-white paint	67.50	-	0.330	0.347
N-WALL	72	50	0.00	4.00	surface	2K205	off-white paint	67.50	-	0.330	0.347
N-WALL1	80	55	0.00	0.90	surface	2K205	off-white paint	67.50	-	0.330	0.347
N-WALL2	73	60	3.70	0.30	surface	2K205	off-white paint	67.50	-	0.330	0.347
N-WORK	71	99	0.80	0.00	work surface	-	-	-	-	-	-



B03 - BEIRUT MUNICIPALITY (1925 - 1928) / LIGHTSWITCH ON-OFF

	North Rooms											East Rooms		South Rooms										West Rooms		Internal Rooms							Total
	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Area	39.66	15.81	16.50	15.48	16.50	9.00	18.77	26.76	26.31	49.85	30.84	101.00	88.56	109.58	17.30	19.12	17.40	19.32	17.80	17.71	18.11	17.91	19.00	35.31	32.66	128.92	78.5	30.67	30.67	51.6	45.3	11.85	1173.77
Power Density (W/m^2)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	-
Total Power (W)	555.24	221.34	231.00	216.72	231.00	126.00	262.78	374.64	368.34	697.90	431.76	1414.00	1239.84	821.85	242.20	267.68	243.60	270.48	249.20	247.94	253.54	250.74	266.00	494.34	457.24	966.90	588.75	230.03	230.03	387.00	339.75	88.88	-
Work Surface Illuminance	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	-
Luminance Efficacy	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	13.33	13.33	13.33	13.33	13.33	13.33	-

Electrical Energy Saved (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.88	0.00	15.38	9.11	8.38	17.44	0.00	8.44	7.97	12.07	12.03	10.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	128.43
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.07	0.00	8.38	9.75	4.46	18.26	0.00	9.04	8.35	8.25	10.41	20.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	130.41
Mar	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.71	0.00	9.48	5.27	4.80	15.92	9.88	9.83	14.41	9.94	10.14	17.00	0.76	0.00	0.00	2.61	7.59	0.00	0.00	0.00	146.25
Apr	7.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.91	16.65	4.44	0.00	0.00	3.73	1.17	0.00	0.00	0.00	89.57
May	6.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.31	13.13	2.81	0.00	0.00	0.00	6.31	0.00	0.00	0.00	31.63
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.04	6.28	3.37	0.00	0.00	0.00	8.45	0.00	0.00	0.00	19.15
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36	14.63	2.85	0.00	0.00	0.00	8.68	0.00	0.00	0.00	27.53
Aug	5.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.73	6.81	6.30	0.00	0.00	0.00	8.30	0.00	0.00	0.00	31.46
Sep	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.98	25.04	3.55	0.00	0.00	4.25	4.55	0.00	0.00	0.00	83.29
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.81	0.00	22.53	6.56	11.73	12.66	0.00	6.08	18.08	17.88	12.34	19.82	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	184.89
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.79	0.00	17.13	9.94	9.04	14.05	0.00	8.70	16.75	16.57	13.11	15.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	137.31
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.49	0.00	10.44	6.03	5.49	10.67	0.00	5.65	7.73	10.45	8.08	7.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	79.66
Year	20.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	256.51	0.00	83.34	46.67	43.90	89.01	9.88	47.73	73.29	75.16	90.43	173.34	24.49	0.00	0.00	10.59	45.06	0.00	0.00	0.00	1089.59

Electrical Energy Consumed (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	319.03	229.29	52.20	65.57	59.58	58.02	69.53	60.74	62.76	57.88	62.19	127.20	127.57	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3572.18
Feb	139.92	55.78	58.21	54.61	58.21	31.75	66.22	94.41	92.82	175.87	108.80	356.33	279.37	207.10	52.65	57.70	56.93	49.90	62.80	53.45	55.55	54.93	56.62	104.14	115.22	242.94	148.37	57.96	57.97	97.52	85.62	22.40	3212.08
Mar	153.99	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	318.20	229.29	58.09	69.41	63.17	59.55	59.65	59.35	56.32	60.02	64.07	120.93	126.81	268.97	164.26	61.56	56.59	107.97	94.79	24.79	3554.35
Apr	142.73	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	284.27	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	65.91	116.82	119.01	260.29	158.96	58.38	60.94	104.49	91.73	23.99	3491.66
May	148.84	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	70.91	124.80	124.76	268.97	164.26	64.18	57.87	107.97	94.79	24.79	3668.98
Jun	149.91	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	334.76	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	70.78	127.19	120.08	260.29	158.96	62.11	53.65	104.49	91.73	23.99	3562.08
Jul	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	72.85	123.29	124.72	268.97	164.26	64.18	55.49	107.97	94.79	24.79	3673.07
Aug	149.59	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	69.49	131.11	121.27	268.97	164.26	64.18	55.88	107.97	94.79	24.79	3669.14
Sep	149.27	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	297.49	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	63.84	108.43	119.90	260.29	158.96	57.86	57.56	104.49	91.73	23.99	3497.94
Oct	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	289.11	229.29	45.04	68.12	56.23	62.81	69.53	63.10	52.66	52.08	61.87	118.10	127.17	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3515.71
Nov	149.91	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	317.97	221.90	48.27	62.34	56.73	58.98	67.28	58.24	51.70	51.13	58.71	118.25	123.45	260.29	158.96	62.11	62.11	104.49	91.73	23.99	3443.93
Dec	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	338.43	229.29	57.13	68.65	62.47	64.79	69.53	63.53	63.01	59.51	66.13	130.30	127.57	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3620.95
Year	1803.81	727.10	758.83	711.92	758.83	413.91	863.23	1230.69	1209.99	2292.60	1418.33	4644.98	3816.37	2699.74	712.29	832.66	756.33	799.52	808.74	766.76	759.59	748.52	783.38	1450.56	1477.54	3166.87	1934.04	745.03	710.59	1271.30	1116.08	291.94	42482.06

Electrical Energy Saved (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.89	0.48	0.48	0.90	0.00	0.48	0.44	0.67	0.63	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.48	0.51	0.26	0.95	0.00	0.51	0.46	0.46	0.55	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Mar	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.55	0.28	0.28	0.82	0.55	0.55	0.80	0.55	0.53	0.48	0.02	0.00	0.00	0.09	0.25	0.00	0.00	0.00	0.12
Apr	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.47	0.14	0.00	0.00	0.12	0.04	0.00	0.00	0.00	0.08
May	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.37	0.09	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.03
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.18	0.10	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.02
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.41	0.09	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.02
Aug	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.19	0.19	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.03
Sep	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.71	0.11	0.00	0.00	0.14	0.15	0.00	0.00	0.00	0.07
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.00	1.30	0.34	0.67	0.66	0.00	0.34	1.00	1.00	0.65	0.56	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.99	0.52	0.52	0.73	0.00	0.49	0.92	0.92	0.69	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.60	0.32	0.32	0.55	0.00	0.32	0.43	0.58	0.43	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Year	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.90	0.00	4.82	2.44	2.52	4.61	0.55	2.69	4.05	4.20	4.76	4.91	0.75	0.00	0.00	0.35	1.47	0.00	0.00	0.00	0.93

Electrical Energy Consumed (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.60	2.09	3.02	3.43	3.42	3.00	3.91	3.43	3.47	3.23	3.27	3.60	3.91	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.04
Feb	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.15	1.89	3.04	3.02	3.27	2.58	3.53	3.02	3.07	3.07	2.98	2.95	3.53	1.88	1.89	1.89	1.89	1.89	1.89	1.89	2.74
Mar	3.88	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.59	2.09	3.36	3.63	3.63	3.08	3.35	3.35	3.11	3.35	3.37	3.42	3.88	2.09	2.09	2.01	1.84	2.09	2.09	2.09	3.03
Apr	3.60	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.21	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.47	3.31	3.64	2.02	2.03	1.90	1.99	2.03	2.03	2.02	2.97
May	3.75	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.73	3.53	3.82	2.09	2.09	2.09	1.89	2.09	2.09	2.09	3.13
Jun	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.73	3.60	3.68	2.02	2.03	2.02	1.75	2.03	2.03	2.02	3.03
Jul	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.83	3.49	3.82	2.09	2.09	2.09	1.81	2.09	2.09	2.09	3.13
Aug	3.77	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.66	3.71	3.71	2.09	2.09	2.09	1.82	2.09	2.09	2.09	3.13
Sep	3.76	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.36	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.36	3.07	3.67	2.02	2.03	1.89	1.88	2.03	2.03	2.02	2.98
Oct	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.26	2.09	2.60	3.56	3.23	3.25	3.91	3.56	2.91	2.91	3.26	3.34	3.89	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.00
Nov	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.59	2.02	2.79	3.26	3.26	3.05	3.78	3.29	2.86	2.86	3.09	3.35	3.78	2.02	2.03	2.02	2.03	2.03	2.03	2.02	2.93
Dec	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.82	2.09	3.30	3.59	3.59	3.35	3.91	3.59	3.48	3.32	3.48	3.69	3.91	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.08
Year	45.48	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	43.09	24.64	41.17	43.55	43.47	41.38	45.44	43.30	41.94	41.79	41.23	41.08	45.24	24.56	24.64	24.29	23.17	24.64	24.64	24.64	1259.27

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Total yearly working hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
Total yearly lamp operation hours (h/a)	3248.72	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3078.12	2940.91	2940.90	3110.66	3104.80	2955.94	3245.37	3092.51	2995.94	2985.26	2989.07	2934.35	3231.45	3285.00	3285.00	3238.98	3089.45	3285.00	3285.00	3285.00	-
Total yearly switch-on hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3279.00	3279.00	3279.00	3280.00	3278.00	3284.00	3280.00	3279.00	3278.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
No art. lighting required refering to working time (%)	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.30	10.50	10.50	5.30	5.50	10.00	1.20	5.90	8.80	9.10	9.00	10.70	1.60	0.00	0.00	1.40	6.00	0.00	0.00	0.00	-

B03 - BEIRUT MUNICIPALITY (1925 - 1928) / IDEAL CONTINUOUS DIMMING

	North Rooms											East Rooms		South Rooms										West Rooms		Internal Rooms							Total
	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Area	39.66	15.81	16.50	15.48	16.50	9.00	18.77	26.76	26.31	49.85	30.84	101.00	88.56	109.58	17.30	19.12	17.40	19.32	17.80	17.71	18.11	17.91	19.00	35.31	32.66	128.92	78.5	30.67	30.67	51.6	45.3	11.85	1173.77
Power Density (W/m²)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	-
Total Power (W)	555.24	221.34	231.00	216.72	231.00	126.00	262.78	374.64	368.34	697.90	431.76	1414.00	1239.84	821.85	242.20	267.68	243.60	270.48	249.20	247.94	253.54	250.74	266.00	494.34	457.24	966.90	588.75	230.03	230.03	387.00	339.75	88.88	-
Work Surface Illuminance	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	-
Luminance Efficacy	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	13.33	13.33	13.33	13.33	13.33	13.33	-

Electrical Energy Saved (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	3.54	0.90	0.94	0.88	0.94	0.51	1.73	1.52	1.50	2.84	1.76	5.75	48.68	33.38	11.31	6.33	6.06	12.18	3.75	7.15	11.22	11.27	11.95	15.69	3.49	9.06	21.50	5.98	4.86	9.90	9.01	2.45	268.02
Feb	4.10	0.88	0.92	0.86	0.92	0.50	1.83	1.49	1.47	2.78	1.72	5.64	49.36	33.78	9.92	6.14	5.08	11.26	4.09	6.20	10.24	9.90	10.50	17.61	3.57	8.89	22.76	6.43	5.43	10.15	9.77	2.43	266.63
Mar	4.83	0.90	0.94	0.88	0.94	0.51	2.39	1.52	1.49	2.83	1.75	5.74	47.00	36.30	8.75	5.19	5.08	9.90	4.34	5.63	9.61	9.22	9.78	19.10	5.19	9.03	29.68	7.64	8.55	11.35	11.46	2.55	280.09
Apr	6.44	0.90	0.94	0.89	0.94	0.55	2.44	1.53	1.51	2.94	1.76	5.78	41.92	34.83	5.75	3.84	3.74	6.63	2.68	3.75	5.83	5.88	6.23	20.06	6.65	9.10	36.25	9.33	6.19	14.79	13.26	2.57	265.91
May	7.87	1.07	1.16	0.99	1.11	0.75	2.13	1.62	1.59	3.19	1.97	6.12	24.50	38.03	3.82	2.76	2.34	3.76	1.03	2.38	3.52	4.17	4.43	15.21	7.62	9.74	44.78	8.83	8.50	20.76	15.79	2.72	254.26
Jun	7.48	1.10	1.34	1.08	1.15	1.09	2.12	1.57	1.55	3.69	2.03	5.53	20.81	41.27	1.22	1.92	2.02	3.12	0.73	2.04	1.27	0.98	1.04	12.65	6.49	8.95	53.92	9.11	10.42	25.06	16.57	2.61	251.94
Jul	7.30	1.11	1.22	1.04	1.16	0.84	2.14	1.62	1.59	3.51	1.87	5.77	21.99	40.69	2.75	2.99	2.47	3.82	0.72	2.27	2.88	2.32	2.46	12.41	6.53	9.29	50.27	9.69	10.75	23.35	16.31	2.73	255.86
Aug	6.22	0.97	1.01	0.95	1.01	0.59	2.20	1.58	1.55	3.17	1.82	5.95	39.81	40.04	4.73	3.02	2.59	4.68	1.59	3.05	4.60	4.81	5.10	17.67	7.42	9.38	43.77	10.22	10.15	19.08	15.41	2.82	276.97
Sep	5.02	0.88	0.92	0.86	0.92	0.50	2.42	1.49	1.46	2.77	1.71	5.61	57.29	40.00	7.84	4.75	4.55	8.03	3.13	4.39	7.57	7.72	8.19	23.58	6.19	8.84	38.67	8.76	8.96	13.27	13.12	2.68	302.06
Oct	4.79	0.90	0.94	0.88	0.94	0.51	2.28	1.53	1.50	2.84	1.76	5.76	69.13	40.99	12.19	6.37	7.48	11.17	4.30	5.90	11.25	11.94	12.67	23.53	5.83	9.07	27.13	7.81	6.79	11.45	11.07	2.72	323.40
Nov	3.49	0.86	0.89	0.84	0.89	0.49	1.56	1.45	1.42	2.70	1.67	5.46	47.05	34.23	11.31	6.90	7.29	12.31	4.00	6.74	11.42	12.51	13.27	16.68	3.46	8.61	21.27	6.05	5.35	9.86	8.89	2.38	271.29
Dec	2.82	0.88	0.92	0.86	0.92	0.50	1.36	1.49	1.47	2.78	1.72	5.64	32.11	27.40	7.85	4.52	4.54	8.19	2.04	4.40	7.59	8.12	8.61	10.57	2.34	8.88	17.25	5.22	4.69	9.11	7.99	2.17	204.98
Year	63.89	11.35	12.13	11.01	11.85	7.35	24.60	18.42	18.11	36.04	21.55	68.76	499.64	440.94	87.45	54.72	53.24	95.04	32.40	53.90	87.01	88.84	94.24	204.78	64.78	108.83	407.23	95.07	90.64	178.12	148.65	30.83	3221.41

Electrical Energy Consumed (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	151.37	60.85	63.51	59.58	63.51	34.64	71.59	103.00	101.27	191.88	118.71	388.76	297.24	195.92	56.26	68.35	61.90	63.29	65.78	62.03	59.52	11.27	62.26	122.23	124.08	259.91	142.76	58.19	59.32	98.07	85.78	22.34	3385.17
Feb	135.82	54.89	57.29	53.75	57.29	31.25	64.39	92.91	91.35	173.09	107.08	350.69	263.08	173.33	51.11	61.32	56.30	56.90	58.71	56.28	53.65	9.90	56.53	106.97	111.66	234.05	125.61	51.54	52.53	87.38	75.85	19.96	3032.45
Mar	150.08	60.86	63.51	59.59	63.51	34.64	70.92	103.00	101.27	191.88	118.71	388.77	298.92	192.99	58.82	69.49	62.88	65.57	65.19	63.54	61.12	9.22	64.43	118.82	122.38	259.93	134.58	56.53	55.63	96.62	83.33	22.24	3369.00
Apr	143.48	58.86	61.43	57.63	61.43	33.47	68.51	99.62	97.95	185.49	114.81	376.00	292.83	187.06	59.64	68.43	62.03	66.40	64.61	63.19	62.63	5.88	65.59	113.41	116.81	251.19	122.71	52.78	55.92	89.70	78.47	21.42	3259.37
May	147.05	60.69	63.29	59.47	63.34	34.40	71.19	102.90	101.17	191.52	118.49	388.38	321.42	191.26	63.75	71.92	65.63	71.71	68.50	66.79	67.22	4.17	69.79	122.71	119.95	259.23	119.48	55.34	55.68	87.21	79.00	22.08	3384.74
Jun	142.43	58.66	61.03	57.43	61.22	32.93	68.83	99.58	97.90	184.75	114.55	376.25	313.95	180.63	64.18	70.35	63.76	69.91	66.55	64.91	67.18	0.98	70.78	120.82	116.96	251.34	105.04	53.00	51.69	79.43	75.16	21.38	3263.56
Jul	147.61	60.64	63.23	59.43	63.29	34.31	71.18	102.90	101.17	191.21	118.59	388.73	323.92	188.60	64.82	71.70	65.49	71.64	68.80	66.91	67.86	2.32	71.75	125.51	121.04	259.67	114.00	54.48	53.43	84.62	78.49	22.07	3379.43
Aug	148.69	60.79	63.44	59.52	63.44	34.56	71.12	102.95	101.22	191.55	118.64	388.55	306.11	189.25	62.85	71.67	65.37	70.78	67.94	66.12	66.14	4.81	69.11	120.25	120.15	259.59	120.49	53.96	54.03	88.89	79.38	21.97	3363.30
Sep	144.90	58.88	61.45	57.65	61.45	33.52	68.53	99.67	97.99	185.66	114.86	376.17	277.47	181.90	57.55	67.53	61.23	65.00	64.15	62.55	60.89	7.72	63.63	109.89	117.27	251.45	120.30	53.35	53.14	91.22	78.62	21.32	3226.91
Oct	150.12	60.85	63.51	59.58	63.51	34.64	71.04	103.00	101.27	191.87	118.70	388.75	276.79	188.31	55.39	68.31	60.48	64.29	65.23	63.28	59.49	11.94	61.55	114.40	121.74	259.90	137.13	56.36	57.39	96.52	83.72	22.07	3331.13
Nov	146.42	58.91	61.48	57.68	61.48	33.53	69.39	99.70	98.03	185.74	114.91	376.32	287.71	187.66	54.08	65.37	58.49	60.72	63.28	60.21	57.03	12.51	58.55	116.79	120.00	251.69	137.70	56.06	56.76	94.63	82.84	21.61	3267.26
Dec	152.10	60.87	63.53	59.60	63.53	34.65	71.96	103.03	101.30	191.93	118.74	388.87	313.81	201.89	59.72	70.17	63.42	67.27	67.48	64.77	63.15	8.12	65.60	127.35	125.23	260.09	147.01	58.96	59.49	98.86	86.80	22.62	3441.91
Year	1760.07	715.75	746.70	700.91	746.98	406.56	838.63	1212.27	1191.89	2256.56	1396.79	4576.23	3573.24	2258.81	708.18	824.61	746.98	793.48	786.23	760.58	745.87	88.84	779.57	1419.13	1437.26	3058.04	1526.81	660.55	665.01	1093.17	967.43	261.10	39704.23

Electrical Energy Saved (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.09	0.06	0.06	0.06	0.06	0.06	0.09	0.06	0.06	0.06	0.06	0.06	0.55	0.30	0.65	0.33	0.35	0.63	0.21	0.40	0.62	0.63	0.63	0.44	0.11	0.07	0.27	0.20	0.16	0.19	0.20	0.21	0.23
Feb	0.10	0.06	0.06	0.06	0.06	0.06	0.10	0.06	0.06	0.06	0.06	0.06	0.56	0.31	0.57	0.32	0.29	0.58	0.23	0.35	0.57	0.55	0.55	0.50	0.11	0.07	0.29	0.21	0.18	0.20	0.22	0.21	0.23
Mar	0.12	0.06	0.06	0.06	0.06	0.06	0.13	0.06	0.06	0.06	0.06	0.06	0.53	0.33	0.51	0.27	0.29	0.51	0.24	0.32	0.53	0.51	0.51	0.54	0.16	0.07	0.38	0.25	0.28	0.22	0.25	0.22	0.24
Apr	0.16	0.06	0.06	0.06	0.06	0.06	0.13	0.06	0.06	0.06	0.06	0.06	0.47	0.32	0.33	0.20	0.22	0.34	0.15	0.21	0.32	0.33	0.33	0.57	0.20	0.07	0.46	0.30	0.20	0.29	0.29	0.22	0.23
May	0.20	0.07	0.07	0.06	0.07	0.08	0.11	0.06	0.06	0.06	0.06	0.06	0.28	0.35	0.22	0.14	0.13	0.19	0.06	0.13	0.19	0.23	0.23	0.43	0.23	0.08	0.57	0.29	0.28	0.40	0.35	0.23	0.22
Jun	0.19	0.07	0.08	0.07	0.07	0.12	0.11	0.06	0.06	0.07	0.07	0.05	0.23	0.38	0.07	0.10	0.12	0.16	0.04	0.12	0.07	0.05	0.05	0.36	0.20	0.07	0.69	0.30	0.34	0.49	0.37	0.22	0.21
Jul	0.18	0.07	0.07	0.07	0.07	0.09	0.11	0.06	0.06	0.07	0.06	0.06	0.25	0.37	0.16	0.16	0.14	0.20	0.04	0.13	0.16	0.13	0.13	0.35	0.20	0.07	0.64	0.32	0.35	0.45	0.36	0.23	0.22
Aug	0.16	0.06	0.06	0.06	0.06	0.07	0.12	0.06	0.06	0.06	0.06	0.06	0.45	0.37	0.27	0.16	0.15	0.24	0.09	0.17	0.25	0.27	0.27	0.50	0.23	0.07	0.56	0.33	0.33	0.37	0.34	0.24	0.24
Sep	0.13	0.06	0.06	0.06	0.06	0.06	0.13	0.06	0.06	0.06	0.06	0.06	0.65	0.36	0.45	0.25	0.26	0.42	0.18	0.25	0.42	0.43	0.43	0.67	0.19	0.07	0.49	0.29	0.29	0.26	0.29	0.23	0.26
Oct	0.12	0.06	0.06	0.06	0.06	0.06	0.12	0.06	0.06	0.06	0.06	0.06	0.78	0.37	0.70	0.33	0.43	0.58	0.24	0.33	0.62	0.67	0.67	0.67	0.18	0.07	0.35	0.25	0.22	0.22	0.24	0.23	0.28
Nov	0.09	0.05	0.05	0.05	0.05	0.05	0.08	0.05	0.05	0.05	0.05	0.05	0.53	0.31	0.65	0.36	0.42	0.64	0.22	0.38	0.63	0.70	0.70	0.47	0.11	0.07	0.27	0.20	0.17	0.19	0.20	0.20	0.23
Dec	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.36	0.25	0.45	0.24	0.26	0.42	0.11	0.25	0.42	0.45	0.45	0.30	0.07	0.07	0.22	0.17	0.15	0.18	0.18	0.18	0.17
Year	1.61	0.72	0.74	0.71	0.72	0.82	1.31	0.69	0.69	0.72	0.70	0.68	5.64	4.02	5.05	2.86	3.06	4.92	1.82	3.04	4.80	4.96	4.96	5.80	1.98	0.84	5.19	3.10	2.96	3.45	3.28	2.60	2.74

Electrical Energy Consumed (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	3.82	3.85	3.85	3.85	3.85	3.85	3.81	3.85	3.85	3.85	3.85	3.85	3.36	1.79	3.25	3.57	3.56	3.28	3.70	3.50	3.29	0.63	3.28	3.46	3.80	2.02	1.82	1.90	1.93	1.90	1.89	1.89	2.88
Feb	3.42	3.47	3.47	3.47	3.47	3.47	3.43	3.47	3.47	3.47	3.47	3.47	2.97	1.58	2.95	3.21	3.24	2.95	3.30	3.18	2.96	0.55	2.98	3.03	3.42	1.82	1.60	1.68	1.71	1.69	1.67	1.68	2.58
Mar	3.78	3.85	3.85	3.85	3.85	3.85	3.78	3.85	3.85	3.85	3.85	3.85	3.38	1.76	3.40	3.63	3.61	3.39	3.66	3.59	3.38	0.51	3.39	3.36	3.75	2.02	1.71	1.84	1.81	1.87	1.84	1.88	2.87
Apr	3.62	3.72	3.72	3.72	3.72	3.72	3.65	3.72	3.72	3.72	3.72	3.72	3.31	1.71	3.45	3.58	3.56	3.44	3.63	3.57	3.46	0.33	3.45	3.21	3.58	1.95	1.56	1.72	1.82	1.74	1.73	1.81	2.78
May	3.71	3.84	3.84	3.84	3.84	3.82	3.79	3.85	3.85	3.84	3.84	3.85	3.63	1.75	3.68	3.76	3.77	3.71	3.85	3.77	3.71	0.23	3.67	3.48	3.67	2.01	1.52	1.80	1.82	1.69	1.74	1.86	2.88
Jun	3.59	3.71	3.70	3.71	3.71	3.66	3.67	3.72	3.72	3.71	3.71	3.73	3.55	1.65	3.71	3.68	3.66	3.62	3.74	3.66	3.71	0.05	3.73	3.42	3.58	1.95	1.34	1.73	1.69	1.54	1.66	1.80	2.78
Jul	3.72	3.84	3.83	3.84	3.84	3.81	3.79	3.85	3.85	3.84	3.85	3.85	3.66	1.72	3.75	3.75	3.76	3.71	3.87	3.78	3.75	0.13	3.78	3.55	3.71	2.01	1.45	1.78	1.74	1.64	1.73	1.86	2.88
Aug	3.75	3.84	3.84	3.84	3.84	3.84	3.79	3.85	3.85	3.84	3.85	3.85	3.46	1.73	3.63	3.75	3.76	3.66	3.82	3.73	3.65	0.27	3.64	3.41	3.68	2.01	1.53	1.76	1.76	1.72	1.75	1.85	2.87
Sep	3.65	3.72	3.72	3.72	3.72	3.72	3.65	3.72	3.72	3.72	3.72	3.72	3.13	1.66	3.33	3.53	3.52	3.36	3.60	3.53	3.36	0.43	3.35	3.11	3.59	1.95	1.53	1.74	1.73	1.77	1.74	1.80	2.75
Oct	3.79	3.85	3.85	3.85	3.85	3.85	3.78	3.85	3.85	3.85	3.85	3.85	3.13	1.72	3.20	3.57	3.48	3.33	3.66	3.57	3.28	0.67	3.24	3.24	3.73	2.02	1.75	1.84	1.87	1.87	1.85	1.86	2.84
Nov	3.69	3.73	3.73	3.73	3.73	3.73	3.70	3.73	3.73	3.73	3.73	3.73	3.25	1.71	3.13	3.42	3.36	3.14	3.56	3.40	3.15	0.70	3.08	3.31	3.67	1.95	1.75	1.83	1.85	1.83	1.83	1.82	2.78
Dec	3.84	3.85	3.85	3.85	3.85	3.85	3.83	3.85	3.85	3.85	3.85	3.85	3.54	1.84	3.45	3.67	3.64	3.48	3.79	3.66	3.49	0.45	3.45	3.61	3.83	2.02	1.87	1.92	1.94	1.92	1.92	1.91	2.93
Year	44.38	45.27	45.25	45.28	45.27	45.17	44.68	45.30	45.30	45.27	45.29	45.31	40.35	20.61	40.94	43.13	42.93	41.07	44.17	42.95	41.19	4.96	41.03	40.19	44.01	23.72	19.45	21.54	21.68	21.19	21.36	22.03	1180.26

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Total yearly working hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
Total yearly lamp operation hours (h/a)	3217.46	3282.28	3281.04	3282.78	3282.28	3275.10	3239.29 [h/	3284.46	3284.46	3281.94	3283.70	3285.00	2925.16	2967.69	2967.69	3126.77	3112.43	2977.52	3260.42	3113.59	2995.94	2985.84	2974.54	2913.65	3190.42	3285.00	2800.65	3100.86	3089.45	3050.36	3074.89	3172.90	-
Total yearly switch-on hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00 [h/	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3279.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
No art. lighting required refering to working time (%)	2.10	0.10	0.10	0.10	0.10	0.30	1.40	0.00	0.00	0.10	0.00	0.00	11.00	9.70	9.70	4.80	5.30	9.40	0.70	5.20	8.80	9.10	9.60	11.30	2.90	0.00	14.70	5.60	6.00	7.10	6.40	3.40	-

B03 - BEIRUT MUNICIPALITY (1925 - 1928) / CONTINUOUS DIMMING OF REFERENCE POINT

	North Rooms											East Rooms		South Rooms										West Rooms		Internal Rooms							Total
	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Area	39.66	15.81	16.50	15.48	16.50	9.00	18.77	26.76	26.31	49.85	30.84	101.00	88.56	109.58	17.30	19.12	17.40	19.32	17.80	17.71	18.11	17.91	19.00	35.31	32.66	128.92	78.5	30.67	30.67	51.6	45.3	11.85	1173.77
Power Density (W/m^2)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	-
Total Power (W)	555.24	221.34	231.00	216.72	231.00	126.00	262.78	374.64	368.34	697.90	431.76	1414.00	1239.84	821.85	242.20	267.68	243.60	270.48	249.20	247.94	253.54	250.74	266.00	494.34	457.24	966.90	588.75	230.03	230.03	387.00	339.75	88.88	-
Work Surface Illuminance	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	-
Luminance Efficacy	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	13.33	13.33	13.33	13.33	13.33	13.33	-

Electrical Energy Saved (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	2.26	0.90	0.94	0.88	0.94	0.51	1.07	1.52	1.50	2.84	1.76	5.75	31.48	16.71	16.12	10.06	9.24	18.27	6.02	9.32	8.88	12.91	13.69	12.55	1.86	9.06	11.97	4.68	4.01	7.87	6.91	1.81	234.30
Feb	2.22	0.88	0.92	0.86	0.92	0.50	1.05	1.49	1.47	2.78	1.72	5.64	37.46	16.40	9.21	10.66	5.36	19.04	7.97	9.88	9.22	9.12	9.67	22.07	1.82	8.89	11.75	4.59	3.88	7.72	6.78	1.77	233.71
Mar	3.16	0.90	0.94	0.88	0.94	0.51	1.07	1.52	1.49	2.83	1.75	5.74	32.30	16.67	10.33	6.28	5.71	16.78	9.88	10.69	15.23	10.81	15.98	18.75	2.60	9.03	11.94	7.06	11.40	7.85	6.89	1.80	249.71
Apr	9.33	0.90	0.94	0.89	0.94	0.51	1.07	1.53	1.51	2.85	1.76	5.78	54.82	16.79	0.99	1.09	1.00	1.11	0.01	1.01	1.04	1.02	1.09	18.42	6.23	9.10	12.03	8.12	5.16	7.91	6.94	1.82	183.72
May	8.37	0.96	1.00	0.94	1.00	0.55	1.14	1.62	1.59	3.02	1.87	6.12	5.37	17.79	1.05	1.16	1.05	1.17	0.01	1.07	1.10	1.09	1.15	15.04	4.74	9.64	12.74	4.98	10.16	8.38	7.35	1.92	135.14
Jun	2.17	0.87	0.90	0.85	0.90	0.49	1.03	1.47	1.44	2.73	1.69	5.53	4.85	16.07	0.95	1.05	0.95	1.06	0.01	0.97	0.99	0.98	1.04	8.10	5.11	8.71	11.52	4.50	11.86	7.57	6.65	1.74	114.74
Jul	2.27	0.90	0.94	0.88	0.94	0.51	1.07	1.53	1.50	2.85	1.76	5.77	5.06	16.77	0.99	1.09	0.99	1.10	0.01	1.01	1.04	1.02	1.09	16.40	4.67	9.09	12.02	4.69	12.27	7.90	6.93	1.81	126.92
Aug	7.57	0.93	0.97	0.91	0.97	0.53	1.11	1.58	1.55	2.94	1.82	5.95	5.22	17.30	1.02	1.13	1.03	1.14	0.01	1.04	1.07	1.06	1.12	8.78	8.12	9.38	12.40	4.84	12.01	8.15	7.15	1.87	130.67
Sep	2.84	0.88	0.92	0.86	0.92	0.50	1.04	1.49	1.46	2.77	1.71	5.61	41.63	16.31	0.96	1.06	0.97	1.07	0.01	0.98	1.01	1.00	1.06	26.65	5.31	8.84	11.68	8.47	8.15	7.68	6.74	1.76	172.35
Oct	2.26	0.90	0.94	0.88	0.94	0.51	1.07	1.53	1.50	2.84	1.76	5.76	61.00	16.73	23.20	7.56	12.56	13.58	5.90	7.00	18.85	18.65	19.76	21.53	2.26	9.07	11.98	4.68	3.97	7.88	6.92	1.81	295.79
Nov	2.15	0.86	0.89	0.84	0.89	0.49	1.02	1.45	1.42	2.70	1.67	5.46	21.31	15.88	17.80	10.82	9.85	14.88	6.57	9.53	17.47	17.28	18.33	16.89	1.77	8.61	11.38	4.44	3.82	7.48	6.56	1.72	242.20
Dec	2.21	0.88	0.92	0.86	0.92	0.50	1.05	1.49	1.47	2.78	1.72	5.64	12.31	16.38	11.23	7.00	6.37	11.57	3.72	6.54	8.61	11.27	11.96	9.46	1.82	8.88	11.74	4.59	4.05	7.71	6.77	1.77	184.21
Year	46.81	10.76	11.23	10.54	11.23	6.13	12.78	18.22	17.91	33.94	21.00	68.76	312.80	199.81	93.85	58.96	55.08	100.78	40.12	59.05	84.50	86.20	95.95	194.65	46.32	108.29	143.14	65.64	90.73	94.09	82.60	21.61	2303.46

Electrical Energy Consumed (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	152.65	60.85	63.51	59.58	63.51	34.64	72.25	103.00	101.27	191.88	118.71	388.76	314.43	212.58	51.45	64.62	58.72	57.19	63.50	59.86	61.85	57.05	60.52	125.37	125.71	259.91	152.29	59.50	60.16	100.10	87.88	22.99	3466.31
Feb	137.70	54.89	57.29	53.75	57.29	31.25	65.17	92.91	91.35	173.09	107.08	350.69	274.98	190.71	51.82	56.79	56.03	49.12	54.83	52.60	54.67	54.07	57.36	102.51	113.40	234.05	136.62	53.38	54.09	89.80	78.84	20.62	3108.77
Mar	151.75	60.86	63.51	59.59	63.51	34.64	72.25	103.00	101.27	191.88	118.71	388.77	313.62	212.63	57.24	68.40	62.25	58.68	59.65	58.48	55.51	59.14	58.24	119.17	124.97	259.93	152.32	57.12	52.78	100.12	87.90	22.99	3450.90
Apr	140.58	58.86	61.43	57.63	61.43	33.51	69.88	99.62	97.95	185.58	114.81	376.00	279.94	205.11	64.40	71.18	64.78	71.92	67.27	65.93	67.42	66.68	70.73	115.05	117.22	251.19	146.93	53.98	56.95	96.58	84.79	22.18	3397.51
May	146.54	60.80	63.45	59.53	63.45	34.61	72.18	102.90	101.17	191.69	118.59	388.38	340.55	211.51	66.53	73.52	66.91	74.29	69.52	68.10	69.64	68.87	73.06	122.88	122.83	259.33	151.52	59.20	54.02	99.60	87.44	22.87	3565.47
Jun	147.74	58.90	61.47	57.67	61.47	33.53	69.92	99.69	98.01	185.70	114.89	376.25	329.91	205.82	64.45	71.23	64.82	71.97	67.27	65.97	67.46	66.72	70.78	125.37	118.35	251.58	147.45	57.51	50.25	96.92	85.09	22.26	3466.49
Jul	152.65	60.85	63.51	59.58	63.51	34.64	72.24	103.00	101.26	191.86	118.70	388.73	340.85	212.52	66.59	73.59	66.97	74.36	69.52	68.16	69.70	68.93	73.13	121.52	122.90	259.88	152.24	59.48	51.91	100.07	87.86	22.98	3573.69
Aug	147.34	60.82	63.48	59.55	63.48	34.62	72.21	102.95	101.22	191.78	118.64	388.55	340.69	211.99	66.55	73.56	66.94	74.32	69.52	68.13	69.67	68.90	73.09	129.14	119.45	259.59	151.86	59.33	52.17	99.82	87.64	22.92	3569.94
Sep	147.08	58.88	61.45	57.65	61.45	33.52	69.91	99.67	97.99	185.66	114.86	376.17	293.12	205.59	64.43	71.21	64.81	71.96	67.27	65.96	67.45	66.70	70.76	106.82	118.14	251.45	147.28	53.63	53.96	96.81	84.99	22.23	3408.88
Oct	152.65	60.85	63.51	59.58	63.51	34.64	72.25	103.00	101.27	191.87	118.70	388.75	284.92	212.56	44.38	67.12	55.41	61.89	63.63	62.17	51.88	51.31	54.43	116.39	125.31	259.90	152.28	59.49	60.20	100.09	87.87	22.99	3404.82
Nov	147.77	58.91	61.48	57.68	61.48	33.53	69.94	99.70	98.03	185.74	114.91	376.32	313.45	206.02	47.59	61.46	55.93	58.15	60.72	57.42	50.99	50.42	53.49	116.58	121.69	251.69	147.59	57.66	58.28	97.01	85.17	22.28	3339.03
Dec	152.70	60.87	63.53	59.60	63.53	34.65	72.27	103.03	101.30	191.93	118.74	388.87	333.61	212.91	56.34	67.68	61.59	63.89	65.80	62.64	62.13	58.69	62.26	128.46	125.75	260.09	152.53	59.59	60.13	100.26	88.02	23.02	3516.40
Year	1777.16	716.34	747.60	701.39	747.60	407.78	850.45	1212.47	1192.09	2258.66	1397.34	4576.23	3760.07	2499.94	701.78	820.37	745.15	787.75	778.51	755.43	748.38	737.48	777.86	1429.26	1455.71	3058.58	1790.91	689.97	664.92	1177.21	1033.48	270.33	41268.19

Electrical Energy Saved (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.36	0.15	0.93	0.53	0.53	0.95	0.34	0.53	0.49	0.72	0.72	0.36	0.06	0.07	0.15	0.15	0.13	0.15	0.15	0.15	0.20
Feb	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.42	0.15	0.53	0.56	0.31	0.99	0.45	0.56	0.51	0.51	0.51	0.62	0.06	0.07	0.15	0.15	0.13	0.15	0.15	0.15	0.20
Mar	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.36	0.15	0.60	0.33	0.33	0.87	0.55	0.60	0.84	0.60	0.84	0.53	0.08	0.07	0.15	0.23	0.37	0.15	0.15	0.15	0.21
Apr	0.24	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.62	0.15	0.06	0.06	0.06	0.06	0.00	0.06	0.06	0.06	0.06	0.52	0.19	0.07	0.15	0.26	0.17	0.15	0.15	0.15	0.16
May	0.21	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.16	0.06	0.06	0.06	0.06	0.00	0.06	0.06	0.06	0.06	0.43	0.15	0.07	0.16	0.16	0.33	0.16	0.16	0.16	0.12
Jun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.15	0.05	0.05	0.05	0.05	0.00	0.05	0.05	0.05	0.05	0.23	0.16	0.07	0.15	0.15	0.39	0.15	0.15	0.15	0.10
Jul	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.15	0.06	0.06	0.06	0.06	0.00	0.06	0.06	0.06	0.06	0.46	0.14	0.07	0.15	0.15	0.40	0.15	0.15	0.15	0.11
Aug	0.19	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.16	0.06	0.06	0.06	0.06	0.00	0.06	0.06	0.06	0.06	0.25	0.25	0.07	0.16	0.16	0.39	0.16	0.16	0.16	0.11
Sep	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.47	0.15	0.06	0.06	0.06	0.06	0.00	0.06	0.06	0.06	0.06	0.75	0.16	0.07	0.15	0.28	0.27	0.15	0.15	0.15	0.15
Oct	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.69	0.15	1.34	0.40	0.72	0.70	0.33	0.40	1.04	1.04	1.04	0.61	0.07	0.07	0.15	0.15	0.13	0.15	0.15	0.15	0.25
Nov	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.24	0.14	1.03	0.57	0.57	0.77	0.37	0.54	0.96	0.96	0.96	0.48	0.05	0.07	0.14	0.14	0.12	0.14	0.14	0.14	0.21
Dec	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.14	0.15	0.65	0.37	0.37	0.60	0.21	0.37	0.48	0.63	0.63	0.27	0.06	0.07	0.15	0.15	0.13	0.15	0.15	0.15	0.16
Year	1.18	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	3.53	1.82	5.42	3.08	3.17	5.22	2.25	3.33	4.67	4.81	5.05	5.51	1.42	0.84	1.82	2.14	2.96	1.82	1.82	1.82	1.96

Electrical Energy Consumed (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.55	1.94	2.97	3.38	3.37	2.96	3.57	3.38	3.42	3.19	3.19	3.55	3.85	2.02	1.94	1.94	1.96	1.94	1.94	1.94	2.95
Feb	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.11	1.74	3.00	2.97	3.22	2.54	3.08	2.97	3.02	3.02	3.02	2.90	3.47	1.82	1.74	1.74	1.76	1.74	1.74	1.74	2.65
Mar	3.83	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.54	1.94	3.31	3.58	3.58	3.04	3.35	3.30	3.07	3.30	3.07	3.37	3.83	2.02	1.94	1.86	1.72	1.94	1.94	1.94	2.94
Apr	3.54	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.16	1.87	3.72	3.72	3.72	3.72	3.78	3.72	3.72	3.72	3.72	3.26	3.59	1.95	1.87	1.76	1.86	1.87	1.87	1.87	2.89
May	3.70	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	1.93	3.85	3.85	3.85	3.85	3.91	3.85	3.85	3.85	3.85	3.48	3.76	2.01	1.93	1.93	1.76	1.93	1.93	1.93	3.04
Jun	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	1.88	3.73	3.73	3.73	3.73	3.78	3.73	3.73	3.73	3.73	3.55	3.62	1.95	1.88	1.88	1.64	1.88	1.88	1.88	2.95
Jul	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	1.94	3.85	3.85	3.85	3.85	3.91	3.85	3.85	3.85	3.85	3.44	3.76	2.02	1.94	1.94	1.69	1.94	1.94	1.94	3.04
Aug	3.72	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	1.93	3.85	3.85	3.85	3.85	3.91	3.85	3.85	3.85	3.85	3.66	3.66	2.01	1.93	1.93	1.70	1.93	1.93	1.93	3.04
Sep	3.71	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.31	1.88	3.72	3.72	3.72	3.72	3.78	3.72	3.72	3.72	3.72	3.03	3.62	1.95	1.88	1.75	1.76	1.88	1.88	1.88	2.90
Oct	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.22	1.94	2.57	3.51	3.18	3.20	3.57	3.51	2.86	2.86	2.86	3.30	3.84	2.02	1.94	1.94	1.96	1.94	1.94	1.94	2.90
Nov	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.54	1.88	2.75	3.21	3.21	3.01	3.41	3.24	2.82	2.82	2.82	3.30	3.73	1.95	1.88	1.88	1.90	1.88	1.88	1.88	2.84
Dec	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.77	1.94	3.26	3.54	3.54	3.31	3.70	3.54	3.43	3.28	3.28	3.64	3.85	2.02	1.94	1.94	1.96	1.94	1.94	1.94	3.00
Year	44.81	45.31	45.31	45.31	45.31	45.31	45.31	45.31	45.31	45.31	45.31	45.31	42.46	22.81	40.57	42.91	42.82	40.77	43.74	42.66	41.32	41.18	40.94	40.48	44.57	23.72	22.81	22.50	21.68	22.81	22.81	22.81	1229.59

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Total yearly working hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
Total yearly lamp operation hours (h/a)	3248.72	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3078.12	2940.91	2940.91	3110.66	3104.80	2955.94	3245.37	3092.51	2995.94	2985.26	2968.04	2934.35	3231.45	3285.00	3285.00	3238.98	3089.11	3285.00	3285.00	3285.00	-
Total yearly switch-on hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3279.00	3279.00	3279.00	3280.00	3278.00	3284.00	3280.00	3279.00	3278.00	3278.00	3285.00	3285.00	3285.00	3285.00	3285.00	3154.00	3285.00	3285.00	3285.00	-
No art. lighting required refering to working time (%)	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.30	10.50	10.50	5.30	5.50	10.00	1.20	5.90	8.80	9.10	9.60	10.70	1.60	0.00	0.00	1.40	6.00	0.00	0.00	0.00	-

B03 - BEIRUT MUNICIPALITY (1925 - 1928) / 2 STEP ON-OFF

	North Rooms											East Rooms		South Rooms										West Rooms		Internal Rooms							Total
	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Area	39.66	15.81	16.50	15.48	16.50	9.00	18.77	26.76	26.31	49.85	30.84	101.00	88.56	109.58	17.30	19.12	17.40	19.32	17.80	17.71	18.11	17.91	19.00	35.31	32.66	128.92	78.5	30.67	30.67	51.6	45.3	11.85	1173.77
Power Density (W/m²)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	-
Total Power (W)	555.24	221.34	231.00	216.72	231.00	126.00	262.78	374.64	368.34	697.90	431.76	1414.00	1239.84	821.85	242.20	267.68	243.60	270.48	249.20	247.94	253.54	250.74	266.00	494.34	457.24	966.90	588.75	230.03	230.03	387.00	339.75	88.88	-
Work Surface Illuminance	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	-
Luminance Efficacy	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	13.33	13.33	13.33	13.33	13.33	13.33	-

Electrical Energy Saved (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.88	0.00	15.38	9.11	8.38	17.44	4.24	8.44	7.97	12.07	12.81	10.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	133.45
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.07	0.00	8.38	9.75	4.46	18.26	4.54	9.04	8.35	8.25	8.76	20.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	133.30
Mar	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.71	0.00	9.48	5.27	4.80	15.92	9.88	9.83	14.41	9.94	15.12	17.00	0.76	0.00	0.00	2.61	7.59	0.00	0.00	0.00	151.24
Apr	7.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.65	4.44	0.00	0.00	3.73	1.17	0.00	0.00	0.00	83.67
May	6.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.13	2.81	0.00	0.00	0.00	6.31	0.00	0.00	0.00	28.32
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.28	3.37	0.00	0.00	0.00	8.45	0.00	0.00	0.00	18.11
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.63	2.85	0.00	0.00	0.00	8.68	0.00	0.00	0.00	26.17
Aug	5.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.61	6.30	0.00	0.00	0.00	8.30	0.00	0.00	0.00	26.74
Sep	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.04	3.55	0.00	0.00	4.25	4.55	0.00	0.00	0.00	75.31
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.81	0.00	22.53	6.56	11.73	12.66	3.05	6.08	18.08	17.88	18.97	19.82	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	194.57
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.79	0.00	17.13	9.94	9.04	14.05	4.37	8.70	16.75	16.57	17.57	15.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	146.14
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.49	0.00	10.44	6.03	5.49	10.67	2.84	5.65	7.73	10.45	11.08	7.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	85.50
Year	20.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	256.51	0.00	83.34	46.67	43.90	89.01	28.92	47.73	73.29	75.16	84.31	173.34	24.49	0.00	0.00	10.59	45.06	0.00	0.00	0.00	1102.51

Electrical Energy Consumed (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	319.03	229.29	52.20	65.57	59.58	58.02	65.29	60.74	62.76	57.88	61.41	127.20	127.57	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3567.15
Feb	139.92	55.78	58.21	54.61	58.21	31.75	66.22	94.41	92.82	175.87	108.80	356.33	279.37	207.10	52.65	57.70	56.93	49.90	58.26	53.45	55.55	54.93	58.28	104.14	115.22	242.94	148.37	57.96	57.97	97.52	85.62	22.40	3209.19
Mar	153.99	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	318.20	229.29	58.09	69.41	63.17	59.55	59.65	59.35	56.32	60.02	59.09	120.93	126.81	268.97	164.26	61.56	56.59	107.97	94.79	24.79	3549.37
Apr	142.73	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	284.27	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	71.82	116.82	119.01	260.29	158.96	58.38	60.94	104.49	91.73	23.99	3497.56
May	148.84	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	74.21	124.80	124.76	268.97	164.26	64.18	57.87	107.97	94.79	24.79	3672.28
Jun	149.91	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	334.76	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	71.82	127.19	120.08	260.29	158.96	62.11	53.65	104.49	91.73	23.99	3563.12
Jul	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	74.21	123.29	124.72	268.97	164.26	64.18	55.49	107.97	94.79	24.79	3674.43
Aug	149.59	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	74.21	131.11	121.27	268.97	164.26	64.18	55.88	107.97	94.79	24.79	3673.87
Sep	149.27	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	297.49	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	71.82	108.43	119.90	260.29	158.96	57.86	57.56	104.49	91.73	23.99	3505.92
Oct	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	289.11	229.29	45.04	68.12	56.23	62.81	66.47	63.10	52.66	52.08	55.25	118.10	127.17	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3506.04
Nov	149.91	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	317.97	221.90	48.27	62.34	56.73	58.98	62.91	58.24	51.70	51.13	54.25	118.25	123.45	260.29	158.96	62.11	62.11	104.49	91.73	23.99	3435.09
Dec	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	338.43	229.29	57.13	68.65	62.47	64.79	66.69	63.53	63.01	59.51	63.13	130.30	127.57	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3615.11
Year	1803.81	727.10	758.83	711.92	758.83	413.91	863.23	1230.69	1209.99	2292.60	1418.33	4644.98	3816.37	2699.74	712.29	832.66	756.33	799.52	789.70	766.76	759.59	748.52	789.50	1450.56	1477.54	3166.87	1934.04	745.03	710.59	1271.30	1116.08	291.94	42469.14

Electrical Energy Saved (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.89	0.48	0.48	0.90	0.24	0.48	0.44	0.67	0.67	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.48	0.51	0.26	0.95	0.26	0.51	0.46	0.46	0.46	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Mar	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.55	0.28	0.28	0.82	0.55	0.55	0.80	0.55	0.80	0.48	0.02	0.00	0.00	0.09	0.25	0.00	0.00	0.00	0.13
Apr	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.14	0.00	0.00	0.12	0.04	0.00	0.00	0.00	0.07
May	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.09	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.02
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.10	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.02
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.09	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.02
Aug	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.02
Sep	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.11	0.00	0.00	0.14	0.15	0.00	0.00	0.00	0.06
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.00	1.30	0.34	0.67	0.66	0.17	0.34	1.00	1.00	1.00	0.56	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.99	0.52	0.52	0.73	0.25	0.49	0.92	0.92	0.92	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.60	0.32	0.32	0.55	0.16	0.32	0.43	0.58	0.58	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Year	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.90	0.00	4.82	2.44	2.52	4.61	1.62	2.69	4.05	4.20	4.44	4.91	0.75	0.00	0.00	0.35	1.47	0.00	0.00	0.00	0.94

Electrical Energy Consumed (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.60	2.09	3.02	3.43	3.42	3.00	3.67	3.43	3.47	3.23	3.23	3.60	3.91	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.04
Feb	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.15	1.89	3.04	3.02	3.27	2.58	3.27	3.02	3.07	3.07	3.07	2.95	3.53	1.88	1.89	1.89	1.89	1.89	1.89	1.89	2.73
Mar	3.88	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.59	2.09	3.36	3.63	3.63	3.08	3.35	3.35	3.11	3.35	3.11	3.42	3.88	2.09	2.09	2.01	1.84	2.09	2.09	2.09	3.02
Apr	3.60	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.21	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.31	3.64	2.02	2.03	1.90	1.99	2.03	2.03	2.02	2.98
May	3.75	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.53	3.82	2.09	2.09	2.09	1.89	2.09	2.09	2.09	3.13
Jun	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.60	3.68	2.02	2.03	2.02	1.75	2.03	2.03	2.02	3.04
Jul	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.49	3.82	2.09	2.09	2.09	1.81	2.09	2.09	2.09	3.13
Aug	3.77	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.71	3.71	2.09	2.09	2.09	1.82	2.09	2.09	2.09	3.13
Sep	3.76	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.36	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.07	3.67	2.02	2.03	1.89	1.88	2.03	2.03	2.02	2.99
Oct	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.26	2.09	2.60	3.56	3.23	3.25	3.73	3.56	2.91	2.91	2.91	3.34	3.89	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.99
Nov	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.59	2.02	2.79	3.26	3.26	3.05	3.53	3.29	2.86	2.86	2.86	3.35	3.78	2.02	2.03	2.02	2.03	2.03	2.03	2.02	2.93
Dec	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.82	2.09	3.30	3.59	3.59	3.35	3.75	3.59	3.48	3.32	3.32	3.69	3.91	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.08
Year	45.48	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	43.09	24.64	41.17	43.55	43.47	41.38	44.37	43.30	41.94	41.79	41.55	41.08	45.24	24.56	24.64	24.29	23.17	24.64	24.64	24.64	1258.52

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Total yearly working hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
Total yearly lamp operation hours (h/a)	3248.72	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3078.12	2940.91	2940.90	3110.66	3104.80	2955.94	3245.37	3092.51	2995.94	2985.26	2968.04	2934.35	3231.45	3285.00	3285.00	3238.98	3089.11	3285.00	3285.00	3285.00	-
Total yearly switch-on hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3279.00	3279.00	3279.00	3280.00	3278.00	3284.00	3280.00	3279.00	3278.00	3278.00	3285.00	3285.00	3285.00	3285.00	3285.00	3154.00	3285.00	3285.00	3285.00	-
No art. lighting required refering to working time (%)	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.30	10.50	10.50	5.30	5.50	10.00	1.20	5.90	8.80	9.10	9.60	10.70	1.60	0.00	0.00	1.40	6.00	0.00	0.00	0.00	-

B03 - BEIRUT MUNICIPALITY (1925 - 1928) / 3 STEP ON-OFF

	North Rooms											East Rooms		South Rooms											West Rooms		Internal Rooms							Total
	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Area	39.66	15.81	16.50	15.48	16.50	9.00	18.77	26.76	26.31	49.85	30.84	101.00	88.56	109.58	17.30	19.12	17.40	19.32	17.80	17.71	18.11	17.91	19.00	35.31	32.66	128.92	78.5	30.67	30.67	51.6	45.3	11.85	1173.77
Power Density (W/m^2)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	-
Total Power (W)	555.24	221.34	231.00	216.72	231.00	126.00	262.78	374.64	368.34	697.90	431.76	1414.00	1239.84	821.85	242.20	267.68	243.60	270.48	249.20	247.94	253.54	250.74	266.00	494.34	457.24	966.90	588.75	230.03	230.03	387.00	339 75	88.88	-
Work Surface Illuminance	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	-
Luminance Efficacy	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	13.33	13.33	13.33	13.33	13.33	13.33	-

Electrical Energy Saved (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.88	0.00	15.38	9.11	8.38	17.44	5.66	8.44	12.21	12.07	12.81	10.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	139.10
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.07	0.00	8.38	9.75	4.46	18.26	6.05	9.04	8.35	8.25	8.76	20.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	134.81
Mar	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.71	0.00	9.48	5.27	4.80	15.92	9.88	9.83	10.05	9.94	15.12	17.00	0.76	0.00	0.00	2.61	7.59	0.00	0.00	0.00	146.87
Apr	7.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.65	4.44	0.00	0.00	3.73	1.17	0.00	0.00	0.00	83.67
May	6.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.13	2.81	0.00	0.00	0.00	6.31	0.00	0.00	0.00	28.32
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.28	3.37	0.00	0.00	0.00	8.45	0.00	0.00	0.00	18.11
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.63	2.85	0.00	0.00	0.00	8.68	0.00	0.00	0.00	26.17
Aug	5.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.81	6.30	0.00	0.00	0.00	8.30	0.00	0.00	0.00	26.74
Sep	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.04	3.55	0.00	0.00	4.25	4.55	0.00	0.00	0.00	75.31
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.81	0.00	22.53	6.56	11.73	12.66	4.07	6.08	18.08	17.88	18.97	19.82	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	195.58
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.79	0.00	17.13	9.94	9.04	14.05	5.83	8.70	16.75	16.57	17.57	15.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	147.60
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.49	0.00	10.44	6.03	5.49	10.67	2.85	5.65	10.57	10.45	11.08	7.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88.35
Year	20.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	256.51	0.00	83.34	46.67	43.90	89.01	34.34	47.73	76.00	75.16	84.31	173.34	24.49	0.00	0.00	10.59	45.06	0.00	0.00	0.00	1110.64

Electrical Energy Consumed (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	319.03	229.29	52.20	65.57	59.58	58.02	63.87	60.74	58.53	57.88	61.41	127.20	127.57	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3561.51
Feb	139.92	55.78	58.21	54.61	58.21	31.75	66.22	94.41	92.82	175.87	108.80	356.33	279.37	207.10	52.65	57.70	56.93	49.90	56.74	53.45	55.55	54.93	58.28	104.14	115.22	242.94	148.37	57.96	57.97	97.52	85.62	22.40	3207.67
Mar	153.99	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	318.20	229.29	58.09	69.41	63.17	59.55	59.65	59.35	60.69	60.02	59.09	120.93	126.81	268.97	164.26	61.56	56.59	107.97	94.79	24.79	3553.73
Apr	142.73	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	284.27	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	71.82	116.82	119.01	260.29	158.96	58.38	60.94	104.49	91.73	23.99	3497.56
May	148.84	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	74.21	124.80	124.76	268.97	164.26	64.18	57.87	107.97	94.79	24.79	3672.28
Jun	149.91	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	334.76	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	71.82	127.19	120.08	260.29	158.96	62.11	53.65	104.49	91.73	23.99	3563.12
Jul	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	74.21	123.29	124.72	268.97	164.26	64.18	55.49	107.97	94.79	24.79	3674.43
Aug	149.59	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.53	69.18	70.74	69.96	74.21	131.11	121.27	268.97	164.26	64.18	55.88	107.97	94.79	24.79	3673.87
Sep	149.27	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	297.49	221.90	65.39	72.27	65.77	73.03	67.28	66.94	68.46	67.70	71.82	108.43	119.90	260.29	158.96	57.86	57.56	104.49	91.73	23.99	3505.92
Oct	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	289.11	229.29	45.04	68.12	56.23	62.81	65.45	63.10	52.66	52.08	55.25	118.10	127.17	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3505.02
Nov	149.91	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	317.97	221.90	48.27	62.34	56.73	58.98	61.45	58.24	51.70	51.13	54.25	118.25	123.45	260.29	158.96	62.11	62.11	104.49	91.73	23.99	3433.64
Dec	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	338.43	229.29	57.13	68.65	62.47	64.79	66.67	63.53	60.17	59.51	63.13	130.30	127.57	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3612.25
Year	1803.81	727.10	758.83	711.92	758.83	413.91	863.23	1230.69	1209.99	2292.60	1418.33	4644.98	3816.37	2699.74	712.29	832.66	756.33	799.52	784.28	766.76	756.88	748.52	789.50	1450.56	1477.54	3166.87	1934.04	745.03	710.59	1271.30	1116.08	291.94	42461.01

Electrical Energy Saved (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.89	0.48	0.48	0.90	0.32	0.48	0.67	0.67	0.67	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.48	0.51	0.26	0.95	0.34	0.51	0.46	0.46	0.46	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Mar	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.55	0.28	0.28	0.82	0.55	0.55	0.55	0.55	0.80	0.48	0.02	0.00	0.00	0.09	0.25	0.00	0.00	0.00	0.13
Apr	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.14	0.00	0.00	0.12	0.04	0.00	0.00	0.00	0.07
May	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.09	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.02
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.10	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.02
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.09	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.02
Aug	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.02
Sep	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.11	0.00	0.00	0.14	0.15	0.00	0.00	0.00	0.06
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.00	1.30	0.34	0.67	0.66	0.23	0.34	1.00	1.00	1.00	0.56	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.99	0.52	0.52	0.73	0.33	0.49	0.92	0.92	0.92	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.60	0.32	0.32	0.55	0.16	0.32	0.58	0.58	0.58	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Year	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.90	0.00	4.82	2.44	2.52	4.61	1.93	2.69	4.20	4.20	4.44	4.91	0.75	0.00	0.00	0.35	1.47	0.00	0.00	0.00	0.95

Electrical Energy Consumed (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.60	2.09	3.02	3.43	3.42	3.00	3.59	3.43	3.23	3.23	3.23	3.60	3.91	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.03
Feb	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.15	1.89	3.04	3.02	3.27	2.58	3.19	3.02	3.07	3.07	3.07	2.95	3.53	1.88	1.89	1.89	1.89	1.89	1.89	1.89	2.73
Mar	3.88	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.59	2.09	3.36	3.63	3.63	3.08	3.35	3.35	3.35	3.35	3.11	3.42	3.88	2.09	2.09	2.01	1.84	2.09	2.09	2.09	3.03
Apr	3.60	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.21	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.31	3.64	2.02	2.03	1.90	1.99	2.03	2.03	2.02	2.98
May	3.75	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.53	3.82	2.09	2.09	2.09	1.89	2.09	2.09	2.09	3.13
Jun	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.60	3.68	2.02	2.03	2.02	1.75	2.03	2.03	2.02	3.04
Jul	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.49	3.82	2.09	2.09	2.09	1.81	2.09	2.09	2.09	3.13
Aug	3.77	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.71	3.71	2.09	2.09	2.09	1.82	2.09	2.09	2.09	3.13
Sep	3.76	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.36	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.07	3.67	2.02	2.03	1.89	1.88	2.03	2.03	2.02	2.99
Oct	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.26	2.09	2.60	3.56	3.23	3.25	3.68	3.56	2.91	2.91	2.91	3.34	3.89	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.99
Nov	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.59	2.02	2.79	3.26	3.26	3.05	3.45	3.29	2.86	2.86	2.86	3.35	3.78	2.02	2.03	2.02	2.03	2.03	2.03	2.02	2.93
Dec	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.82	2.09	3.30	3.59	3.59	3.35	3.75	3.59	3.32	3.32	3.32	3.69	3.91	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.08
Year	45.48	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	43.09	24.64	41.17	43.55	43.47	41.38	44.06	43.30	41.79	41.79	41.55	41.08	45.24	24.56	24.64	24.29	23.17	24.64	24.64	24.64	1258.06

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Total yearly working hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
Total yearly lamp operation hours (h/a)	3248.72	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3078.12	2940.91	2940.91	3110.66	3104.80	2955.94	3245.37	3092.51	2985.26	2985.26	2968.04	2934.35	3231.45	3285.00	3285.00	3238.98	3089.11	3285.00	3285.00	3285.00	-
Total yearly switch-on hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3279.00	3279.00	3279.00	3280.00	3278.00	3284.00	3280.00	3278.00	3278.00	3278.00	3285.00	3285.00	3285.00	3285.00	3285.00	3154.00	3285.00	3285.00	3285.00	-
No art. lighting required refering to working time (%)	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.30	10.50	10.50	5.30	5.50	10.00	1.20	5.90	9.10	9.10	9.60	10.70	1.60	0.00	0.00	1.40	6.00	0.00	0.00	0.00	-

B03 - BEIRUT MUNICIPALITY (1925 - 1928) / 4 STEP ON-OFF

	North Rooms											East Rooms		South Rooms										West Rooms		Internal Rooms							Total
	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Area	39.66	15.81	16.50	15.48	16.50	9.00	18.77	26.76	26.31	49.85	30.84	101.00	88.56	109.58	17.30	19.12	17.40	19.32	17.80	17.71	18.11	17.91	19.00	35.31	32.66	128.92	78.5	30.67	30.67	51.6	45.3	11.85	1173.77
Power Density (W/m²)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	-
Total Power (W)	555.24	221.34	231.00	216.72	231.00	126.00	262.78	374.64	368.34	697.90	431.76	1414.00	1239.84	821.85	242.20	267.68	243.60	270.48	249.20	247.94	253.54	250.74	266.00	494.34	457.24	966.90	588.75	230.03	230.03	387.00	339.75	88.88	-
Work Surface Illuminance	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	-
Luminance Efficacy	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	13.33	13.33	13.33	13.33	13.33	13.33	-

Electrical Energy Saved (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.88	0.00	15.38	9.11	8.38	17.44	6.02	8.44	7.97	12.07	12.81	10.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	135.23
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.07	0.00	8.38	9.75	4.46	18.26	7.97	9.04	8.35	8.25	8.76	20.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	136.72
Mar	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.71	0.00	9.48	5.27	4.80	15.92	9.88	9.83	14.41	9.94	15.12	17.00	0.76	0.00	0.00	2.61	7.59	0.00	0.00	0.00	151.24
Apr	7.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.49	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	16.65	4.44	0.00	0.00	3.73	1.17	0.00	0.00	0.00	83.68
May	6.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	13.13	2.81	0.00	0.00	0.00	6.31	0.00	0.00	0.00	28.33
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	6.28	3.37	0.00	0.00	0.00	8.45	0.00	0.00	0.00	18.12
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	14.63	2.85	0.00	0.00	0.00	8.68	0.00	0.00	0.00	26.18
Aug	5.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	6.81	6.30	0.00	0.00	0.00	8.30	0.00	0.00	0.00	26.75
Sep	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.27	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	25.04	3.55	0.00	0.00	4.25	4.55	0.00	0.00	0.00	75.32
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.81	0.00	22.53	6.56	11.73	12.66	5.90	6.08	18.08	17.88	18.97	19.82	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	197.41
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.79	0.00	17.13	9.94	9.04	14.05	6.57	8.70	16.75	16.57	17.57	15.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	148.33
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.49	0.00	10.44	6.03	5.49	10.67	3.72	5.65	7.73	10.45	11.08	7.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	86.38
Year	20.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	256.51	0.00	83.34	46.67	43.90	89.01	40.12	47.73	73.29	75.16	84.31	173.34	24.49	0.00	0.00	10.59	45.06	0.00	0.00	0.00	1113.70

Electrical Energy Consumed (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	319.03	229.29	52.20	65.57	59.58	58.02	63.50	60.74	62.76	57.88	61.41	127.20	127.57	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3565.37
Feb	139.92	55.78	58.21	54.61	58.21	31.75	66.22	94.41	92.82	175.87	108.80	356.33	279.37	207.10	52.65	57.70	56.93	49.90	54.83	53.45	55.55	54.93	58.28	104.14	115.22	242.94	148.37	57.96	57.97	97.52	85.62	22.40	3205.76
Mar	153.99	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	318.20	229.29	58.09	69.41	63.17	59.55	59.65	59.35	56.32	60.02	59.09	120.93	126.81	268.97	164.26	61.56	56.59	107.97	94.79	24.79	3549.37
Apr	142.73	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	284.27	221.90	65.39	72.27	65.77	73.03	67.27	66.94	68.46	67.70	71.82	116.82	119.01	260.29	158.96	58.38	60.94	104.49	91.73	23.99	3497.55
May	148.84	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.52	69.18	70.74	69.96	74.21	124.80	124.76	268.97	164.26	64.18	57.87	107.97	94.79	24.79	3672.27
Jun	149.91	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	334.76	221.90	65.39	72.27	65.77	73.03	67.27	66.94	68.46	67.70	71.82	127.19	120.08	260.29	158.96	62.11	53.65	104.49	91.73	23.99	3563.11
Jul	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.52	69.18	70.74	69.96	74.21	123.29	124.72	268.97	164.26	64.18	55.49	107.97	94.79	24.79	3674.42
Aug	149.59	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	345.91	229.29	67.57	74.68	67.96	75.46	69.52	69.18	70.74	69.96	74.21	131.11	121.27	268.97	164.26	64.18	55.88	107.97	94.79	24.79	3673.86
Sep	149.27	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	297.49	221.90	65.39	72.27	65.77	73.03	67.27	66.94	68.46	67.70	71.82	108.43	119.90	260.29	158.96	57.86	57.56	104.49	91.73	23.99	3505.91
Oct	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	289.11	229.29	45.04	68.12	56.23	62.81	63.63	63.10	52.66	52.08	55.25	118.10	127.17	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3503.20
Nov	149.91	59.76	62.37	58.51	62.37	34.02	70.95	101.15	99.45	188.43	116.57	381.78	317.97	221.90	48.27	62.34	56.73	58.98	60.72	58.24	51.70	51.13	54.25	118.25	123.45	260.29	158.96	62.11	62.11	104.49	91.73	23.99	3432.90
Dec	154.91	61.75	64.45	60.46	64.45	35.15	73.32	104.52	102.77	194.71	120.46	394.50	338.43	229.29	57.13	68.65	62.47	64.79	65.80	63.53	63.01	59.51	63.13	130.30	127.57	268.97	164.26	64.18	64.18	107.97	94.79	24.79	3614.22
Year	1803.81	727.10	758.83	711.92	758.83	413.91	863.23	1230.69	1209.99	2292.60	1418.33	4644.98	3816.37	2699.74	712.29	832.66	756.33	799.52	778.51	766.76	759.59	748.52	789.50	1450.56	1477.54	3166.87	1934.04	745.03	710.59	1271.30	1116.08	291.94	42457.95

Electrical Energy Saved (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.89	0.48	0.48	0.90	0.34	0.48	0.44	0.67	0.67	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.48	0.51	0.26	0.95	0.45	0.51	0.46	0.46	0.46	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Mar	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.55	0.28	0.28	0.82	0.55	0.55	0.80	0.55	0.80	0.48	0.02	0.00	0.00	0.09	0.25	0.00	0.00	0.00	0.13
Apr	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.14	0.00	0.00	0.12	0.04	0.00	0.00	0.00	0.07
May	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.09	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.02
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.10	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.02
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.09	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.02
Aug	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.02
Sep	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.11	0.00	0.00	0.14	0.15	0.00	0.00	0.00	0.06
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.00	1.30	0.34	0.67	0.66	0.33	0.34	1.00	1.00	1.00	0.56	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.99	0.52	0.52	0.73	0.37	0.49	0.92	0.92	0.92	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.60	0.32	0.32	0.55	0.21	0.32	0.43	0.58	0.58	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Year	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.90	0.00	4.82	2.44	2.52	4.61	2.25	2.69	4.05	4.20	4.44	4.91	0.75	0.00	0.00	0.35	1.47	0.00	0.00	0.00	0.95

Electrical Energy Consumed (kwh/m2/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.60	2.09	3.02	3.43	3.42	3.00	3.57	3.43	3.47	3.23	3.23	3.60	3.91	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.04
Feb	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.15	1.89	3.04	3.02	3.27	2.58	3.08	3.02	3.07	3.07	3.07	2.95	3.53	1.88	1.89	1.89	1.89	1.89	1.89	1.89	2.73
Mar	3.88	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.59	2.09	3.36	3.63	3.63	3.08	3.35	3.35	3.11	3.35	3.11	3.42	3.88	2.09	2.09	2.01	1.84	2.09	2.09	2.09	3.02
Apr	3.60	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.21	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.31	3.64	2.02	2.03	1.90	1.99	2.03	2.03	2.02	2.98
May	3.75	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.53	3.82	2.09	2.09	2.09	1.89	2.09	2.09	2.09	3.13
Jun	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.60	3.68	2.02	2.03	2.02	1.75	2.03	2.03	2.02	3.04
Jul	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.49	3.82	2.09	2.09	2.09	1.81	2.09	2.09	2.09	3.13
Aug	3.77	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	2.09	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.71	3.71	2.09	2.09	2.09	1.82	2.09	2.09	2.09	3.13
Sep	3.76	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.36	2.02	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.07	3.67	2.02	2.03	1.89	1.88	2.03	2.03	2.02	2.99
Oct	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.26	2.09	2.60	3.56	3.23	3.25	3.57	3.56	2.91	2.91	2.91	3.34	3.89	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.98
Nov	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.59	2.02	2.79	3.26	3.26	3.05	3.41	3.29	2.86	2.86	2.86	3.35	3.78	2.02	2.03	2.02	2.03	2.03	2.03	2.02	2.92
Dec	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.82	2.09	3.30	3.59	3.59	3.35	3.70	3.59	3.48	3.32	3.32	3.69	3.91	2.09	2.09	2.09	2.09	2.09	2.09	2.09	3.08
Year	45.48	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	45.99	43.09	24.64	41.17	43.55	43.47	41.38	43.74	43.30	41.94	41.79	41.55	41.08	45.24	24.56	24.64	24.29	23.17	24.64	24.64	24.64	1257.89

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Total yearly working hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
Total yearly lamp operation hours (h/a)	3248.72	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3078.12	2940.91	2940.91	3110.66	3104.80	2955.94	3245.37	3092.51	2995.94	2985.26	2968.04	2934.35	3231.45	3285.00	3285.00	3238.98	3089.11	3285.00	3285.00	3285.00	-
Total yearly switch-on hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3279.00	3279.00	3279.00	3280.00	3278.00	3284.00	3280.00	3279.00	3278.00	3278.00	3285.00	3285.00	3285.00	3285.00	3285.00	3154.00	3285.00	3285.00	3285.00	-
No art. lighting required refering to working time (%)	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.30	10.50	10.50	5.30	5.50	10.00	1.20	5.90	8.80	9.10	9.60	10.70	1.60	0.00	0.00	1.40	6.00	0.00	0.00	0.00	-

B03 - BEIRUT MUNICIPALITY (1925 - 1928) / MANUAL ON-OFF PROBABILITY

	North Rooms											East Rooms		South Rooms										West Rooms		Internal Rooms							Total
	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Area	39.66	15.81	16.50	15.48	16.50	9.00	18.77	26.76	26.31	49.85	30.84	101.00	88.56	109.58	17.30	19.12	17.40	19.32	17.80	17.71	18.11	17.91	19.00	35.31	32.66	128.92	78.5	30.67	30.67	51.6	45.3	11.85	1173.77
Power Density (W/m²)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	-
Total Power (W)	555.24	221.34	231.00	216.72	231.00	126.00	262.78	374.64	368.34	697.90	431.76	1414.00	1239.84	821.85	242.20	267.68	243.60	270.48	249.20	247.94	253.54	250.74	266.00	494.34	457.24	966.90	588.75	230.03	230.03	387.00	339.75	88.88	-
Work Surface Illuminance	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	-
Luminance Efficacy	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	13.33	13.33	13.33	13.33	13.33	13.33	13.33	-

Electrical Energy Saved (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.56	0.22	0.23	0.22	0.23	0.13	0.27	0.38	0.37	0.71	0.44	1.44	27.97	0.83	15.56	9.35	8.59	8.90	8.20	8.66	8.20	12.27	13.02	11.15	0.46	0.45	0.60	0.23	0.07	0.39	0.35	0.09	140.57
Feb	0.77	0.31	0.32	0.30	0.32	0.18	0.37	0.52	0.51	0.97	0.60	1.97	34.55	1.14	8.67	10.08	4.77	9.68	8.92	9.33	8.65	8.56	9.08	20.98	0.64	0.61	0.82	0.32	0.12	0.54	0.47	0.12	145.18
Mar	1.45	0.21	0.22	0.21	0.22	0.12	0.25	0.36	0.35	0.66	0.41	1.35	28.75	0.78	9.70	5.52	5.02	10.62	9.79	10.05	14.62	10.16	15.34	17.42	1.19	0.42	0.56	2.81	7.73	0.37	0.32	0.08	157.06
Apr	7.73	0.24	0.25	0.23	0.25	0.13	0.28	0.40	0.39	0.74	0.46	1.51	51.69	0.88	0.26	0.29	0.26	0.00	0.00	0.26	0.27	0.27	0.28	17.12	4.89	0.47	0.63	3.95	1.27	0.41	0.36	0.09	96.26
May	6.73	0.28	0.30	0.28	0.30	0.16	0.34	0.48	0.47	0.90	0.55	1.82	1.59	1.06	0.31	0.34	0.31	0.00	0.00	0.32	0.33	0.32	0.34	13.66	3.38	0.57	0.76	0.30	6.43	0.50	0.44	0.11	43.68
Jun	0.43	0.17	0.18	0.17	0.18	0.10	0.21	0.29	0.29	0.55	0.34	1.11	0.97	0.64	0.19	0.21	0.19	0.00	0.00	0.19	0.20	0.20	0.21	6.61	3.71	0.34	0.46	0.18	8.54	0.30	0.27	0.07	27.49
Jul	0.48	0.19	0.20	0.19	0.20	0.11	0.23	0.33	0.32	0.61	0.38	1.23	1.08	0.71	0.21	0.23	0.21	0.00	0.00	0.22	0.22	0.22	0.23	14.95	3.23	0.38	0.51	0.20	8.78	0.34	0.30	0.08	36.56
Aug	5.86	0.23	0.24	0.23	0.24	0.13	0.27	0.39	0.38	0.73	0.45	1.47	1.29	0.85	0.25	0.28	0.25	0.00	0.00	0.26	0.26	0.26	0.28	7.28	6.73	0.46	0.61	0.24	8.42	0.40	0.35	0.09	39.20
Sep	1.11	0.19	0.20	0.18	0.20	0.11	0.22	0.32	0.31	0.59	0.37	1.20	38.22	0.70	0.21	0.23	0.21	0.00	0.00	0.21	0.21	0.21	0.23	25.43	3.92	0.37	0.50	4.42	4.61	0.33	0.29	0.08	85.36
Oct	0.47	0.19	0.20	0.18	0.20	0.11	0.22	0.32	0.31	0.59	0.36	1.19	57.67	0.69	22.71	6.78	11.93	6.55	6.03	6.28	18.27	18.07	19.17	20.17	0.79	0.37	0.50	0.19	0.06	0.33	0.29	0.08	201.27
Nov	0.49	0.20	0.20	0.19	0.20	0.11	0.23	0.33	0.33	0.62	0.38	1.25	17.79	0.73	17.29	10.15	9.23	9.22	8.49	8.89	16.91	16.73	17.74	15.59	0.40	0.39	0.52	0.20	0.06	0.34	0.30	0.08	155.61
Dec	0.56	0.22	0.23	0.22	0.23	0.13	0.27	0.38	0.37	0.70	0.44	1.43	8.69	0.83	10.61	6.26	5.70	5.91	5.45	5.86	7.93	10.63	11.27	8.06	0.46	0.44	0.59	0.23	0.08	0.39	0.34	0.09	95.02
Year	26.66	2.65	2.77	2.60	2.77	1.51	3.15	4.49	4.42	8.37	5.18	16.95	270.27	9.85	85.96	49.71	46.68	50.89	46.88	50.53	76.08	77.89	87.19	178.42	29.82	5.28	7.06	13.28	46.17	4.64	4.07	1.07	1223.24

Electrical Energy Consumed (kwh/month)

Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	154.35	61.53	64.21	60.24	64.21	35.03	73.05	104.14	102.39	194.01	120.02	393.07	317.94	228.46	52.02	65.33	59.37	66.56	61.32	60.52	62.54	57.68	61.19	126.77	127.11	268.52	163.66	63.94	64.11	107.58	94.45	24.70	3560.04
Feb	139.15	55.47	57.89	54.31	57.89	31.58	65.86	93.89	92.31	174.90	108.20	354.36	277.89	205.96	52.37	57.38	56.61	58.48	53.88	53.15	55.24	54.63	57.96	103.60	114.59	242.33	147.55	57.65	57.85	96.99	85.14	22.27	3197.30
Mar	153.47	61.54	64.23	60.26	64.23	35.03	73.07	104.17	102.42	194.05	120.05	393.16	317.16	228.51	57.87	69.17	62.94	64.84	59.74	59.13	56.12	59.80	58.87	120.50	126.38	268.55	163.70	61.37	56.45	107.61	94.47	24.71	3543.54
Apr	142.19	59.53	62.12	58.28	62.12	33.89	70.67	100.75	99.06	187.69	116.12	380.27	283.06	221.02	65.14	71.99	65.51	73.03	67.28	66.68	68.19	67.43	71.54	116.35	118.56	259.82	158.34	58.16	60.83	104.08	91.37	23.90	3484.97
May	148.18	61.47	64.15	60.19	64.15	34.99	72.98	104.04	102.29	193.82	119.91	392.69	344.32	228.24	67.26	74.34	67.65	75.46	69.53	68.86	70.41	69.63	73.87	124.27	124.19	268.40	163.50	63.88	57.75	107.48	94.35	24.68	3656.93
Jun	149.48	59.59	62.19	58.34	62.19	33.92	70.74	100.86	99.16	187.89	116.24	380.67	333.79	221.25	65.20	72.06	65.58	73.03	67.28	66.75	68.26	67.50	71.61	126.86	119.74	259.95	158.50	61.93	53.57	104.19	91.47	23.93	3553.74
Jul	154.43	61.56	64.25	60.28	64.25	35.04	73.09	104.20	102.45	194.11	120.09	393.28	344.84	228.58	67.36	74.45	67.75	75.46	69.53	68.96	70.52	69.74	73.98	122.97	124.34	268.58	163.75	63.98	55.40	107.64	94.50	24.72	3664.05
Aug	149.05	61.52	64.21	60.24	64.21	35.02	73.04	104.13	102.38	193.99	120.01	393.04	344.63	228.44	67.32	74.40	67.71	75.46	69.53	68.92	70.47	69.70	73.94	130.64	120.84	268.51	163.65	63.94	55.76	107.57	94.44	24.70	3661.41
Sep	148.80	59.57	62.17	58.33	62.17	33.91	70.73	100.84	99.14	187.84	116.21	380.58	296.54	221.20	65.19	72.05	65.57	73.03	67.28	66.73	68.24	67.49	71.59	108.04	119.53	259.92	158.46	57.68	57.49	104.16	91.44	23.92	3495.87
Oct	154.44	61.57	64.25	60.28	64.25	35.05	73.09	104.21	102.46	194.12	120.10	393.31	288.24	228.60	44.86	67.90	56.04	68.92	63.49	62.89	52.47	51.89	55.04	117.75	126.78	268.60	163.76	63.98	64.11	107.65	94.50	24.72	3499.34
Nov	149.42	59.57	62.17	58.32	62.17	33.91	70.72	100.82	99.13	187.82	116.19	380.53	316.96	221.17	48.11	62.13	56.54	63.81	58.79	58.05	51.54	50.97	54.08	117.89	123.05	259.90	158.44	61.90	62.05	104.15	91.43	23.92	3425.63
Dec	154.35	61.53	64.22	60.25	64.22	35.03	73.05	104.15	102.39	194.01	120.02	393.08	337.22	228.46	56.96	68.42	62.27	69.55	64.08	63.32	62.81	59.33	62.94	129.86	127.11	268.52	163.67	63.94	64.10	107.58	94.45	24.70	3605.58
Year	1797.31	724.45	756.07	709.33	756.07	412.40	860.08	1226.20	1205.58	2284.24	1413.16	4628.04	3802.60	2689.89	709.67	829.62	753.55	837.64	771.74	763.95	756.80	745.79	786.62	1445.48	1472.22	3161.59	1926.99	742.34	709.48	1266.66	1112.01	290.87	42348.41

Electrical Energy Saved (kwh/m2/month)

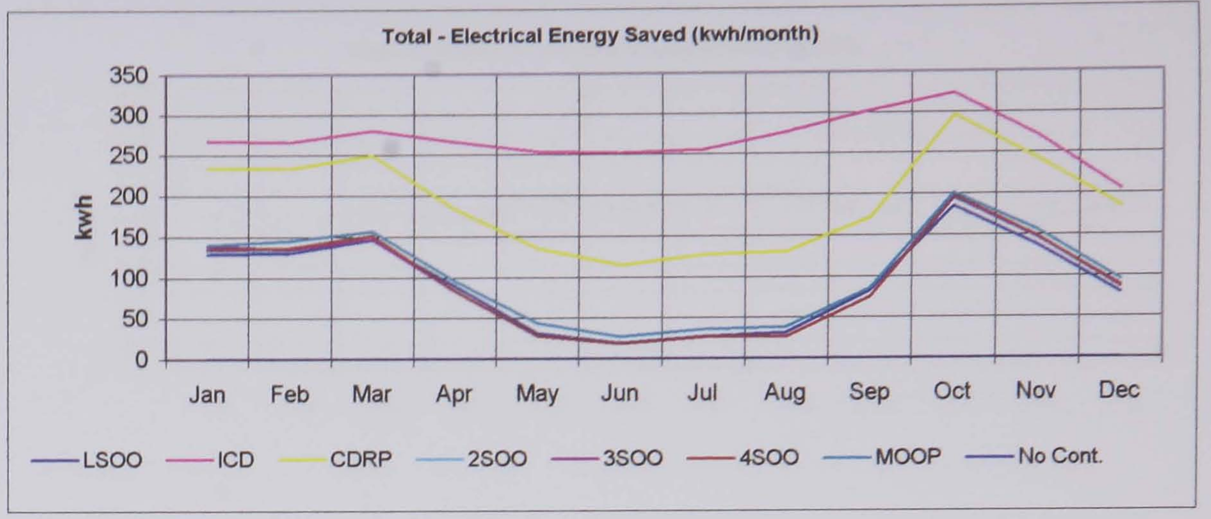
Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.32	0.01	0.90	0.49	0.49	0.46	0.46	0.49	0.45	0.69	0.69	0.32	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.12
Feb	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.39	0.01	0.50	0.53	0.27	0.50	0.50	0.53	0.48	0.48	0.49	0.59	0.02	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.12
Mar	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.32	0.01	0.56	0.29	0.29	0.55	0.55	0.57	0.81	0.57	0.81	0.49	0.04	0.00	0.01	0.09	0.25	0.01	0.01	0.01	0.13
Apr	0.19	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.58	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.48	0.15	0.00	0.01	0.13	0.04	0.01	0.01	0.01	0.08
May	0.17	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.00	0.00	0.02	0.02	0.02	0.02	0.39	0.10	0.00	0.01	0.01	0.21	0.01	0.01	0.01	0.04
Jun	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.19	0.11	0.00	0.01	0.01	0.28	0.01	0.01	0.01	0.02
Jul	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.42	0.10	0.00	0.01	0.01	0.29	0.01	0.01	0.01	0.03
Aug	0.15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.21	0.21	0.00	0.01	0.01	0.27	0.01	0.01	0.01	0.03
Sep	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.43	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.72	0.12	0.00	0.01	0.14	0.15	0.01	0.01	0.01	0.07
Oct	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.65	0.01	1.31	0.35	0.69	0.34	0.34	0.35	1.01	1.01	1.01	0.57	0.02	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.17
Nov	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.20	0.01	1.00	0.53	0.53	0.48	0.48	0.50	0.93	0.93	0.93	0.44	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.13
Dec	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.10	0.01	0.61	0.33	0.33	0.31	0.31	0.33	0.44	0.59	0.59	0.23	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.08
Year	0.67	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	3.05	0.09	4.97	2.60	2.68	2.63	2.63	2.85	4.20	4.35	4.59	5.05	0.91	0.04	0.09	0.43	1.51	0.09	0.09	0.09	1.04

Electrical Energy Consumed (kwh/m2/month)

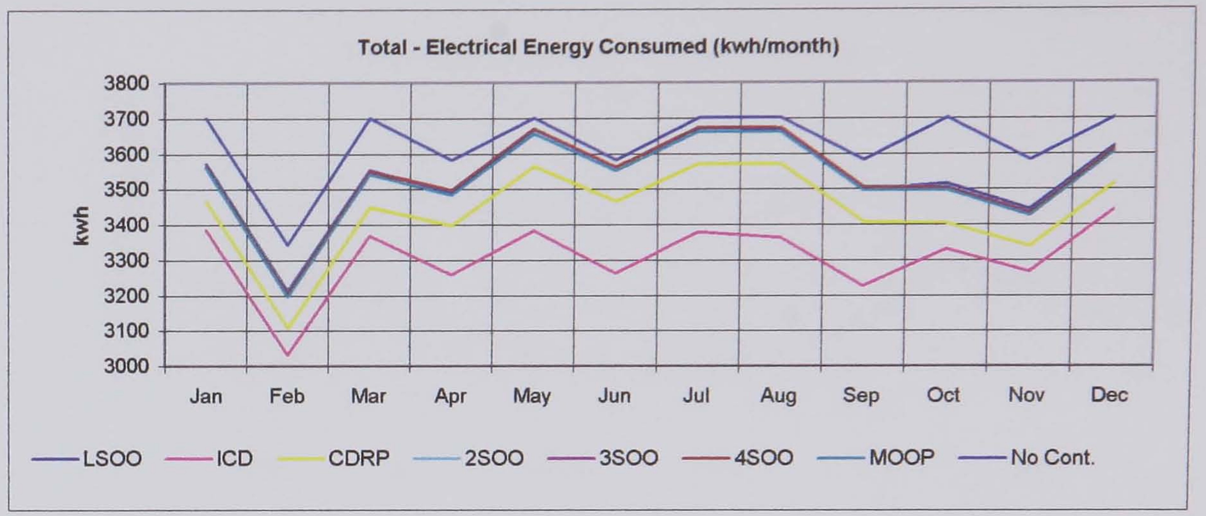
Month	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Jan	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.59	2.08	3.01	3.42	3.41	3.45	3.45	3.42	3.45	3.22	3.22	3.59	3.89	2.08	2.08	2.08	2.09	2.08	2.08	2.08	3.03
Feb	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.14	1.88	3.03	3.00	3.25	3.03	3.03	3.00	3.05	3.05	3.05	2.93	3.51	1.88	1.88	1.88	1.89	1.88	1.88	1.88	2.72
Mar	3.87	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.58	2.09	3.35	3.62	3.62	3.36	3.36	3.34	3.10	3.34	3.10	3.41	3.87	2.08	2.09	2.00	1.84	2.09	2.09	2.09	3.02
Apr	3.59	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.20	2.02	3.77	3.77	3.77	3.78	3.78	3.77	3.77	3.77	3.77	3.30	3.63	2.02	2.02	1.90	1.98	2.02	2.02	2.02	2.97
May	3.74	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	2.08	3.89	3.89	3.89	3.91	3.91	3.89	3.89	3.89	3.89	3.52	3.80	2.08	2.08	2.08	1.88	2.08	2.08	2.08	3.12
Jun	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	2.02	3.77	3.77	3.77	3.78	3.78	3.77	3.77	3.77	3.77	3.59	3.67	2.02	2.02	2.02	1.75	2.02	2.02	2.02	3.03
Jul	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	2.09	3.89	3.89	3.89	3.91	3.91	3.89	3.89	3.89	3.89	3.48	3.81	2.08	2.09	2.09	1.81	2.09	2.09	2.09	3.12
Aug	3.76	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	2.08	3.89	3.89	3.89	3.91	3.91	3.89	3.89	3.89	3.89	3.70	3.70	2.08	2.08	2.08	1.82	2.08	2.08	2.08	3.12
Sep	3.75	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.35	2.02	3.77	3.77	3.77	3.78	3.78	3.77	3.77	3.77	3.77	3.06	3.66	2.02	2.02	1.88	1.87	2.02	2.02	2.02	2.98
Oct	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.25	2.09	2.59	3.55	3.22	3.57	3.57	3.55	2.90	2.90	2.90	3.33	3.88	2.08	2.09	2.09	2.09	2.09	2.09	2.09	2.98
Nov	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.58	2.02	2.78	3.25	3.25	3.30	3.30	3.28	2.85	2.85	2.85	3.34	3.77	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.92
Dec	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.81	2.08	3.29	3.58	3.58	3.60	3.60	3.58	3.47	3.31	3.31	3.68	3.89	2.08	2.08	2.08	2.09	2.08	2.08	2.08	3.07
Year	45.32	45.82	45.82	45.82	45.82	45.82	45.82	45.82	45.82	45.82	45.82	45.82	42.94	24.55	41.02	43.39	43.31	43.36	43.36	43.14	41.79	41.64	41.40	40.94	45.08	24.52	24.55	24.20	23.13	24.55	24.55	24.55	1255.31

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	RM08	RM09	RM10	RM11	RM12	RM13	RM14	RM15	RM16	RM17	RM18	RM19	RM20	RM21	RM22	RM23	RM24	RM25	RM26	RM27	RM28	RM29	RM30	RM31	RM32	TOTAL
Total yearly working hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	-
Total yearly lamp operation hours (h/a)	3248.72	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3078.12	2940.91	2940.90	3110.66	3104.80	2955.94	3245.37	3092.51	2995.94	2985.26	2989.07	2934.35	3231.45	3285.00	3285.00	3238.98	3089.11	3285.00	3285.00	3285.00	-
Total yearly switch-on hours (h/a)	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3279.00	3279.00	3279.00	3280.00	3278.00	3284.00	3280.00	3279.00	3278.00	3285.00	3285.00	3285.00	3285.00	3285.00	3285.00	3154.00	3285.00	3285.00	3285.00	-
No art. lighting required refering to working time (%)	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.30	10.50	10.50	5.30	5.50	10.00	1.20	5.90	8.80	9.10	9.00	10.70	1.60	0.00	0.00	1.40	6.00	0.00	0.00	0.00	-

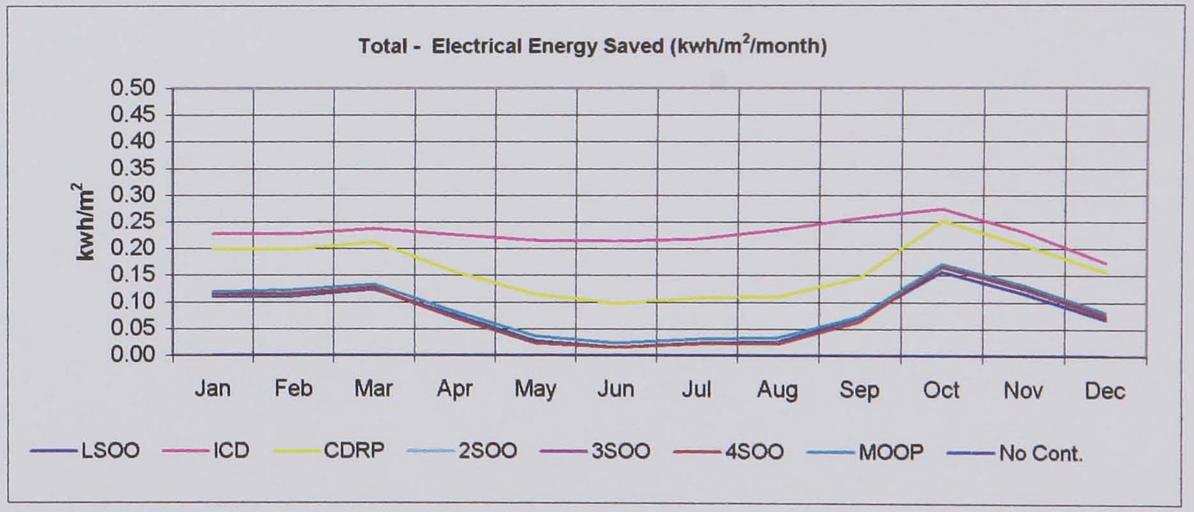
Electrical Energy Saved (kwh/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	128.43	268.02	234.30	133.45	139.10	135.23	140.57	0.00
Feb	130.41	266.63	233.71	133.30	134.81	136.72	145.18	0.00
Mar	146.25	280.09	249.71	151.24	146.87	151.24	157.06	0.00
Apr	89.57	265.91	183.72	83.67	83.67	83.68	96.26	0.00
May	31.63	254.26	135.14	28.32	28.32	28.33	43.68	0.00
Jun	19.15	251.94	114.74	18.11	18.11	18.12	27.49	0.00
Jul	27.53	255.86	126.92	26.17	26.17	26.18	36.56	0.00
Aug	31.46	276.97	130.67	26.74	26.74	26.75	39.20	0.00
Sep	83.29	302.06	172.35	75.31	75.31	75.32	85.36	0.00
Oct	184.89	323.40	295.79	194.57	195.58	197.41	201.27	0.00
Nov	137.31	271.29	242.20	146.14	147.60	148.33	155.61	0.00
Dec	79.66	204.98	184.21	85.50	88.35	86.38	95.02	0.00
Year	**1089.59**	**3221.41**	**2303.46**	**1102.51**	**1110.64**	**1113.70**	**1223.24**	**0.00**



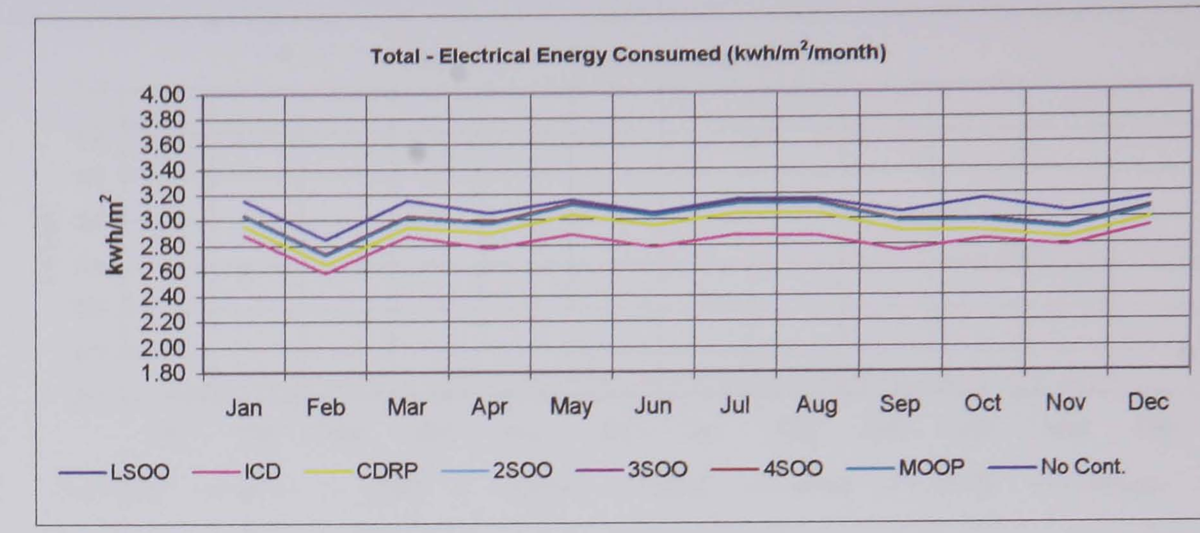
Electrical Energy Consumed (kwh/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	3572.18	3385.17	3466.31	3567.15	3561.51	3565.37	3560.04	3701.38
Feb	3212.08	3032.45	3108.77	3209.19	3207.67	3205.76	3197.30	3343.18
Mar	3554.35	3369.00	3450.90	3549.37	3553.73	3549.37	3543.54	3701.38
Apr	3491.66	3259.37	3397.51	3497.56	3497.56	3497.55	3484.97	3581.98
May	3668.98	3384.74	3565.47	3672.28	3672.28	3672.27	3656.93	3701.38
Jun	3562.08	3263.56	3466.49	3563.12	3563.12	3563.11	3553.74	3581.98
Jul	3673.07	3379.43	3573.69	3674.43	3674.43	3674.42	3664.05	3701.38
Aug	3669.14	3363.30	3569.94	3673.87	3673.87	3673.86	3661.41	3701.38
Sep	3497.94	3226.91	3408.88	3505.92	3505.92	3505.91	3495.87	3581.98
Oct	3515.71	3331.13	3404.82	3506.04	3505.02	3503.20	3499.34	3701.38
Nov	3443.93	3267.26	3339.03	3435.09	3433.64	3432.90	3425.63	3581.98
Dec	3620.95	3441.91	3516.40	3615.11	3612.25	3614.22	3605.58	3701.38
Year	**42482.06**	**39704.23**	**41268.19**	**42469.14**	**42461.01**	**42457.95**	**42348.41**	**43580.71**



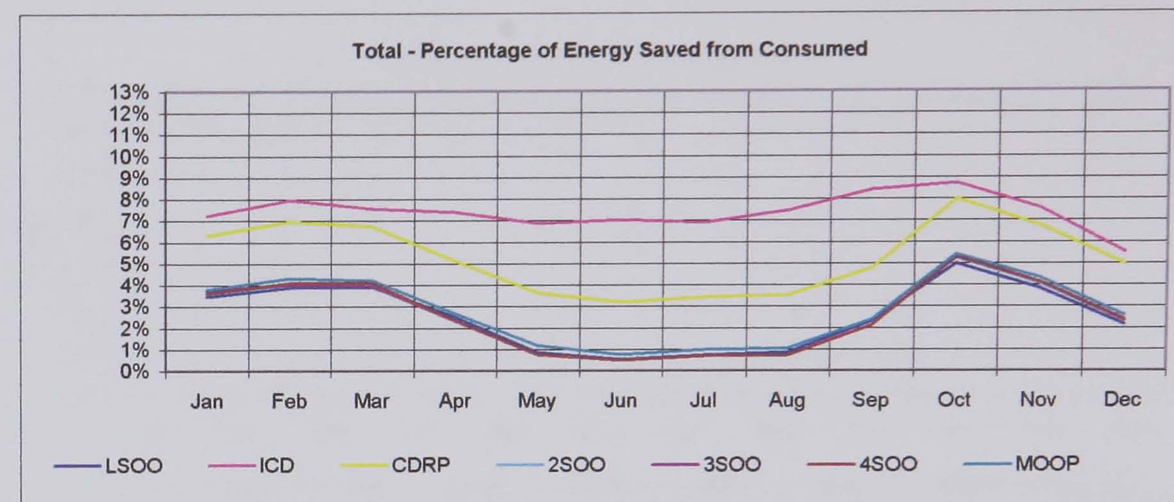
Electrical Energy Saved (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	0.11	0.23	0.20	0.11	0.12	0.12	0.12	0.00
Feb	0.11	0.23	0.20	0.11	0.11	0.12	0.12	0.00
Mar	0.12	0.24	0.21	0.13	0.13	0.13	0.13	0.00
Apr	0.08	0.23	0.16	0.07	0.07	0.07	0.08	0.00
May	0.03	0.22	0.12	0.02	0.02	0.02	0.04	0.00
Jun	0.02	0.21	0.10	0.02	0.02	0.02	0.02	0.00
Jul	0.02	0.22	0.11	0.02	0.02	0.02	0.03	0.00
Aug	0.03	0.24	0.11	0.02	0.02	0.02	0.03	0.00
Sep	0.07	0.26	0.15	0.06	0.06	0.06	0.07	0.00
Oct	0.16	0.28	0.25	0.17	0.17	0.17	0.17	0.00
Nov	0.12	0.23	0.21	0.12	0.13	0.13	0.13	0.00
Dec	0.07	0.17	0.16	0.07	0.08	0.07	0.08	0.00
Year	**0.93**	**2.74**	**1.96**	**0.94**	**0.95**	**0.95**	**1.04**	**0.00**



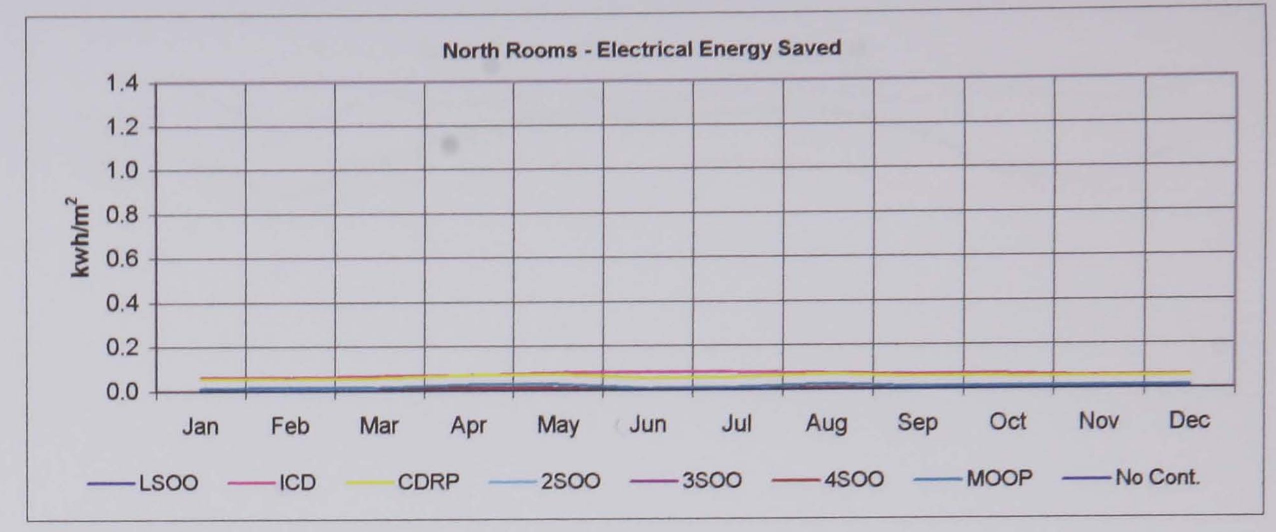
Electrical Energy Consumed (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	3.04	2.88	2.95	3.04	3.03	3.04	3.03	3.15
Feb	2.74	2.58	2.65	2.73	2.73	2.73	2.72	2.85
Mar	3.03	2.87	2.94	3.02	3.03	3.02	3.02	3.15
Apr	2.97	2.78	2.89	2.98	2.98	2.98	2.97	3.05
May	3.13	2.88	3.04	3.13	3.13	3.13	3.12	3.15
Jun	3.03	2.78	2.95	3.04	3.04	3.04	3.03	3.05
Jul	3.13	2.88	3.04	3.13	3.13	3.13	3.12	3.15
Aug	3.13	2.87	3.04	3.13	3.13	3.13	3.12	3.15
Sep	2.98	2.75	2.90	2.99	2.99	2.99	2.98	3.05
Oct	3.00	2.84	2.90	2.99	2.99	2.98	2.98	3.15
Nov	2.93	2.78	2.84	2.93	2.93	2.92	2.92	3.05
Dec	3.08	2.93	3.00	3.08	3.08	3.08	3.07	3.15
Year	**36.19**	**33.83**	**35.16**	**36.18**	**36.17**	**36.17**	**36.08**	**37.13**



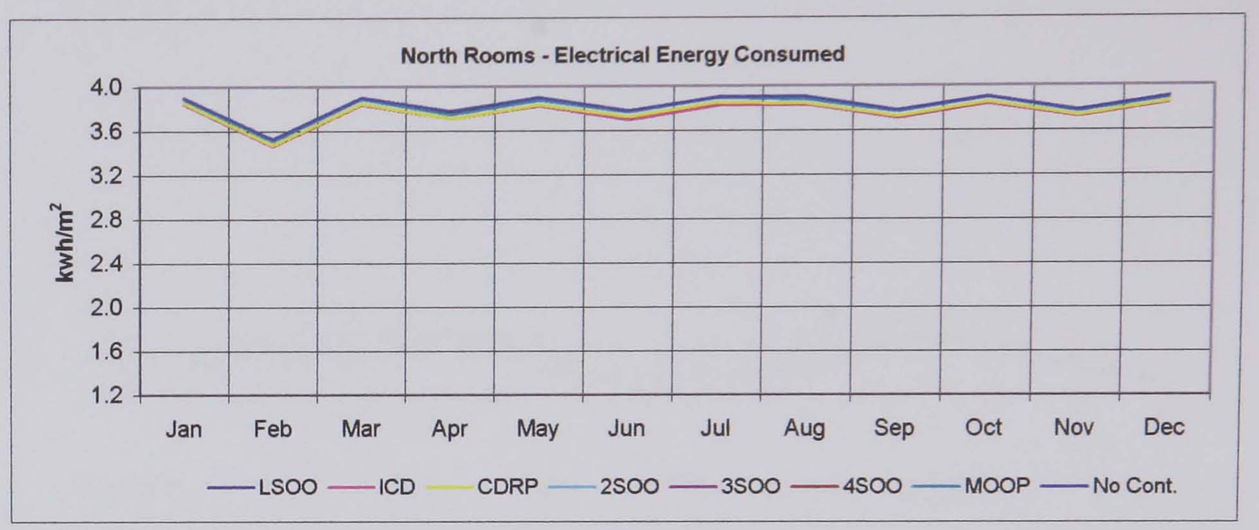
Percentage of Energy Saved from Consumed							
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP
Jan	3.47%	7.24%	6.33%	3.61%	3.76%	3.65%	3.80%
Feb	3.90%	7.98%	6.99%	3.99%	4.03%	4.09%	4.34%
Mar	3.95%	7.57%	6.75%	4.09%	3.97%	4.09%	4.24%
Apr	2.50%	7.42%	5.13%	2.34%	2.34%	2.34%	2.69%
May	0.85%	6.87%	3.65%	0.77%	0.77%	0.77%	1.18%
Jun	0.53%	7.03%	3.20%	0.51%	0.51%	0.51%	0.77%
Jul	0.74%	6.91%	3.43%	0.71%	0.71%	0.71%	0.99%
Aug	0.85%	7.48%	3.53%	0.72%	0.72%	0.72%	1.06%
Sep	2.33%	8.43%	4.81%	2.10%	2.10%	2.10%	2.38%
Oct	5.00%	8.74%	7.99%	5.26%	5.28%	5.33%	5.44%
Nov	3.83%	7.57%	6.76%	4.08%	4.12%	4.14%	4.34%
Dec	2.15%	5.54%	4.98%	2.31%	2.39%	2.33%	2.57%
Year	2.50%	7.39%	5.29%	2.53%	2.55%	2.56%	2.81%



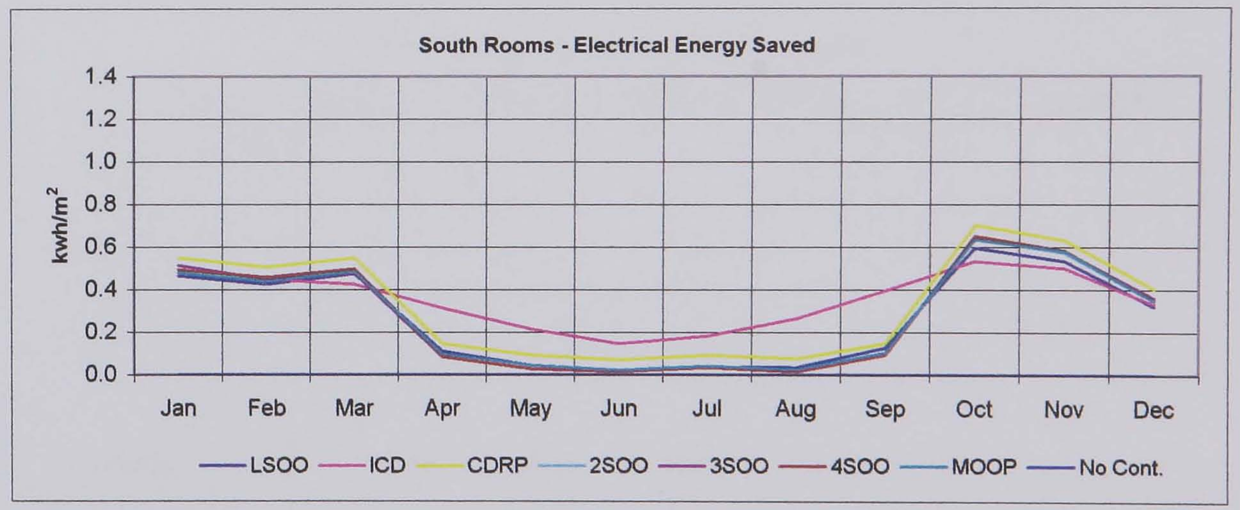
North Rooms - Electrical Energy Saved (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	0.00	0.06	0.06	0.00	0.00	0.00	0.01	0.00
Feb	0.00	0.06	0.06	0.00	0.00	0.00	0.02	0.00
Mar	0.00	0.07	0.06	0.00	0.00	0.00	0.02	0.00
Apr	0.02	0.07	0.07	0.02	0.02	0.02	0.03	0.00
May	0.01	0.08	0.07	0.01	0.01	0.01	0.03	0.00
Jun	0.00	0.09	0.05	0.00	0.00	0.00	0.01	0.00
Jul	0.00	0.08	0.06	0.00	0.00	0.00	0.01	0.00
Aug	0.01	0.07	0.07	0.01	0.01	0.01	0.03	0.00
Sep	0.00	0.07	0.06	0.00	0.00	0.00	0.01	0.00
Oct	0.00	0.07	0.06	0.00	0.00	0.00	0.01	0.00
Nov	0.00	0.06	0.05	0.00	0.00	0.00	0.01	0.00
Dec	0.00	0.06	0.06	0.00	0.00	0.00	0.01	0.00
Year	**0.04**	**0.84**	**0.72**	**0.04**	**0.04**	**0.04**	**0.21**	**0.00**



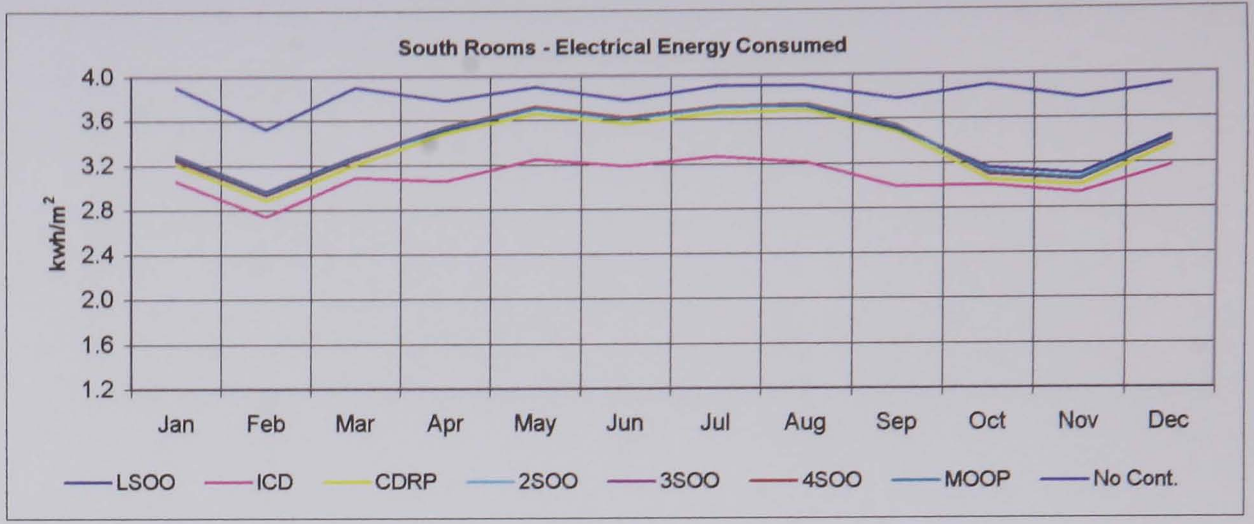
North Rooms - Electrical Energy Consumed (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	3.91	3.84	3.85	3.91	3.91	3.91	3.89	3.91
Feb	3.53	3.46	3.47	3.53	3.53	3.53	3.51	3.53
Mar	3.90	3.84	3.85	3.90	3.90	3.90	3.89	3.91
Apr	3.76	3.71	3.71	3.76	3.76	3.76	3.75	3.78
May	3.89	3.82	3.83	3.89	3.89	3.89	3.88	3.91
Jun	3.78	3.69	3.73	3.78	3.78	3.78	3.77	3.78
Jul	3.91	3.82	3.85	3.91	3.91	3.91	3.89	3.91
Aug	3.89	3.83	3.84	3.89	3.89	3.89	3.88	3.91
Sep	3.78	3.71	3.72	3.78	3.78	3.78	3.77	3.78
Oct	3.91	3.84	3.85	3.91	3.91	3.91	3.89	3.91
Nov	3.78	3.72	3.73	3.78	3.78	3.78	3.77	3.78
Dec	3.91	3.85	3.85	3.91	3.91	3.91	3.89	3.91
Year	**45.95**	**45.15**	**45.27**	**45.95**	**45.95**	**45.95**	**45.78**	**45.99**



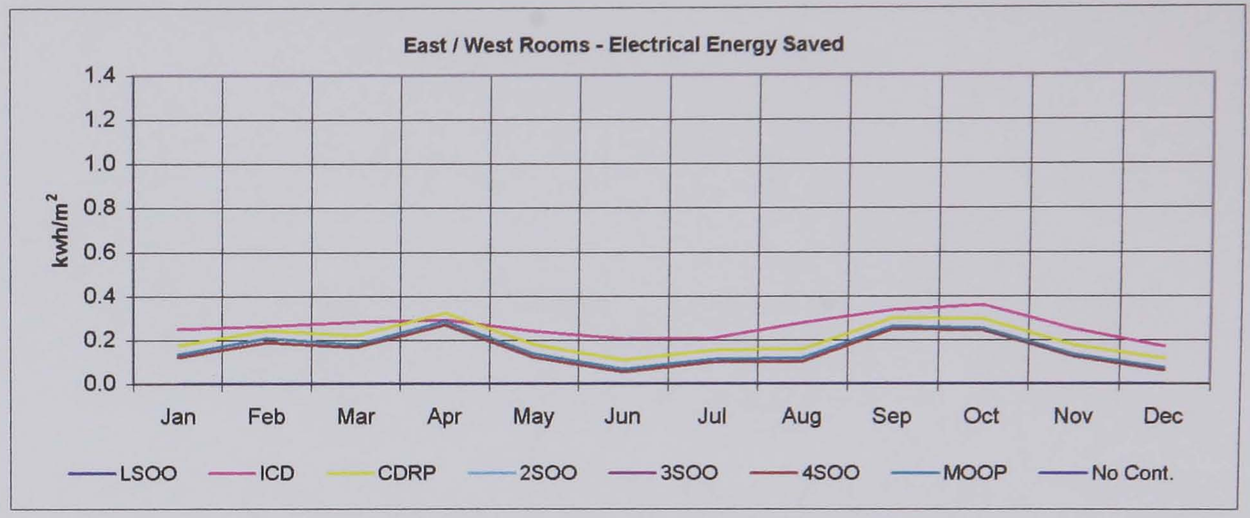
South Rooms - Electrical Energy Saved (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	0.47	0.48	0.55	0.49	0.51	0.50	0.48	0.00
Feb	0.43	0.45	0.51	0.44	0.45	0.46	0.44	0.00
Mar	0.48	0.43	0.55	0.50	0.48	0.50	0.48	0.00
Apr	0.11	0.32	0.15	0.09	0.09	0.09	0.10	0.00
May	0.05	0.22	0.09	0.03	0.03	0.03	0.05	0.00
Jun	0.02	0.15	0.07	0.01	0.01	0.01	0.02	0.00
Jul	0.04	0.18	0.09	0.03	0.03	0.03	0.04	0.00
Aug	0.04	0.27	0.08	0.02	0.02	0.02	0.03	0.00
Sep	0.13	0.40	0.15	0.09	0.09	0.09	0.10	0.00
Oct	0.60	0.53	0.71	0.64	0.65	0.65	0.64	0.00
Nov	0.53	0.50	0.63	0.57	0.58	0.58	0.58	0.00
Dec	0.32	0.33	0.40	0.35	0.36	0.35	0.35	0.00
Year	**3.20**	**4.25**	**3.99**	**3.27**	**3.30**	**3.32**	**3.31**	**0.00**



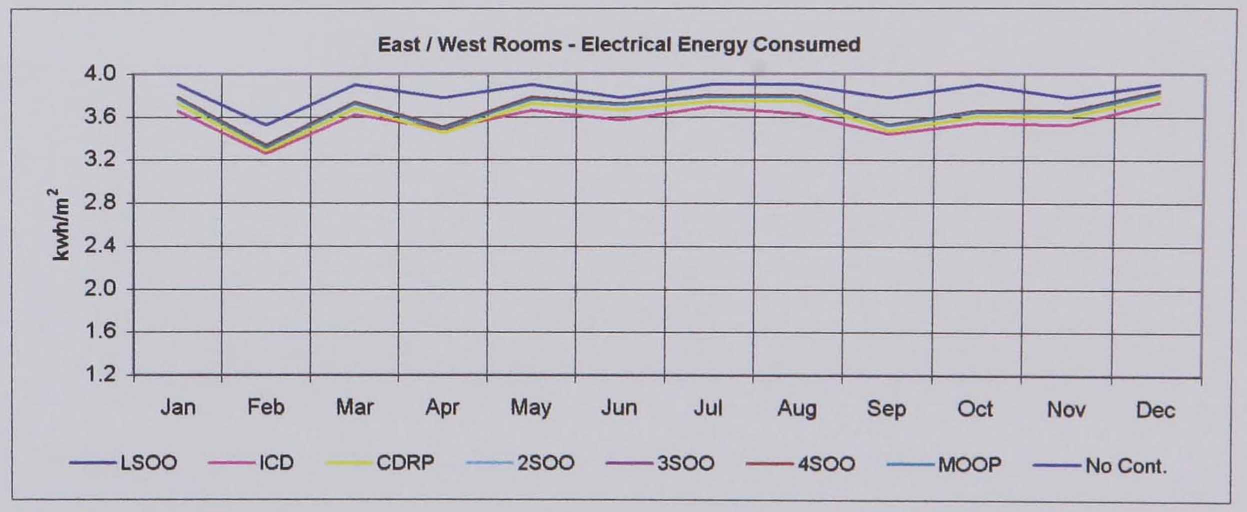
South Rooms - Electrical Energy Consumed (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	3.29	3.05	3.21	3.27	3.24	3.26	3.28	3.91
Feb	2.96	2.74	2.88	2.95	2.94	2.93	2.95	3.53
Mar	3.28	3.09	3.20	3.26	3.28	3.26	3.27	3.91
Apr	3.52	3.06	3.49	3.55	3.55	3.55	3.54	3.78
May	3.71	3.25	3.66	3.72	3.72	3.72	3.71	3.91
Jun	3.61	3.18	3.56	3.62	3.62	3.62	3.61	3.78
Jul	3.71	3.27	3.66	3.72	3.72	3.72	3.71	3.91
Aug	3.72	3.21	3.68	3.74	3.74	3.74	3.73	3.91
Sep	3.50	2.99	3.48	3.54	3.54	3.54	3.53	3.78
Oct	3.16	3.01	3.05	3.11	3.11	3.10	3.12	3.91
Nov	3.10	2.93	3.00	3.06	3.05	3.05	3.05	3.78
Dec	3.43	3.17	3.35	3.41	3.40	3.40	3.41	3.91
Year	**41.01**	**36.96**	**40.22**	**40.94**	**40.91**	**40.89**	**40.90**	**45.99**



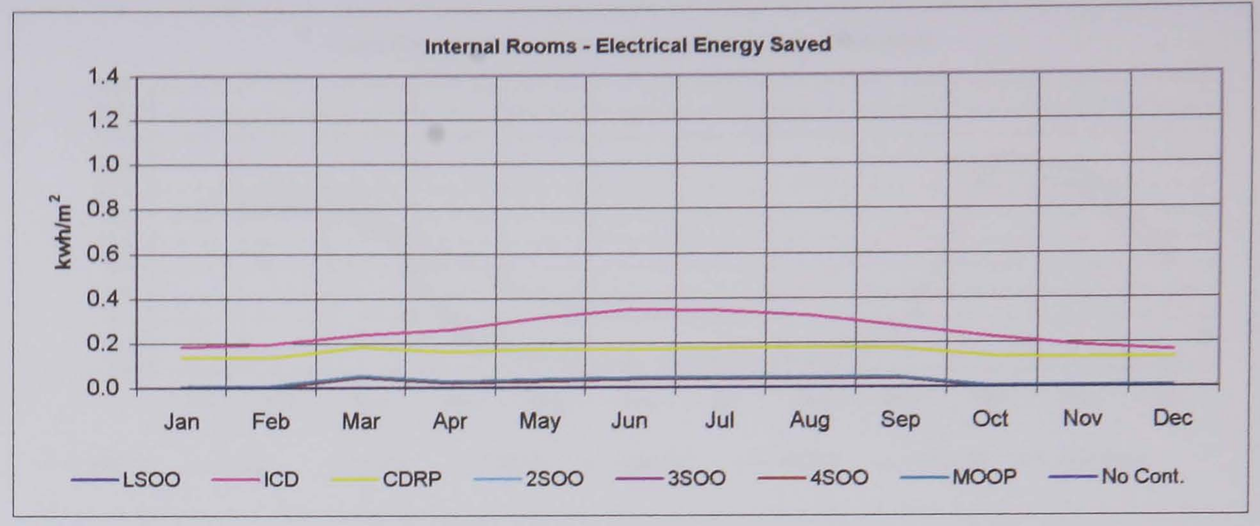
East / West Rooms - Electrical Energy Saved (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	0.12	0.25	0.18	0.12	0.12	0.12	0.13	0.00
Feb	0.19	0.26	0.24	0.19	0.19	0.19	0.21	0.00
Mar	0.17	0.28	0.22	0.17	0.17	0.17	0.18	0.00
Apr	0.27	0.29	0.32	0.27	0.27	0.27	0.29	0.00
May	0.12	0.24	0.18	0.12	0.12	0.12	0.14	0.00
Jun	0.06	0.21	0.11	0.06	0.06	0.06	0.07	0.00
Jul	0.10	0.21	0.16	0.10	0.10	0.10	0.11	0.00
Aug	0.10	0.28	0.16	0.10	0.10	0.10	0.12	0.00
Sep	0.25	0.34	0.30	0.25	0.25	0.25	0.26	0.00
Oct	0.24	0.36	0.30	0.24	0.24	0.24	0.25	0.00
Nov	0.12	0.25	0.18	0.12	0.12	0.12	0.14	0.00
Dec	0.06	0.17	0.11	0.06	0.06	0.06	0.07	0.00
Year	**1.81**	**3.14**	**2.46**	**1.81**	**1.81**	**1.81**	**1.97**	**0.00**



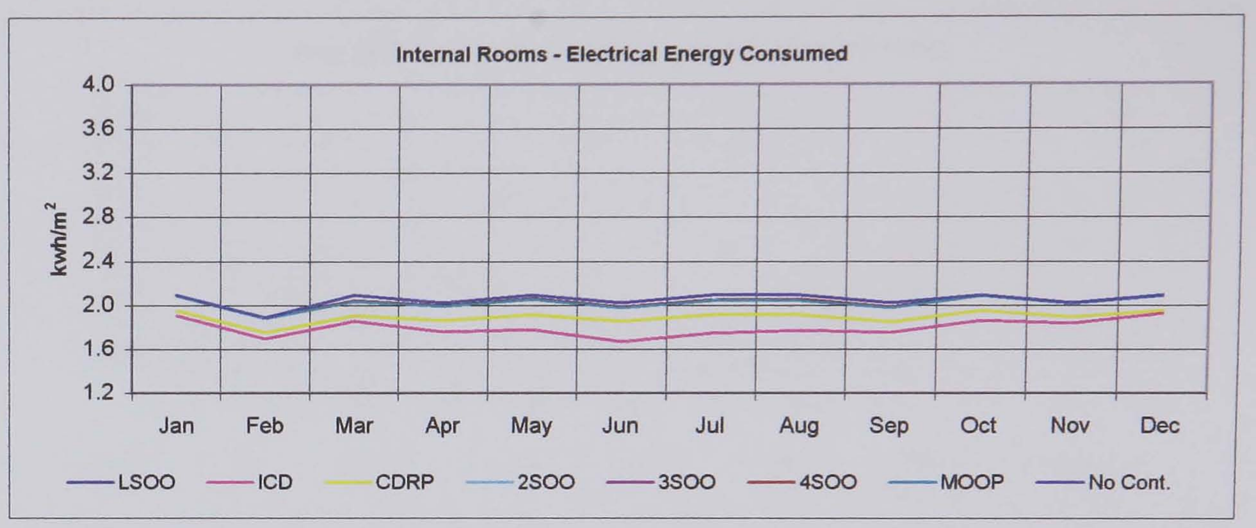
East / West Rooms - Electrical Energy Consumed (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	3.78	3.66	3.73	3.78	3.78	3.78	3.77	3.91
Feb	3.34	3.26	3.28	3.34	3.34	3.34	3.32	3.53
Mar	3.74	3.62	3.68	3.74	3.74	3.74	3.73	3.91
Apr	3.51	3.49	3.46	3.51	3.51	3.51	3.49	3.78
May	3.78	3.67	3.73	3.78	3.78	3.78	3.77	3.91
Jun	3.72	3.57	3.67	3.72	3.72	3.72	3.71	3.78
Jul	3.81	3.70	3.75	3.81	3.81	3.81	3.79	3.91
Aug	3.80	3.63	3.74	3.80	3.80	3.80	3.79	3.91
Sep	3.53	3.44	3.48	3.53	3.53	3.53	3.52	3.78
Oct	3.66	3.55	3.61	3.66	3.66	3.66	3.65	3.91
Nov	3.66	3.53	3.60	3.66	3.66	3.66	3.64	3.78
Dec	3.85	3.73	3.79	3.85	3.85	3.85	3.83	3.91
Year	**44.18**	**42.85**	**43.53**	**44.18**	**44.18**	**44.18**	**44.02**	**45.99**



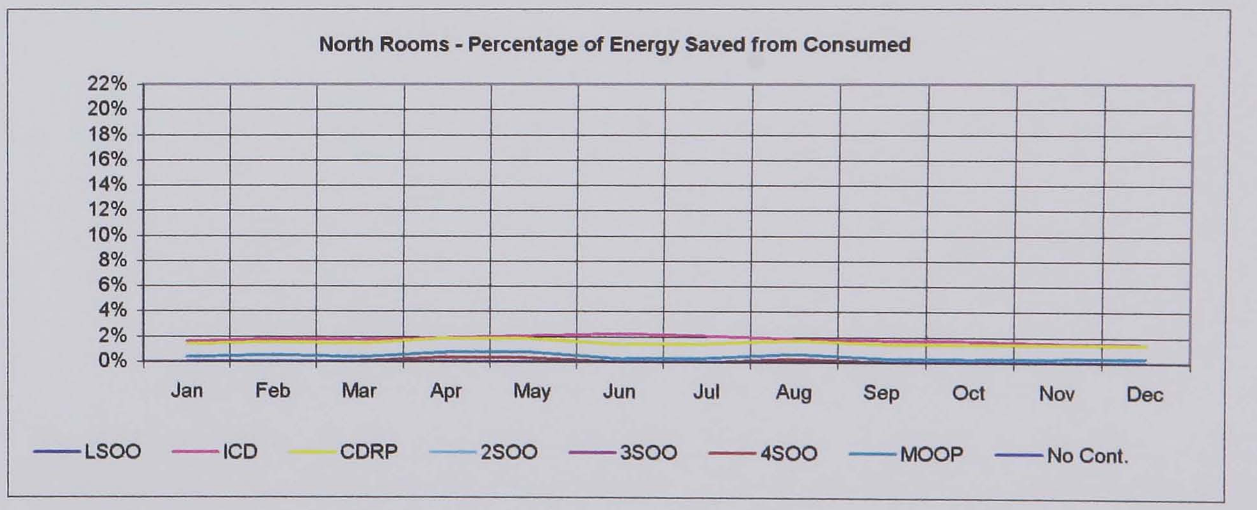
Internal Rooms - Electrical Energy Saved (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	0.00	0.18	0.14	0.00	0.00	0.00	0.01	0.00
Feb	0.00	0.19	0.13	0.00	0.00	0.00	0.01	0.00
Mar	0.05	0.24	0.18	0.05	0.05	0.05	0.05	0.00
Apr	0.02	0.26	0.16	0.02	0.02	0.02	0.03	0.00
May	0.03	0.31	0.17	0.03	0.03	0.03	0.04	0.00
Jun	0.04	0.35	0.17	0.04	0.04	0.04	0.04	0.00
Jul	0.04	0.35	0.18	0.04	0.04	0.04	0.05	0.00
Aug	0.04	0.32	0.18	0.04	0.04	0.04	0.05	0.00
Sep	0.04	0.27	0.17	0.04	0.04	0.04	0.05	0.00
Oct	0.00	0.23	0.14	0.00	0.00	0.00	0.01	0.00
Nov	0.00	0.19	0.13	0.00	0.00	0.00	0.01	0.00
Dec	0.00	0.16	0.14	0.00	0.00	0.00	0.01	0.00
Year	**0.26**	**3.06**	**1.89**	**0.26**	**0.26**	**0.26**	**0.33**	**0.00**



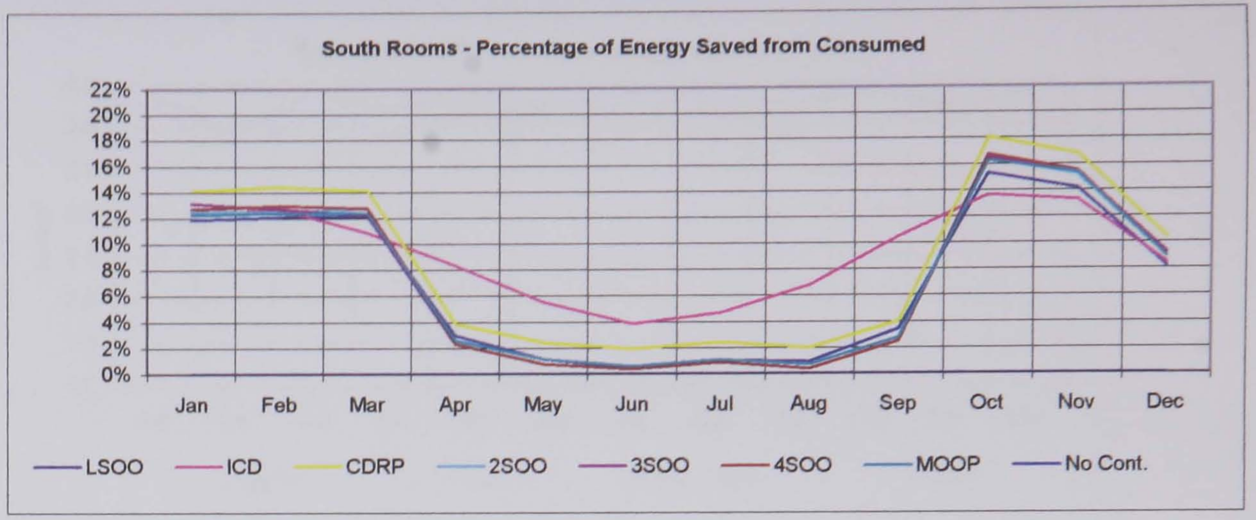
Internal Rooms - Electrical Energy Consumed (kwh/m²/month)								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	2.09	1.91	1.95	2.09	2.09	2.09	2.09	2.09
Feb	1.89	1.69	1.75	1.89	1.89	1.89	1.88	1.89
Mar	2.04	1.85	1.91	2.04	2.04	2.04	2.04	2.09
Apr	2.00	1.76	1.86	2.00	2.00	2.00	1.99	2.03
May	2.06	1.78	1.92	2.06	2.06	2.06	2.05	2.09
Jun	1.98	1.67	1.85	1.98	1.98	1.98	1.98	2.03
Jul	2.05	1.75	1.92	2.05	2.05	2.05	2.05	2.09
Aug	2.05	1.77	1.91	2.05	2.05	2.05	2.05	2.09
Sep	1.98	1.75	1.85	1.98	1.98	1.98	1.98	2.03
Oct	2.09	1.86	1.95	2.09	2.09	2.09	2.09	2.09
Nov	2.02	1.84	1.89	2.02	2.02	2.02	2.02	2.03
Dec	2.09	1.93	1.96	2.09	2.09	2.09	2.09	2.09
Year	**24.37**	**21.57**	**22.74**	**24.37**	**24.37**	**24.37**	**24.29**	**24.64**



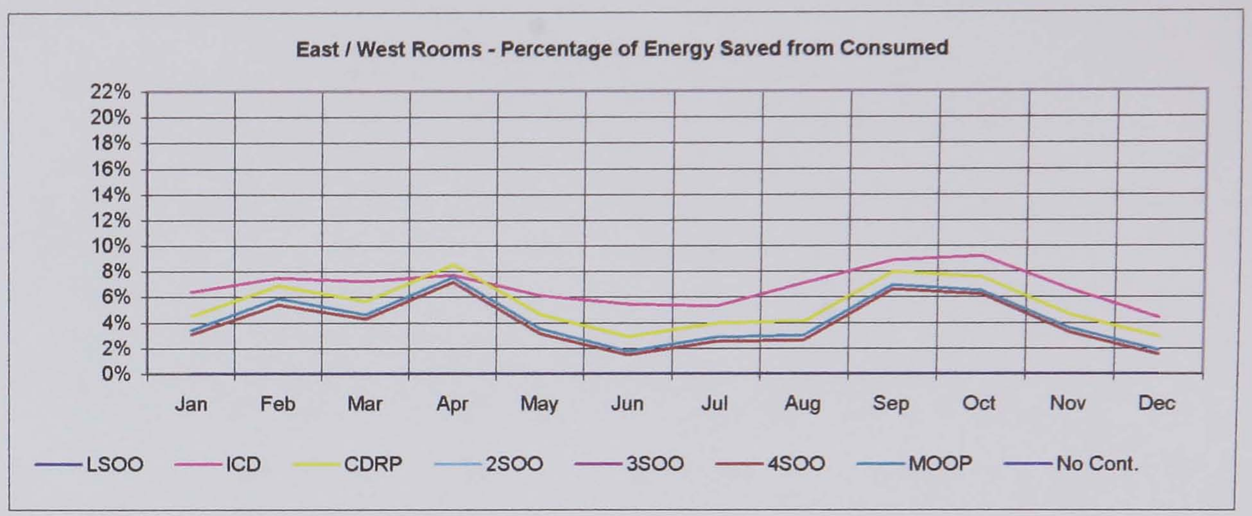
North Rooms - Percentage of Energy Saved from Consumed								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	0.00%	1.60%	1.46%	0.00%	0.00%	0.00%	0.36%	0.00%
Feb	0.00%	1.79%	1.58%	0.00%	0.00%	0.00%	0.55%	0.00%
Mar	0.05%	1.74%	1.50%	0.05%	0.05%	0.05%	0.39%	0.00%
Apr	0.40%	1.92%	1.91%	0.40%	0.40%	0.40%	0.79%	0.00%
May	0.33%	2.08%	1.87%	0.33%	0.33%	0.33%	0.78%	0.00%
Jun	0.00%	2.26%	1.45%	0.00%	0.00%	0.00%	0.29%	0.00%
Jul	0.00%	2.10%	1.46%	0.00%	0.00%	0.00%	0.31%	0.00%
Aug	0.29%	1.89%	1.79%	0.29%	0.29%	0.29%	0.66%	0.00%
Sep	0.04%	1.79%	1.51%	0.04%	0.04%	0.04%	0.35%	0.00%
Oct	0.00%	1.73%	1.46%	0.00%	0.00%	0.00%	0.30%	0.00%
Nov	0.00%	1.57%	1.43%	0.00%	0.00%	0.00%	0.33%	0.00%
Dec	0.00%	1.50%	1.43%	0.00%	0.00%	0.00%	0.36%	0.00%
Year	**0.09%**	**1.83%**	**1.57%**	**0.09%**	**0.09%**	**0.09%**	**0.46%**	**0.00%**



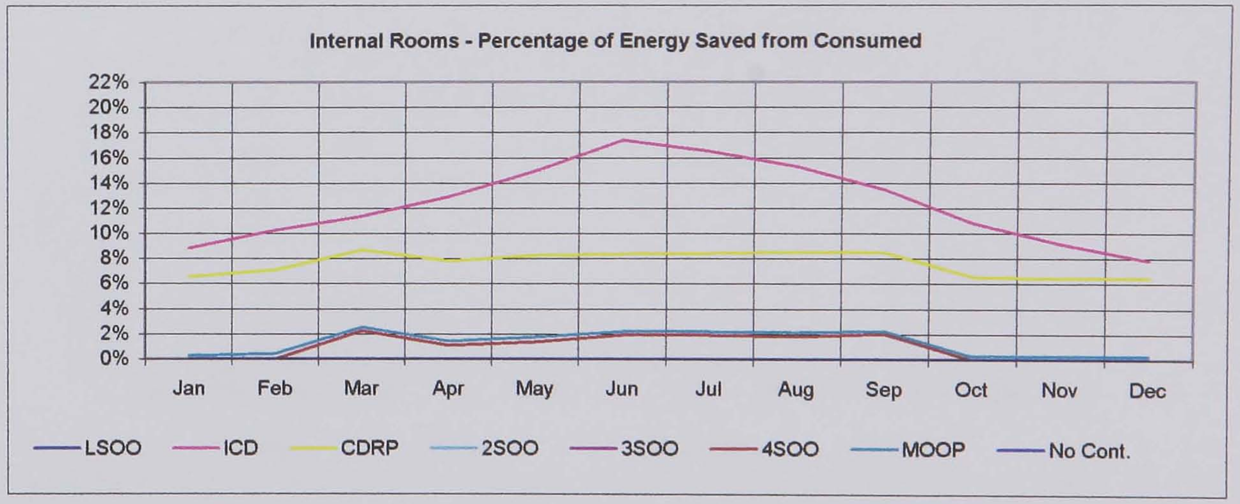
South Rooms - Percentage of Energy Saved from Consumed								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	11.91%	12.28%	14.07%	12.50%	13.17%	12.72%	12.28%	0.00%
Feb	12.11%	12.72%	14.44%	12.51%	12.71%	12.96%	12.42%	0.00%
Mar	12.19%	10.90%	14.11%	12.74%	12.23%	12.75%	12.40%	0.00%
Apr	2.98%	8.36%	3.86%	2.30%	2.30%	2.30%	2.60%	0.00%
May	1.16%	5.55%	2.42%	0.79%	0.79%	0.79%	1.15%	0.00%
Jun	0.51%	3.87%	1.92%	0.39%	0.39%	0.39%	0.62%	0.00%
Jul	1.04%	4.72%	2.42%	0.88%	0.88%	0.89%	1.12%	0.00%
Aug	0.94%	6.81%	2.00%	0.41%	0.41%	0.41%	0.71%	0.00%
Sep	3.42%	10.50%	4.01%	2.49%	2.49%	2.49%	2.74%	0.00%
Oct	15.29%	13.65%	18.05%	16.40%	16.52%	16.74%	16.30%	0.00%
Nov	14.13%	13.27%	16.75%	15.19%	15.37%	15.46%	15.36%	0.00%
Dec	8.20%	8.48%	10.35%	8.87%	9.21%	8.98%	8.90%	0.00%
Year	**6.97%**	**9.23%**	**8.68%**	**7.10%**	**7.18%**	**7.22%**	**7.19%**	**0.00%**

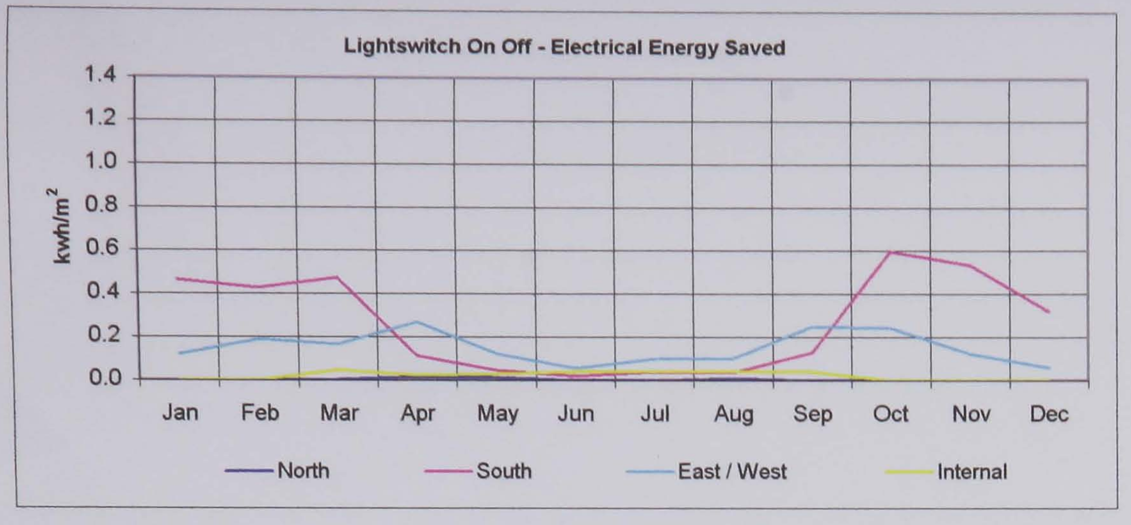


East / West Rooms - Percentage of Energy Saved from Consumed								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	3.11%	6.39%	4.52%	3.11%	3.11%	3.11%	3.45%	0.00%
Feb	5.40%	7.51%	6.89%	5.40%	5.40%	5.40%	5.91%	0.00%
Mar	4.30%	7.22%	5.69%	4.30%	4.30%	4.30%	4.63%	0.00%
Apr	7.19%	7.75%	8.59%	7.19%	7.19%	7.19%	7.56%	0.00%
May	3.13%	6.14%	4.63%	3.13%	3.13%	3.13%	3.56%	0.00%
Jun	1.49%	5.48%	2.91%	1.49%	1.49%	1.49%	1.77%	0.00%
Jul	2.57%	5.33%	3.99%	2.57%	2.57%	2.57%	2.86%	0.00%
Aug	2.66%	7.13%	4.13%	2.66%	2.66%	2.66%	3.02%	0.00%
Sep	6.64%	8.92%	8.01%	6.64%	6.64%	6.64%	6.94%	0.00%
Oct	6.22%	9.23%	7.59%	6.22%	6.22%	6.22%	6.50%	0.00%
Nov	3.28%	6.62%	4.66%	3.28%	3.28%	3.28%	3.60%	0.00%
Dec	1.54%	4.41%	2.94%	1.54%	1.54%	1.54%	1.89%	0.00%
Year	**3.94%**	**6.83%**	**5.36%**	**3.94%**	**3.94%**	**3.94%**	**4.29%**	**0.00%**

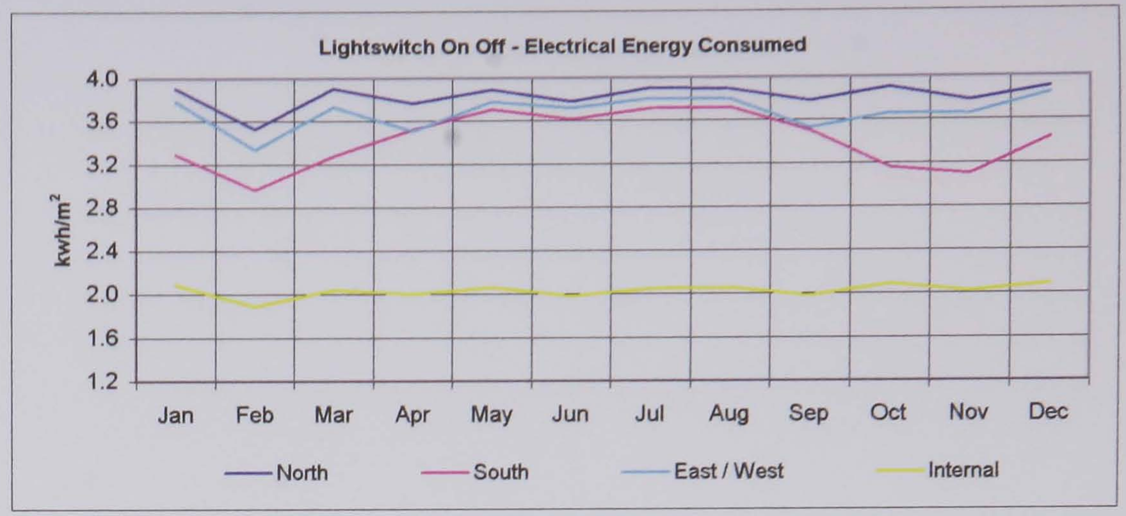


Internal Rooms - Percentage of Energy Saved from Consumed								
MONTH	LSOO	ICD	CDRP	2SOO	3SOO	4SOO	MOOP	No Cont.
Jan	0.00%	8.84%	6.58%	0.00%	0.00%	0.00%	0.30%	0.00%
Feb	0.00%	10.30%	7.13%	0.00%	0.00%	0.00%	0.46%	0.00%
Mar	2.27%	11.36%	8.74%	2.27%	2.27%	2.27%	2.56%	0.00%
Apr	1.13%	12.94%	7.88%	1.13%	1.13%	1.13%	1.45%	0.00%
May	1.41%	14.96%	8.31%	1.41%	1.41%	1.41%	1.79%	0.00%
Jun	1.94%	17.39%	8.38%	1.94%	1.94%	1.94%	2.19%	0.00%
Jul	1.93%	16.53%	8.44%	1.93%	1.93%	1.93%	2.20%	0.00%
Aug	1.85%	15.31%	8.56%	1.85%	1.85%	1.85%	2.16%	0.00%
Sep	2.02%	13.48%	8.51%	2.02%	2.02%	2.02%	2.28%	0.00%
Oct	0.00%	10.84%	6.58%	0.00%	0.00%	0.00%	0.25%	0.00%
Nov	0.00%	9.16%	6.46%	0.00%	0.00%	0.00%	0.27%	0.00%
Dec	0.00%	7.84%	6.47%	0.00%	0.00%	0.00%	0.30%	0.00%
Year	**1.05%**	**12.42%**	**7.67%**	**1.05%**	**1.05%**	**1.05%**	**1.36%**	**0.00%**

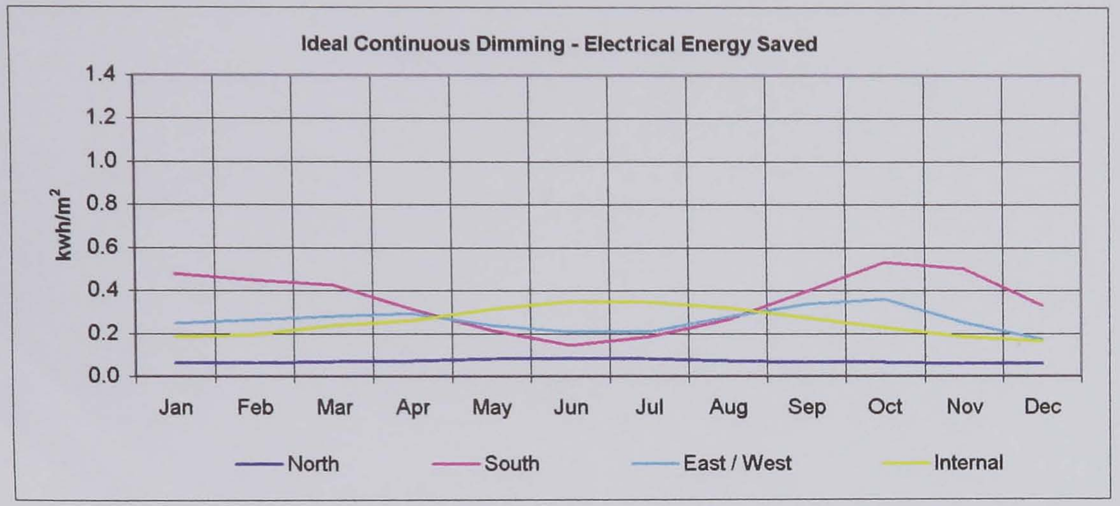




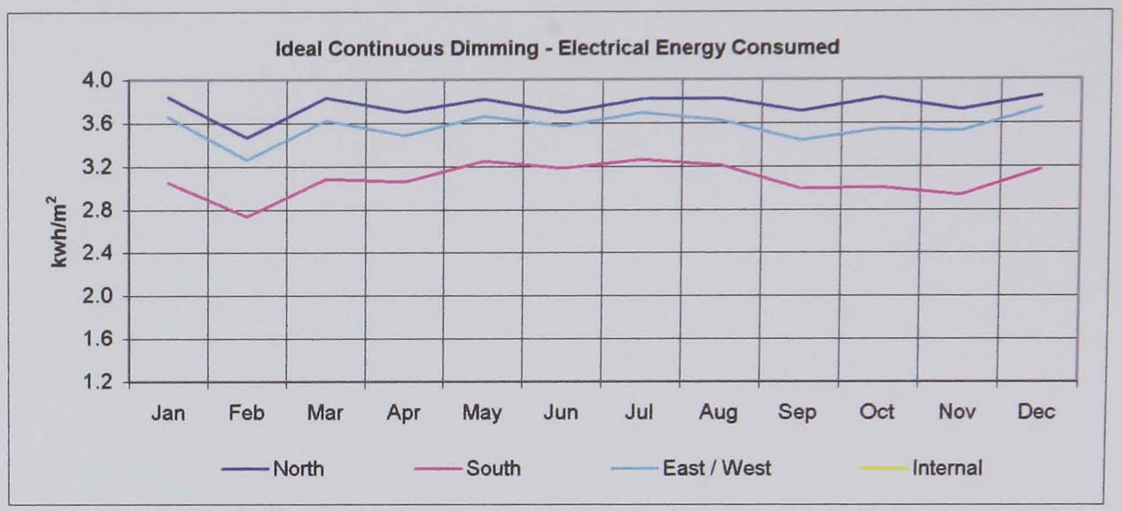
Lightswitch On Off - Electrical Energy Saved
kwh/m2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
North South East / West Internal



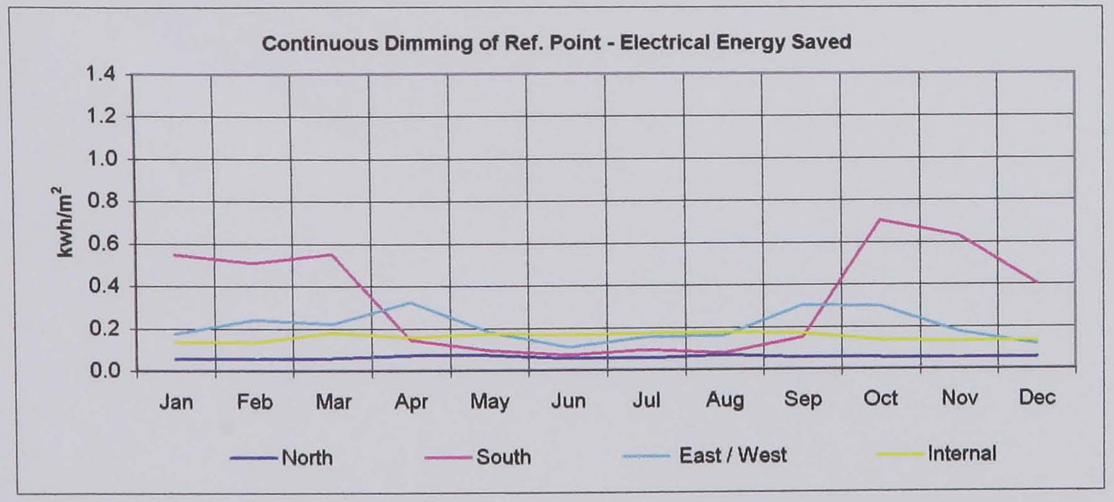
Lightswitch On Off - Electrical Energy Consumed
kwh/m2
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
North South East / West Internal



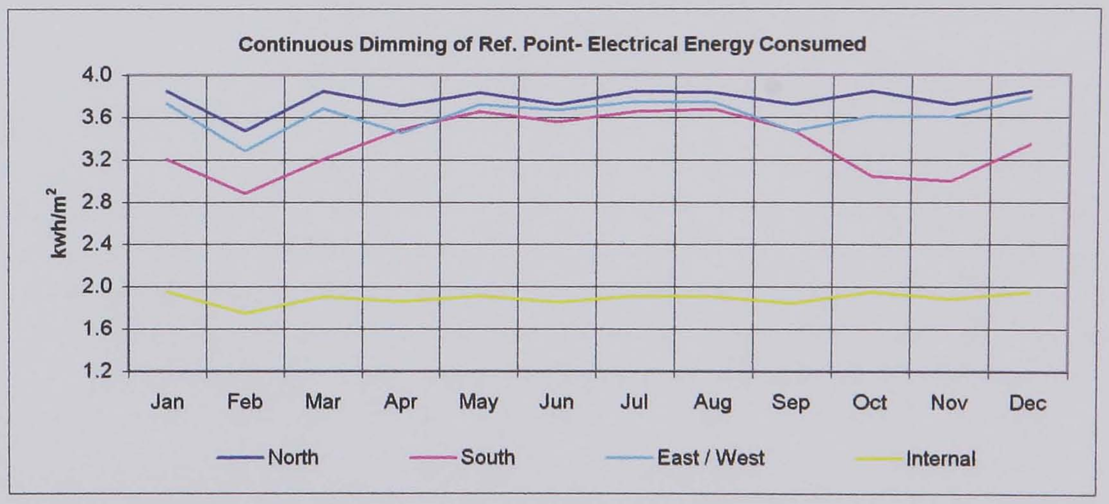
Ideal Continuous Dimming - Electrical Energy Saved
kwh/m2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
North South East / West Internal



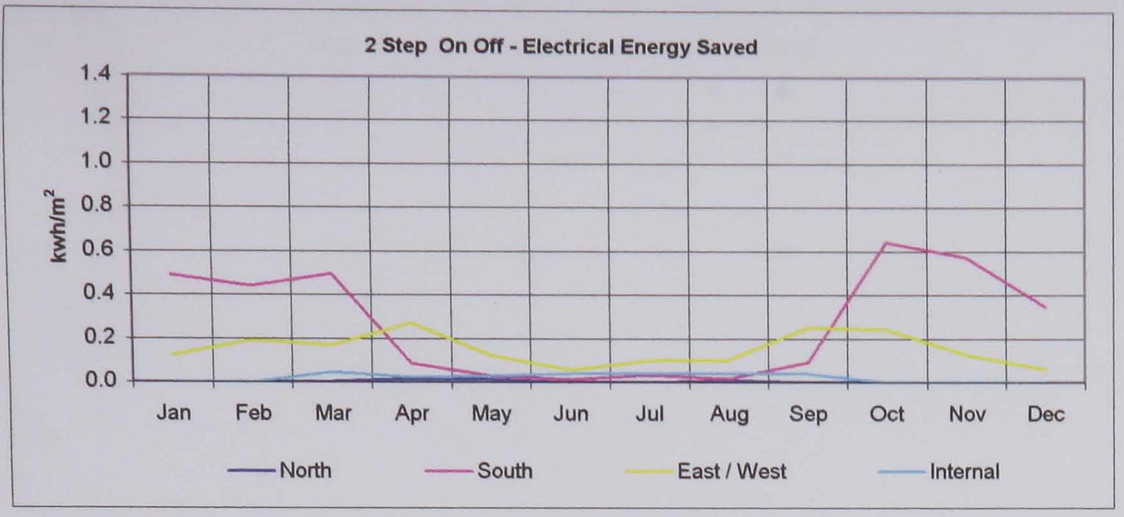
Ideal Continuous Dimming - Electrical Energy Consumed
kwh/m2
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
North South East / West Internal

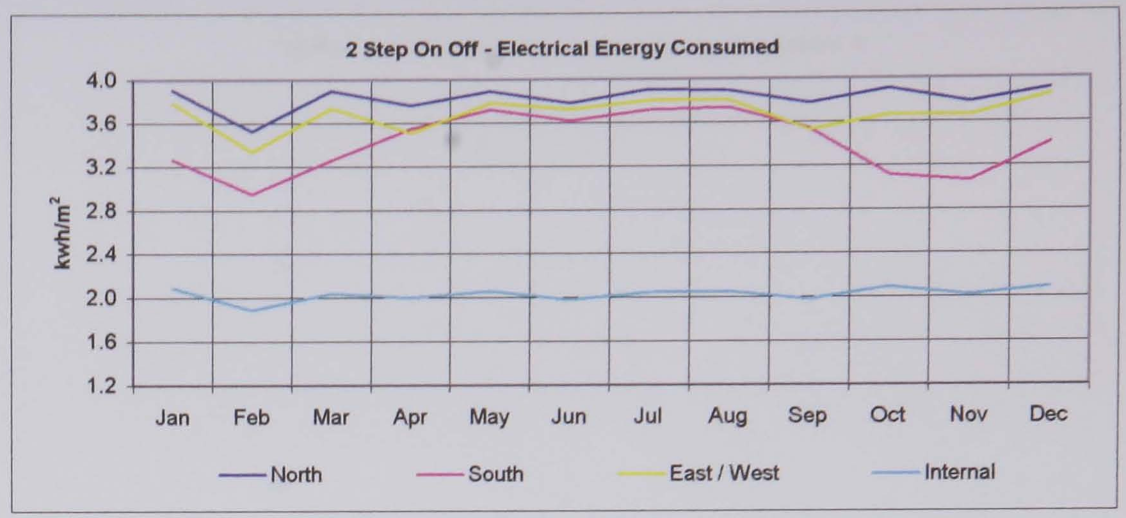


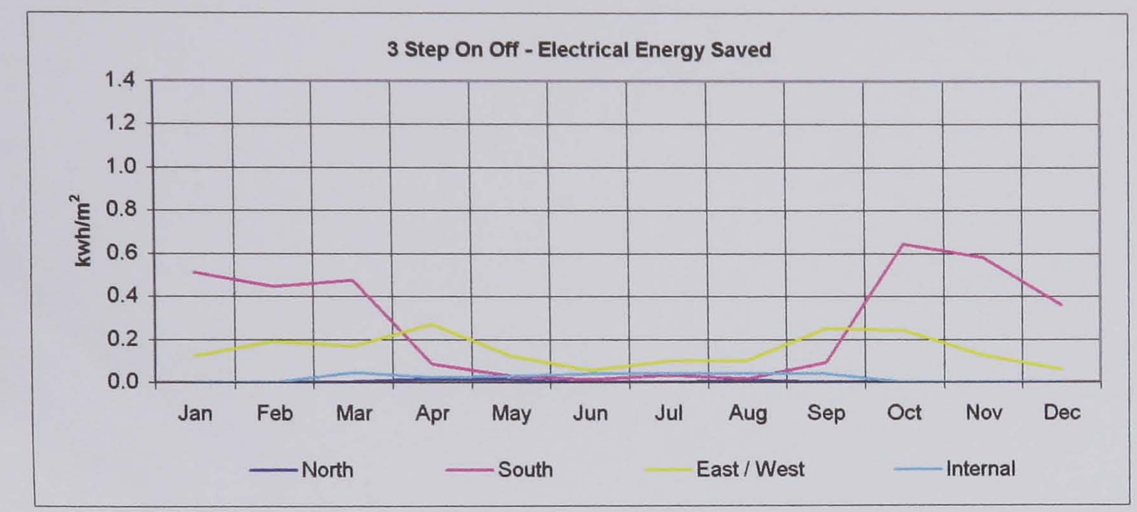
Continuous Dimming of Ref. Point - Electrical Energy Saved
kwh/m2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
North South East / West Internal

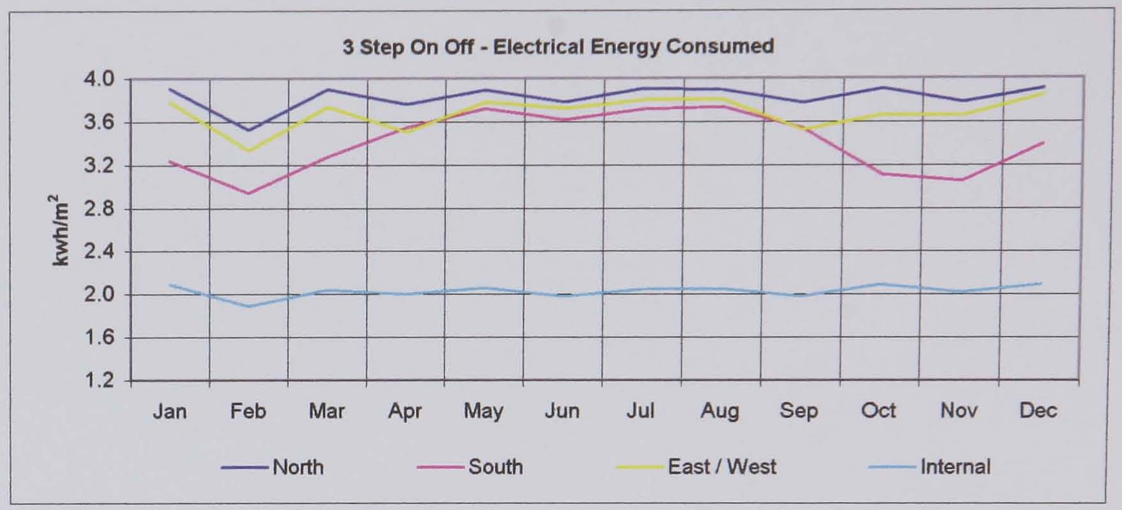


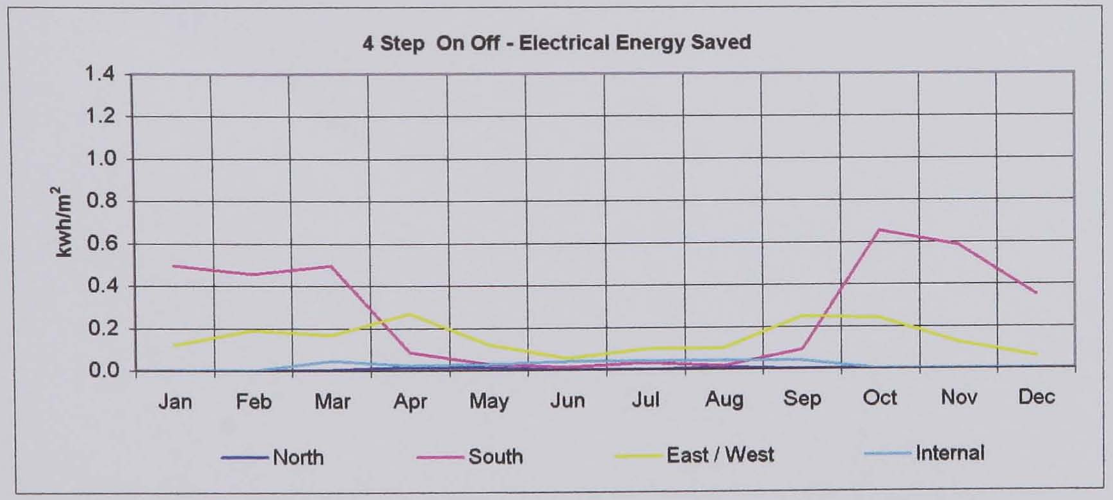
Continuous Dimming of Ref. Point- Electrical Energy Consumed
kwh/m2
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
North South East / West Internal

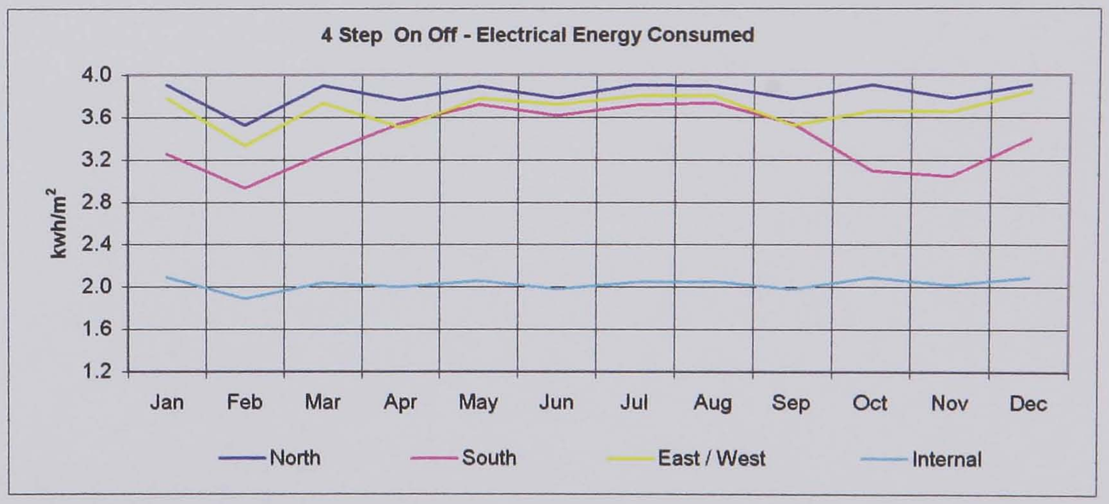

2 Step On Off - Electrical Energy Saved
kwh/m2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
North
South
East / West
Internal

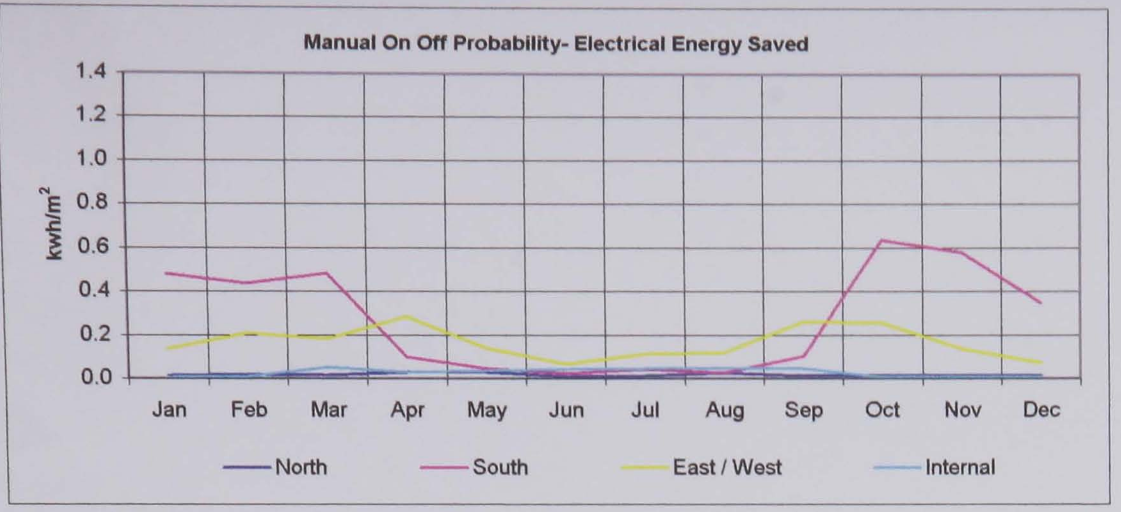

2 Step On Off - Electrical Energy Consumed
kwh/m2
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
North
South
East / West
Internal

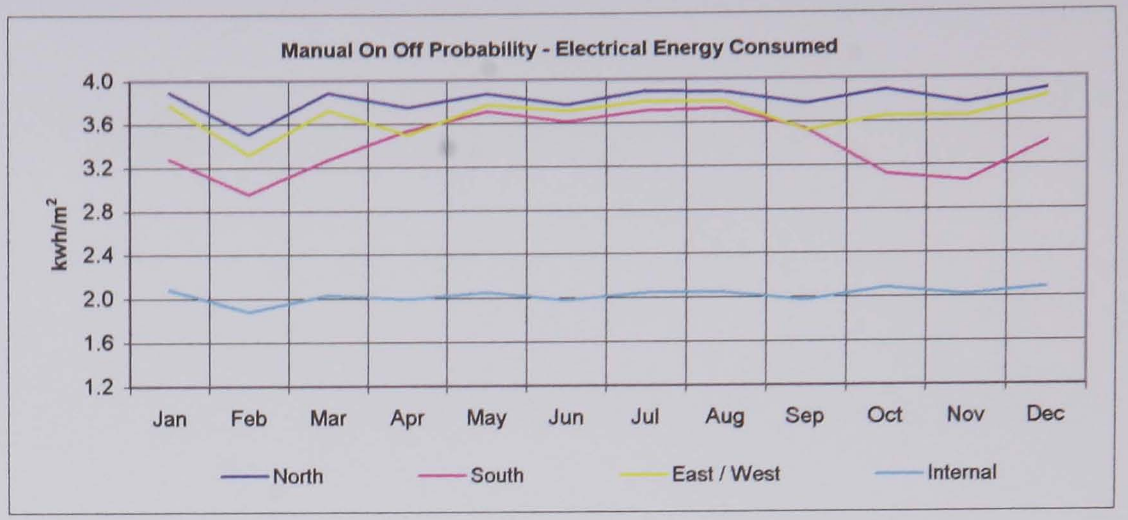

3 Step On Off - Electrical Energy Saved
kwh/m2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
North
South
East / West
Internal


3 Step On Off - Electrical Energy Consumed
kwh/m2
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
North
South
East / West
Internal


4 Step On Off - Electrical Energy Saved
kwh/m2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
North
South
East / West
Internal


4 Step On Off - Electrical Energy Consumed
kwh/m2
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
North
South
East / West
Internal


Manual On Off Probability- Electrical Energy Saved
kwh/m²
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
North
South
East / West
Internal


Manual On Off Probability - Electrical Energy Consumed
kwh/m²
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
North
South
East / West
Internal

Appendix VI. POE Questionnaire

Lighting Conditions Survey
(Post-Occupancy Evaluation of Daylighting)

The aim of this survey is to gauge the opinion of occupants on the lighting conditions in order to help with the future design and planning of buildings and workplaces. In order to have a more holistic approach towards the impact of daylighting in the building, the content of the questionnaire should consider the physical environment as a whole (also including noise and thermal conditions). Thus the user has the opportunity to rate the importance of lighting quality against other qualities of work environment and work conditions. The survey complements measurements of daylight and artificial light as well as energy consumption.

This building is one of the office buildings in Beirut that are being monitored Please answer for this building. Please be frank and honest and try to fill in as many questions as you can. Write any further comments in the space provided at the end of the questionnaire.

The questionnaire is used for academic purpose only and the information collected will be treated as completely confidential by the researcher. Survey reports will use summaries of information and not reveal the identities of individuals.

Thank you very much for your time and cooperation

Queries: If you have any queries please contact Sawsan Saridar (e-mail: Sawsan.Saridar@ncl.ac.uk)

Building Name: .... Room No.: .... Floor: ....
Name: .... Date: .... Time: ....

1. Background

Please note: we ask about age and sex because there are relevant to people's needs in buildings. We ask for names so that we can follow up any matters that arise.

1. Age ☐ under 30 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60 and over

2. Sex ☐ Male ☐ Female

3. Are you right-handed or left-handed? ☐ right-handed ☐ left-handed

4. Please describe briefly the work you carry out in the building:

....

5. How many days do you spend in the building on a normal working week? ....days / week

6. How many hours / day do you spend in the building on a normal working day?.................. hours / day

7. How many hours / day do you spend on your desk in a normal working day? .... hours / day

8. How many hours / day do you spend working with a computer screen (VDU)?.................. hours/day

2. Your Desk or Work Area

9. Is you office or work area is

☐ a room closed with full height walls?

☐ an open room with no dividers or furniture that blocks the view?

☐ a workstation space enclosed (or mostly enclosed) by dividers pants or file cabinets. In an otherwise open office have little or no view of other employees?

☐ a workstation having some dividers that tend to break up an open room but do not enclose the workspace (can easily see other employees)?

10. How many persons share your current room or work space?

☐ have a room on my own ☐ shared with 1 other ☐ shared with to 2-4

☐ shared with to 5-8 persons ☐ shared with more than 8 persons

3. Physical Environment

11. Mark the three physical features that are most important to you in making a workplace a pleasant one for you to work in. Mark from 1 to 3, with 1– the most important.

☐ Comfortable temperature ☐ Freedom from noise ☐ Good Light
☐ Privacy ☐ Good ventilation ☐ Plenty of space
☐ Window(s) ☐ View out ☐ General environment
☐ Others (please specify) (colour, carpet, furniture, decoration, etc.) ....

12. How satisfied are you with the following aspects of your workplace? (Please tick your rating on each scale)

	very dissatisfied		fair		very satisfied
a - overall lighting	☐	☐	☐	☐	☐
b – odour	☐	☐	☐	☐	☐
c – freedom from noise	☐	☐	☐	☐	☐
d – temperature	☐	☐	☐	☐	☐
e – window size	☐	☐	☐	☐	☐
f – privacy	☐	☐	☐	☐	☐
g – lots of space	☐	☐	☐	☐	☐
h – view	☐	☐	☐	☐	☐
i – general environment	☐	☐	☐	☐	☐

13. How much control do you personally have over the following aspects of your working environment?

	No control	Fair	Full control	please tick if important to you
a - heating	☐	☐	☐	☐
b - cooling	☐	☐	☐	☐
c - ventilation	☐	☐	☐	☐
d - lighting	☐	☐	☐	☐
e - noise	☐	☐	☐	☐

14. Is there anything you particularly like about this building? ☐ Yes ☐ No
If Yes, what do you like?..

15. Is there anything you particularly dislike about this building? ☐ Yes ☐ No
If Yes, what do you like?..

4. Health and Productivity

16. Do you feel less or more healthy when you are in the building?

less healthy ☐ ☐ ☐ ☐ ☐ more healthy

17. Do you suffer from particular disturbances of your health and well being?

	Very strong	strong	moderate	barely	not at all
a – concentration weakness	☐	☐	☐	☐	☐
b – rapid fatigue	☐	☐	☐	☐	☐
c – sleepiness	☐	☐	☐	☐	☐
d – irritability	☐	☐	☐	☐	☐
e –visual impairments	☐	☐	☐	☐	☐
f – headaches	☐	☐	☐	☐	☐
g – dry eyes	☐	☐	☐	☐	☐
h – burning eyes	☐	☐	☐	☐	☐

18. Please estimate how you think your productivity at work is increased or decreased by the environmental conditions in the building. (Please tick one point on the scale)

Productivity decreased by — Productivity increased by

☐ -40 %≥ ☐ -30% ☐ -20% ☐-10% ☐ 0% ☐+10% ☐+20% ☐+30% ☐+40%≤

5. Daylight and Relationship to Windows

19. How important is it to you to have a window in your room / work area?
☐ not important ☐ moderately important ☐ very important

20. Do you sit next to a window at your normal workspace? ☐ Yes ☐ No (**If No, move to question # 31**)

21. How is your workplace oriented in relation to the window?
☐ you are facing window ☐ you are facing wall between windows
☐ the window is at your left ☐ the window is at your right ☐ no windows

22. What is the approximate distance to the nearest window?
☐ less than 1m ☐ 1-2m ☐ 2-4m ☐ 4-6m ☐ more than 6m

23. How about the size of your window? Is it
☐ too small ☐ about right ☐ too big

24. Do you ever work using only the light from the windows?
☐ very often ☐ often ☐ sometimes ☐ only occasionally ☐ never
If it happens, can you specify when? ....

25. Does the daylight ever cause glare strong enough to bother you?
☐ very often ☐ often ☐ sometimes ☐ only occasionally ☐ never
If it happens, can you specify when? ....

26. Does it ever become too hot because of the sunshine coming in through the windows?
☐ very often ☐ often ☐ sometimes ☐ only occasionally ☐ never
If it happens, can you specify when? ....

27. When the sunlight on your workplace feels too warm and cause glare, how do you respond? (check all that apply)
☐ close external blinds / other devices ☐ close internal drapes / blinds
☐ open a door / window to the outdoors ☐ open an interior door / window
☐ move to a more comfortable location in my workspace ☐ work elsewhere in the building
☐ adjust the thermostat (AC) ☐ nothing

28. Do you ever notice cold draughts near the windows?
☐ very often ☐ often ☐ sometimes ☐ only occasionally ☐ never

29. Listed below are some advantages of windows. Make the three that are most important to you at your workplace. Mark 1 to 3, with 1 – the most important.
☐ let you tell the time of day ☐ let sunshine in ☐ let you know what the weather is
☐ let in warmth ☐ view out ☐ let you see what's going outside
☐ provide light for plants ☐ break monotony ☐ way for fresh air to enter
☐ make room more spacious ☐ other (please specify)...

30. Listed below are some disadvantages of windows. Make the three that are most important to you at your workplace. Mark 1 to 3, with 1 – the most important.
☐ let in too much heat in summer ☐ cause glare ☐ let in too much cold air in winter
☐ reduce privacy ☐ let in outside noise ☐ limit ways furniture can be placed
☐ give too much sunlight ☐ present hazard ☐ others (please specify).........................

6. Light Conditions and Electric Light Usage

31. Do you have a desktop lamp or similar at your workplace? ☐ Yes ☐ No

If Yes, do you use it ☐ always ☐ often ☐ seldom ☐ never

If No, do you think desktop lamp would improve the light conditions ☐ Yes ☐ No

32. Do you prefer working in natural light, artificial light or a combination?

☐ natural light ☐ artificial light ☐ combination

33. In general how do you rate the light level, artificial and natural combined?

	too little light		about right		too much light
a – at the workplace	☐	☐	☐	☐	☐
b – in the room in general	☐	☐	☐	☐	☐
c – at the VDU (computer screen)	☐	☐	☐	☐	☐

34. Does the artificial light ever cause glare strong enough to bother you?

	very often	often	sometime	only occasionally	Never
a – at the workplace	☐	☐	☐	☐	☐
b – at the VDU	☐	☐	☐	☐	☐

35. Does the lighting cause reflections that in your work material?

	not disturbing	slightly disturbing	sometimes	moderately disturbing	never disturbing
a – from ceiling lighting	☐	☐	☐	☐	☐
b – from desk top lighting	☐	☐	☐	☐	☐
c – from the daylight	☐	☐	☐	☐	☐

36. If there are reflections that disturb you in what work material do they occur?

☐ glossy paper ☐ VDU screen ☐ other (please specify)........................

7. Additional Information

If you have further comments on the topics raised, please add them in the provided space.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

8. Thank You for Your Help

Please leave the questionnaire in a prominent place, and it will be collected later tomorrow.

Appendix VII. List of Publications

Refereed Journal Papers

Saridar, S. and H. Elkadi (2001) The impact of applying recent façade technology on daylighting performance in buildings in eastern Mediterranean, *Building and Environment*, 37 (11), 1205-1212.

Refereed International Conferences

Saridar, S. and H. Elkadi (1999) The impact of skin technology on daylighting performance in buildings, In Sustainability in Desert Regions, SDR'99, Vol. Theme A, Al-Ain, UAE, 20 - 22 November, 1999. United Arab Emirates University, pp. 237-248.

Saridar, S. and H. Elkadi (2001) Daylighting flow pattern and intelligent façade features in office buildings, In Sharjah Solar Energy 2001, Sharjah, UAE, 19-22 February, 2001. University of Sharjah.

Saridar, S. and H. Elkadi (2001) Daylighting flow pattern and intelligent façade features in office buildings, In International Conference on Building Envelope Systems and Technologies, ICBEST 200, Vol. 2, Ottawa, Canada, 26-29 June, 2001. National Research Council of Canada, pp. 169-174.

Saridar, S. and H. Elkadi (2001) Daylighting flow patterns and intelligent façade features in office buildings, In The 7th REHVA World Congress, Clima 2000, Naples, Italy, 14-18 September, 2001. CD Publication.

Saridar, S. and H. Elkadi (2004) The globalization of architecture in Beirut, In Ninth Conference of the International Association for the Study of Traditional Environments (IASTE), Sharjah, UAE, 14 - 18 December, 2004.