بسم الله الرحمن الرحيم

A Study of Energy Conservation in the Existing Apartment Buildings in Makkah Region, Saudi Arabia

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ABSTRACT

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Despite great development in residential buildings that Saudi Arabia has witnessed over the last two decades, there is still a lack of understanding and of evaluating the thermal performance aspects of the buildings. The rapid developments that took place in such a short time have ignored environmental considerations and produced exotic buildings that have poor thermal performance.

The existing residential building stock built during the economic boom of the 70's and afterwards is having problems balancing between a comfortable indoor climate and reasonable usage of energy. To resolve this issue, the thermal performance of these buildings needs to be improved. But, in the absence of proper knowledge about the performance of these buildings, any proposed suggestions will be a matter of speculations.

The research aims to address the notion of energy conservation in existing apartment building in Makkah, Saudi Arabia. It is concerned with identifying the thermal characteristics and the quality of indoor environment in this building type as well as investigating the behaviour of the occupants and their domestic energy demands. This background sets the base to test energy saving measures and to review their effectiveness and their applicability. The study provides information for the parties with direct relation to this issue, authority and policy makers, building professionals, and occupants to assist them in understanding the current situation and promote the selection of the most appropriate strategy.

In this study, a comprehensive fieldwork survey, that comprises social survey of 600 apartments and physical measurement survey for eight case studies, have been performed. Thermal performance of the different building components and their dynamic interaction has been simulated thoroughly by a computer program for building energy analysis (VisualDOE-2.5).

The simulation has been employed to theoretically predict the thermal roles of building components and the impact the occupants have as building users. The program tested strategies for potential energy savings. The simulation model has demonstrated a 19% and 31% reduction in cooling load as a result of applying insulation materials and shading device in respective order.

The findings have been integrated to highlight the problems of energy conservation issues in existing apartment buildings, producing recommendations and suggestions for further research avenues to complement work.

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I would like to thank my special wife and my special daughter Lmaa for being with me all the way.

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TABLE OF CONTENTS

CHAPTER 3
CLIMATIC CONTEXT
The Significance of Climate in the Human Environment

CHAPTER 4
BUILT FORM AND INTERNAL ENVIRONMENT

CHAPTER 5
THE SURVEY RESEARCH
Investigating the Existing Apartment Buildings in Makkah

CHAPTER 6
THE QUESIONNAIRE SURVEY
The Questionnaire Survey Data Analysis

CHAPTER 7
THE MEASUREMENTS SURVEY DATA ANALYSIS
Data Analysis of the Sleeted Case Studies

CHAPTER 8
THERMAL PERFORMANCE ANALYSIS
The Simulation

CHAPTER 9
THE SIMULATION RESULTS ANALYSIS

LIST OF FIGURES

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8

Chapter 9

Chapter 10

LIST OF TABLES

Chapter 1

Introduction

Chapter 1

INRODUCTION

1.1 Overview

Energy resources have been recognised, as an essential tool for securing development needs for human settlements. The valuable heritage from these materials inside the earth is suffering from rapid depletion with human extravagance uses. These are a finite and diminishing resources in sense that more is being used than is discovered, and is nearly impossible to compensate for this depletion.

The chemical energy in the organic structure of coal, oil, and gas represent the forms of energy with us today. These sources are dispersed all over the world with an uncertain amount of reserves. Furthermore, the information about the resources of the fossil fuel and natural energy is limited and there was little Global interest in this issue in the past. This shortsighted view for energy future might be attributable to the consideration such as: -

- The temporary abundance of natural resources
- Energy independent applications (before the industrial revolution)
- Low energy price
- Simple life style
- Over-production of fuel, weak demands and enfeebled economic performance.

The depletion of world energy resources is demonstrated by supply deficiencies arising from the four major energy consuming sectors which are, electricity generation, transportation, industry, and the cooling and heating of buildings. Recent fuel prices have shown that the fuel costs permeate the whole economy. Thus, as the availability of fossil fuels becomes strained, standard of living indices will be negatively affected.

1.2 International Energy Profile

Fossil fuel is dominant as an energy generator and as a major traded commodity. The history of energy transition has started during the 19th century with coal. In 1870 and afterward, coal come to stage with the Industrial Revolution. This source was pre-eminent as the main fuel until the middle of 1940s when oil took over. (Gibbons, 1982)

Oil as a major source of energy has ruled the fossil fuel scene and has taken prominence over other types of fuels; it has controlled the world of economy for a last 80 years. The world economy of the twentieth century has been the economy of the oil barrel and it will remain so for a long time before one of the renewable sources of energy can take its place

As far as the historical profile of the oil economy is concerned, the world has witnessed two major recessions that affected the growth of international economy, and sent the world into an abrupt crisis. The first shock come from the Arab oil embargo in 1973-74, while the second one come later in 1979-80 as a result of the Iranian revolution.

Before 1970 the course of world energy consumption was a simple affair, fuel was available, price was not a crucial factor and economies were growing steadily. The period since 1970 has seen a strategy calling for a reduction on oil dependence and spurred the search for other supplies of oil, e.g. North Sea.

In the eighties and early nineties a large surplus of oil flooded the international markets and created an oil glut. This surplus of supply over demand was the major cause of a steady world economic upturn.

During the oil crises, the centrally planned economies in the world showed an increase in demand; the less developed countries showed a high rate of consumption. Meanwhile, consumption in the industrialised countries has fallen. (Hedley, 1986)

Oil unseen problems drives from the fact that oil cannot be underestimated as vital energy generator, and any violent movements in oil price up or down could therefore be equally dangerous to the world economy. The potential for further upward oil price movement will exist as oil surplus is gradually eliminated from markets, as demand starts to exceed production. If we take into account the level of depletion of the reserves and the world's potential to increase supply, the important question that has to be answered: is for how long can these reserves go before they run out?

Figure 1.1 illustrates the global rate of energy consumption from 1970 to 1992, and it denotes clearly the continued growth in energy consumption.

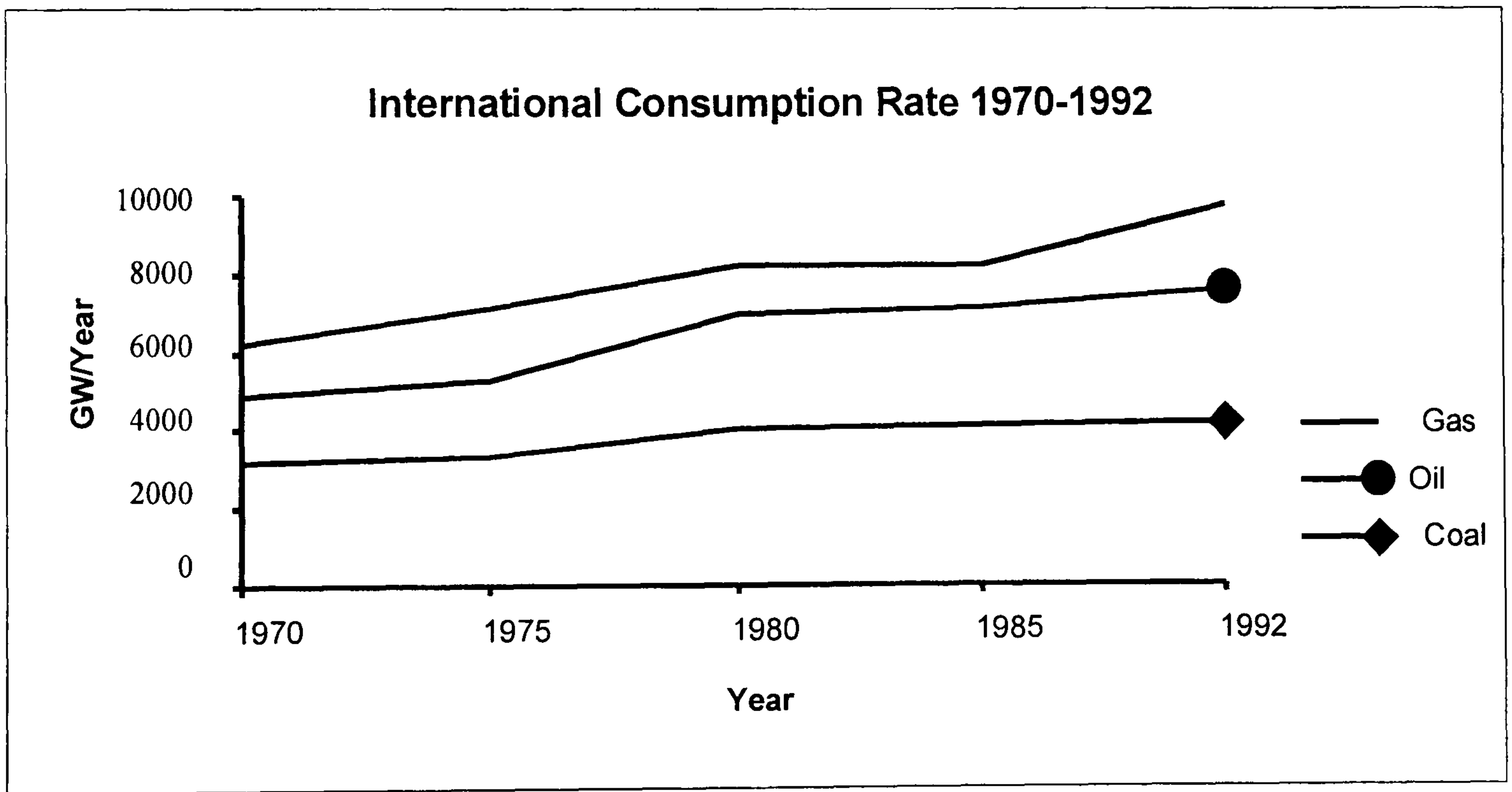


Figure 1.1: Global Energy Consumption Profile. Source: IEA, 1997.

1.3 The Concept of Conservation

It was the oil crisis that brought the revolution of energy conservation seriously into view. Before 1973, conservation was a seldom-used word with little government and media support. It was used in the context of slowing the depletion rate of finite, diminishing fossil fuel resources.

After that energy conservation become an economic imperative, a way of coping with massive cost increases, and a policy for maintaining a stable at economic growth.

> "Conservation, the extraordinary event necessary to enable all the ordinary events to continue" (Wills 1978, p.27).

Conservation has been defined as " the wise utilisation of a natural product especially a manufacturer so as to prevent waste and ensure future use of resources that have been depleted". Also conservation means " planned management of natural resources to prevent exploitation, destruction, or neglect" (Webster, 1993)

The measure of conservation is the amount of energy required to produce a single unit of economic growth, and this relationship known as the energy coefficient. Until the early seventies and before the conservation policies, this relationship was regarded as a lock step relationship; in other words a certain level of economic growth required a certain amount of fuel consumption.

Recent history has disproved this relationship, and in the Eighties the major western industrial nations were using 17% less energy per unit of economic growth than they were in 1973 (Hedley, 1986). This difference is sufficient to justify energy conservation plans and polices.

The concept of saving energy generally depends on two major approaches in order to achieve the aim. The first approach is defined under the energy efficiency (performing the same task using less energy); the second approach can be seen under energy conservation measures (making do with less energy).

The results of adapting this attitude at national level are strongly tangible. Reviews of the experience of different countries in this field have shown that, for example, Denmark had saved 30% and France 25% of energy consumption, and the UK have managed to save up to 17% through the Energy Efficiency Office. The Office promoted the view that greater efficiency in energy use can play a major role in industry's rising profitability. Other countries have increased their fuel efficiency and oil substitution budgets or alternatively launched new policy initiatives.

In Australia the scope of national energy conservation program broaden to include not only petrol saving but the conservation of all forms of energy. In Belgium tax deduction for industrial conservation investment rose in 1982. Sweden has introduced a 25% investment subsidy for changing from oil to peat burning. In Italy a new bill will provide incentives for conservation and fuel switching (Hedley, 1986).

The success of energy conservation in these countries is clearly attributable to the high level of investment in energy saving plans, investments, which are expected to payback with profits in the long term.

1.4 Energy Conservation, the Implication of Building Industry

Buildings process and users dominate energy use and represents the greater share, almost two-third, of the total energy consumption (O'Callaghan, 1978). This industry may be considered to be a continuous cycle of energy consuming, starting from the early design stage and going through the estimated useful lifetime of the building.

The function required from the buildings is to satisfy human needs, which may range from the most basic protection from the surrounding environment to the moral expression of the cultural, social, economical, and intellectual status of the people, the place, and the time. Climate has important effects on the energy performance of buildings. The conservation of energy in building stocks often hinges on the ability to resist or delay the effect of climate on the fabric.

Energy is basically used in building context to moderate the indoor environment and to improve people's standard of living. The amount of energy consumed by any type of buildings can give an indication of the thermal performance of the building and the behaviour pattern of the occupants. A high rate of consumption might reflect the need for conservation measures. Although that there are many factors that govern the consumption rate in addition to the building envelope, the control of climate in building design, as far as human comfort is concerned, still has a significant influence in energy consumption.

Without a great deal of increased discomfort or cost to the building occupants, it is technically possible to reduce the cooling/heating energy consumption by at least 50% (Sinden, 1978). The important strategies practically applied to save energy can be listed as following:

- To utilise the passive cooling techniques in design and construction
- To improve thermal properties of building fabric
- To improve energy efficiency of different related aspects
- To improve the utilisation of natural resources (i.e. light and ventilation)
- To encourage alternative energy source, (i.e. solar energy)
- To optimise and control the pattern of energy usage (i.e. energy management)

Data from the literature suggests that an improved thermal design building (i.e. orientation, insulation, reduction of infiltration etc.) can save up to 40% from the energy consumed. If energy conservation measures are carried out to full potential, the saving will increase to 60% (Szokolay, 1981).

1.5 The Kingdom of Saudi Arabia

1.5.1 Forward

The kingdom of Saudi Arabia is a vulnerable place as far as the international community is concerned. This vulnerability recognised by the role it plays in the Islamic World as well as in the international economy. The Islamic significance of

Saudi Arabia comes from the holy cities (i.e. Makkah, Al-Madinah), that are located within its vast geographical area, which has an approximate size of 2,240,000 square kilometers (Figure 1.2).

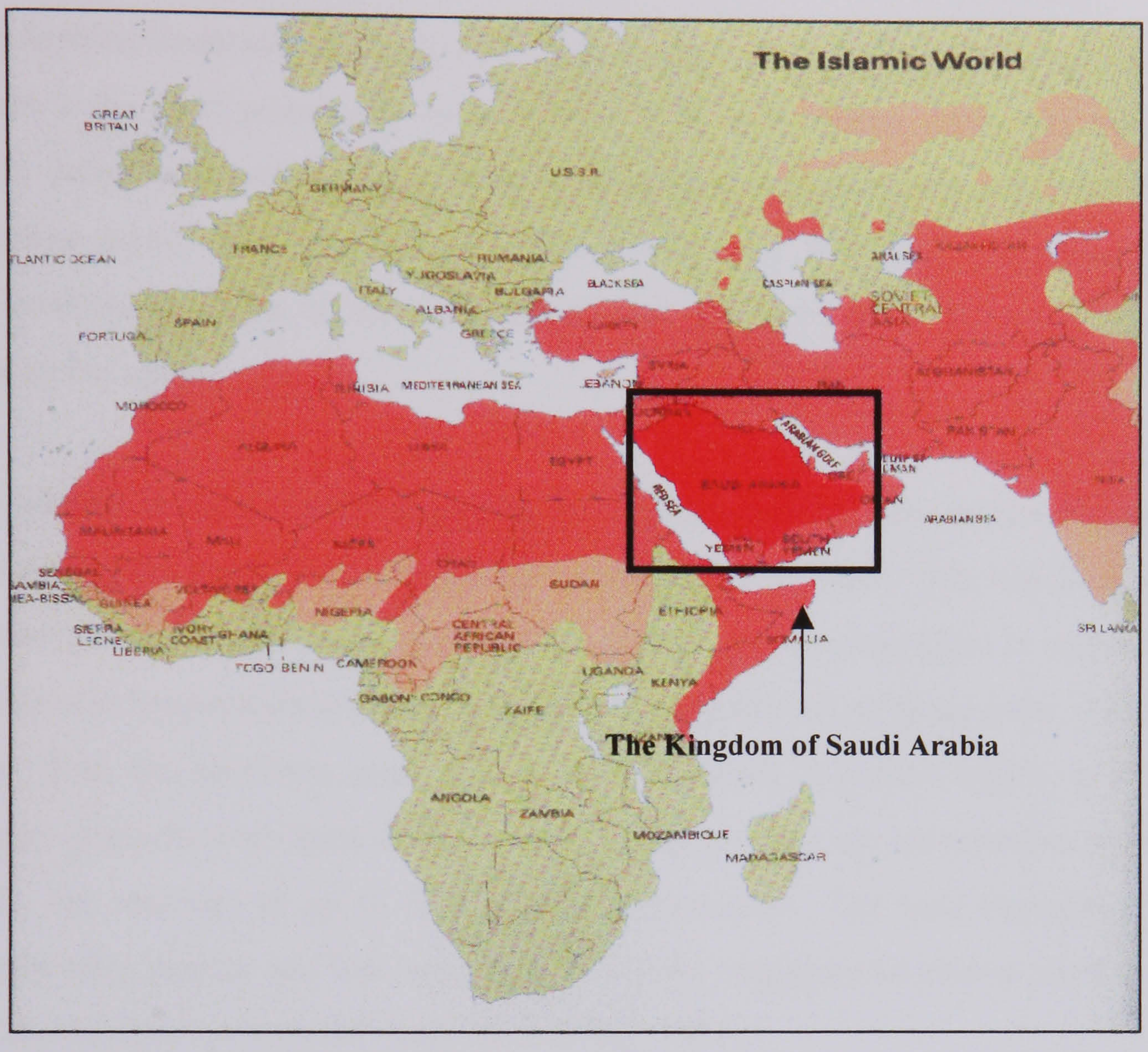


Figure 1. 2: The Kingdom of Saudi Arabia

Discovery of oil in commercial quantities in 1939 was the major catalyst that transformed various aspects of the Kingdom. It has the world's largest oil reserves and extensive oil processing facilities. The huge revenues from the sale of oil enable the government to launch large-scale development programmes by the early 1970s. Such programs initially focused on the creation of infrastructures in the areas of transportation, telecommunications, electrical power, and water. The programs also addressed the field of education, health and social welfare (MOI, 1992).

The Kingdom's economy had been strong and stable before the consequences of the Gulf War in early 1990s, which was the major event effecting Saudi Arabia and other Gulf states (MFNE, 1997).

1.5.2 Geographical and Climatic Setting

The Arabian Peninsula is a geographic region that is occupied by the Kingdom. The desert is the most prominent feature of the Arabian Peninsula. Although vast, arid tracts dominate Saudi Arabia, but the country also includes long stretches of arid coastline along the Arabian Gulf to the east and the Red Sea to the west. The environment situation is not uniform and this is due to the vast area of land the country occupies.

The climate in Saudi Arabia in general is a hot-dry climate characterised by extreme heat during the day and an abrupt drop in temperature at night. The rainfall is slight, and because of the influence of many fluctuations in elevation there is considerable variation in temperature and humidity between northern and southern areas. However, apart from the east/west coast regions and the south mountain region, a uniform climate prevails over most of the country. The average air temperature is around 40°C, but readings of up to 54°C are not uncommon. The heat becomes intense shortly after sunrise and last until sunset. Winter temperatures seldom drop to 0°C, and the cold period is usually very short (Metz, 1992).

1.5.3 Local Energy Outlook

1.5.3.1 Oil Energy

The energy sector occupies a central position in Saudi economy since the Kingdom is a major producer and exporter of oil, furthermore, it posses the largest proven oil reserves in the world. The pattern of domestic energy consumption is inhibiting the maximisation of potential economic return from oil and its products. Crude oil and diesel are used as fuel for electric power generation and desalination plants.

Low price policies for energy in the domestic market have lead to rapidly rising consumption, thus, hindering rationalisation of such consumption and the conservation of natural resource. The low price reflects the high level of direct subsidy offered by the government.

1.5.3.2 Electricity Power

Electricity is the basic source of socio-economic development. It is a form of energy with high degree of flexibility and ease of transmission, distribution, and use. This makes it a basic input to all sectors of the economy. The storage technique of this kind of energy has not been resolved yet, which subjects the generated power to wide loss if not being used.

Over the course of the first five development plans (cover the period from 1970 to 1990), substantial efforts have been made by the government to extend the benefits of electricity to all sectors and regions of the Kingdom. During the fifth plan, all major indicators of the electricity sector witnessed notable progress in demands. In some cases, it exceeded the plan targets as a result of the unforeseen development. Electrical energy consumption grew at an average annual rate of 7.7% between 1989 and 1993 (MOP, 1995).

The reduction of the electricity price lead to an increase in the demand for the electricity, because low price does not induce rational consumption patterns and reduce the effectiveness of the tariff structure as a demand management tool.

> "It is imperative to review the electricity tariff structure and its level in order to use it as an effective demand management tool and to rationalise the consumption, thereby ensuring the continuity of electrical services and to focus on energy conservation, reliability, efficiency, and demand rationalisation'' (MOP, 1995).

This statement has been quoted from the government document, which set strategies for the development plans in the Kingdom of Saudi Arabia. Therefore, the interest in conservation issue clearly demonstrated through the context.

One of the Government policies that it is worth to mentioning here has approached conservation as follows "flexible pricing policy will be adapted based on periodic tariff reviews, with structure and level prices focused on energy conservation and demand utilisation."

1.5.4 The Need for Energy Conservation in Saudi Arabia

The concept of energy conservation in Saudi Arabia has launched nominally, but the real context of the word has not yet been put into practice, and the results are most inferior so far. This is not due to the lack of interest or underestimation of the problem but due to the difficulties in formulating rules and regulations that work in local social structure, and due to the lack of expertise in this field.

The growth of demand for electricity in rapidly expanding development in Saudi Arabia far exceeds the power being made available. The relatively low electric tariff, as mentioned earlier, has also contributed in this increase of demands due to uneconomic usage of electricity that resulted from this policy.

The national level of energy consumption is still in escalation (Figure 1.3). Although this figure might be attributed to the rapid development plans that were undertaken by the government, statistics showed that 47% of the energy sold was consumed by the residential sector (Figure 1.4). A report released by the Saudi Consolidated Electric Companies (SCECO) in the eastern province showed that 65% of the energy consumed in residential building goes to air-conditioning system (MIE, 1996).

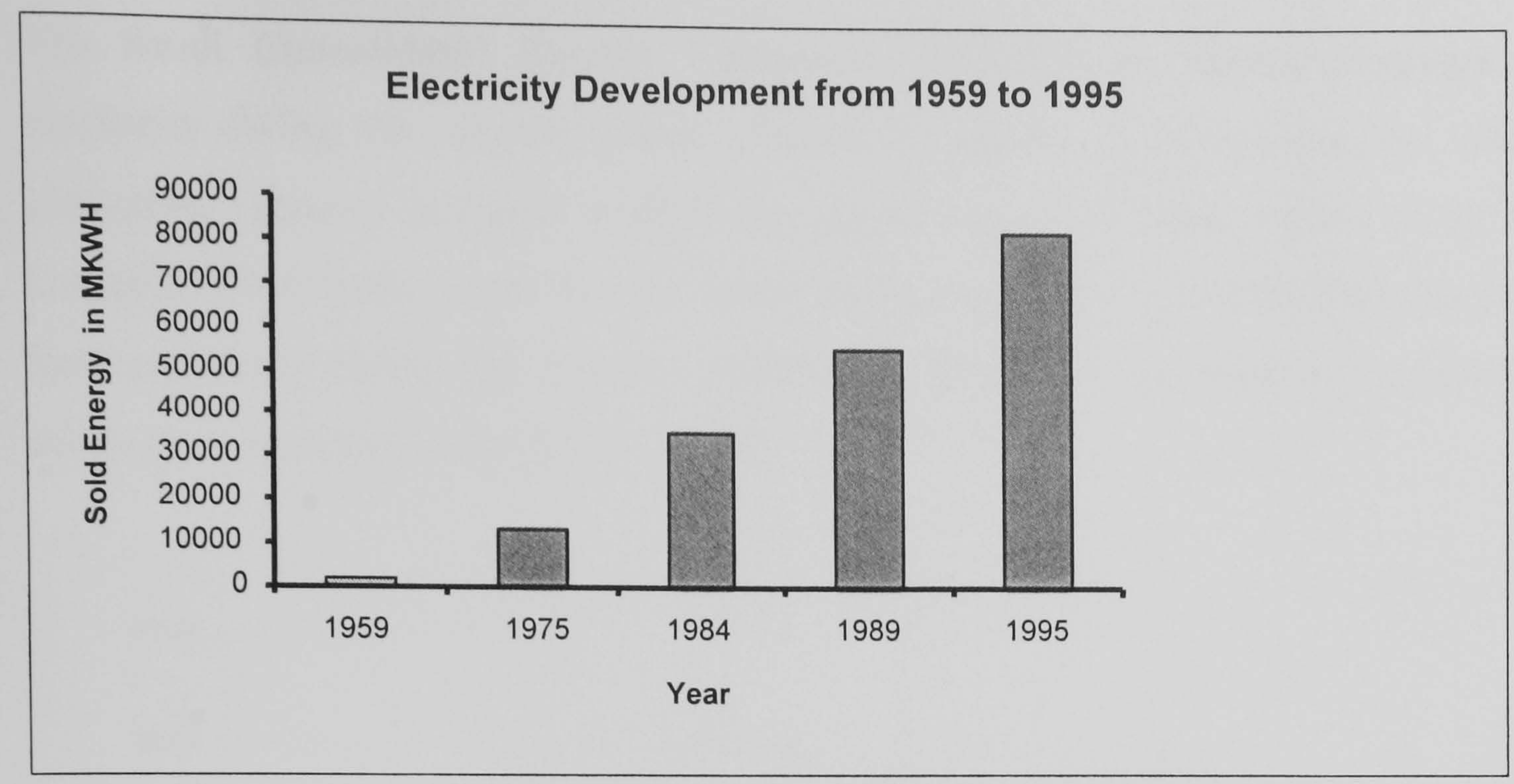


Figure 1.3: Sold Energy Profile in Saudi Arabia. Source: MIE, 1996.

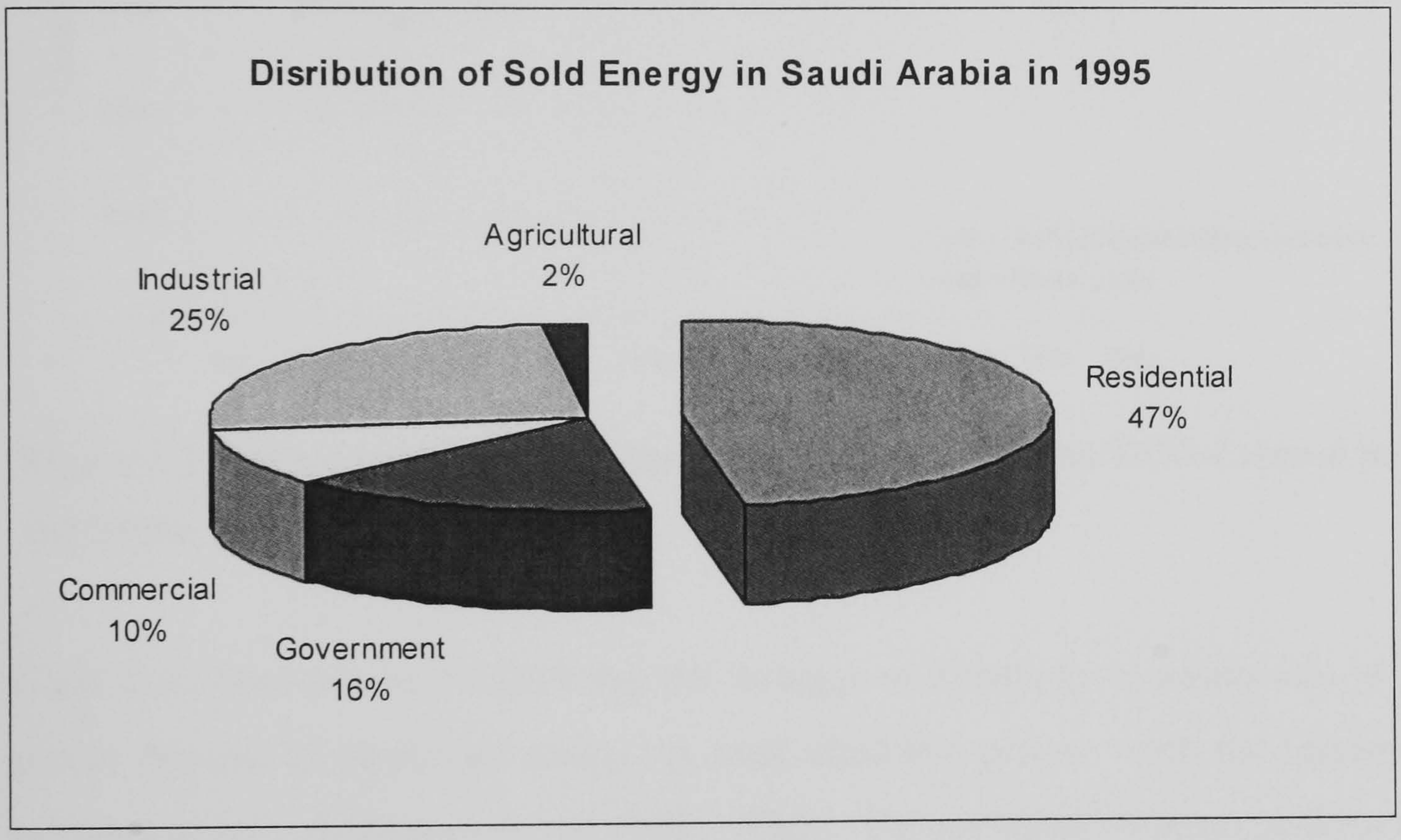


Figure 1.4: Energy Distribution Profile in Saudi Arabia. Source: MIE, 1996

The 1996 yearly report that published by the Ministry of Industry and Electricity has stated that the electrical energy generated by the utility companies for the year of 1996 reached 75.9 million MWh, which equals approximately 18 times that generated in the year of 1975. The total energy production in the Kingdom during the year of 1996 exceeded 97.8 million MWh (the excess energy comes from imported energy produced by desalination plants). Peak loads during the year 1996 reached 17706 MW, which equals approximately 21 times that for the year 1975. (MIE, 1996)

The Saudi Consolidated Electric Companies (SCECO) are facing shortages of electricity during the summer period. Figure 1.5 shows, as an example, the actual generating capacity and peak load of the central region of Saudi Arabia (SCECO-Central). This figure shows that the actual generating capacity is lower than the peak load especially during the summer period and SCECO-C is forced to import the shortage of electricity from SCECO-East.

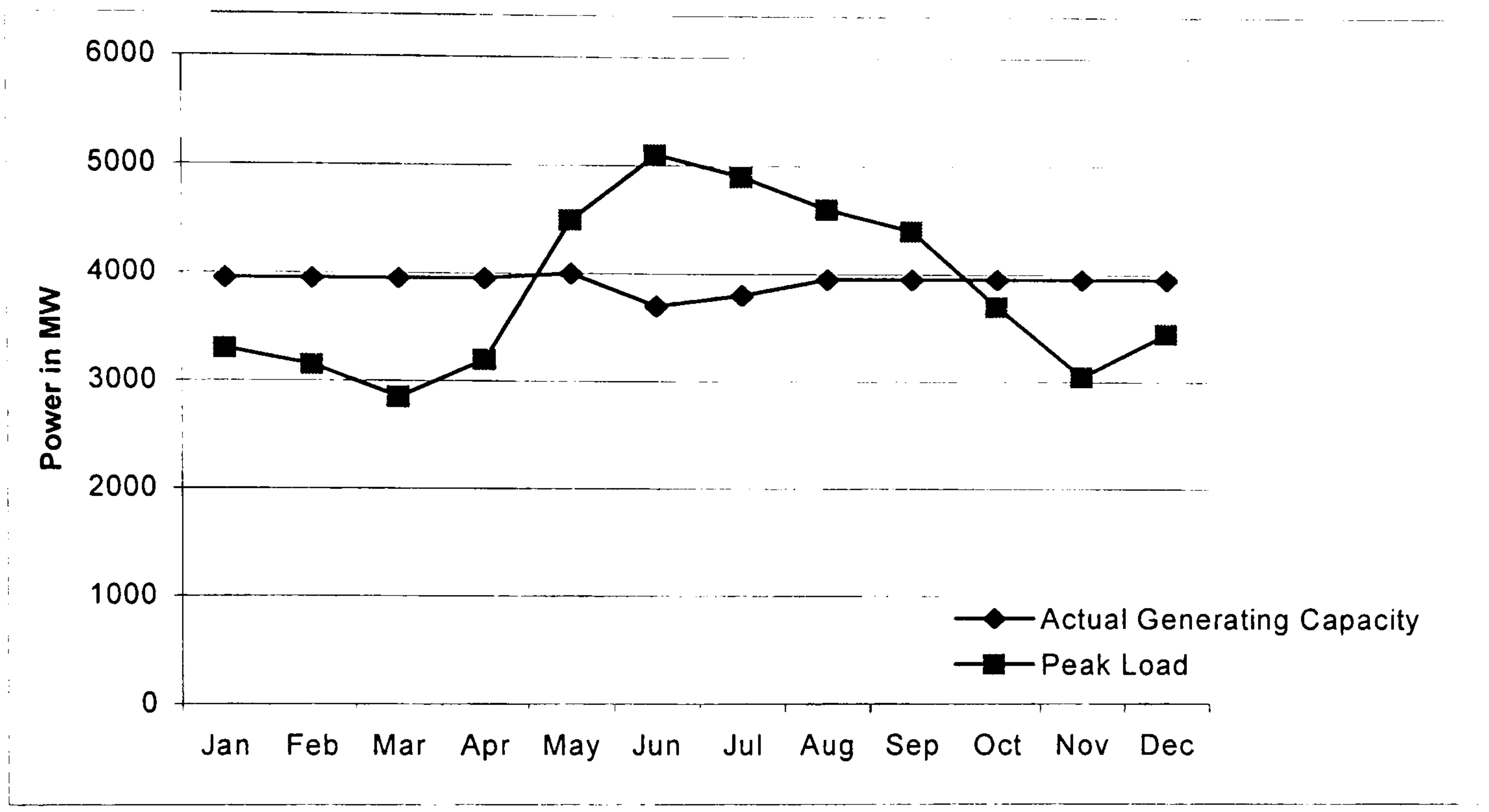


Figure 1.5: Actual Generating Capacity and Peak Load of SCECO-Central in 1995/1996. Source: MIE, 1996.

It has been observed by SCECO that the shortage of electricity is mainly due to the greater demand of electricity during the peak afternoon period, when the maximum numbers of air conditioners are on (MIE, 1996). The prevailed situation justifies the significance of energy conservation in residential buildings sector and the necessity to determine the practical strategies that reduce consumption.

The harsh climate of Saudi Arabia imposed the major challenge for the concept of conservation as applied to thermal comfort inside buildings. This is not the only obstacle governing the level of consumption; there is also a further important factor involved which is the behaviour of occupants.

The discussion of the problem of reducing electrical consumption in the context of buildings environment with special reference to thermal performance, leads to the following strategies that make affective contribution to the problem:

- **The Passive Cooling Design Strategies**

This means to employ energy efficient design features from the conceptual design stage of the building. It incorporates the promotion of traditional design features in response to climate, such as the evaporative cooling strategy, courtyard, wind catcher, massive wall, orientation, and minimum openings.

- **Energy Management Strategies**

To integrate the relationship between energy, economy, and environment in order to optimise the available energy with reasonable cost and without disturbing the environment.

- **Energy Saving Measures Retrofit Strategy**

To upgrade and restore the existing situation in order to enhance the indoor environment with less energy demand. Applying and improving thermal insulation tend to be the most commonly known strategy, which has tangible results among the forgoing strategies specially when dealing with the existing building.

The recent trend show an increasing awareness of thermal insulation, as an energy conservation measure, in Saudi Arabia as a result of the current unstable economy situation resulted from continuous changing in oil prices in the world market. Also, the increasing cost of energy as a result of enforcing the new electrical cost brackets system of 1992. Currently, the cost of 1 kWh of electricity ranges from 0.05 Saudi Riyals (SR) for dwellings consuming less than 4000 kWh/month to 0.15 SR for those consuming 6000 kWh/month or more (£ 1= 6 SR).

Table 1.1 illustrates the history of electricity selling price in the Kingdom of Saudi Arabia.

Year	Bracket in kWh	Price in SR/kWh
1974-1984	For any amount	0.07
1984-1985	The 1st 1-1000	0.07
	The 2nd 1001-2000	0.10
	The 3rd 2000-above	0.15
1985-1992	The 1st 1-3000	0.07
	The 2nd 3001-4000	0.10
	The 3rd 4001-above	0.15
1992-up to date	The 1st 1-4000	0.05
	The 2nd 4001-6000	0.07
	The 3rd 6001 above	0.15

Table 1.1: Energy Selling Price Brackets in Saudi Arabia. Source: SASO, 1989.

There were no rules to enforce the use of thermal insulation in residences, and the choice has been left open for the owner. Furthermore, specifying thermal insulation or even considering energy conservation in design decisions and documentation was not essential for obtaining a building permit.

At present time the increase of government awareness regarding the issue has turned to practical action. The Saudi government together with the Gulf Co-operation Council (GCC) has set rules to enforce the use of thermal insulation in buildings construction.

The GCC members set a minimum insulation standard to be implemented gradually for all building types with a phased introduction over three years for each stage, commencing from 1987 for the government buildings. These standards define the U-value to be 0.74 $W/m^2\ ^oC$ and 0.57 $W/m^2\ ^oC$ for walls and roof respectively (Walter, 1988).

For the present time however, the insulation has become a mandatory for all new buildings under construction, and to ensure the public compliance to this regulation electricity will not be installed in case of violation (MMRA, 1989).

The policy of energy conservation in building environment in Saudi Arabia basically is a product of three major bodies influencing each other (Figure 1.6). These bodies are:

- The Government (decision makers)
- The Architects (building makers)
- The Public (building users)

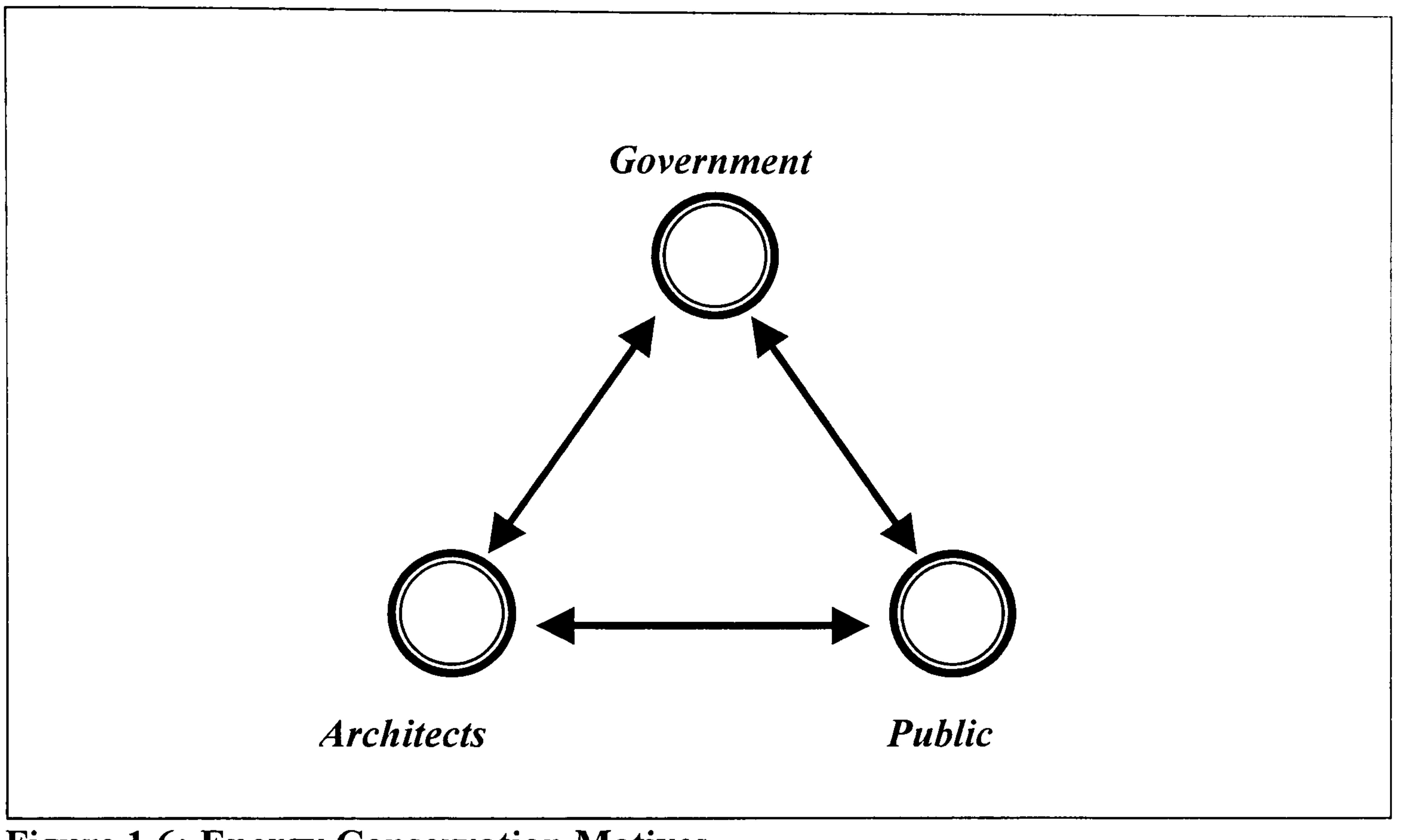


Figure 1.6: Energy Conservation Motives

Each part is well disposed towards the concept of conservation, and each part has its role to play in the strategies and on the implementation process. However, the individual efforts from these three bodies should be integrated into one comprehensive system in order to be successful and more effective.

- ***The Government Role***

This can be evaluated from the economic point of view. One of the factors that exhaust the national economy is the electrical energy subsidisation plan. The actual product of electricity costs about 0.24 SR/kWh, while the subsidised selling price to the public is about 0.05 SR/kWh. This is 79% of the actual price (MIE, 1995).

In other words, the higher the demand on electricity the more the economy is depleted. Therefore, conservation has been recognised by the Saudi Arabia government, however the major obstacles delaying it introduction fall into the following categories:

1. No code of practice for energy conservation in Saudi Arabia
2. No co-ordinating official body (i.e. Department of Energy)
3. Lack of experienced people in this field
4. No mechanism for implementation process

- ***The Architects' Role***

Architectural practice in Saudi Arabia has, somehow lost the connection to energy conscious design. Many architects are not familiar with the technical matters associated with this subject; also, many of them are not well informed about the technical aspect of thermal insulation and the evaluating techniques for different system.

For the architects who posses these knowledge, they find it waste of time to implement it as they are not paid for it, and projects can be realised without this information

- ***The Public Role***

The public, as the main consumers, is also concerned with energy as an economical problem. The influence of the public (i.e. occupants and facility users) on this issue is tremendous, because they represent a large sector of uncontrolled consumers.

The government institution can enforce rules on the public to achieve the goals of energy conservation, and the rules have already been in place for the new residential buildings. The majority of the owners of existing buildings need persuasion more than compulsion to make them act voluntarily in the same direction. The approach to the solution in this sector can be achieved through the following arrangement:

- First: by rising energy awareness and promoting a positive attitude towards the concept of conservation (an active information media and public campaign would give a good result)

- Second: by improving the physical context of their living environment, by upgrading the thermal properties of building fabric and enhancing thermal performance in general.

This is a very difficult task to handle, since the results will be surrounded by uncertainty. Moreover, there are no motives for owners to encourage them towards innovations.

1.6 Statement of the Problem

The average of energy consumption in the residential sector of Saudi Arabia is high (2-3 times the average consumption in a similar climate) (Al-Hammd, 1992). The Literature has proved the potential for energy conservation in residential buildings in Saudi Arabia. Furthermore, existing situation reflects the poor thermal conditions of buildings and the major concern of people and the government about the high consumption rates in this sector (Al-Naimi, 1989).

Many efforts have been made to address the subject of conservation in residential buildings and to study the possible practical ways to improve their thermal conditions. The potential improvement can be explained in the light of two major contexts:

- Controlled Improvement
- Uncontrolled Improvement

The first context is concerned with the possibility of enforcing energy conservation measures as rules and legislation for all residential buildings under design and construction. In this context the problem is less complex and there is a good chance to achieve substantial results.

The uncontrolled improvement, which represents the vast bulk of the problem, is concerned with existing buildings. The uncontrolled improvement is a term used to indicate the difficulty to apply any conservation measures to improve the situation in these buildings.

The foreseen difficulties may arise from the lack of research on existing situation in order to gain more understanding on real bases. Also, the difficulties may be connected to the absence of facts, cost effectiveness studies and an incentive policy in relation to the occupants and owners of these buildings.

Between these two notions it is clear that the practical innovation for achieving energy conservation simply comes through the improvement in building fabric with appropriate management for indoor energy utilization.

Building fabric can be improved by installing insulation materials and many studies have been concerned with this issue. Other studies on the same subject considered specifically the economic performance of thermal insulation in terms of application techniques and construction composition, and concluded that design and installation are the most significant factors affecting the performance of insulated walls, which *per contra* have profound effect on economical performance. (Tewfik, 1993)

The findings that voted in favour of insulation might be misleading because the assumptions within these studies were always based on the interactive relationship between thermal insulation and electrical consumption. This relationship is true to a large extent, but there is an associated shortcoming in the case of insulation failure to reduce the electricity consumption. In practice, this probability is always there. Most of these studies have based their work on insulation effect on building fabric and neglect the internal gains that have a pronounce effect on energy consumption.

Following the electrical cost brackets system mentioned earlier, we could observe that insulation could be a cost-effective tool if its application causes the electrical load to fall within the lower cost brackets. However, in practice, the application of thermal insulation may have no significant effect on electricity cost due to some other factors.

Occupants' behaviour in utilising electrical fixtures and appliances is a crucial matter in calculation. If this utilisation is high enough to cause monthly electricity loads to fall within the upper cost bracket, then the economic benefit is not realised regardless of thermal insulation.

This shortcoming can take place frequently. Therefore the relation between the insulation and the direct electrical load does not represent the whole picture. In order to assess the effectiveness of energy saving measures to be applied in a given context we need to know first the nature of energy demand and energy usage behaviour.

Energy consumption is also a product of a very important factor which is the internal loads resulted from occupants activities. This factor is not simple to evaluate due to the involvement of human behaviour and human comfort. As far as human comfort is concerned, few efforts have been made to assess the effectiveness of different energy saving measures on the indoor climate especially when no mechanical cooling is in use.

The national target is to reduce the demands for energy and to enhance the national economy. Existing residential building sector aims for a comfortable indoor living standard, low energy dependence, and low running cost. The task to solve this equation is difficult, taking into consideration the huge numbers of existing buildings that required appropriate and practical strategies.

1.7 Case Study

Building industry sector in Saudi Arabia has expanded in the last three decades. Different housing styles have been constructed to accommodate the rapid population growth.

During the economic boom of the 1970s, development plans aimed to achieve many objectives in a very short time. Within this race against the time, the environmental considerations were totally ignored, and the consequent results were buildings with poor resistance to climate and, moreover, heavily energy dependent.

The advert of new building techniques and new building materials in local markets has substituted the indigenous style with an alien one. Therefore, substantial changes in vernacular architecture were produced and constructed.

This study will be carried out within the specific climatic, construction and economic context of Makkah, Saudi Arabia. The city of Makkah, as a case study, has the typical hot arid climate that prevailed all over Saudi Arabia, which make it a proper case for research investigation.

The common residential building types are either detached villas or apartments.
But due to the geographical nature of Makkah, which supports vertical expansion, the apartment buildings are predominant. Moreover, the majority of occupants are classified under the middle-income group who cannot afford to have an independent house.

Saving can be a crucial matter for this group but physical comfort inside their dwellings is of equal importance. Therefore, this study will be directed to investigate this problem in the apartment buildings.

1.8 Objectives

This study aims to investigate the thermal performance of existing apartment buildings sector in Makkah. The study is to tackle this subject from the following points:

- Physical characteristics and building performance
- Domestic energy requirements and energy demands
- Occupants behaviour characteristics

This study also aims to assess the effectiveness of different energy saving measures on the indoor's thermal quality and the economy of the household. It is hoped that the final findings of this study will be able to present guidelines for the three bodies concerned in this issue;

1. For the government authority, to find a proper framework for implementing energy conservation polices, and subsequently increases the efficiency behind any proposed management tool.

2. For architects, to gain more understanding of the features characterising building thermal performance and energy consumption, hence reflecting this knowledge on their future work.

3. For the public, to propose a factual information for thermal/economic benefits expected from applying energy saving measures, which will help uncover all uncertainties behind the investment in upgrading; furthermore, to bring closer the image of improvements to public awareness.

1.9 Research Organisation

The process of identifying the thermal characteristics and energy behaviour of the existing apartment buildings is based on the integrity of the following issues:

- Factual information (data collection from actual field)
- Theoretical simulation (data extracted from simulated actual situation)
- Collective and comparative information (configuration of the above two)

These issues have been embodied in the thesis chapters as a major part of the research contribution to the problem. This thesis has been organized into 11 chapters:

Chapter 1 sets the base for the global importance of energy issue in general and in Saudi Arabia in particular. It also represents the associated statement of problem, the aims of this research, the approach to be followed, and the organization of this thesis.

Chapter 2 introduces the cultural background of Makkah City as a host case study location. This information provided in this chapter sets a base for the cultural, social, and economical background that forms the architectural entity for this city and characterizes its problematic issues form energy perspective view.

Chapter 3 focuses on the climatic context of Makkah and its significant impact on building environment. Evaluation of climatic characteristics of Makkah has been carried out in order to help understanding their prospective roles in relationship to human requirements for thermal comfort inside the residential dwellings.

Chapter 4 reviews the literature about the thermal analysis of building envelopes. Energy efficiency in buildings and the approaches used, have also been reviewed thoroughly.

Chapter 5 discusses the methodology of the field survey and illustrates the relationship between planning, preparation, execution, and information handling. This chapter describes the data gathering that has been adopted for this research and sheds light on the obstacles usually found in the existing situation with relation to the survey execution.

Chapter 6 shows the analysis procedure and the findings of the questionnaire survey. The aim of this chapter is to recognize the social characteristics with respect to energy behaviour patterns for existing apartment buildings in Makkah. This chapter is an assessment of public awareness towards energy conservation and an assessment of the prospective type of problems needs to be solved.

Chapter 7 discusses the analysis procedure for the second part of the field survey (the measurement survey). This part of the thesis identifies the thermal quality of the indoor environment inside apartment buildings as well as provides the reader with a clear picture of the physical problems initiated by the different kind of building components.

Chapter 8 provides the theoretical basis to assess different building components' thermal performance and tries to predict energy requirements and energy behaviour inside apartment units by simulation. In this chapter, the methodology of investigation by simulation has been discussed together with different energy analysis approaches. A simulation tool has also been adopted and the model for simulation has been established and its preparation procedure has also been demonstrated

Chapter 9 shows the simulation results and identifies the thermal role of building components. Also, this chapter studies the different thermal characteristics of building materials and reports the findings based on simulation analysis output. Alternative modifications, which represent different energy saving strategies, with special emphases on thermal insulation and shading devices, have been evaluated according to their physical, social, and economical returns.

Chapter 10 discuses the application of energy saving measures, their effect on energy consumption, and their applicability. Economical considerations for applying these measures have been studied under the cost effectiveness concept. Obstacles to implementation have been evaluated in the sequence.

Chapter 11 Concludes the thesis and areas for further research have been suggested.

Chapter 2

Cultural Background of Makkah

Chapter 2

CULTURAL BACKGROUND OF MAKKAH

2.1 Introduction

Renowned as a holy city for Muslims, Makkah is in the western part of Saudi Arabia 45 miles (72 km) inland from the Red Sea port of Jeddah on latitude of 21° 25' north and a longitude of 39° 44' east. The city is located in the dry beds of the Wadi Ibrahim and several of its short tributaries and is surrounded by the Sirat Mountains, where the coastal plain meets the foothills of the high terrain of Hijaz (LOC, 1997).

Entrance to the city is gained through four gaps in the surrounding mountains. The passes lead from the northeast to Mina, Arafat, and Taif, from the northwest to Madinah, from the west to Jeddah; and from the south to Yemen. The gaps have also to some extent defined the direction of the contemporary expansion of the city. Makkah has no airport, and the major access route to the city is through the Red Sea port of Jeddah (MMRA, 1985). (Figure 2.1& 2.2)

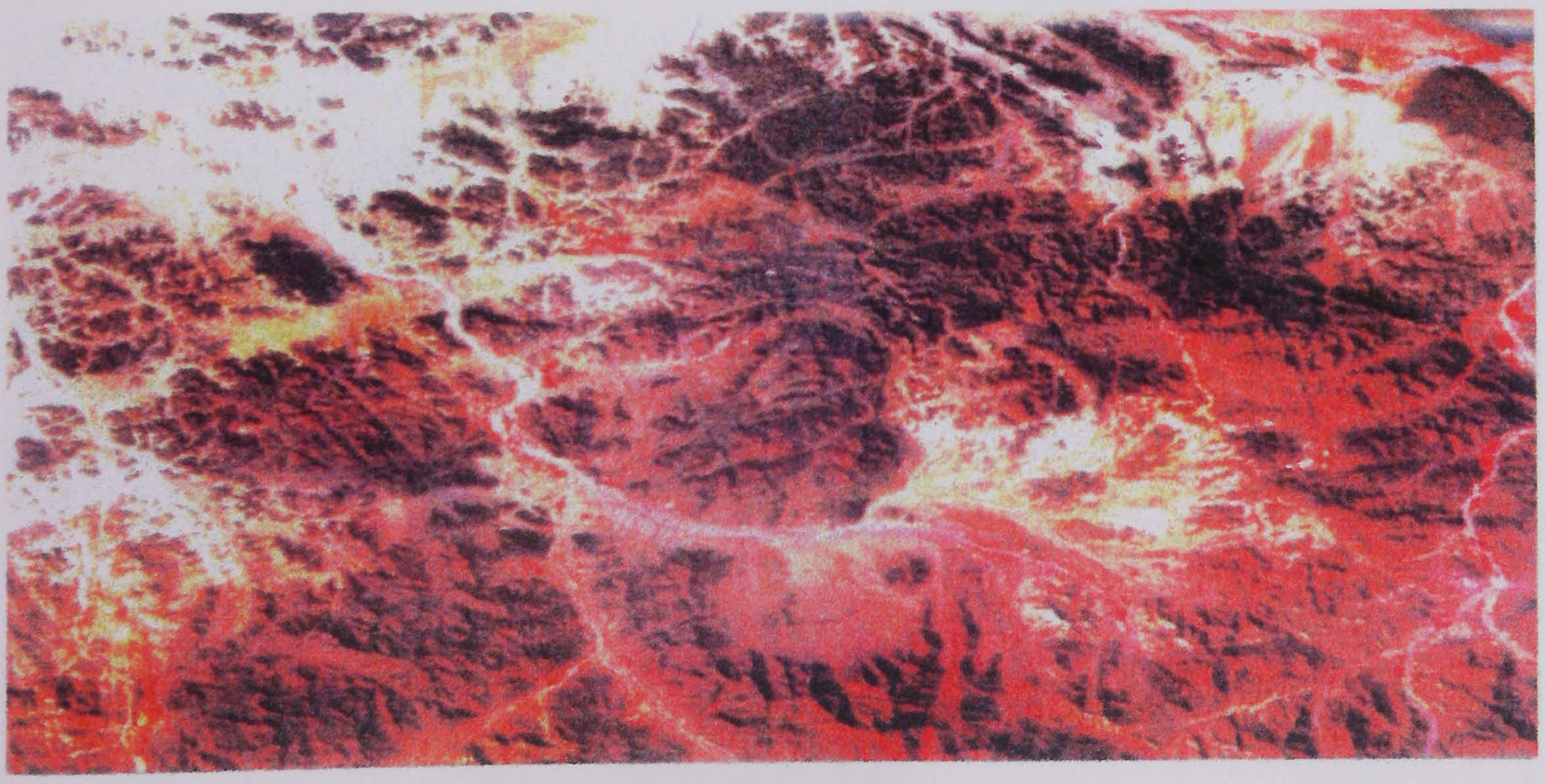


Figure 2.1: Satellite Picture for Makkah taken by Land Sat, 1975.
Source: Department of Geography, 1980.

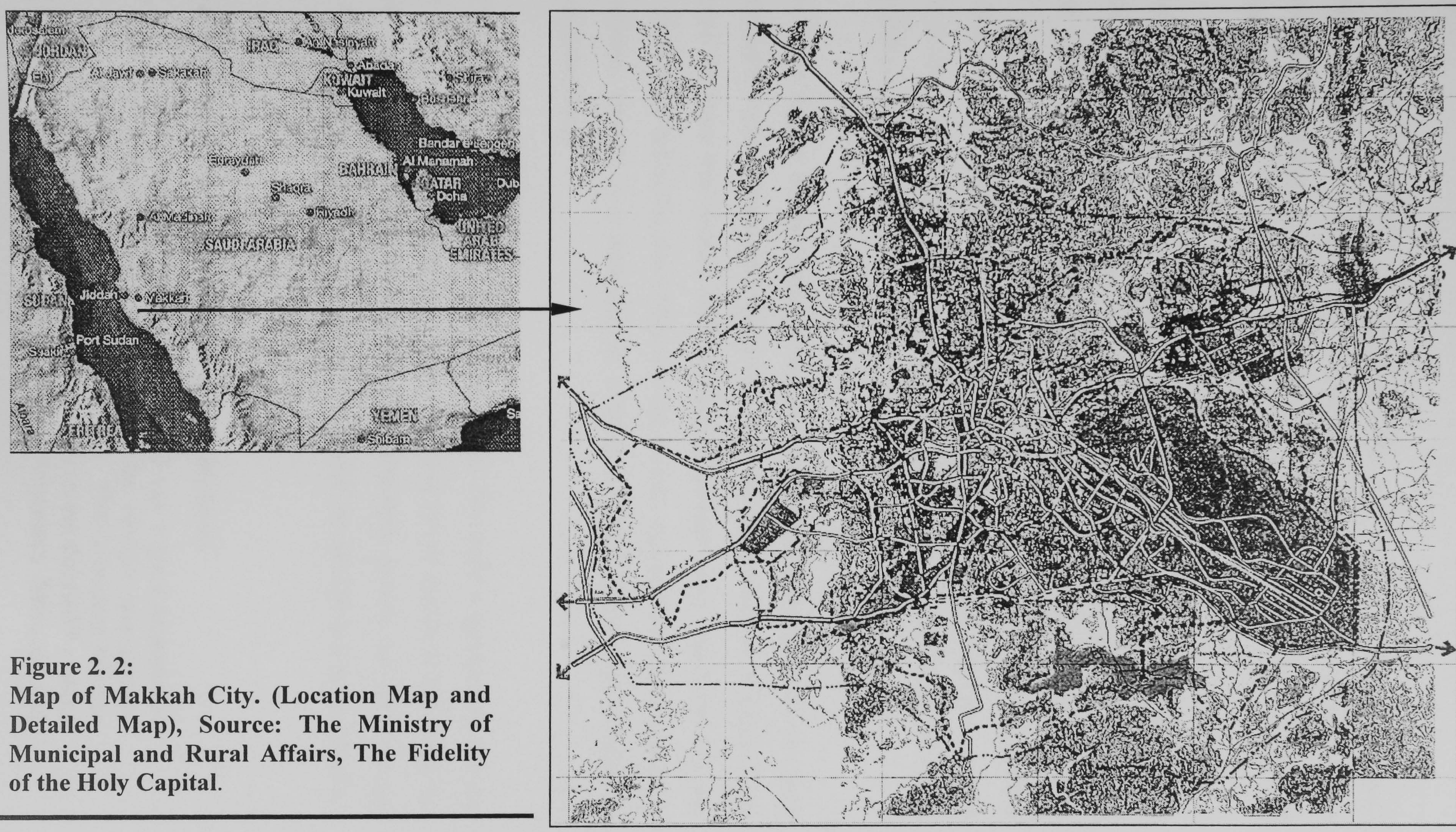


Figure 2. 2:
Map of Makkah City. (Location Map and Detailed Map), Source: The Ministry of Municipal and Rural Affairs, The Fidelity of the Holy Capital.

2.2 Historical Background

The importance of Makkah as a religious site goes back to pre-Islamic times. According to Muslim tradition this location became the residence of the prophet Ibrahim (Abraham) and his family when God led them there from a more flourishing environment in Syria.

The prophet Ibrahim built the Ka'aba, which now stands in the centre of the Great Mosque and is the central point of the Muslim *hajj* or pilgrimage, and Makkah became a focus of religious importance to the Arab tribes even before the rise of Islam. The Ka'aba remained of spiritual significance through its tenure by several Arab tribes and Makkah has been in the focus of attention to the merchants as it is located in the middle of old trade caravan route connecting South (Yemen) to North (Syria) (Mirza, 1985).

Despite of its unique location among chains of mountains, Makkah never has been geographically isolated from other parts of world. Thus the tradition of the Ka'aba, and hence the town that became Makkah, as a pilgrimage centre had been to some extent established before the rise of Islam in the seventh century AD. Islam continued this tradition, though as a monotheistic religion it abolished the idol worship of previous generations.

It was the second Caliph, Omar Ibn al-Khtab, who first built a Mosque around the Ka'aba about 638 AD. During the Caliphate period in the centuries following the establishment of Islam Makkah experienced intermittent growth and the Mosque itself, on which the city was centred, was enlarged on several occasions (Makki, 1978).

Makki describes Makkah before Ottoman rule in these terms:

> Up to 1100 AH (1689 AD) Makkah was a good example of the Arabian Muslim town, where the Mosque and squares represent the basic centre of the city. This is because Islamic instruction, guidance and social affairs were directed by rulers of the cities from such places. Afterward, Mosques and

> squares that surrounded the rulers' houses functioned as basic centres for these cities' activities and collective behaviour. By this time Makkah included an important core, the Holy Mosque, and an open square around it that was bounded by residential buildings. Small shops filled in where possible and smaller Mosques were built scattered throughout the city. (p. 25)

Later in the Ottoman period, which lasted until 1924 AD, Makkah came under greater Turkish influence as far as its physical appearance was concerned, with Turkish architectural styles seen all over the city. The basic Arabic character of the city, however, was retained. In later Ottoman times Makkah grew considerably in size, in part in response to the rise in the number of pilgrims, a development that was in turn partly due to the completion of the Hijaz railway.

Following the establishment of the Kingdom of Saudi Arabia (unified in 1932 AD) and up to the present day the city of Makkah has seen great growth, both in terms of physical spread and population. The discovery and exploitation of oil in Saudi Arabia speeded this development, as it brought considerable wealth to the Kingdom and allowed for the expansion of transport systems and other aspects of the infrastructure.

Special consideration has been given to the holy city from the government of Saudi Arabia. The great Mosque has witnessed great expansion schemes, and plans for further expansion have been put in process. The developments have also included all institutions within the city and the government has adopted a unique planning system that work in compatibility with the unique natural and socio-cultural circumstances of Makkah (Abdulbagi, 1984).

The modern city centres upon the great Mosque (*Al-Haram*) and the sacred well (*Zamzam*), located inside the Mosque. The compact built-up area around the Mosque comprises the old city, which stretches to the north and southwest but is limited on the east and west by the nearby mountains. Much of the urban area is hilly, and although some of these hills have been built upon, or even in some cases levelled for construction requirements, they add to the topographical attraction of the city (Al-Afghani, 1987).

New Neighbourhoods and districts have exceeded the central mountain belt. The transportation network has adopted mountain tunnels, ring roads and radial roads systems in order to make the great Mosque accessible from every part of the city.

2.3 Socio-Economic Background

Makkah has to accommodate a large number of pilgrims during the *hajj*. Its population therefore fluctuates, varying from an estimated permanent population of between 550,000 and 800,000 to over two million at *hajj* time. This means that Makkah has to have a more developed infrastructure than other cities of a comparable size, and it has developed a good road network, partly because *hajj* pilgrims must follow a prescribed route entailing visits to some locations distant from the city centre. The actual space available, however, for many other types of development in Makkah is restricted by the geographical surroundings of the city, and this has caused a number of environmental difficulties (MMRA, 1985).

The central part of Makkah has become very congested due, at least in part, to the large number of motor vehicles, which are accompanied by pollution and noise. The appearance of parts of the city has undergone change through the rise of new building developments, and the natural landscape has suffered not only outwardly but also in terms of features such as natural drainage. Even the historic central part of Makkah has seen the construction of some high rise buildings. The pressure on space has had a negative effect on the environment, in both aesthetic and ecological terms (Abdulbagi, 1991).

We have noted that the number of persons resident in the city of Makkah increases greatly at the *hajj* period, but it also varies at other times of the year. This is largely due to the fact that certain months are favoured for the performance of the *omrah* (the lesser pilgrimage). Although residence within the city is restricted to Muslims, it is nevertheless extremely cosmopolitan, being home to many people from the Islamic countries of Africa and Asia. People of the same national origin tend to live together in various parts of the city. The position of Makkah as the religious centre of Islam provides the basis for its economy, since it is not in an oil-producing region and has no other substantial industry. The provision of goods and services to *hajj* pilgrims is the main trading activity of the citizens (Al-Ghamdi, *et al,* 1985).

The infrastructure developments within Makkah, and the requirements of this infrastructure have attracted considerable investment to the city, especially government investment. This investment in infrastructure has supplied an important economic link between local and national economies through the transmission of resources. Public investment in connection with *hajj*-related activities has also generated much employment in the construction industry.

Indeed within Saudi Arabia several ministries have amounts set aside for projects connected with pilgrimage, so that a great deal of money has been spent on it, to the great benefit over the years of the city of Makkah. As far as actual levels of private financial activity are concerned, it is estimated that *hajj* pilgrims contribute up to 50 percent of the total of private expenditure in Makkah (MMRA, 1985).

The pattern of land use in Makkah has some similarities to, as well as some differences from, other Saudi cities. As in other cities the central district of Makkah is of vital economic importance. But unlike other cities, this district is not a central business precinct, but, as we have noted above, the area of the Great Mosque. This is the focus of the life of the city and around it are grouped the major religious, social, civic, cultural, and commercial institutions of Makkah.

In the immediate neighbourhood of the Mosque land is put to a variety of uses. As well as parking areas, there are private homes, apartment blocks, and commercial premises, many of these being high-rise buildings. Communication routes radiate from this central area, often leading to smaller suburbs or neighbourhoods, each of which has its own commercial and trading premises to serve the immediate vicinity.

Many buildings have taken place on some of the hilly areas within Makkah. This level of construction activity has been reinforced by the desire of so many pilgrims to live within relatively easy reach of the Great Mosque (Figure 2.3) in order to be able to perform the five prayers daily in time (Al-Afghani, 1987; Makki, 1981).

Figure 2.3: Arial View for the City Centre Surrounded the Holy Mosque. Source: Al-Gamdi, 1985.

2.4 Architectural Background

The city of Makkah is an international city that combined different cultures from all parts of the world. Nevertheless, it retains distinguish architectural identity that emerged from a balanced mixture from all these cultures. The architectural identity of Makkah can be seen in its traditional style which has been developed with full attention to people's religious and socio-cultural needs and full response to local climate and local resources (Figure 2.4).

This identity has been standing very clear until the middle of the 1970's, when the wheel of new development started to roll. Incidentally at this time, the post-modern architecture movement was dominant. With this synchronisation between urban development in Saudi Arabia in general, and in Makkah in particular, and international architecture development, Saudi and foreigner architects have found a unique opportunity to design and construct many projects that carry features from one or more of the post modern architecture schools (Al-Bis & Al-Harbi, 1993).

Figure 2.4: Natural Composition of the Peaceful Harmony of Traditional Architecture of Local Environmental Setting. Source: Al-Ghamdi, 1985.

Architecture in Makkah can be explained under the light of two major divisions: traditional architecture and contemporary (post 1970) architecture. Makkah's houses in 1970 are more compacted in the old city than the newly developed residential areas. With the new projects which have been established, many houses, especially those in the old city, have been removed to enlarge the area of the Holy Mosque and allow the construction of new and wider roads. The development projects force clearing in the city centre and expansion on the periphery of the city where new architectural styles have been introduced.

2.4.1 Traditional Architecture

The architectural history of the city of Makkah divides into three main periods. The first of these was the pre-Islamic period of domestic culture, when Makkah was a trading centre for nomadic people. The second period followed upon the rise of Islam, when many Muslims who settled in Makkah introduced architectural characteristics that carried on features of their earlier life. The third was the time of Ottoman rule, when the Turkish influence had some effect. Many buildings in the city from this period stood until recent years (Al-Abdaly, 1975).

2.4.1.1 General Description

The traditional houses of Makkah supplied the space and the internal features required to provide for the social needs of the family and seasonal activities such as affording accommodation for *hajj* pilgrims.

The indigenous architecture of Makkah was determined by and gave expression to a number of factors: building materials, climate, technical skill, topographical constraints, artistic values, social requirements, etc. Architecture in the old Makkah was thus a physical and visual embodiment of the culture and way of life of the inhabitants, and those old houses which are still standing provide a manifestation of this culture. The architecture was typically simple but vigorous, with simple geometry, thick walls, projecting balconies, the juxtaposition of irregular heights, and aesthetic values expressed in a balanced and austere way. Building materials were locally obtained, except for wood (mainly teak), which had to be imported from India and Java. The construction and materials of the traditional buildings of Makkah are dealt with more fully below.

In the case of dwelling houses, usually more than one floor, one factor in the decision to erect such a building may have been the wish of the owner to rent part of the premises to pilgrims during the *hajj*. However, the limitation availability of land and high land values are behind the vertical expansion in this area.

Traditional houses in Makkah, we may say, adhere to local conditions and local cultural and social values, while displaying considerable variety in detail and elaboration.

2.4.1.2 Urban Pattern

Makkah is considered to be one of the most ancient cities in the world. Thorough-out the history, urban development in Makkah has expanded randomly where ever then need arise for the expansion. This need has, fundamentally, been connected to number of pilgrimages; the more pilgrims the more the demand on accommodation. The population has gradually inhabited the central area around the Grand Mosque and the expansion of the city, therefore, took place on the top of the surrounded mountains. Makkah's valleys are narrow and there was no infrastructure and no cars to service. The only forms of roads were narrow alleys established according to natural topography of the land and the random settlement of houses (Figure 2.5).

Figure 2. 5: Urban Settlement is Totally Restricted by Natural Topography and the Availability of Flat Surfaces. Source: Al-Ghamdi, 1985.

The traditional urban fabric of old Makkah is compacted tissue separated by the narrow alleys that always lead to the Grand Mosque.

The hills surrounding Makkah have constrained the development of built-up areas to some extent, though there has been construction on some of the peripheral elevated areas. The holy places, by their very nature, had to remain in the centre of things, and this has dictated to some extent the directions of expansion.

Urban pattern for Makkah City has taken the radial type and the Grand Mosque is in the focal point. The development of the city emerged from this part and their major road axis followed the natural topography.

The location of the hills has meant that there has been more urban spread north and south from this central area than east and west. The restricted terrain available for horizontal expansion has meant, however, that a solution has been sought in high-rise buildings, and we have seen that the centre of the city features many such developments. The growth of buildings of this type has meant that the appropriate technical design and construction skills, supplemented by expertise from foreign sources, have been developed.

The external public spaces can be found in form of small neighbourhood (*Harah*), winding alleys (*Zogag*), and closed yard (*Baraha*). As far as the urban pattern in areas of traditional architecture is concerned, buildings are often located in narrow winding lanes and shaded paths, though there is no street arrangement so common that it can be regarded as the unambiguous norm. This can be seen in the old central area around the Grand Mosque (Figure 2.6).

In the case of neighbourhood, it is common to see adjacent houses were in the possession of relatives. Also, it is common to see in this pattern that houses separated by narrow streets are jointed together at the second floor (*Sagifa*). These houses use the area over the street for expansion while also providing pleasant shade (Fadan, 1980).

In general the fronts of houses face on to wider roads than the sides and obtain more direct heat from the sun. The fronts of dwellings therefore commonly have large oriel windows (*Mashrabia*), which help to reduce glare and the passage of uncomfortably warm air in the summer. These oriel windows, which often feature framed latticed screens with bar supports, also allow the required privacy for female members of the household.

Burckhardt (1968) wrote in his description of old Makkah:

> Makkah may styled be handsome town. Its streets are in general broader than those of eastern cities, the houses lofty, and built of stone, and numerous windows that face the streets give them a more lively and European aspects than those of Egypt or Syria, where the houses present but few windows towards the exterior. At Makkah it was necessary to leave the passage wide, for the innumerable visitors who here crowded together, and it is in the houses adapted for the reception of pilgrimages and other sojourners, that the windows are so contrived as to command a view of the street. The only public place in the body of the town is the ample square of the Great Mosque; no trees or gardens to cheer the eye (Burckhardt, 1968, p. 103).

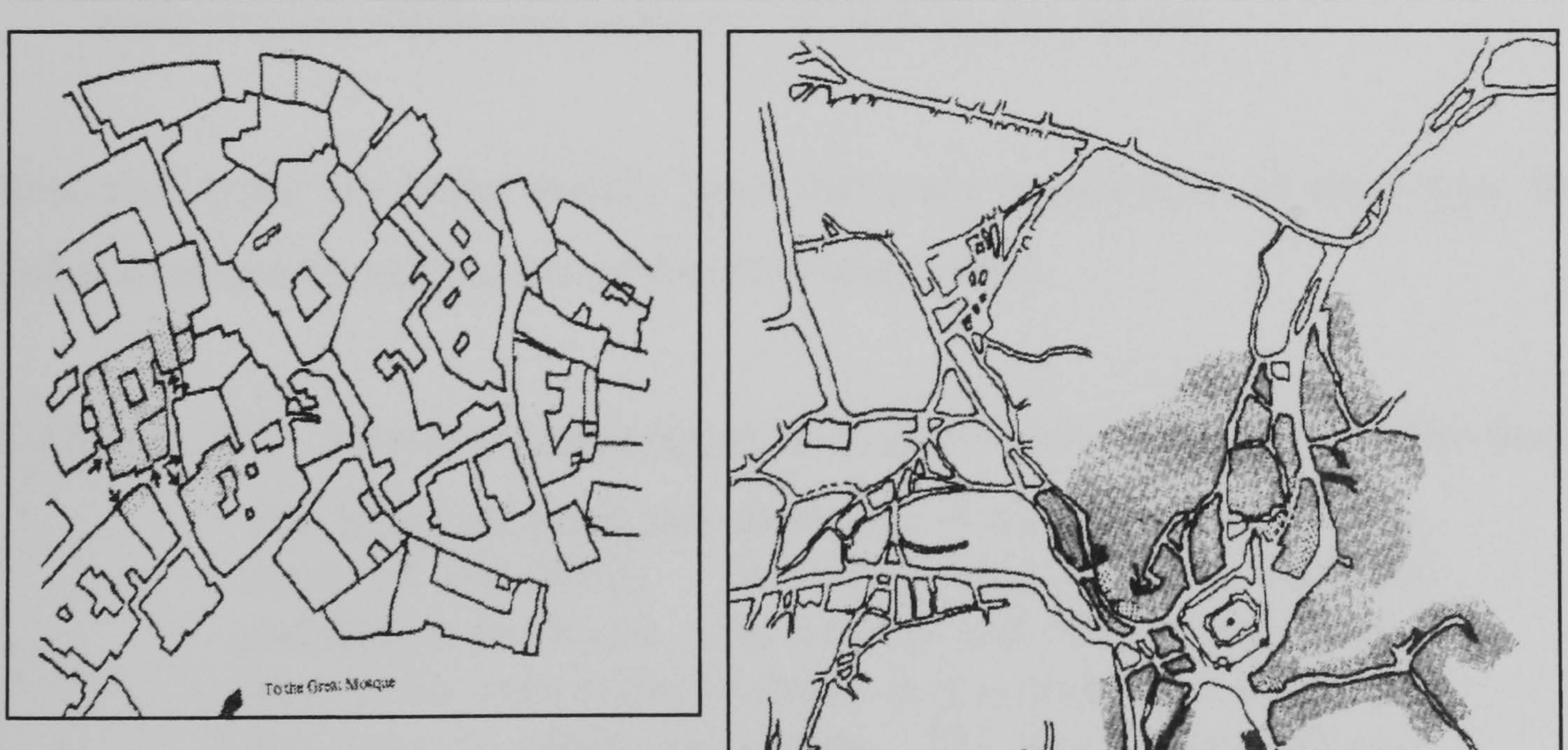


Figure 2. 6: Makkah Traditional Urban Fabric. Source: Fadan Y., 1980.

2.4.1.3 House Description

Traditional houses in Saudi Arabia differed from houses in the western world in many aspects. One of the most important in cultural terms being the way in which they were designed so that specific internal (and external) spaces were intended for specific functions and for use by specific groups according to whether they were male or female, family members or not, and so on. The requirements of the maintenance of privacy between the sexes were always of great importance and usually lead the design developments.

The traditional house in Makkah is a row house type and at least one side of the house is adjacent to a neighbour house. Makkah traditional houses can generally be classified to three major types:

- Simple house: small size for small family. (Simple plan house)
- Large house: usually for high income people with relatively large family and consist of more units. (Compound plan house)
- Multi-units house: usually occupied by large and rich families and consist of many clusters within one periphery. (Complex plan house)

These plan types are based mainly upon the space organization of each type, the number of elements, and the size of the lot (Fadan, 1980).

Al-Afghani, 1991, set a typical description of a typical traditional Makkah house thus:

> The house reflected the sensitivity of the old builders to the needs of the family. This was observed in the different elements in the house. The entrance hall (Dihliz) was located next to the main entrance door. It is considered a traditional area between public and private. The sitting room (Magad) was next to the entrance hall on the first level. This room served as a business office and for receiving male friends. The reception room (Majlis) was usually located towards the main façade and was used for receiving family guests. The anteroom (Suffh) was an ante-chamber to the reception room. It was small, with the same breadth as the reception room. Family rooms were usually located on the upper floor levels. They were multi-purpose spaces, which served various aspects

> of family life, such as sitting, eating, and sleeping. Some of the houses had basements which were used to store tents and large pieces of equipment which were used during the Hajj season.
>
> The terrace also presented a space for the family activities. The terrace provided space for sleeping and for drying clothes. there was a night room (Mabit) located at one side of the terrace, usually used for storing beds, and used for sleeping during rainy, stormy, and cold nights. (p. 110.)

Though spaces were specifically intended for particular purposes, it should not be thought that the house arrangements described above were always rigid. Families organised their space according to the time of use, the physical constraints of the building, and so on. But always the separation between male and female quarters was maintained, and in houses of more than one storey the commonest way to do this was through a vertical distribution of social activities.

The family living rooms in larger dwellings of more than one storey are often quite spacious. This space is one of the most important parts of a house, as this is where the family members spend much of their time talking, eating, and resting. It is located on the top floor in close proximity to the roof terrace; in a climate like that of Makkah this offers a respite, particularly in the evening breeze. If the conditions allow, this space can become a sleeping area. Within the family area there are several rooms, each with a specific function, and each of these will have access to the roof terrace.

Makkah's traditional houses did not usually have low ceilings, a minimum of four metres being common in order to allow the circulation of cool air. The entire internal environment of a house with its filtered light and cool air provided a peaceful and relaxed ambience for its inhabitants (Figure 2.7).

Despite the stress on privacy requirements in the older houses of Makkah and their concentration on interior arrangements for family life, they still generally had extensive outside openings, usually in the form of wooden balconies and lattice screens. The teakwood of which they were made was able to resist the potentially damaging effects of climate and insects.

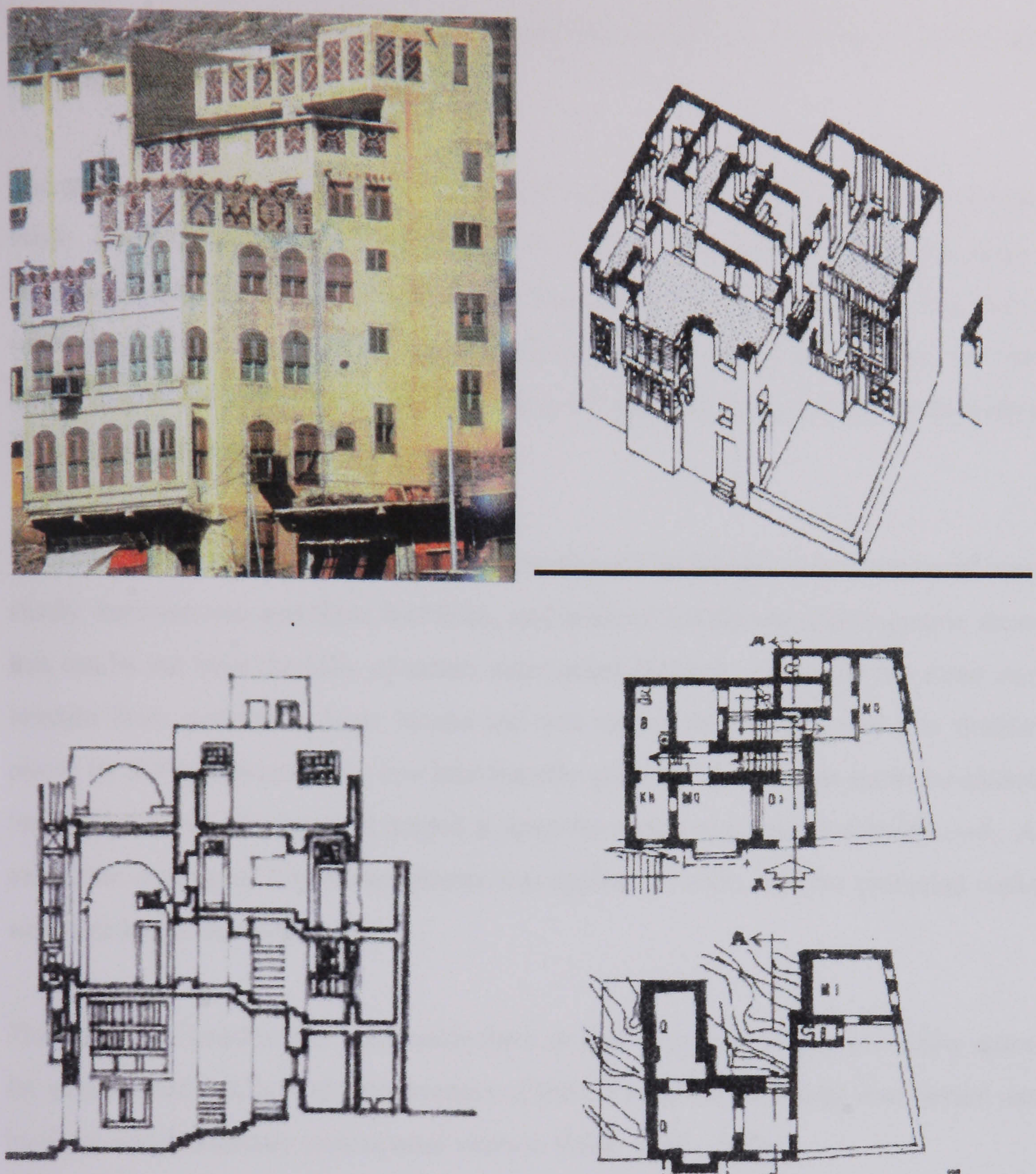


Figure 2.7: Typical Traditional Architecture of Makkah City. Source: Fadan Y., 1980.

2.4.1.4 Construction and Materials

Traditional architecture is a homogeneous composition that employed simple construction techniques developed locally by master builders and the vernacular materials. The common traditional building materials in Makkah were natural stones, for walls and foundation construction, and clay bricks for the upper part of the building (Kano, 1971).

The prevailed construction system was a load bearing wall structures of stone and clay brick. Roofing system was constructed with wood joists and covered by mats, straws or branches of palm trees. Wood has also been used in many applications, e.g. doors windows and some times as whole building facade (*Roshan*). Wood for this application is not available locally and has to be imported from outside Saudi Arabia (from Java and India).

The outer and inner walls of Makkah's traditional buildings were commonly very sturdy, between two and three feet thick, and made of locally obtainable granite stone that can be cut from the hilly mountain surrounded Makkah. Generally the stone was brought from quarries in large blocks and was cut on the building site into smaller pieces by skilful labours. The low heat transfer qualities of this stone made it suitable for Makkah's hot climate, as it helped to keep the inside of a house relatively cool. A protective coating of lime-based plaster was applied to walls, and the protected walls were finished with whitewash.

The traditional houses were commonly three or four storeys in height, providing space for an extended family. All construction of these traditional buildings was carried out by hand, and it normally took several years to finish (HRC, 1991).

The construction process was usually supervised by a master builder. Many of these had their skills enhanced through the periodic enlargement projects of the Great Mosque. Indeed, it was additions made to the Mosque and carried out by builders from such other Arab centres as Damascus, Baghdad, and Cairo that provided the models for arches and columns which became typical of houses in Makkah (Fadan, 1983).

A craftsman like the traditional master builder would bear little resemblance to a modern architect and he did not work from drawings or designs. The master builder marked out the proposed outline of a building on the ground and oversaw each part of the building process. Alterations, sometimes in consultation with the owner, were made on the spot.

The outer walls of the older Makkah houses with several floors were often reinforced by horizontal wooden beams - usually of a cheaper wood than the teak used for doors etc. - set into the wall at certain intervals.

The houses of old Makkah had flat roofs, already described above. These roofs suited the city's climate, and meant that they were often used as sleeping, laundry, or children's recreational areas. The surface of the roof was commonly a lime-based plaster on top of layers of planks, mats, earth, and lime-and-ground-pebbles mixture. The roofs were surrounded by high parapets to ensure security and privacy. Roofs often had a slight slope tilting towards a drainage outlet to collect rainwater, which was then led to a storage tank.

2.4.1.5 Indigenous Climatic Responsive Features

Mention has already been made of some of the features of the traditional architecture of Makkah, such as the thick walls, that respond to climatic conditions. Other architectural elements of value in combating harsh weather are the latticed wooden windows, the roof terraces, and whitewash.

Oriels *Mashrabiyas*, typical also of other cities in the western part of Saudi Arabia, such as Jeddah and Madinah, reduce heat by breaking up the rays of the sun and softening glare. The double wooden layers and the side cavities typical of oriels retard the transmission of heat to interior of the house. Oriels *Mashrabiya* also have the function of allowing female members of the household to look out without being seen, in accord with privacy requirements. The space between the window frame and its external lattice screen is often used to cool drinking water stored in jars there overnight (Figure 2.8).

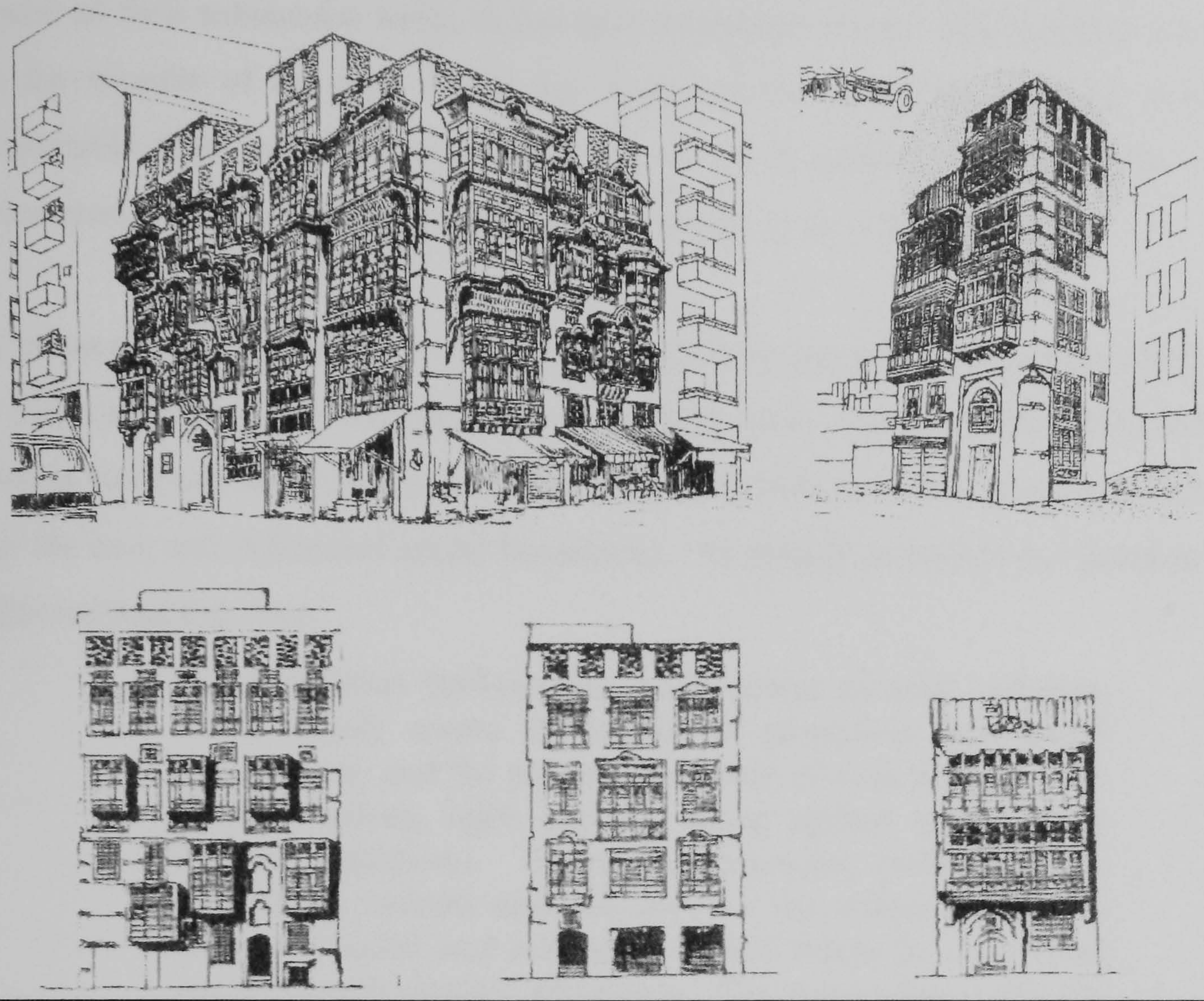


Figure 2. 8: Mashrabya and Rowshan (Distinguished Climatical Features of Traditional Architecture in Western Province). Source: Fadan Y., 1980.

Roof terraces also help to cool the oppressive heat, as they benefit from cooler breezes during the night, though the advantage they confer is confined to the upper floors of a house. The perforated stonework found at the front of the terrace acts to break up the prevailing winds blowing over the city.

A further feature of traditional Makkah dwellings that acts against the heat is the whitewashing of external wall surfaces. It is well known to local people that the colour of a surface affects the amount of the sun's radiation that it absorbs and this is why Makkah and other cities in hot regions have adopted the whitewashing technique. It affords a very considerable reduction of temperature, and adds greatly to the comfort of those in the house. The initial absorption of solar during the day is prevented, and this also acts in turn against the potential discomfort of any re-radiation.

Makkah's traditional buildings were also made more comfortable dwelling houses because of their substantial walls, as has been mentioned above. The thickness meant that the transfer of the heat of the day from outside the house to inside took a considerable time and this allowed members of the household to move to the roof terrace area, which by that time was becoming cooler, in the evening.

The urban pattern of traditional Makkah also played its part in moderating the effect of the harsh climate. The compactness of the built areas created by the relationship between buildings and voids (roads and courtyards) both provided maximum shelter from the heat and delineated social boundaries. Al-Abdaly describes the situation in traditional Makkah thus:

> The integration between the active power of solid volumes, which mainly create the means of protection from harsh environment, and the passive resistance of void necessary for communications, light, etc. are acting against unfavourable weather conditions. These two elements create climatic equilibrium indoors and outdoors for the whole pattern, as alternate shaded and unshaded volume reacts in a coherent way to benefit climatic adaptation. The simple fact is that the volume of buildings related to the roads and closed squares reacts exactly like the courtyard and the surrounding rooms to provide coolness (Al-Abadly, 1975, p. 67).

Another feature of traditional architecture that is worth stating is that it works with compatibility and harmony with human scale. The major units for measurements were human height, arm, span, and footsteps. These units have reflected the human proportion in building design and outdoor setting.

It is clear that the traditional buildings of Makkah were suited to their environment not only in that they expressed the traditional social and cultural values, but also in that their design and construction reduced the worst effects of the hot climate of the region. Unfortunately the traditional features have not be maintained or developed; instead it completely swapped by modern concepts that do not well fit in this locality. One strong reason behind the disappearance of this traditional style is the extinction of local building crafts which gradually disappeared with the skilful master builders.

2.5 Contemporary Architecture Style

2.5.1 Overview

As in any city, housing in Makkah has a social significance that stretches beyond analysis in simple market terms of supply and demand. It is this social significance that has led governments to regulate the housing market with measures ranging from rent control, to more indirect methods such as making finance and land easy to obtain for potential developers. In Makkah, however, the situation has a further dimension because of the city's importance as a pilgrimage centre and the location of the holy Mosque.

The topography of Makkah has a limiting effect on the ground available for building, particularly in those parts of the city where it is not easy to enforce relevant regulations. In addition to this, the special requirements of the vast numbers of *hajj* and *omrah* pilgrims have also had a considerable influence on housing in the city. These visitors are seldom able to afford any other than cheap housing, and this has had an effect on the quality and appearance of much contemporary architecture.

Despite the antiquity of Makkah as a settlement and despite its historic significance, much of the city's architecture is comparatively new. Within the last three decades many older buildings have been demolished and there has been a great amount of new construction, so that over 70 percent of all houses in Makkah are less than 30 years old. However, because of the pressure, indicated above, to produce a large amount of cheap housing the fact that many dwelling houses in the city are new does not mean that they are of high quality. Building quality usually associated with the quality of the contractors and often this party cannot retain skilful builders due to economical consideration. Top classified contractors charge more and usually employed a highly qualified team while unclassified contractors can do the job for less and the quality of work is never guaranteed.

2.5.2 Characteristics of Contemporary Architecture

As mentioned earlier that the Post-Modern architecture have influenced greatly the modern architecture development in Saudi Arabia. Arnold Toynbee, the English historian, was the first to use this expression in his non-architecture writing in the beginning of 1938 and followed by Joseph Hundunt in 1949 who mentioned this term in architectural document. In 1975, the term has been employed with its actual agreed definition in architectural articles of the architect Charles Jenkens (Jencks, 1988).

This expression has been in practice internationally with two different main concepts which are:

- American concept: this view see the modernisation from historical prospective, known by *New Historicism*, which based on two major points: firstly, the ornament features borrowed from old classical styles and secondly, the general form of building and its elevations.
- European concept; this view concentrate on the revival of old styles for the cities and towns of the Middle Ages. It can be understood as a reaction to the problems that the modern civilisation has created and an attempt to bring back some of the peaceful example from the old days.

The theories and trends that influenced the local architecture in Makkah, hence, shaped the contemporary architecture for the city can be interpreted into the following trends:

1. Historicism (the Revival of Islamic Architectural Styles and Classic Ornament):

It is one of the important trends that accompanied the modern development and gained wide interest from the architectural society and the planners mainly in all Arab World. The expansion of the Holy Mosque is based on architectural features following this school.

2. New Localism (the Revival of Traditional Architecture):

This trend is recently having an official and public support. This favoured adoption for this trend has resulted from the national call for preserving the traditional and the cultural heritage of local cities in order to rebuilt their images that have almost been substituted by exotic forms of architecture. Traditional architecture or national architecture is the same meaning for one essence which gives distinguish identity to specific nation so that it can be recognised and differentiated by their special features which dictated by religion culture, climate and local resources.

3. Ir-rationalism Style

This trend has also appeared in some of urban development but not in large scale. The examples on this trend revealed a personal attitude and desire for uniqueness. This school totally misunderstands and ignores many realities in relation to the locality and culture.

The development has struggled with these trends and a large variety of styles have been produced. The first two trends sound very acceptable for a city searching for its architectural identity. However, there have been great shortcomings resulted from the lack of knowledge of the society and locality needs (Al-Bis, 1991).

The characteristics of the contemporary architecture in Makkah are versatile and not governed by a clear order. All styles and material types can be seen in the city but no particular image can be conceived. The reasons behind these bizarre styles are many, but among of these reasons are the absence of local qualified architects, the strong presence of foreign architects who planted many of exotic styles, and the fast growth of the developments. (Figure 2.9)

Figure 2. 9: Contemporary Architecture of the Apartment Buildings

2.5.3 Building Construction, Typology, and Materials

Generally speaking, the Kingdom of Saudi Arabia has consistently been traditional in its building style until late fifties, the date when some new building materials and techniques were brought in from other countries and begun to be used in various combination. An intensive use for this material has been experienced through out the last three decades.

Almost all types of building constructions have been built by reinforced concrete which participate considerably in achieving the imported and exotic building shapes of the foreigner designers. Definitely, this material was a revolution by all means in the field of building industry as far as building structural is concerned. However, this material does not enjoy the same performance when it comes to the thermal properties. Reinforced concrete construction has a poor thermal behavior under hot climate which make it a weak barrier in front of heat flow.

In addition to this, the early stage of national development was encouraging the move towards the new materials. As a result, traditional building construction declined very rapidly in the seventies. This decline of the use of construction materials other than concrete was in fact, encouraged by municipalities and Real Estate Development Fund (REDF). The REDF adopted a policy of refusing to finance any type of construction other than reinforced concrete, while municipalities limited issuing permits for traditional construction. Recently, new building production systems were introduced to the country by large foreign contractors and manufacturers to construct housing, schools, hospitals etc.

The conventional system of building construction is reinforce concrete frame with cement and ceramic blocks and bricks as outer layers. Load bearing wall systems with reinforce concrete (RC) floors have been practised on limited scale. The structural system can be described as a cast in-situ RC frame composed of cement, beams, floors, slabs, and foundations. The frame is then filled with cement block or brick walls and externally and internally covered by cement stucco.

The developments of the seventies have increased the demand on building materials, and this, in turn attracted the investment in this field. Many manufactures have been established and pumped wide lines of different building materials. The basic materials that have been introduced to building industry and accompanied the appearance of the contemporary architecture can be listed as follows:

- <u>Cement</u>
- <u>Concrete Products:</u>
  . Blocks
  . Bricks
  . Tiles
- <u>Steel Products:</u>
  . Construction bars
  . Sheets and panels
  . Columns and beams
  . Girders and joists

- Gypsum
- Marble
- Calcium Cilicat Products:
  . Blocks
  . Bricks
  . Tiles
- Red Clay Bricks
- Glass
- Insulation Materials
  . Thermal insulation
  . Water proof insulation

The local market currently is overwhelmed by fast ranges of design and sizes of these materials. However, many products have also been imported and updated regularly.

2.5.4 Building Typology

Makkah has a higher residential density than any other Saudi city, particularly in the area around the Great Mosque, with comparatively few detached houses and more apartment buildings than some other cities. However, because the population falls outside the pilgrimage season, there is no greater overcrowding in human terms than in many other Saudi cities.

Residential area in Makkah can be classifies according to its population density to the following classes:

- Low-density area; this occupied an area of 99.53 $km^2$and represent a 25.05% from the total area of the city.
- Middle density area; occupied an area of 24.8 km^2 and represent a 6.24% from the total area of the city
- High density area; occupied an area of 7.95 km^2 and represent a 2% from the total area of the city (MMRA, 1998).

This density usually in force the type of building to be permitted in each zone. The common residential building types that have been constructed lately can be either one of the following categories:

- Detached Villas
- Apartment Buildings

As with other cities in Saudi Arabia, Makkah has seen in the last three decades a period of design and planning by western planners and builders using western ideas and techniques. Since detached villas are typically the favoured house design of high-income groups in western countries, dwellings of this type were introduced, aimed at higher income groups, in Makkah and other Saudi cities. Some of these villas, with splendid garden surrounds, might be considered luxury dwellings, but many were of more modest design, though detached and still with individual gardens.

The villa style, of course, was quite alien to traditional Saudi architecture. Many of these villas were planned for the period of the second of the Saudi Five-Year National Development Plans (1976-81), which overall cover the period 1970 to 2000 (MOP, 1985, 1995).

In addition to detached houses for the upper section of the market, houses of more modest cost, including apartment blocks generally five storeys high, were planned for those who were on lower incomes.

Where the land value is high, a relatively high-rise apartment blocks are constructed (10-15 story high). This type of building usually allocated to accommodate pilgrimages and visitors during the year.

It is not only the design and the physical layout of the detached villa type of house that is alien to Makkah (and indeed to the whole of Saudi Arabia), but also the materials of which they have been built. Much of modern Saudi housing is constructed out of reinforced concrete, with buildings often faced with brick or block. Little use is made of materials widely available locally. Insulation materials are seldom used, and houses made of concrete are poorly insulated against heat (see below for a fuller discussion of thermal problems).

The average household size in Makkah is 5-7 persons. Almost two thirds of Makkah's family homes were in multi-story buildings, with traditional houses and the more modern villas accounting for around 20 percent and 8.5 percent of residential accommodation respectively. Few houses were exceptionally small, the prevalent pattern being that of three-room dwelling.

2.5.5 Contemporary Problematic Issues

We have already noted, when describing traditional architecture in Makkah, the importance that has been attached to climatic matters, in particular to reducing the effects of the hot climate. Traditional houses dealt very well with the problems posed by the climate of the area. While other influences, including those from western countries, have now affected the house style and the urban design of Makkah, builders still have the harsh climate to deal with. Whether current construction and design can cope with the conditions of extreme heat as well as traditional techniques is a matter of considerable doubt.

Modern buildings of a non-traditional style tend to be unsatisfactory to many Saudis for a variety of reasons, in addition to their failure to deal adequately with climate. Criticism has often been made of them on aesthetic grounds, both in terms of internal and external appearance and in terms of the landscaping of surroundings, and on the grounds that the building materials are unsuitable in the first instance and that they are in any case not being used correctly (e.g. bad concrete work due to improper mixing and poor workmanship).

It is often felt that there is an inadequate understanding locally of the performance potential of new building materials and of plumbing, electrical, and carpentry techniques that they demand. Materials in any case have generally to be imported from outside the local area, so that less use is made of resources available in Saudi Arabia.

One of the problems of modern non-traditional house design and construction is not just that many Saudis do not like what they see or do not know how to deal with materials, but that the new materials and styles are singularly inappropriate in dealing with thermal problems. The building materials themselves do not have the capacity to reduce and disperse the heat in the way, outlined above, that traditional stone and whitewash did. Furthermore, the actual design of the house means that there is no longer, for example, the cooling effect of the roof terrace and its attendant features.

In addition, the difficulty in regard to climate lies not only in the poor heat dispersal capacities of house design and in building materials, but also in the failure of modern house design to take proper account of traditional Islamic social values. Setback regulations have given many buildings more elevation than they once had. Because of this elevation, household members have been tempted to open windows without restriction. But this in effect is out of line with traditional privacy need, especially since windows are now often plain glass (itself something which tends to increase internal heat) without latticework or any other type of screen or protection.

Various moves have been made by householders in reaction to this in order to protect privacy, and as far as thermal control is concerned one reaction has been that windows which may be intended to help in reducing the effects of heat might not be used for that purpose, as they often remain closed because to open them would be to compromise the privacy requirements of female household members (Al-Hussayen, 1980).

Another problem is that, in an attempt to compensate for the failure of modern design and materials to reduce heat, air conditioning systems are usually fitted. There is, however, a lack of technical understanding of these systems in a country which has never traditionally used them. This, especially in view of the fact that air conditioning units are often unreliable, means that outside engineers may have to enter houses to carry out repairs at inconvenient times or in inconvenient locations (from the privacy point of view).

Air conditioning units are also a poor answer to the problem of thermal control since they are often noisy, unreliable, physically intrusive, economically exhaustive, and aesthetically displeasing. When they do function they are often too efficient, delivering an unnaturally low temperature indoors, so that the effect of moving outside into extreme heat is often more debilitating than would be the case if the temperature difference were less. People who live in air-conditioned environments have come to give no thought to the benefits of natural air.

The increase in paved areas around some types of new building and the absence of vegetation in those which do not have extensive gardens has been a further factor increasing the thermal problems of houses due to indirect solar radiation from outside surfaces.

Modern buildings in Makkah (as indeed in other Saudi cities) therefore fail to deal with climatic conditions as well as traditional houses because they suffer from faults of design, of materials, and of environment from which traditional architecture is free.

The imported modernization of the Kingdom has either led to the reconstruction of entire cities e.g. the case in Makkah City, or construction of new cities that resulted in the loss of the local architecture identity. (Kilical, 1990)

2.6 Summary

The city of Makkah, through out its historical background, has witnessed dramatic developments through being the most important city in the Islamic world. These developments took place in the first place to meet the continuous demand of services required by pilgrimage. The heart of the developments is the Holy Mosque, which has been the driving force that dictates the policy of expansion and development for the city.

The successive rulers of this city were very keen to leave their personal mark on the history on the architecture of the Holy Mosque and on the development that they were able to achieve during their ruling period.

The architectural identity, which forms the special image of the city, was established during the late Ottoman period. This identity was distinguished for its ordered integration of the local people, local climate, and the living environment. The pilgrimage demands were fully accommodated, as the number of the pilgrimage was at first very low in comparison to recent times. Under the era of the Saudi government, Makkah has witnessed a great development that matches with the great increase in pilgrimage numbers and the flourishing economic status of the oil returns.

The last development was carried out hastily and it has not given any chance for calculated and logical transformation to modernisation to occur. The results turned out not as well as expected. No doubt the development has updated the city with the latest transportation network and buildings. However, many social and climatic factors have been altered or completely lost during this process and the change has failed to cope with this rapid movement.

Almost 70% of the existing buildings have been built in the last three decades. They sound new, time-wise, but they are not up to the expected standard as far as performance is concerned due to many administrative and professional mistakes. The shortcomings of the building industry have affected two major issues: these are the socio-cultural issue and the climatic response issue.

The socio-cultural issue is a crucial matter that involves many complicated factors to do with the change of people's behaviour as a product of the spatial change, and how the new architecture development has impacted upon cultural identity. However, it is not the aim of this research to look at this problem, as this subject needs intensive and independent research to tackle it. The problem of the climatic performance of these building is emphasised in this research due to the national calls and demand for energy conservation.

The nature of the problem for the existing building stock in relation to the second issue can be summarised as follows: the vast majority of the existing building stock is not performing, thermally, well in terms of energy consumption and in terms of indoor comfort. Thus, two options for correction are theoretically possible, the first is to demolish these buildings and build a new stock with high building standards, and the second is to improve the existing situation by elevating building standards from the performance point of view.

The first approach is not logical and cannot be applied in practice by any means. The second approach is the more realistic one; hence it has been adopted in this study. This study will try to investigate the problem, diagnose the causes, and suggest the solutions. This chapter has revealed many aspects, features, advantages and disadvantages of both traditional architecture and contemporary architecture (post 1970s architecture). This information is vital for evaluating the current situation in line with the good ideas of the past and the promising technology of the present.

Chapter 3

Climatic Context

Chapter 3

CLIMATIC CONTEXT

The Significance of Climate in the Human Environment

3.1 Introduction

Architecture is a product of various disciplines, each discipline with its distinctive impact on the final appearance and the style of the built environment. Architectural identity is a reflection of many factors, the most importance among them being socio-cultural considerations, which are by-products of religious beliefs, economical considerations, and climatic impacts.

Climate has always has been a significant force influencing building design strategies, i.e. building layout, structural elements, constructional techniques, materials, landscape, land use, etc., and climate-responsive buildings are these which react positively with surrounding environmental conditions to create comfortable living settings for people.

Of the hot arid regions of the world which host human populations most are to be found in developing countries. The challenge imposed by such a hostile climate on buildings and people in these countries is great, bearing in mind the escalating problems of energy availability and prices, and the task of searching for practical solutions has become more difficult now.

To understand this influence imposed by such a hot arid climate, it is important to examine its basic features; in order to do so the processing and the analysing of climatological data usually undertaken in the following order:

1. Analysing data in order to understand climatic conditions.

2. Analysing data in order to understand their interaction with building design, and to assess the overheating period, cooling load, and energy requirements (Bitan, 1984).

3.2 Characteristics of Hot Dry Climates

Hot dry regions (desert) are found in the sub-tropical zones of Africa, central and western Asia, south western part of north America and south America, and in central and western Australia, as can be seen in Figure 3.1.

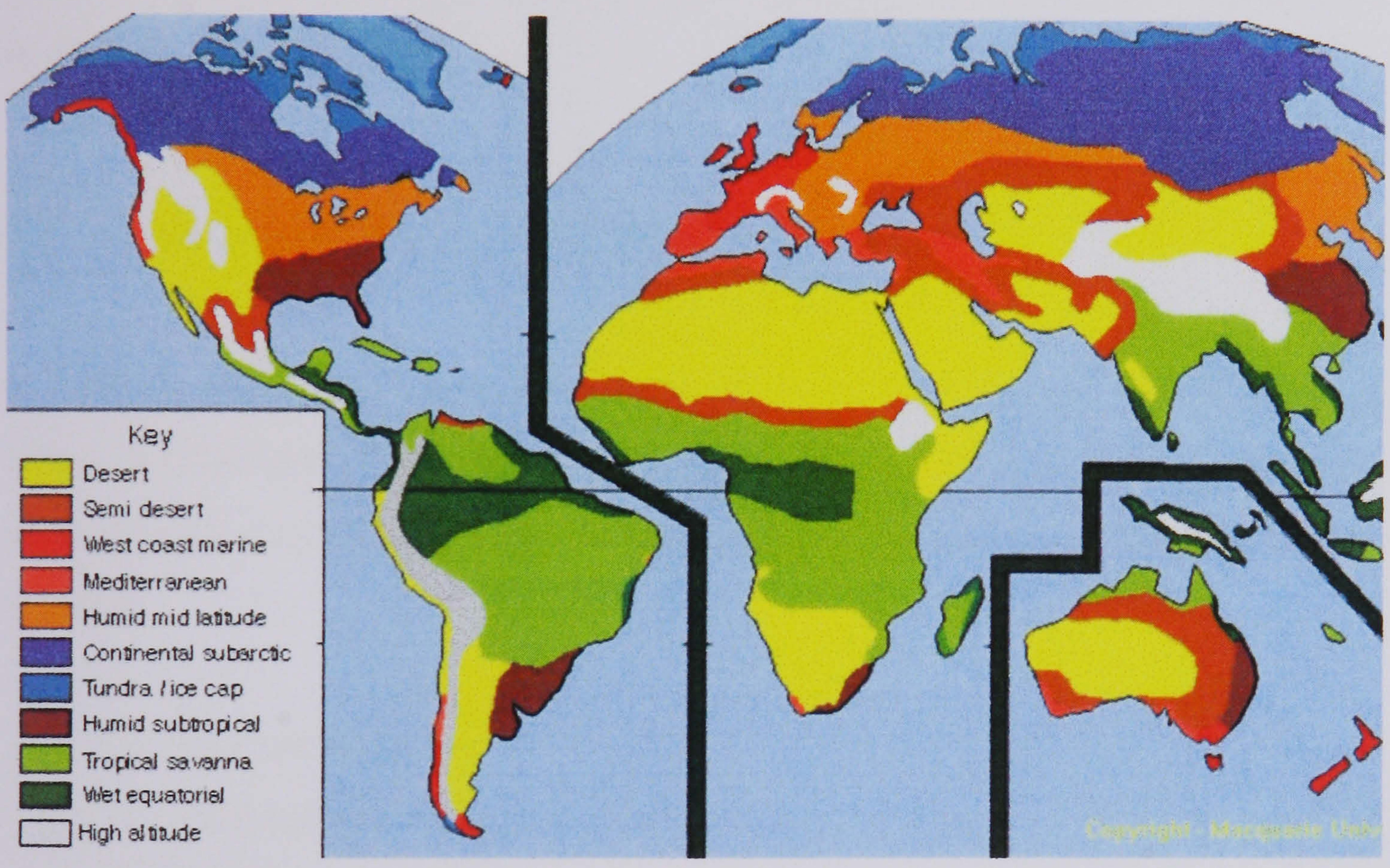


Figure 3.1: The Distribution of the World's Hot Dry Regions (Desert). Source: Macquarie University, 2001.

These regions are characterized by intense direct solar radiation on horizontal surfaces, and this is further augmented by radiation reflected from adjacent light coloured terrain. The sky is without cloud for the greater part of the year. However, dust and storms are frequent, caused by convection currents due to intensive heating of the air near the ground, mainly in the afternoon.

Low humidity and the absence of clouds result in a very wide temperature range. In summer the unobstructed solar rays heat the land surface up to about 70°C at midday. At night the rapid loss of this heat by long wave radiation cools the ground surface to

15°C or below. The fluctuation in air temperature is much smaller, but even so a daily range of 20°C is not uncommon. The summer temperature during the day is around 40-50°C, and at night the range is about 15-25°C.

Relative humidity fluctuates with air temperature, and ranges from below 20% in the afternoon to over 40% at night. Periods of rain are few, and far between. Although precipitation sometimes starts at high altitude, the water evaporates completely before reaching the ground. Wind speeds are generally low in the morning, rising towards noon to reach their maximum in the afternoon, and winds are frequently accompanied by dust and sand (Konya, 1980).

3.3 Climatic Elements and Building Design

In building design the major factors affecting both heat transfer through building fabrics and the thermal comfort of people are the regional climate and the surrounding micro-climate conditions. These conditions comprise the following principal climatic elements :

1. Solar radiation
2. Temperature
3. Humidity
4. Wind
5. Precipitation

These elements are linked to a global system which is the result of the constant radiation of energy from the sun and the 24-hours rotation and planetary movement in the solar system. Solar radiation energy has a dominating influence on all climatic elements and phenomena The relationship between these climatic elements produces the effects on buildings and stimulates their thermal behaviour. It is therefore desirable to design in harmony with, not against, these natural forces, and to make use of their potential to create better living conditions.

Design decisions are strongly related to the above mentioned aspects, which are powerful enough to dictate the appropriate roles and strategies of design. 'Climatic balance' is a term used to express a structure which can reduce undesirable climate stress, and make full utilization of natural resources in such a way that human comfort is best catered for.

It is not easy to achieve a perfect balance, especially in harsh climate. But a house of good thermal performance and low energy consumption is possible if a systematic approach to climatic and behaviour balance is followed (Olgyay, 1973).

3.4 Climatic Analysis for Makkah City

Makkahs' climatic features are influenced by many regional and local factors which control its seasonal types and characteristics. Among these factors are:

Location:
The city of Makkah, is located at a latitude of 21°26'16" north of the equator, with an elevation of 241 meters above sea level and internally located in west province of the Kingdom of Saudi Arabia.

Geography:
The topography of Makkah is situated in the hilly terrain of the Sirat mountains in the middle of the eastern coastal plain of the Red Sea. It lies in a valley slightly more than half a mile wide, between steep rock hills, which in some places reach nearly 670 meters above the city. The rocky hills surrounding the valley are composed of basalt, granite, and some limestone. Vegetation is extremely sparse due to the absence of water resources and agricultural soil (Al-Saibi, 1965).

In order to establish an overall understanding of the implication of Makkah's climate on the built environment, there follows a descriptive analysis of climatic elements and their relationship to aspects of building design.

3.4.1 Solar Radiation

Solar radiation is an electromagnetic radiation emitted from the sun. Radiation transfer occurs with the speed of light in the form of different wavelength, or so-called solar spectrum, that range from about 0.28 to 3.0 microns. The solar spectrum is broadly divided into three regions: the ultra-violet (u.v.), the visible and the infra-red (i.r.). Only the small section of the spectrum between 0.4 and 0.76 micron is light visible to eye; waves shorter than 0.4 micron are u.v. radiation and wave longer than 0.76 micron are i.r. Although the peak intensity of solar radiation is in the visible range, over one-half of the energy is emitted as i.r. radiation. It is the major source of energy on the earth that influences all the climatic phenomena. As radiation penetrates the earth's atmosphere, its intensity is decreased and the spectral distribution is altered by absorption, reflection, and scattering (Konya, 1980).

Clouds reflect back a significant amount of solar radiation to outer space, but the remainder reaches the earth's surface in a diffused form and in various amounts. The amount of solar energy actually reaching earth depends on many factors, among which are solar output, the distance of the earth from the sun, the altitude of the sun, and day length. Figure 3.2 shows these factors.

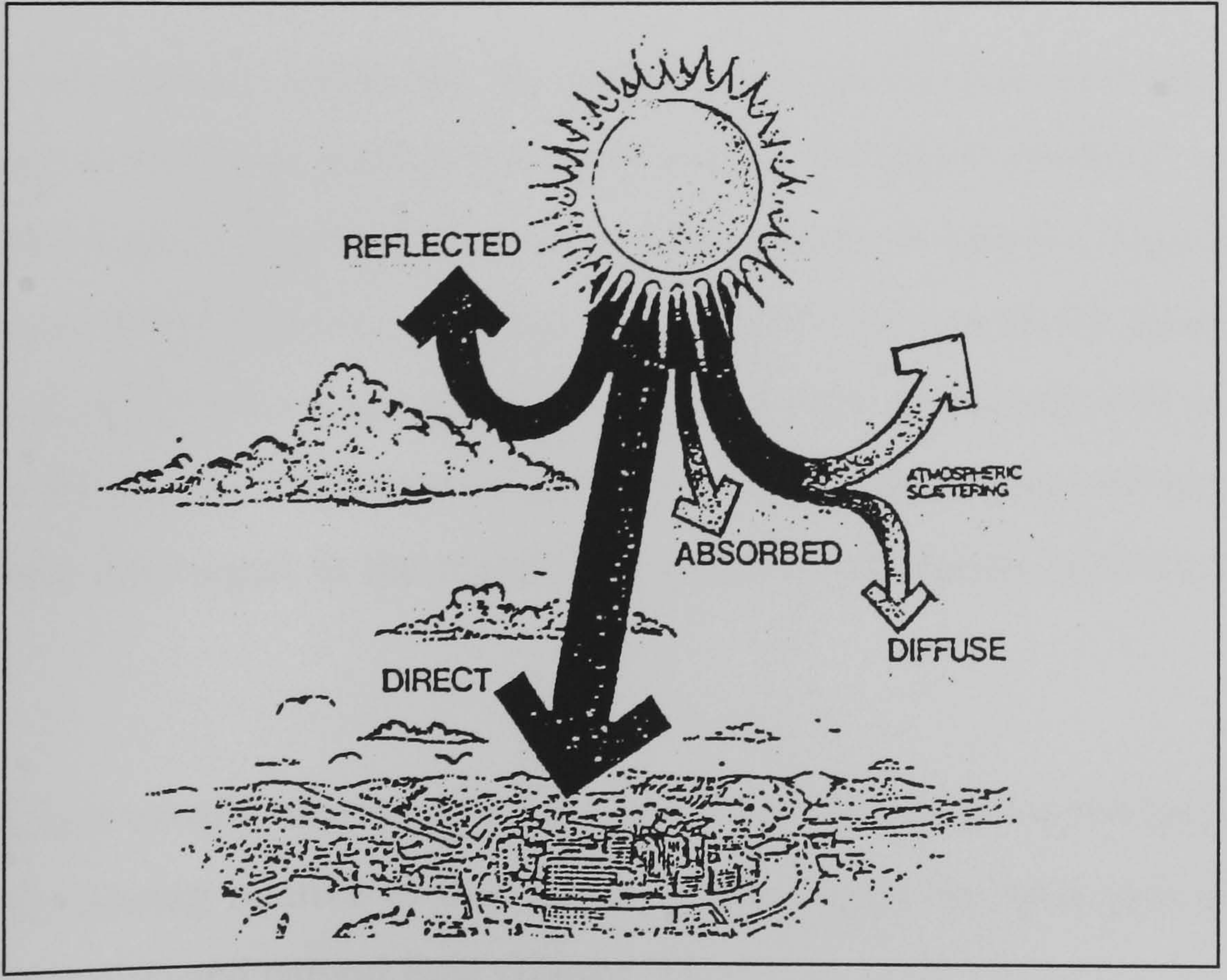


Figure 3.2: Solar Radiation System. Source: Mazria, 1979.

The amount of solar radiation also depends on the clarity of the sky with respect to clouds, and the purity of the air with respect to dust and water vapour. However, solar geometry and sun position for a particular time and location plays a major role in determining most of these phenomena.

The three fundamental facts which the geometry of the sun are, earth revolve around the sun once a year (produce the four seasons on the earth), the earth also rotates about its own axis once a day (produce day and night phenomena), and the earth's axis is not perpendicular but is tipped $23^{\circ} 27'$ to the plane in which it orbits the sun. The earth is divided into three major sections in relation to sun position and these sections are the northern hemisphere, the equator, the southern hemisphere. Apparent sun motion is symmetrical about the equator, but whatever happens in the northern hemisphere will be repeated in the southern hemisphere six months later.

The change in season on the earth is explained by the fact that as the earth orbits the sun, its axis always tipped in the same direction, pointing towards the Polaris. This means that at one point in the orbit the axis leans a way from the sun, and at the opposite point, half a year later, the axis is tipped towards the sun. these time are known as winter solstice and summer solstice.

When it is the summer solstice in the northern hemisphere, it is the winter solstice in the southern hemisphere, and all these phenomena are exactly reversed. At the point in the earth's orbit halfway between the summer and winter solstice, the earth's axis is perpendicular to the incoming sun rays. At this point the sun stands directly over the equator and everywhere on the globe the days and night are exactly twelve hours long (except at the poles). This time is called equinox (which means the time when the length of the days equal to the nights) and occurs in the spring equinox and autumn equinox.

Sun position is usually measured by the angle of its altitude above the horizon and the angle of its bearing relative to true south. These angles are important in designing building elevation and natural light (Figure 3.3).

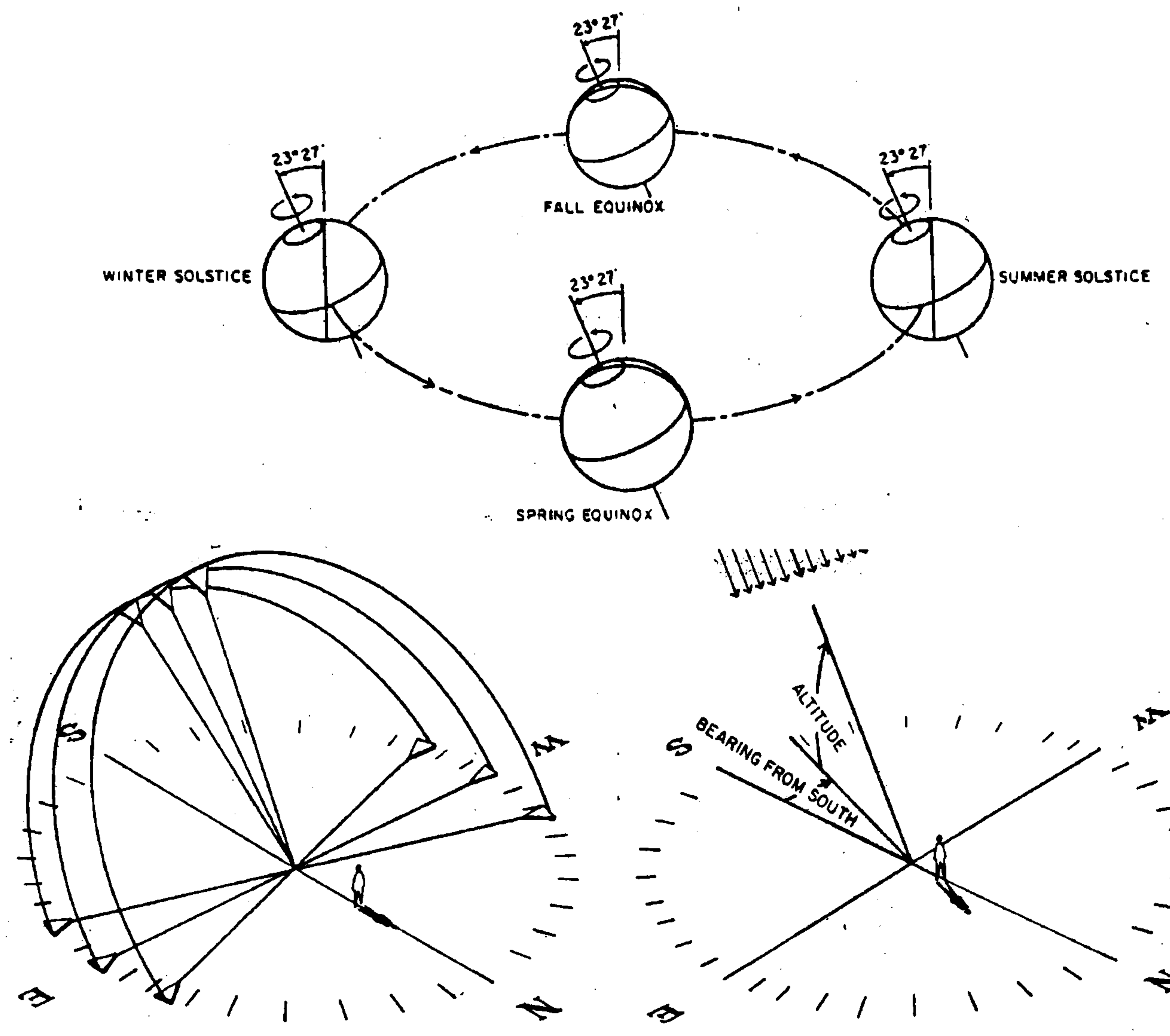


Figure 3. 3: Solar Geometry and Sun Movement Angles. Source: Givoni, 1981.

Solar radiation is a critical issue affecting building enclosure. It is customarily divided into five main categories, listed below in decreasing intensity:

- Direct short wave radiation from the sun.
- Diffuse short wave radiation reflected from surrounding surfaces.
- Long wave radiation from heated ground objects.
- Outgoing long wave radiation exchange from building to sky.

Direct and diffuse radiation make a substantial natural contribution to heat gain in dwellings. They affect the building in two ways, firstly by entering through windows and being absorbed by internal surfaces, thus causing a heating effect, and secondly by entering through walls and being absorbed by the outside surfaces of the building, creating a heat input, a large proportion of which is conducted through the structure and eventually emitted into the interior.

The combined effect of outdoor air temperature and solar radiation produces a further increase in heat stress, and hence a significant heat flow through the building envelope.

This combined effect is known as sol-air temperature, and it expresses the temperature of the outdoor air which, in the absence of all radiation exchanges, would give the same rate of heat entry into the surface as would exist with the actual combination of incident solar radiation, radiant energy exchange with the sky and outdoor surroundings, and connective heat exchange with the outdoor air (ASHRAE, 1985).

The CIBSE definition of the sol-air temperature concept is "the outside temperature which, in the absence of solar radiation, would give the same temperature distribution and rate of energy transfer through the wall or roof as exists with the actual outside temperature and incident solar radiation" (CIBSE, 1986). The impact of solar radiation is not constant and is subject to many variables. However, we may identify the following factors as being those mainly involved in determining the quantity of solar radiation:

- Sunshine duration.
- Intensity.
- Incident angle.

The number of sunshine hours per day is linked to whether the sky is clear or not. The intensity of solar radiation varies according to the earth's distance from the sun, solar activity, geographic location, and altitude. The average intensity on a surface perpendicular to solar rays (on the equator) is 1.97 cal/m2/min(or 1353 $W/m^{2)}$, this value is called the solar constant (Olgyay, 1957)

The greatest amount of radiation is found in two broad bands encircling the earth between latitudes of 15° and 30° north and south of the equator where, in most areas, the percentage of direct radiation is very high. The mean average monthly global solar radiation (direct and diffused) for 0^{o}N is 500 cal/ m^2/day, 600 cal/ m^2/day for 20^{o}N, and 530 cal/ m^2/day for 30^{o}N.

3.4.2 Solar radiation in Makkah

The geographical location of Makkah and its clear sky play a part in intensifying the amount of solar radiation in the city. The diagrams in Figures 3.4 and 3.5 show the profile of monthly mean for the global radiation usually experienced in this location and the profile of sunshine duration respectively.

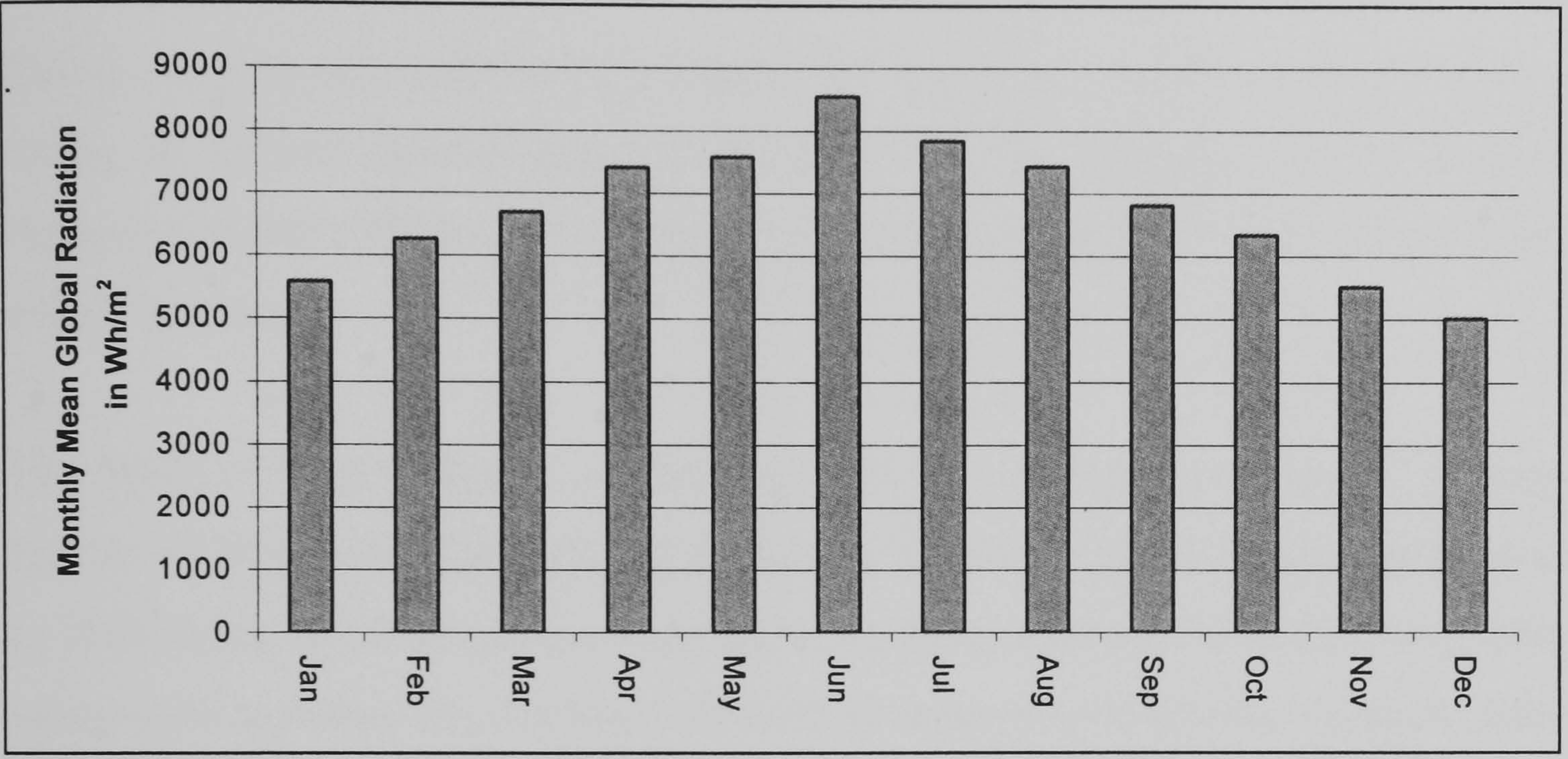


Figure 3.4: Monthly Direct Mean Solar Radiation Profile. Source: KACST, 1983.

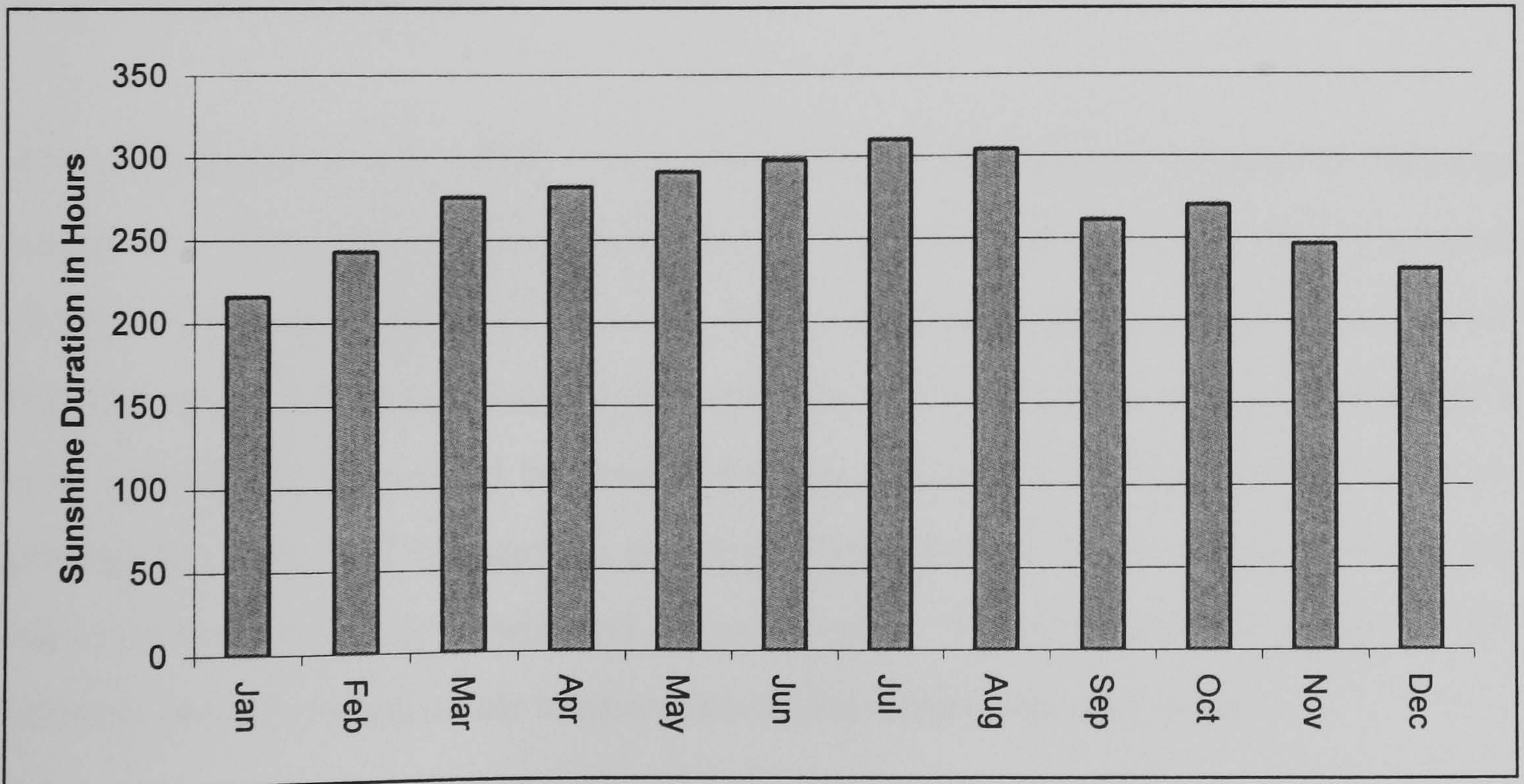


Figure 3.5: Sunshine Duration Profile. Source: KACST, 1983.

As shown from the graphs, all the months have high readings of solar radiation exceeding 5000 Wh/m^2. Summer months predictably have the highest irradiance, around 7424-8547 Wh/m^2. The peak intensity of 8547 Wh/m^2. is found in the month of June. This happens due to the summer solstice when the sun becomes perpendicular to the Tropic of Cancer (23.5° North), where the sun's rays penetrate a minimum distance through the atmosphere to reach the earth. Average monthly global radiation if 6330 Wh/m^2 and the daily mean radiation is 211 Wh/m^2.

The sky is generally clear over the whole year, the duration of sunshine being long during the summer months, between 300 and 310 hours. The other months receive between 216 and 290 hours of sunshine. Average daily sunshine hours is 9 hours all around the year.

The effect of solar radiation on buildings can be screened by means of shading devices, reflective and light colored surfaces, a modified exterior micro-climate, and by minimizing building surfaces exposed to the sun's radiation. However, very little can be done to reduce the combined effect of air temperature and solar radiation, (sol-air) temperature, which works directly on building fabric materials.

3.4.3 Air Temperature

Air temperature is one of the most important of atmospheric properties affecting human life. This element is very well known to people as an indicator to the prevailed climatic situation in its simplest form. It is commonly used to express how people feel and react to their surrounding environment. The distribution of air temperature over the earth is influenced by several factors, among them the amount of radiation present, the nature of the surface concerned, the distance from bodies of water, the nature of the prevailing winds, and ocean currents. The classification of the world's climatic zones is based on air temperature characteristics for each zone.

Air temperature characteristics are almost constant for each zone all the year round, but seasonal variations in temperature inside each zone are frequent, resulting largely from seasonal variation in the amount of insolation at different locations in the globe.

Temperatures are highest in summer when insolation is greatest and lowest in winter when insolation is lowest. At any point near the ground the air temperature is dependent upon the amount of heat gained or lost at the earth's surface and any other surfaces with which the air has recently been in contact. During the day, as surfaces are heated by solar radiation, the air nearest to the ground acquires the highest temperature. In calm conditions the air within 2miles of the ground remains stratified in layers of different temperatures. Mixing of the hotter and cooler layers takes place as the heat build-up in the lowest layer becomes great enough to cause an upward eddy of warmer, lighter air (Olgyay, 1957).

In hot arid climates, a large diurnal temperature range can usually be expected due to the differences in the daytime heating and night-time cooling processes. During the daytime a high degree of solar radiation reaches the ground and elevates the temperature rapidly; at night, a rapid cooling also occurs through long wave radiation emitted from the hot ground to the clear sky. This process is called nocturnal radiative cooling, and is a factor that could be utilized for cooling down the external surfaces of buildings at night. The moisture content in air is very low however, air capacity for water vapour increases progressively with its dryness.

3.4.4 Air Temperature in Makkah

Being located inside the tropical zone, on its dry edge, and at the concourse line of the two great continents (Asia and Africa) away from any water bodies, the temperature in Makkah is characterized by its high readings through all the months of the year.

In general, the range of monthly maximum, minimum, and mean are 37°C, 23°C, and 29.9°C in respective order. This average puts Makkah climate on the top of the highest temperature recorded in comparison with other hot arid zones world wide.

The average temperature in Equatorial zone is 27°C and in the tropical (include hot-arid desert zone) is 30°C (Strahler, 1969).

Makkah's temperature profile shown in Figure 3.6 illustrates the main characteristics of the prevailing conditions in this area. Temperature profile follows the normal profile of an equatorial zone, where the lowest recorded temperature occurs in January and the highest occurs in July. Seasonal differences are small in Makkah and the disparity can hardly be observed (except for summer peak and winter peak). The hot period extends from May till September where the temperatures recorded usually fall above 36°C. However, a relatively cool period is presented by the months of December and January, where temperatures decrease to their minimum.

The other months of the year can be classified as a fairly hot, though more than a 6°C difference, from the comfort line, can be noticed in this period. The variation between the mean maximum temperature and the mean minimum temperature is very significant, and frequently exceeds 15°C. This variation indicates diurnal (day and night) variations that have to be considered by the designer. It also indicates the presence of intensive solar radiation by day, and hence strong outgoing long wave radiation to clear skies at night. Nevertheless, during the hot period, the minimum temperature does not fall below the comfort line of 27°C.

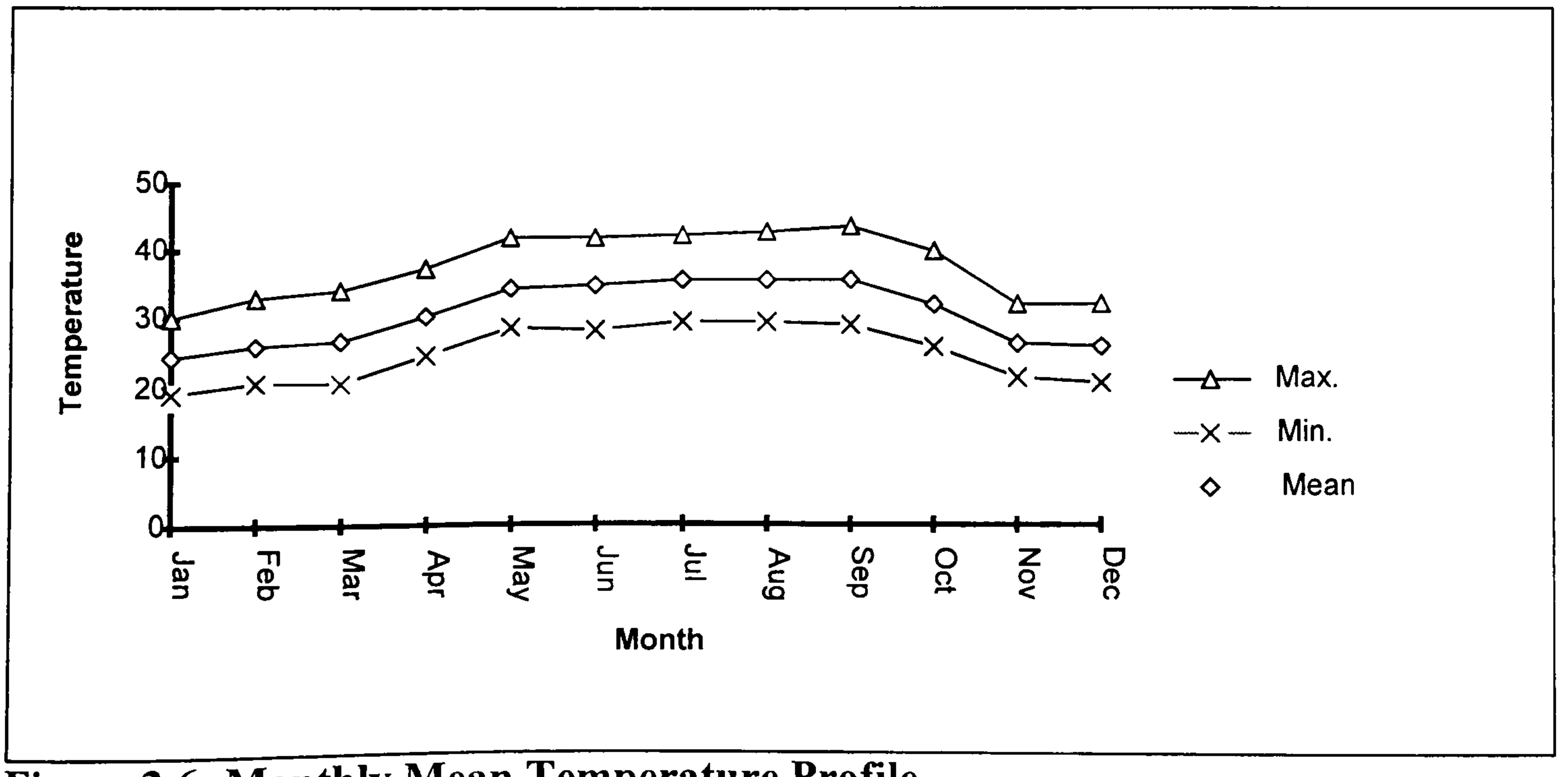


Figure 3.6: Monthly Mean Temperature Profile

3.4.5 Humidity

Atmospheric humidity refers to the water vapour content of atmosphere gained as a result of evaporation from exposed water surfaces and moist ground (Geiber, 1975). Air can carry water in the form of vapour; this capacity is a function of air temperatures differ. The hotter the temperature are, the more water can be held.

In hot arid climates a low relative humidity, the term used to express the moisture content of the air, is commonly noticed all around the year and in summer in particular. This factor has its effect on building fabric and on the rate of evaporation from the human body, the natural cooling system. Extremely hot humid weather is totally uncomfortable, because it considerably reduces the evaporation rate from the human body. However, the low relative humidity found in hot arid climates promotes the evaporative cooling strategy and lowers the temperature by a few degrees (Markus, 1980).

As is shown in Figure 3.7, the mean relative humidity profile in Makkah is considerably low all year round, especially in the summer months.

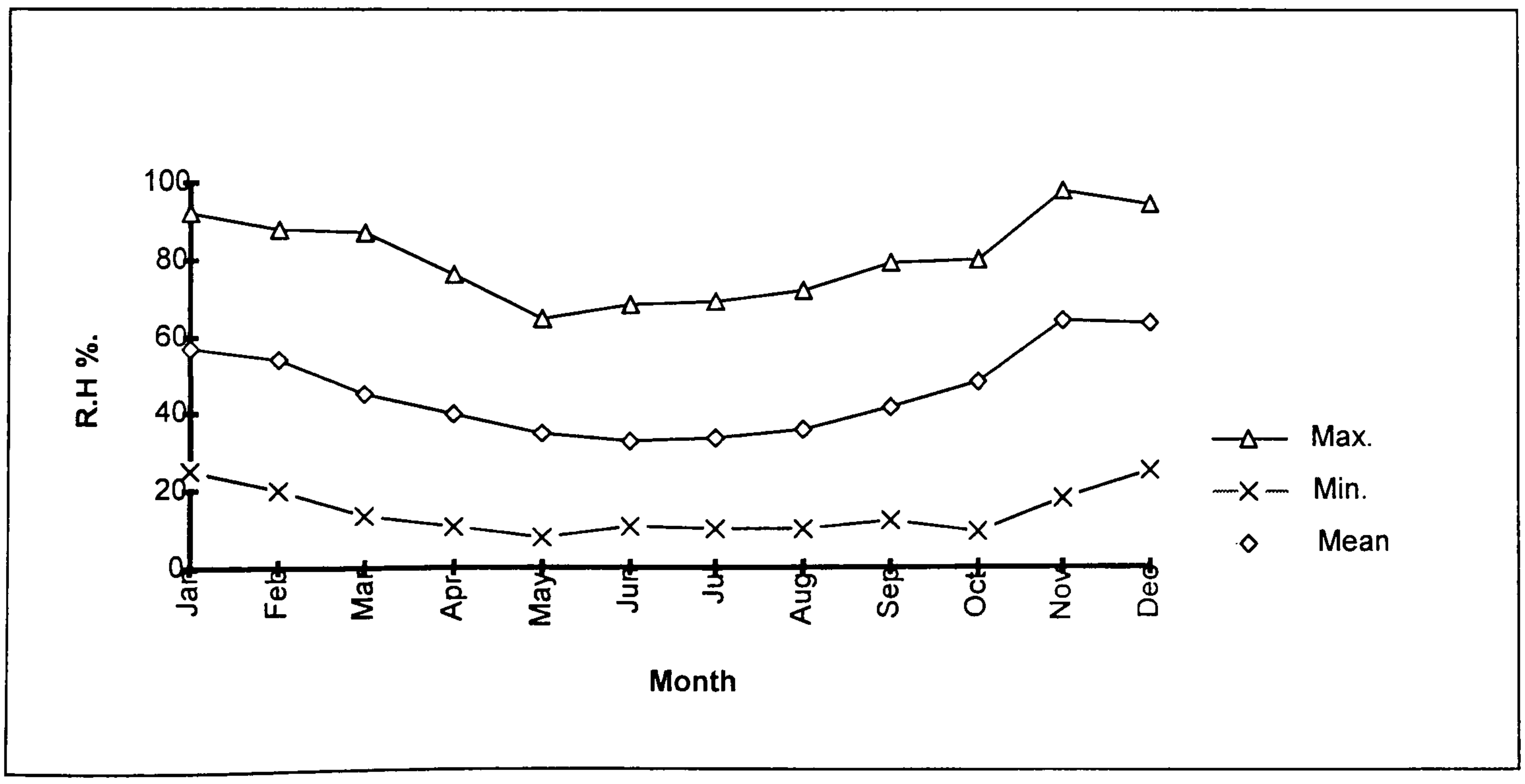


Figure 3. 7: Monthly Mean Relative Humidity

The mean R.H. values for ten months are below the line of 60%, where a R.H. of 60% is considered to be a desirable percentage for the biological evaporation system of human body as variation in R.H. between 30% and 85% are almost imperceptible and only when air is almost saturated are feelings of dampness noticeable (Jenning, 1959).

Mean values of R.H. in Makkah is low as expected in arid climate. If a comparison to be held between R.H. in Makkah and some other surrounding cities, Makkah present a transitional zone between humid coastal zone of the Red Sea and the inland dry zone in the heart of the desert.

The dryness of air can positively promote the evaporation rate from the human body if the surroundings are furnished with appropriate humidification devices. Furthermore, a reduction of 6°C can be achieved in ambient temperature if a suitable addition of moisture to dry air is introduced (Saini, 1980).

3.4.6 Wind

The important characteristics of wind are direction, speed, storming, and frequency of calms, properties which are unstable and fluctuate greatly in a very short time. Wind speed and direction are the two factors which can be assessed for climate analysis. There are many atmospheric phenomena behind the distribution and the other characteristics of wind, but the major determinants are differences in atmospheric pressure, the rotation of the earth, the daily variation in heating and cooling of land and sea, and surface topography.

The nature of topography affects wind velocity in association with the height of the wind above the ground; the higher the altitude the greater is the speed of the wind; this relationship is called the wind velocity gradient.

Windy climates create a difference in pressure between the inside and the outside of a building. These differences can affect the ventilation system and also affect the rate of infiltration. They may force air to enter buildings from the windward pressure side, or exit the building from the leeward pressure side , the suction side , through openings of various kinds, whether features of building design or cracks, holes, and gaps. Such gaps. Such uncontrolled air flow in and out of buildings can cause heat loss or heat gain, and hence negate the effect of any mechanical treatment that may be in operation. The topography of Makkah forms a protective shield against wind, since the city is surrounded by mountains. The velocity of wind is low (between 2 m/s – 4 m/s) and can be characterized by calmness all over the year. March and April have relatively the highest speed of more the 4 m/s, while the other months have a wind speed under 4 m/s. These values do not have much influence as far as building design is concerned. However, they affect the ambient air temperature by holding it steady, and also reduce the rate of evaporation, which is totally dependent on wind speed. The prevailing wind usually blows from the northeast, south east, and south west (Figure 3.8).

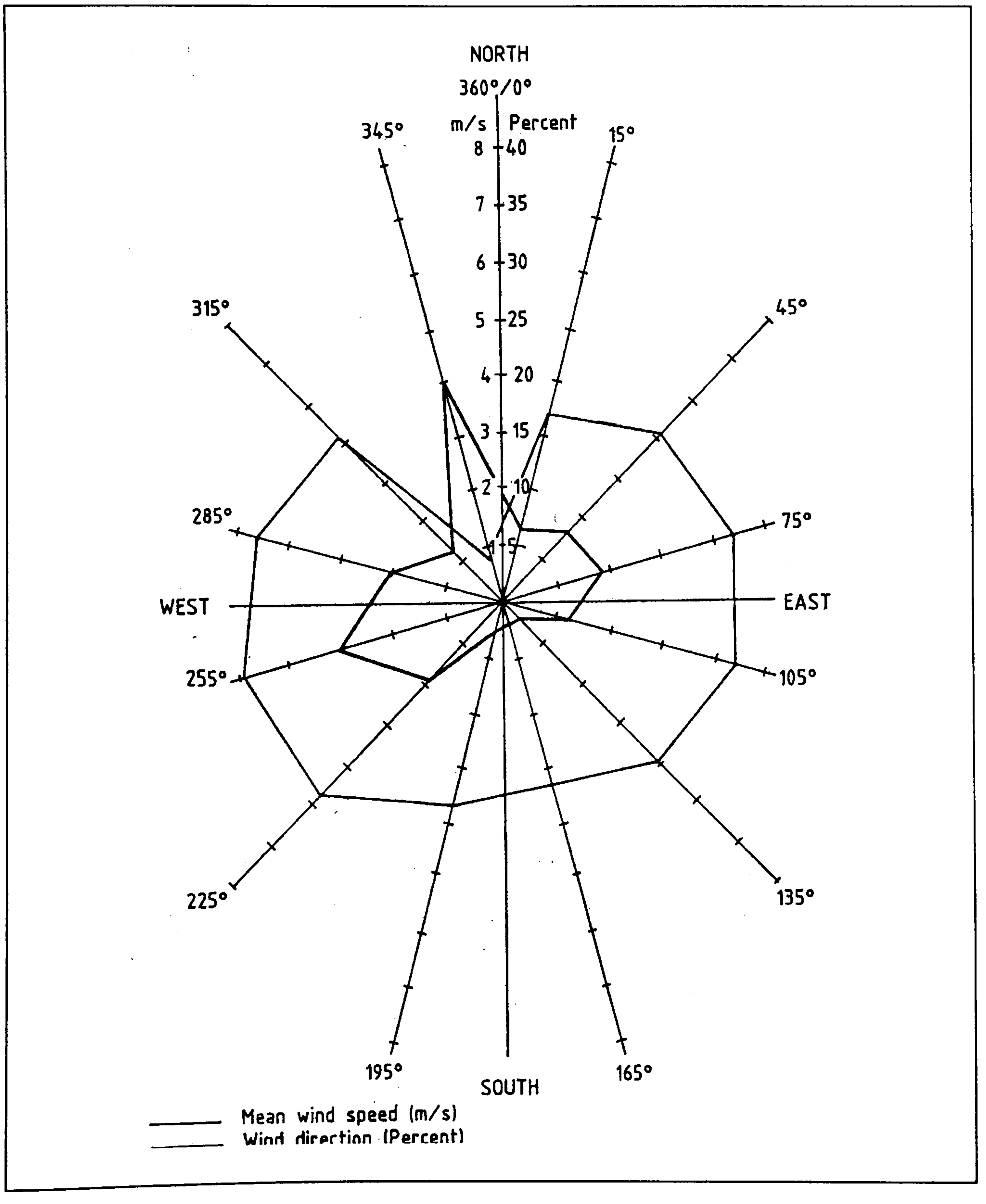


Figure 3. 8: Prevailing Wind Profile. Source: KACST, 1986.

3.4.7 Precipitation

The process of cloud formulation is a result of the evaporation released from water surfaces on the ground. Condensation develops inside these clouds due to changes in temperature. When clouds reach saturation point, where no more moisture can be held, the release of their contents comes in the form of countless drops of rain, snow, sleet, and hail.

In the hot arid climate of Makkah precipitation on a regular basis is almost non-existent. Figure 3.9 shows that, compared to other months, November witnesses an unusual amount of stormy rain; the rain level measured in this month is about 156mm, as opposed to the months of January, May, September, and December, where the rain level is about 15-18mm. The precipitation for the other months is too small to be mentioned.

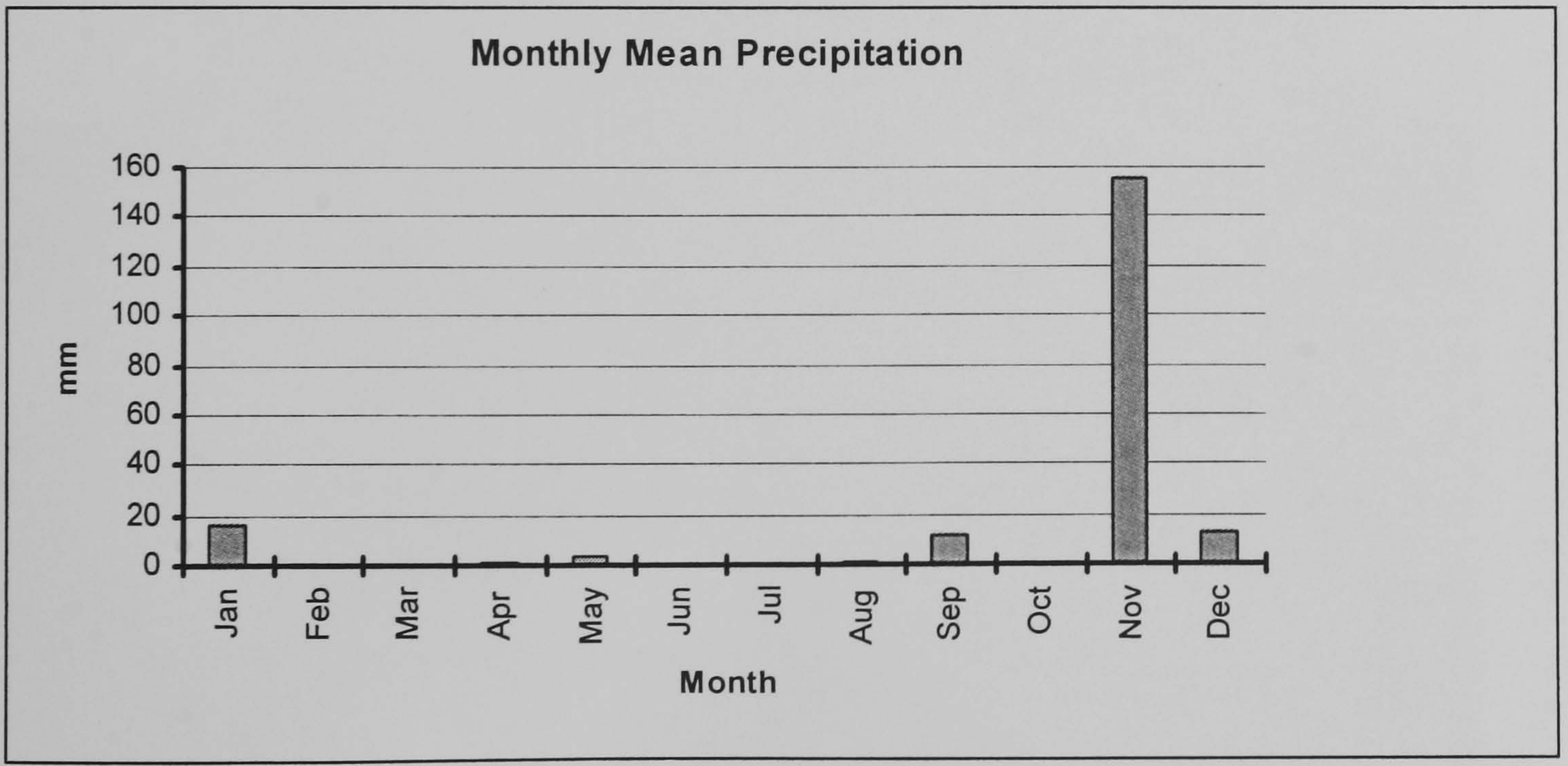


Figure 3.9: Mean Monthly Precipitation Profile

3.4.8 Cooling, Comfort and Overheating Periods

According to the classification of the common climatical theories developed by Martin, Quin, and Thornthwaite, Makkah has been classified as a real desert climate

(Ahmad, 1992). This type of climate, mentioned earlier, is characterized by dryness and shortage of rains accompanied with high temperature and low relative humidity. Suliman (1992) has classified the year, climatically, into three major periods; cold period, comfort period, and hot period.

The cold period, according to Suliman, is limited by only 4% from the year. Cold is a relative definition in comparison with the actual meaning of the term as may experience by another climate regions, for example Europe or Canada.

Comfort period is limited by 20% from the year and the hot overheating period is represented by 76% (Figure 3.10). This infers that more than two thirds of the year falls in hot period where the need to cope with this situation, architecturally, is overwhelming.

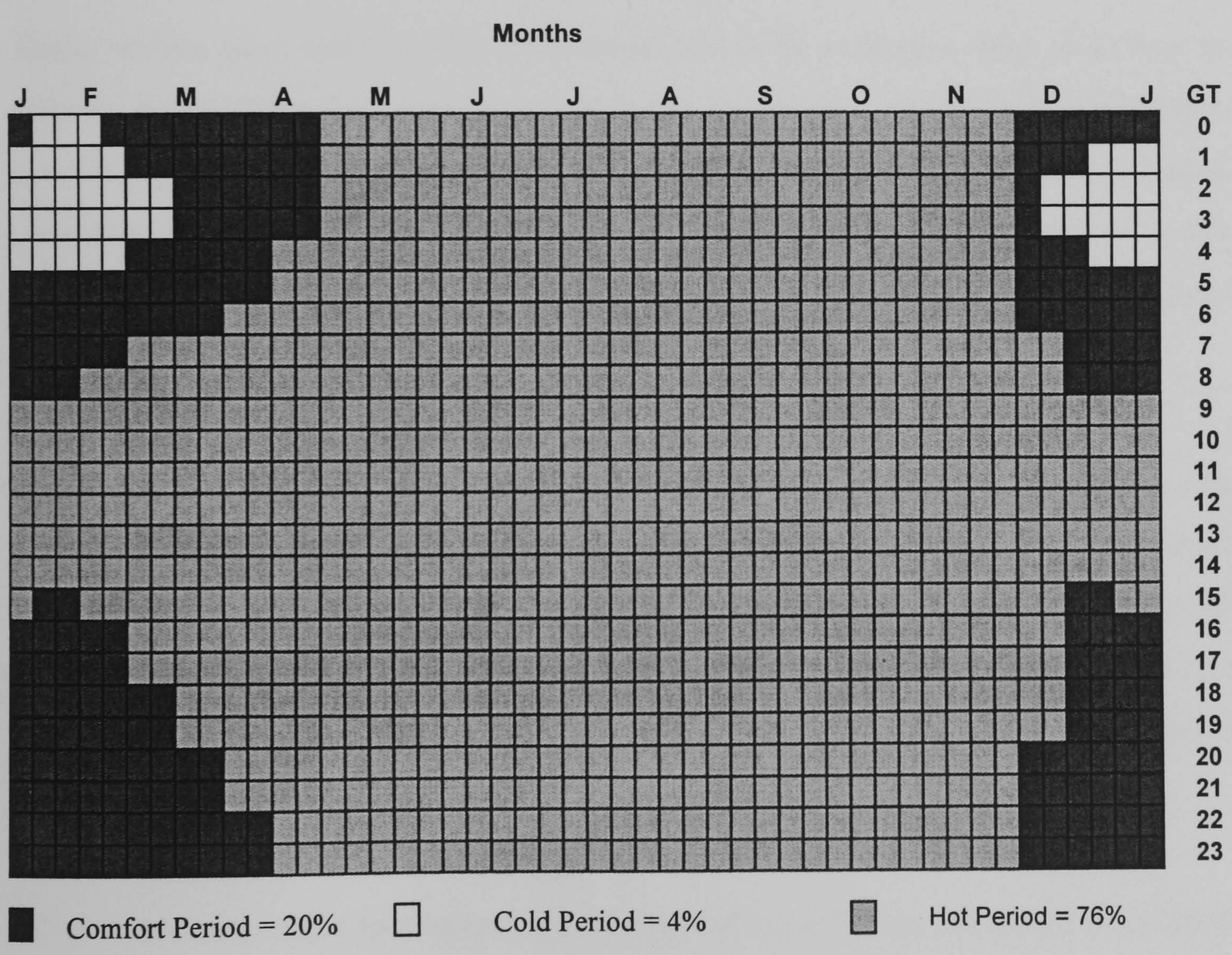


Figure 3.10: Isopleth Chart for Makkah. Source: Suliman, B. 1992.

3.5 Thermal Comfort and Bio-climatic Analysis

3.5.1 Introduction

The concept of thermal comfort has been developed to apply to the degree of satisfaction that human beings find in the thermal environment. It is generally agreed that intellectual, manual, and perceptual performance are maximised when the environment can be described as comfortable. Since thermal comfort is the purpose of most heating and air-conditioning systems, many studies have been conducted into it over the last fifty years, and appear in the literature. This extensive research has generally been in the form of field studies, and thousands of observations have been made in a wide range of climates, from very cold to very hot.

These studies have been in the main concerned with seeking a way of giving an account of the thermal environment which can be correlated with human response, and with stating clearly the range of conditions acceptable to the population concerned (Humphreys, 1977). The results of these studies have been treated statistically and generally the most appropriate ambient temperature for the group under observation has been established.

An essential feature in this exploration of thermal comfort is the realisation that subjective factors, on the part of those studied, play a part in evaluating the degree of comfort. Nevertheless as high a degree of objectivity as possible must be the target of measuring and assessment techniques, so that a reliable empirical account of response to the thermal environment may be produced in order to facilitate the prediction of thermal comfort.

Efforts have been made to measure the empirical factors that are important to defining comfort, however, it is difficult to generalise field study results into thermal comfort and to apply these to conditions other than those in which they were generated.

The concept of thermal comfort is dates back to the 1920's with ASHRAE's efforts to provide the design engineer with technical information necessary for a successful air-conditioning design and with a guidelines for establishing the proper conditions necessary for thermal comfort. In 1922 the first comfort chart has been published by ASHRAE followed with the code of minimum requirements for comfort air-conditioning (published in 1938), and then Standard 55-66 has been introduced in 1966 for thermal comfort conditions.

This standards has been developed for architects and engineers to control air-conditioning systems and other factors that affect indoor thermal comfort. Standard 55-66 has defined thermal comfort as 'that condition of mind [rather than the body] which expresses satisfaction with the thermal environment' (Nevins and McNall, 1972).

Ever since, huge amount of field and laboratory experiments have been carried out in this field. One of the most recognised piece of work in this field is the classic work of Olaf Fanger in 1973. Fanger has developed a heat balance equation that can predict thermal comfort with regards to physical parameters of the human body. Comfort and discomfort levels are dependant on how far this equation is satisfied in a particular environment.

Followed this work, many researches have either been developing or criticising the equation. Moreover, The recent researches on this subject tends to localise the issue in order to establish a base line for thermal comfort in certain localities. Auliciems (1997) recognised the correlation of psychological response and physiological activity and proposed the following definition of thermal comfort: "Thermal comfort in the mental state achieved when (1) physiologically the thermoregulatory mechanisms are minimally activated, and (2) psychologically the perceiver is satisfied with the thermal environment" (pp. 14-15). Auliciems, also, accepts that thermal comfort is a mental, not a physical state.

The issue of thermal comfort has been vital to the development of the HAVC system in building industry but it is still a complicated subject to understand. The aim of creating thermal comfort has a major impact on the construction of buildings, affecting not just design but choice of materials and location. Indeed Fnager states: Viewed in a wider perspective, it can perhaps even be maintained that man's dependence on thermal surroundings is the main reason for building houses at all, at least in the form in which we know them today (Fanger, 1973, p. 14).

3.5.2 Human Requirements for Thermal Comfort

It has been inferred that a widely accepted definition of thermal comfort stresses the psychological response to thermal conditions (the 'condition of the mind') rather than physical features of an environment or even the human physiological state. Nevertheless it is apparent that, despite the fact that thermal comfort in the final analysis is a psychological rather than a physical condition, the state of the physical environment is clearly a major determining factor in the condition of the mind in relation to thermal comfort. Further, the environment can be relatively readily measured and, at least indoors, controlled.

Generally speaking, to achieve physiological thermal comfort in hot arid regions, buildings must address extreme summer conditions. Winter space heating loads are low and can be readily met using appropriate planning orientation but summer cooling loads present a much greater challenge to the bio-climatic designer.

In the context of human reaction to the thermal environment, we must guard against confusing what we may call thermal balance (or thermal equilibrium) with thermal comfort, as thermal balance may be controlled by the activation of thermoregulatory mechanisms.

The human thermal comfort zone is subject to complex parametric relationships. Equations by MacFarlane (1978) from Fanger assume that during rest or exercise, comfort is associated with thermal equilibrium, and with a mean skin temperature of 33°C. But field studies emphasise the fact that the heat equation approach to comfort such as that of Fanger, does not adequately cope with acclimatisation and the time sequence of changes that takes place in people living in hot cold regions.

Humphreys (1975) has analysed many of the completed questionnaire studies of comfort, and found the face value of comfort zones ranged from 17°C in England to 30°C in Iraq and India. This variation of comfort level is attributed to the following factors:

- Physiological Response
- Behavioural Response and adaptation
- Habituation
- Acclimatisation

These factors influence the comfort sensation significantly, as they deal with people of different environmental backgrounds

3.5.2.1 Physiological Responses

The physiology of temperature regulation which involves the subjective sensation of warmth or coldness, the feeling of discomforts, and the impression of unpleasantness is controlled by temperature-sensitive nerve cells. These cells respond to the temperature of the blood, and in the preoptic area of the brain, the rate of firing of neurons changes with temperature. Some cells fire more rapidly when it is cold than when the brain is heated. Activity of the cold-sensitive neurons lead to shivering and vasoconstriction and that of heat sensitive nerve cells to sweating and vasodilation.

It should not be overlooked that, although feeling cold and hot implies the existence of sensing mechanisms, the state of the mind in expressing dissatisfaction with the environment is definitely associated with the physiological changes that take place in response to the environment

Wyon (1980), adapted a comfort relationship with thermal environment by expressing task performance by arousal level as a function of ambient temperature. i.e. people tend to be soporific at high temperature and alert at lower temperature. The theory is that, for every activity there is an appropriate level of arousal, levels above or below tends to depress performance.

Wyon's chart in Figure 3.11 expresses this relationship, with a comfort span between 18^{0}C at the lower level and 27°C at upper level, Sensation of heat discomfort starts beyond the upper level and cold discomfort starts below the lower level.

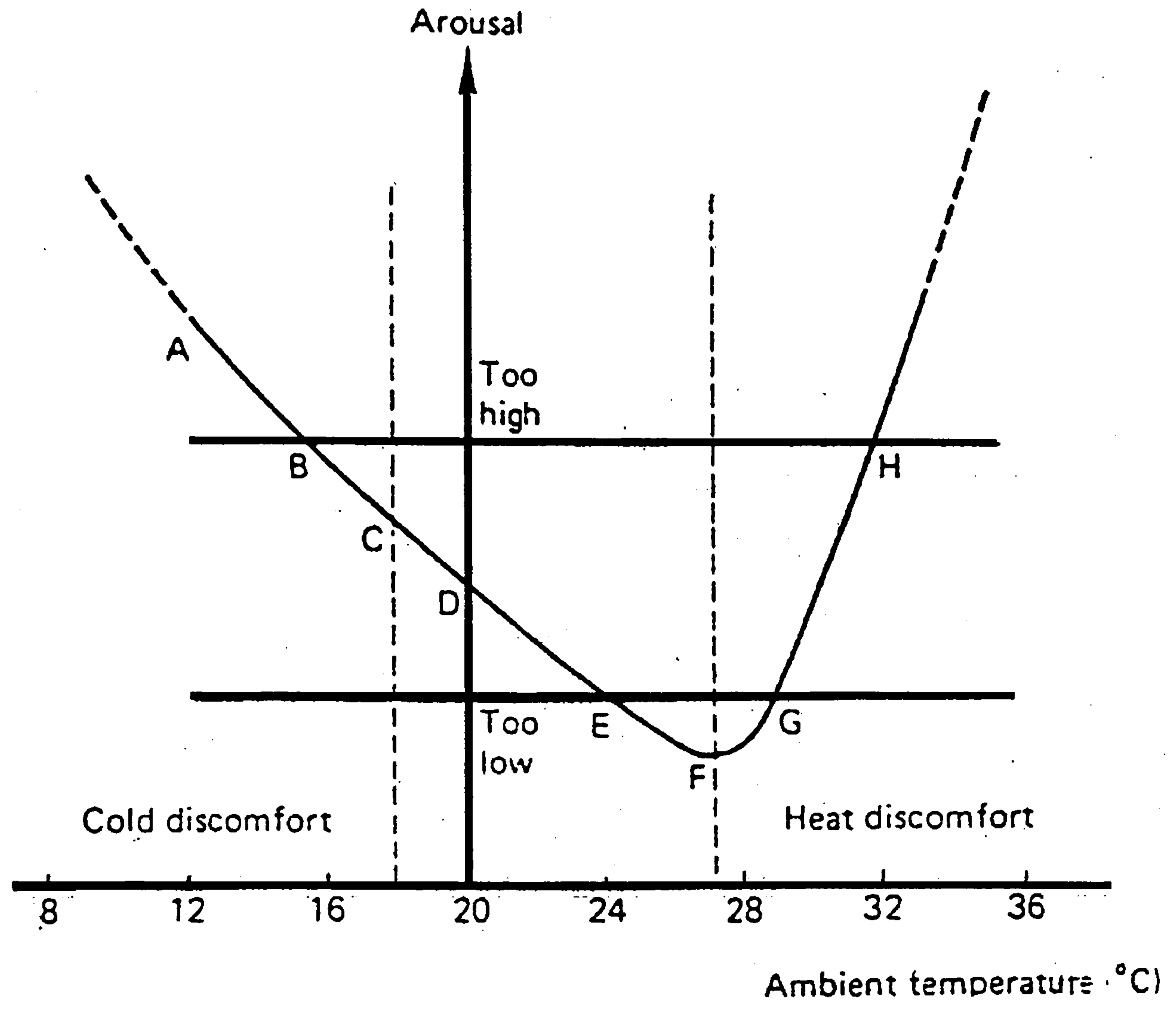


Figure 3.11: Wyons' Comfort Scale. Source: Markus and Morris, 1980.

3.5.2.2 Behavioural Responses and Adaptation

The long-term behavioural characteristic due to exposure to hot ambient conditions is another natural response for humankind. In addition to physiological changes to meet heat stress, there an obvious need to make some behavioural adaptation in the routine of daily activities.

Taking a prolonged rest at midday and delaying some demanding activities until evening are matters of course in hot climates, taking off clothing, drinking to compensate for sweat loss, moving from sun to shade, and turning on air conditioning plants, are different forms of behavioural responses. Such behavioural adjustment may differ from one person to another or from one nation to another due to a process known as habituation.

3.5.2.3 Habituation

According to Macfarlane the habituation effect on comfort perception arises from repeated exposure of the nervous system to stimuli and thus reduction of central neuronal response.

The frequency of firing from skin receptors for heat does not decrease in habituation, but the amount of information passing through the spinal cord into the brain is reduced significantly. For example Giles (1889) noted that, during hot desert nights, he as an Englishman was unable to sleep because of the heat, yet the Aboriginal slept soundly through the night on the hard substrate, exposed to same hot environment.

The question arises whether this phenomenon is due to habituation, which might be construed, as 'mind over matter" in a particular context: or is it due to physiological changes embraced by the term "acclimatisation".

3.5.2.4 Acclimatisation

Regular exposure to heat also improves tolerance in that automatic physiological responses reveal reduced strain. The lungs are less active, the skin more so and circulation lessens. The ability to adapt upon transition from one temperature zone to another is called acclimatisation. Kamon (1978) infers that acclimatisation alters the habituation system and modifies it to cope with new environmental circumstances. Europeans going to live in the tropics, habituate to the temperature so that after 2 or 3 years exposure they accept environment, that were initially difficult and unpleasant, and the converse hold true, for people from tropics going to live in cold climate.

Habituation and acclimatisation may be influenced by several factors that significantly alter tolerance level, which could be more dominant than thermal comfort, in other words people aspire to a tolerable environment rather than a conformable one, depending on socio-occupational and climatic circumstances. Thus the factors differ as different groups of people experience different life styles and are subjected to different environmental situations.

For example, outdoor manual workers in direct exposure to the climate, will tolerate greater temperature extremes than indoor white collar workers in air conditioned space, even allowing for clothing and metabolic differentials.

Tolerance is then subjected to economical parameters, whereby people of low income will tolerate relatively high temperatures since they cannot pay for an air conditioning system and its energy cost. On the other hand, more prosperous people will find it essential to condition their, indoor living spaces, to a such lower comfort level.

The acclimatisation process has long been acknowledged in the sense of climate and thermal comfort, but not in health influence. For example, Parkes in 1878 pointed out that there is no acclimatisation in any sense of the word for malaria, and recommended to discontinue use of the term acclimatisation which has several meanings in favour of 'accommodation'. Hence, it is difficult to determine the comfort zone precisely, but generally speaking the human comfort zone in the desert climate is somewhat different from the other climatic zones.

The margin of permissible condition for comfort in hot climate is generally set higher than other climate zones by two or three degrees. The summer comfort zone range given by Kamon is 26°C to 30°C, on other hand during the cooler months the comfort temperature rises to 20-21°C for acclimatised people at rest or engaged in sedentary activity.

Bearable interior climate, and less heat stress can be achieved during the hottest period with careful handling of building planning, design, and construction details.

3.5.3 Parameters Affecting Thermal Comfort

From the studies discussed above and from other work done in the area, six main environmental determinants of human comfort have been identified in the literature. These are: air temperature, mean radiant temperature, humidity, air velocity, all of which can be controlled to some extent by human beings but are essentially natural phenomena, and the two factors which can only be controlled by man, clothing and activity level (or metabolic rate as it is described in some studies).

3.5.3.1 Air Temperature

The dry bulb temperature of the air is the most straightforward measure of heat or cold in ordinary indoor conditions, though its use as a single indicator of thermal comfort is limited, for example when sweating or when high-power radiant sources are present. The measurement of air temperature is relatively simple providing the effects of thermal radiation between the sensor and surrounding surfaces are eliminated, which is the case with standard thermometers and other measuring devices.

As far as air temperature effects on the body are concerned, the temperature of the air must be lower than that of the skin if heat is to be lost by convection. When air temperature increases the difference between it and the temperature of the skin lessens, as does the dissipation of heat by convection. When air temperature is greater than the temperature of the skin there is heat gain rather than heat loss through convection, though this may be countered by cooling through evaporation if the air velocity is sufficiently high.

3.5.3.2 Mean Radiant Temperature

The mean radiant temperature at any specific point is a function related to the temperatures of all surface areas viewed from that point. In a context of thermal comfort it correlates with the shape and surface radiative characteristics of the human body with respect to surrounding surfaces.

For thermal comfort to be maintained in high ambient air temperatures a lower radiant temperature is required, while at low surrounding air temperatures the radiant temperature has to be high to maintain comfort. In practice there would, however, be relatively few situations where there was a wide difference between air temperature and mean radiant temperature without considerable loss of comfort.

3.5.3.3 Humidity

Humidity is the proportion of water vapour present in the air, and is most commonly measured by a combination the wet and dry bulb thermometer. Extremes of humidity, whether low or high, will cause discomfort for human beings. The feeling of dampness in high humidity and the feeling of dryness, particularly orally or in the upper respiratory tract, that is characteristic of low humidity are obvious examples of discomfort. It is generally accepted that such discomfort is unlikely to occur within the range 20% to 80% relative humidity.

3.5.3.4 Air Velocity

Air movement is important for thermal comfort, as heat and moisture have to be carried away from the body in order to prevent the build up of a surrounding layer of stagnant and moist air. The air velocity around an individual commonly is determined by the combination of free convective flows and forced air movement, the surface boundary layers being generally turbulent.

Air velocity affects the body by determining the convective heat exchange of the body and also the rate of surface evaporation and thus the evaporative heat loss from the body.

When the air temperature is below skin temperature, then any increase in air speed will increase heat loss from the body, and in extremes this may be felt as wind-chill. When the temperature is hotter than skin temperature, however, increases in air velocity will have two contrasting effects: one will be the tendency to increase an individual's body temperature through convective heat gain from the environment, but the other will be to increase the evaporation rate, thus tending to cool body temperature. Under such circumstances there is in fact an optimum air velocity, below which the evaporative cooling is inhibited and above which convective heat gain exceeds evaporative cooling.

3.5.3.5 Clothing

The level of clothing has an obvious effect on the level of thermal comfort. It forms a barrier to the convective and radiative transfer of heat and to the transfer of moisture, in the form of sweat evaporation, between the surface of the skin and the environment. In studies on thermal comfort, the unit the 'clo', indicating the thermal insulative capacity of clothing is used (Gagge, 1941). The standard clo unit represents approximately the thermal resistance of a lounge suit worn with normal underwear. The higher the clo value the greater the thermal insulating effect of clothes worn, and the greater the tolerance of the individual thus clothed to low temperatures.

As far as the relation of clothing level to environment is concerned, studies suggest that people find it easier to function lightly clothed in a comfortable environment than heavily clothed in a cool environment (Humphreys, 1977).

Indeed in this context it might be noted that the temperature regarded as most conducive to thermal comfort has risen by about 5°C in the last hundred years, which may well be related to the tendency to favour lighter indoor clothing as well as other life-style factors.

3.5.3.6 Activity

The final environmental determinant of human comfort identified by studies is the level of activity. The body's metabolic rate (the energy released by the oxidation processes) is mainly related to the level of physical energy. With an increase in the metabolic rate more oxygen is needed by the muscles and greater amounts of heat are transferred through the skin into the environment.

The main research done in relation to these six parameters has been carried out by Fanger (1973). His main concern was to characterise human comfort in terms of the state and reactions of the body rather than those of the surrounding conditions. Thus, for example, skin temperature and not air temperature was the ultimate defining factor. Fanger's three requirements for thermal comfort are:

- The body should be in thermal balance such that its heat loss rate to the environment is equal to its rate of heat production.
- Mean skin temperature should be comfortable.
- The rate of sweating should not be uncomfortable.

The two latter requirements are necessary because thermal balance might be achieved by physiological processes but in a way that is uncomfortable. By taking account of all the heat transfer routes related to the body a heat balance equation can be attained, and if this equation is not satisfied then, according to Fanger, discomfort results.

Fanger's comfort model has produced two major comfort indices known as Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). The first index predict the degree of discomfort and the second index predict the percentage of people who will experience discomfort for any combination of the comfort parameters that measured in practice. The PMV index is a seven point scale based on ASHARE seven point scale for psycho-physical thermal sensation and these points can be listed as follows;

-3	Cold
-2	Cool
-1	Slightly Cool
0	Neutral
+1	Slightly warm
+2	Warm
+3	Hot

the PMV gives the predicted mean vote for a large group of people exposed to the same environmental circumstances. It measures the degree of discomfort in term of thermal load that each person may experienced under the given environment and then, establish a relationship between the predicted vote and the load on the above mentioned scale. The PMV is an expression for general degree of discomfort for the group under investigation as a whole, but the difficulty lay on how to interpret the magnitude of PMV in a practical case. A relationship between PPD and PMV has been established and Fanger found that for a mean vote of zero, PPD is 5%. At this point, the optimal comfort condition is represented. He concluded that in practice, the number of dissatisfied should not be more than half as large as the minimum value, i.e. for PPD = 10%, the correspondent PMV value is = ± 0.5 which means that only 10% of people are uncomfortable but 80% are comfortable and this means that the comfort situation is prevailed (Figure 3.12).

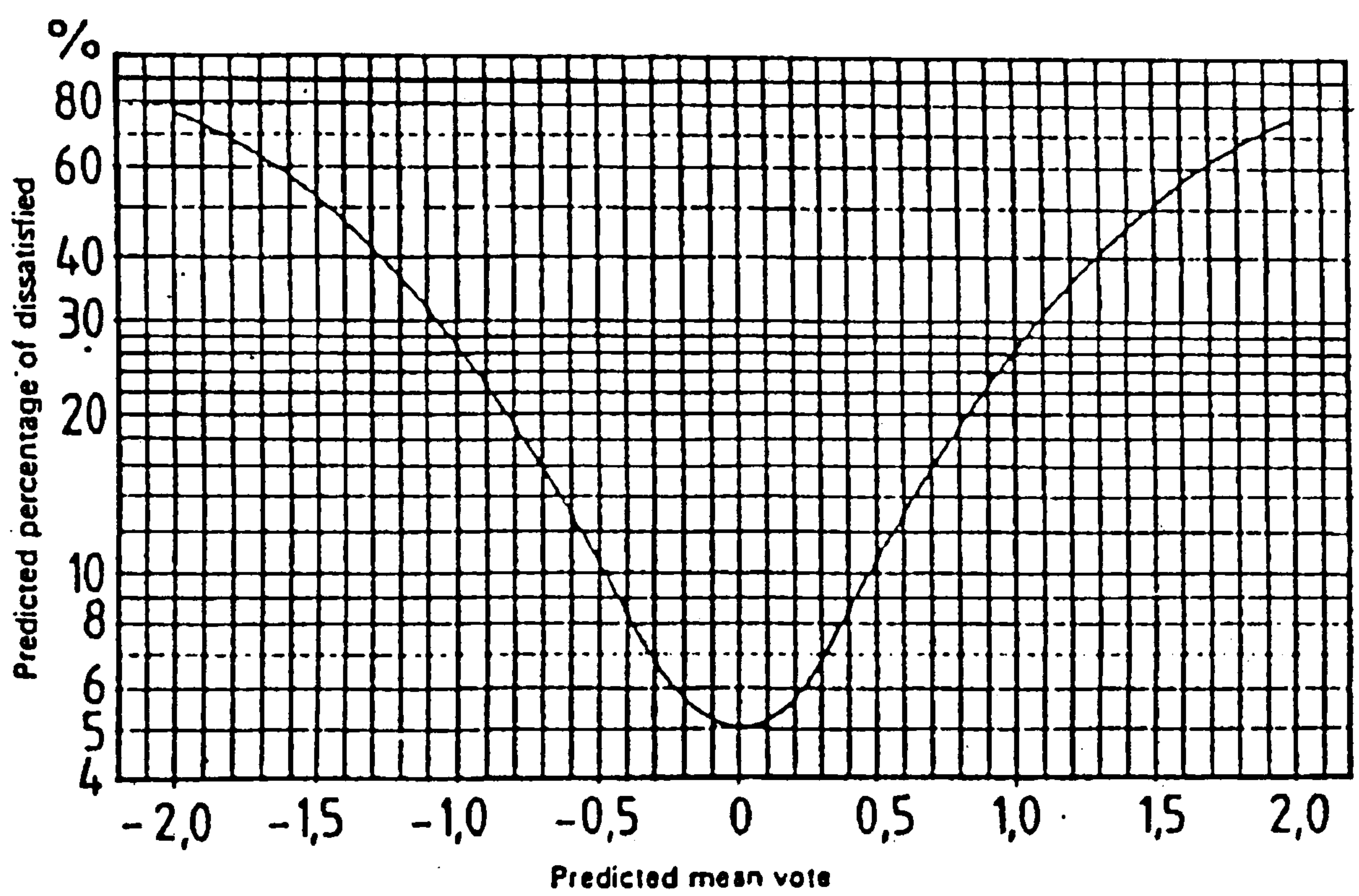


Figure 3.12: Fanger's Thermal Comfort Indices the PMV and the PPD. Source: Fanger, P.O., 1970.

Fanger's work has been criticised, however, on the grounds that his studies were undertaken on individuals who are not representative of people in general, and that the conditions under which they were carried out were untypical. Other researchers, such as Griffiths, found that Fanger's predicted desired temperatures for houses and for offices were several degrees too high (Newsham, 1990). Others have questioned Fanger's position that skin temperature is a better thermal comfort indicator than ambient air temperature, and results from many field studies indicate that variations in air and mean radiant temperature are more closely related than Fanger's work suggests to human thermal comfort response (Humphreys, 1975).

Besides the main determinants discussed above, various other parameters have been identified as affecting thermal comfort. Factors such as age, weight, height, and sex are also important, and indeed these affect metabolism. Thus conditions that a youngish man might find comfortable would not be so acceptable to an elderly woman (Hoppe, 1988)

Other features of the indoor environment which are important for comfort include the quality of light, the level of noise, the furnishings provided, and the décor. These, however, are general environmental matters and not in themselves related to thermal comfort.

The parameters affecting thermal comfort, discussed above, have to be taken into account by all those involved in the design and construction of buildings. It is easy to assume that the building envelope has as its primary purpose to provide shelter from unpleasant climatic conditions such as wind, rain, and strong sunlight. However, studies have shown that to provide the optimum environment, whether for relaxing or working, other factors have to be taken into consideration.

Though the thermal comfort response may in the last analysis be an individual psychological response, there is sufficient research to indicate that responses in broad general terms are similar between individuals, as indeed might be expected when it is appreciated that the response determinants are to a large extent common human physiological features.

Reliable measurement instruments and techniques are now available in relation to the indoor climatic environment, as are indeed the technologies to provide adequate construction, air control, and heat control devices. Perhaps because of this, it is sometimes assumed that a straightforward simple heating system or air-conditioning system is sufficient to deliver adequate thermal comfort. What we have seen from the literature, however, is that the situation is more complex than this. While it may be true that temperature regulation is the biggest single factor in determining thermal comfort, local thermal discomfort may occur within, for example, an office building, due perhaps to the proximity of hot or cool surfaces.

3.5.4 Thermal Comfort Condition in Makkah's Climate

The bio-climate and environmental studies of Makkah city have been very few if not rare. This is may referred to the lack of interest, knowledge and the shortage in specialist that can carry out such researches. The only study of bio-climate analysis of Makkah has been curried out by Suliman (1992). Olgyay bio-climatic approach has been followed in this research in order to identify the climate characteristics with relation to thermal comfort inside buildings environment.

Suliman stated that the average dry bulb temperature and the R.H. for Makkah, the two factors which usually lay the base for the bio-climate analysis, range from 20°C to 43°C and from 23% to 75% respectively. The comfort zone adopted in this study ranges between 22°C to 27°C and R.H ranges from 15% to 50%. The bio-climate of Makkah city is fallen outside the upper limit of the comfort boundaries for most of the year time. With regards to comfort zones, there is no studies have been carried out on this subject and for this area in particular. However, many investigations have been done in hot-dry region with similar climate circumstance as in Makkah.

Koenigsberger (1974) has defined the comfort zone in hot-arid region as lower limit (22 °C), optimum (25°C), and upper limit (27 °C). Drysdale reported that the optimum air temperature needed to achieve comfort is about 23.7 °C and the maximum air temperature defining the upper limit is 28.9 °C for subjects from Australia. Another study which has been curried out in Sydney by MacPherson observed that 80% of the subjects under investigation were comfortable at a dry-bulb temperature of 22.5 °C. however, 50% of the subjects reported that the lower and the upper limits of the comfort zone is defined by 19°C and 27°C dry-bulb temperature respectively. Roa, Ambler, and Grocott have reached to conclusion that the optimum comfort temperature is represented by 26°C. Fanger reported that the preferred temperature predicted by the comfort equation that he had developed was around 25.6°C, he concluded with reasonable accuracy, that this would apply to those living in tropical regions.

Regardless the findings of these studies, generalization of these results is a critical task to be decided and should only be taken as guide. The discussion that carried out earlier in this chapter informed that human comfort is a very complex factor that can not be precisely predicted or calculated . Moreover, it is the state of mind and the psychology of human being which have the great influence on the feeling of comfort or discomfort beside the habituation and the acclimatization factors, discussed earlier, that make the disagreement between the subjects inevitable.

Following Givonis' bio-climatic approach, Makkah bio-climatic analysis is illustrated in Figure 3.12. Average readings of dry bulb temperature and R.H. is plotted on the modified bio-climatic chart. This chart has been introduced by Givoni based on the original work of Olgyay whereas an important extension has been made. The new chart is called " Building Bio-Climatic Chart" and limits of climate control strategies have been plotted on a standard psychosomatic chart.

The chart determined limits of effectiveness of different building practices in meeting bio-climatic comfort needs. Each strategy is delineated by an effectiveness zone which can be visualized as an extension of the comfort zone. The building bio-climatic chart indicates that whenever ambient outdoor temperature and humidity conditions fall within the designated limits of control strategy, then the interior of the building design to execute that strategy will remain, expectedly, comfortable. Seventeen zones can be read from the chart. One of these is the comfort zone, while the others indicate the relevance and appropriateness of specific climatic control strategies to achieve comfort. These zone can be read as follows:

1. Zones 1-5 represent total heating zones <20°C
2. Zones 9-17 represent total cooling zones >26°C
3. Zone 7 represent s comfort zone from 20°C to 26°C ET – 0.7 kPa to 80% RH
4. Zones 8-9, 15-16 represent dehumidification zones
5. Zones 6A, 6B, 14 represent humidification zones

According to this analysis, March, April, most of May, part of October, and November fall in zone No.11. this zone encourages the application of the passive cooling strategies, i.e. building with thick walls, use night ventilation, and evaporative cooling, in order to achieve comfort for these months. The rest of the months fall within the active cooling strategy zone where the use of A/C is a necessity for thermal comfort. However, the best results from these proposed methods can be gained in the early stage of the design. Yet, some strategies such as evaporative cooling and ventilation can be easily applied to existing buildings. Table 3.1 summarize the bio-climatic situation in Makkah according to the above discussion.

Month	Effectiveness Zone
January	5, 11
February	5, 11, 13
March	5, 7, 13, 14
April	7, 17
May	11, 17
Jun	11, 17
July	11, 17
August	11, 17
September	11, 17
October	11, 17, 7
November	5,7, 17, 13, 11
December	5, 11

Table 3. 1: Bio-climatic Analysis for Makkah Area

The bio-climate condition that characterized Makkah is manifested with reference to thermal comfort zone and other interactive zones proposed by the chart can be described as follows: April, part of March, part of October, and part of November fall in zone No.7 (the comfort zone). The rest of the year is located outside the comfort zone and distributed on the zones 10,11,12,16, and 17 (Figure 3.13). Daily temperature and relative humidity profiles is shown in Figure 3.14 for typical summer and winter days.

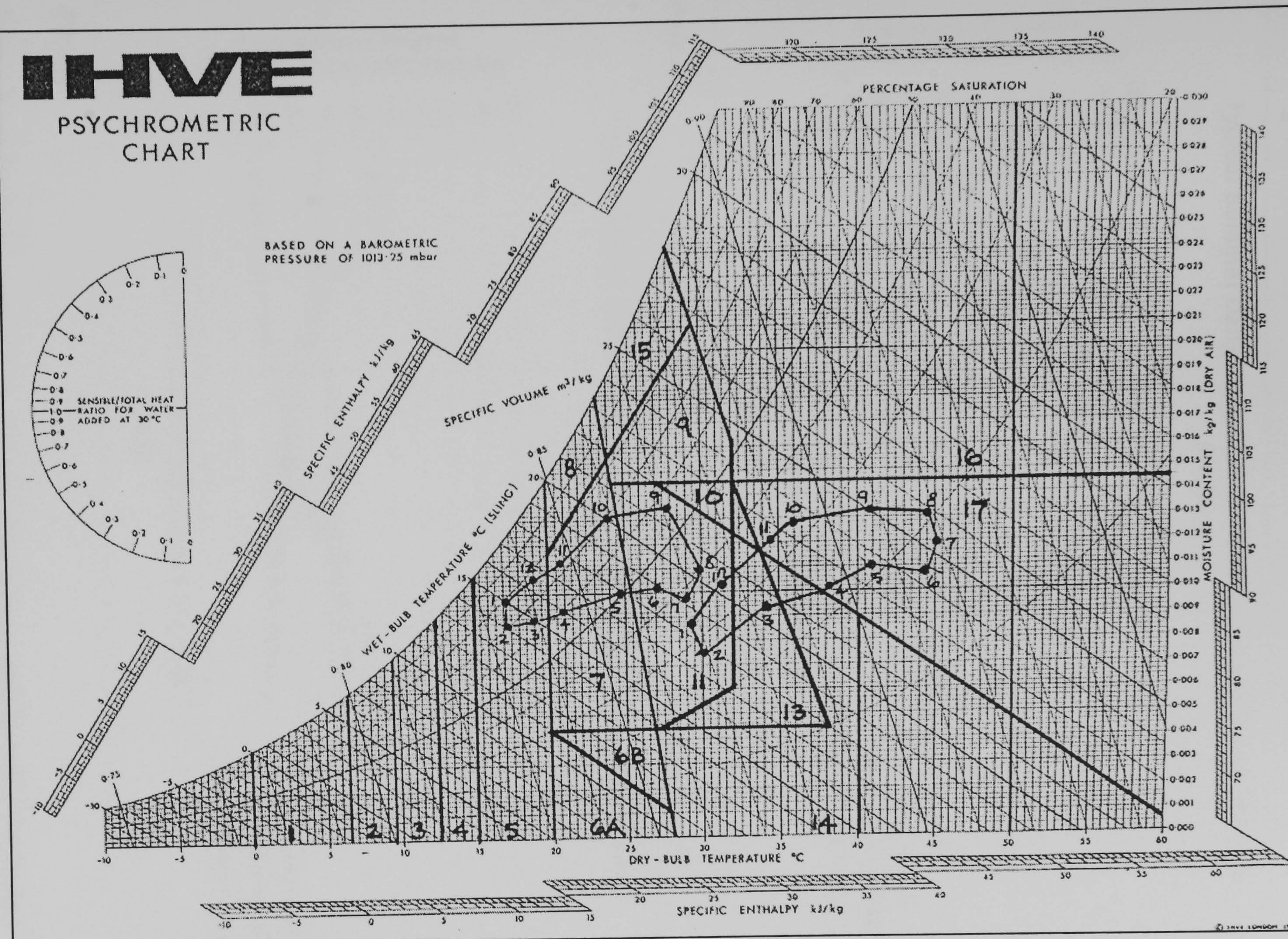
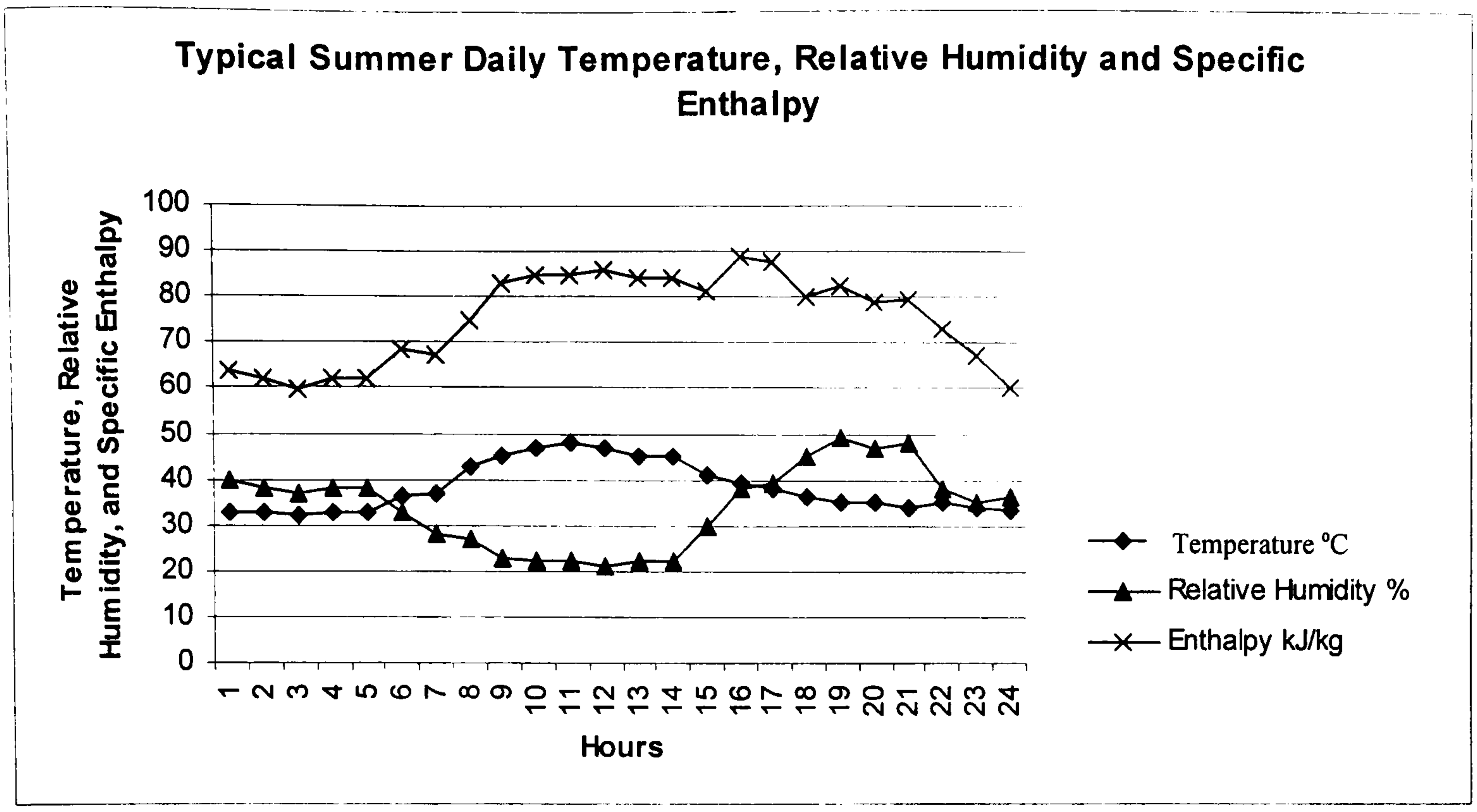
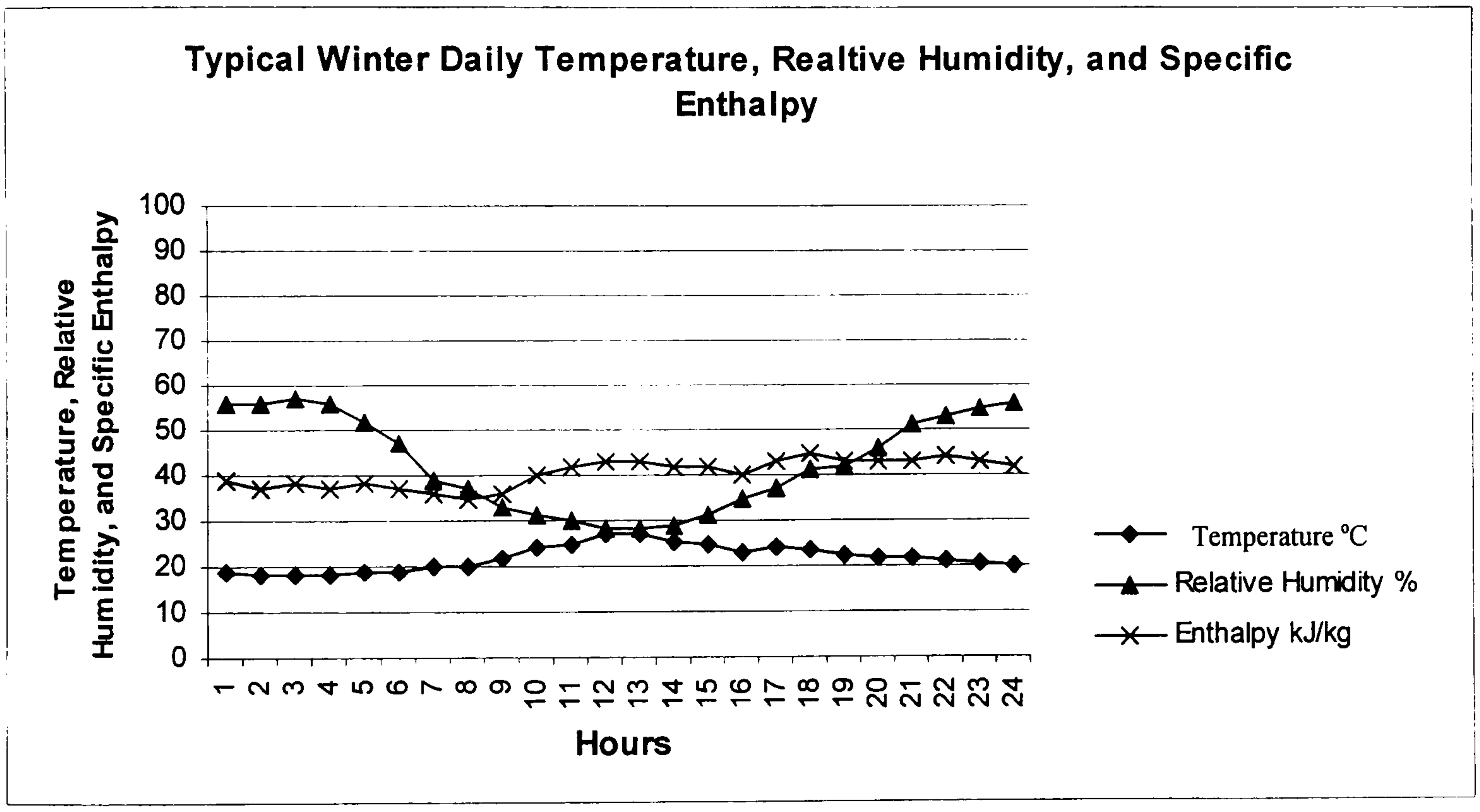


Figure 3.13:
Bio-Climatic Chart for Makkah Region



Part A



Part B

Figure 3.14: Daily Temperature, Relative Humidity, and Specific Enthalpy Profiles.

Daily temperature, relative humidity, and specific enthalpy profile for typical summer and winter days. In part A, substantial cooling load is needed to meet peak temperature (47°C) occurring around the middle of the day and also to moderate indoor temperature for the rest of the day. Part B shows a lower temperature profile. However, internal gain still represents an additional source to be considered in this period and would require little or no A/C for cooling.

Chapter 4

Built Form and Internal Environment

Chapter 4

Built Form and Internal Environment

4.1 Prologue:

In practice, unfortunately, energy and environmental issues are rarely given the attention they deserve considering their importance to the global environment and their effect on the well-being and productivity of building occupants. Early consideration for this issue in design is important to ensure that building take full account of the site and local climate. If energy and environmental issues are not adequately addressed at the very beginning of the design process, they may not be addressed at all. The detail design stage is no less critical where at this stage the consideration of this issue will be reflected on running building performance and possible environmental discomfort.

Potential benefits from incorporating the principles of low-energy buildings at design are reduction in environment pollution, improvement in occupant comfort levels, and reduction in capital and running costs.

A key factor in the lack of attention to this issue is mainly attributed to the shortage of qualified designers, experienced energy advisers, technical information, and public awareness. These are essential factors that could guarantee successful plans for energy conservation in any society if they have been given full attention.

This chapter reviews the notion of energy efficiency in building design with relation to the environmental context and reviews all the associated strategies affecting design decisions and future performance of buildings. It also sheds some light on the principles of thermal analysis of building envelope and their associated factors that affecting the thermal quality inside the buildings.

4.2 Energy Efficiency in Buildings

4.2.1 Introduction

A clear appreciation of the main issues involved is necessary, to enhance the environmental performance of buildings. With regards to the Global environment issue, the interrelation of ozone depletion, acid rain, global warming, chlorofluorocarbons, tropical hardwoods, and so on must be understood within this context. Essential as these things are, they are of course not the only factors that should be taken into consideration when decisions about the environmental performance of buildings are made. The needs of the occupants and the type of building have to be also taken into account.

The focus of much attention in the last two decades is on the layer of ozone gas round the earth at stratosphere level, which filters out harmful ultraviolet light from the sun. As is well known, this ozone layer has suffered recent depletion through the use of the man-made chemical chlorofluorocarbon (CFC) and other agents. CFCs react with sunlight to produce chlorine, and this destroys ozone by turning it into oxygen. Further, CFCs are stable, so that once released, they remain in the atmosphere for a long time.

CFCs are directly related to the construction of buildings. They are used in some types of insulation, as well as in air conditioning, refrigeration plant, and fire safety systems. They are also to be found in some types of foam used in packaging, and in soft furnishings. Although the effect of the use of CFCs is now widely recognised, there is a problem with finding a solution to the problems they cause, as no satisfactory substitutes have been found, in at least some cases.

The urgent need, however, to develop insulation and climate control systems, which do not depend on CFCs, should continue. The fact that there is a lack of satisfactory CFC substitutes does not mean that none will be found.

In the meantime international protocols have been developed to control and, ultimately, prohibit the use of CFCs (for example the Montreal Protocol of 1987 and various European Union measures in the 1990s), (Johanson, 1993).

While finding suitable substitutes for CFC is one way forward in the fight against the depletion of the ozone layer. Other measures might include utilising different design solutions, such as the use of mineral fibre thermal insulation rather than a CFC related material such as extruded polystyrene (Baldwin, 1990).

Global warming has also received much publicity in the last two decades. The earth's troposphere contains some protective gases including carbon dioxide, methane, CFCs, and nitrous oxide. While allowing some light to reach the earth, this blanket absorbs some infrared radiation, and in fact the sunlight that reaches the earth is warmer after passing through it than before. For this reason it has been referred to as the greenhouse effect. This action is necessary for the sustenance of life on earth, but it is now generally recognised that this blanket of greenhouse gases is becoming thicker for a number of reasons. One is the increased release of CFCs already referred to above, another is the emission of carbon dioxide in the burning of fossil fuels, and another is the increase in the production of methane, related to intense agricultural activity. The resulting more substantial layer of greenhouse gases absorbs infrared radiation more efficiently and this increases temperatures on the surface of the earth-global warming (Evans, 1989).

It is hard to find agreement about the extent of global warming or on its likely course, but possible outcomes include partial melting of the polar ice caps, with subsequent loss of low-lying land due the thermal expansion of the world's oceans. Climatic change would also have other effects, such as a shifting of the location of deserts and of fertile regions, as well as changes in the requirements of the thermal qualities of buildings (Henderson, 1990).

In this context, CFCs and carbon dioxide are the greenhouse gases most closely related to the use of buildings. Indeed carbon dioxide makes up about half of all such gases being produced and in some countries, such as the UK, around fifty percent of carbon dioxide released is directly connected to the use of buildings; electricity, for example, is usually generated through the burning of fossil fuels (Henderson, 1990). Thus, in order to reduce this total effect, two strategies must be adopted: one is to seek alternative energy resources; the other is to utilise current energy more efficiently. Energy is used in so many ways in buildings. It is used in heating, cooling, ventilation, lighting, services, etc., and what approach is taken to handling energy will involve many factors such as the use of the building, whether it stands already or is at the design stage, and so on (Evans, 1989)

One way to control the energy efficiency of buildings is through regulations. Such regulations can lay down the thermal performance to be produced for new structures, and it seems probable that such controls will become more thorough in time. In particular regulations relating to CFCs may be expected, since CFCs are implicated both in the depletion of the ozone layer and global warming (BRE, 1991).

But regulations are only one way to deal with the situation. Other techniques need to be explored, and two which have been advocated are climate adaptive architecture (or bioclimatic architecture) and passive cooling.

The distinction between these two is not always clear. The appropriate architectural design for hot regions, often termed 'climate adaptive architecture', and the design and applications of passive cooling systems are confused, but it is important to differentiate them.

Any building is heated up during the day, and it cools down during the night as a result of heat loss by convection and by radiant loss. These natural cooling processes occur even when the building is not provided with specialised passive cooling systems. Daytime heating and night cooling result in an indoor average temperature that is higher than the outdoor air temperature average, because solar radiation is absorbed in the building's envelope and penetrates through the windows. All the heat gained during the day is lost during the night. This is the pattern which occurs when the climate is stable, with about the same average over a period of several days.

Thus even if the windows are effectively shaded and the building envelope has a reflective colour, the indoor average would be above the outdoor average. This applies even in an unoccupied building, and it is a result of some unavoidable solar energy absorption in the envelope. Higher solar gain, when the envelope has darker colours and heat is generated inside the structure by occupants (through cooking, lighting, and so on), increases this indoor temperature elevation.

From the point of view of thermal performance, as far as cooling in summer is concerned, bioclimatic architectural design therefore can only minimise the sol-air temperature elevation, that is, the raising of the daytime indoor average temperature above the outdoor average. Any lowering of the indoor average below the outdoor level can only occur through the input of cooling energy obtained from natural renewable sources. This is what is meant, operationally, by a passive cooling system: a simple technique which lowers indoor temperatures through the use of natural energy resources (Givoni, 1994).

Thus bioclimatic architecture in hot climates, on this understanding, involves architectural design and choice of materials aimed at providing comfort while cutting the demand for energy used to cool a building. It seeks to curtail heat gain by the building, curbing solar heating of the envelope and solar penetration through windows, providing comfort by means of natural ventilation, and so on.

Architectural means for achieving these aims include consideration of traditional design factors such as the layout and orientation of the building, the number, size, location, and design of its windows the shading devices that surround it, and the thermal resistance and heat capacity of the building envelope. These factors can bring the average indoor temperature close to the level of the outdoor average, but rarely below it.

On the other hand, passive cooling systems are able to divert heat from a building to various natural heat sinks, and they involve the application of special design details to the structure.

The relation between climate adaptive architecture and the use of passive cooling systems in a hot climate is therefore ideally one where the appropriate architectural design acts as a precondition for the application of passive cooling systems.

4.2.2 Climate Adaptive Architecture

A climate adaptive architecture approach involves environmental planning for human comfort using the natural climatic features available. This method has sometimes been referred to as 'bioclimatic design', and was put forward by Olgyay and Olgyay in the 1950s. Watson, (1993) states:

> The integration of design, climate, and human comfort – "the bioclimatic approach to architectural regionalism" – was first proposed in the mid-1050s by Victor and Aladar Olgyay. Their intention was to highlight the belief that architectural design should begin with understanding the physiological needs of human comfort and take advantage of the local climatic elements to optimise there requirements naturally and efficiently. in the mid-1970s, the terms "passive solar design" and "energy-conscious design" were used to describe this attitude. Applied as a balanced approach to designing for all seasons, climatic design is now the accepted basis of environmentally responsive architecture. (p. ix)

The technique, however, has been recognised and developed since the 1920s, most notably at the Tropical Design Unit of the Architectural Association in London (Cook, 1989).

But it would be mistaken to think of climate adaptive architecture as a purely modern concept. The idea of fitting architectural design to climate is one that has always featured in successful construction through the centuries, and is mentioned in the work of the Roman architect Vitruvius (Steadman, 1975). Indeed before modern times architects and craftsmen had little else except local materials, natural resources, and their own imagination, experience, and skill to enable them to construct buildings which catered for human shelter, safety, and comfort in the surrounding climate.

Ways had to be developed to utilise the sun for warmth and shade and wind for cooling, and these largely dictated the design and construction of familiar features such as fireplaces, windows, ventilation devices, and courtyards (Watson & Labs, 1992). The methods and designs of builders from the earliest times has led to the development of many of the features of regional and national architectural styles, some of which show similarities even though separated by thousands of kilometres precisely because they were intended to meet similar needs in similar conditions. Thus, for example, builders in areas as far apart as the Swiss mountain regions and the Himalayas produced houses of comparable design, and similar features of underfloor heating may be found in Korea and Russia as in the Roman baths at Ostia near Rome.

In the course of the twentieth century conscious moves towards what we now call climate adaptive architecture began. In the USA in the 1930s attention was given to orientation and other design features which led to what we may call the first 'solar houses', and such important figures in the development of architecture as Gropius, Breuer, and Wright applied to the design of their own homes features which were intended to maximise the energy saving potential of local climatic conditions.

Climatic architectural design was encouraged before the general public in the USA in the 1950s through magazine articles in *House Beautiful* as well as in architectural literature, and means of making use of architectural features such as reflective roofs for warm climates and solar orientation for cool climates were promoted (Watson, 1993).

Thus, the fact that climate adaptive architecture has not been given a name or has not been the subject of conscious study until recent times does not mean that it has not been in regular use; quite the opposite is true.

However, it was at the same time as climate adaptive architecture was being propagated in the middle of the twentieth century that the economic and technical means arose to permit the luxury of designing buildings without paying due attention to the climate. The advances in technology of the 1950s and 1960s made it possible to achieve a high degree of comfort through the control of heating and cooling within buildings independently of the climatic conditions. The result was that designing to fit the climate was often ignored, and the overall design of a structure could be much the same whether it was to be located in a hot arid region or a cold one. Heat resistant glass and advances in air conditioning meant that there appeared to be no longer any need to take local climatic conditions into account.

Developments in construction involving such features as heat-absorbing glass led to the modern style of glass-curtain wall dominating architecture in all corners of the world, no matter what the local climatic environment. Watson describes the buildings constructed in these terms:

> Sleek and modern-looking, they were copied throughout the globe, regardless of climate and orientation and far from the ideal of climate-responsive design. Their costs in comfort, energy efficiency, and environmental quality only later became fully evident. (Watson, 1993, p. viii).

However, as has been noted, there has been a conscious move back towards climate adaptive architecture in the last generation. This has partly been a result of meteorological and ecological factors such as have been mentioned above, but it was also related to energy shortages in the 1970s.

The move to climate adaptive architecture was reinforced by the OPEC oil embargo of 1973, since one of the results of oil shortages was a revival of interest in the use of solar energy to heat buildings. In the years following the oil embargo climate adaptive architecture was one of three categories into which the design of buildings all over the world tended to fall. These categories were:

1. The continuation of local styles. Here buildings continued to be designed and constructed according to long-standing norms. Often these were fitting for the climate of the area and to the materials available, though at times the tradition was continued because of economic necessity rather because of appropriate architectural choice.

2. Modernism. Methods and techniques were introduced that tended to reflect international trends and styles. Materials not indigenous to an area became more widely available, design and planning schemes from outside the area were more easily accessed and imitated, and the construction technology which had been developed made it possible to reproduce materials and styles in various environments. Buildings erected in this context were often dependent on external or parasitic energy. The style of choice for many organisations throughout the world during this period tended to be modernism. Cook (1989) writes:

> Typically everywhere the business community, institutions, and government offices chose "Modernism" as their approved style in every sense. Many developing countries have constructed tracts of *hornos* in their attempts to join the modernity of the twentieth century. They became victims of their own lack of material or intellectual or cultural resources to do the whole job. (p. 14)

3. Climate adaptive architecture (bioclimatic designs). Designs appropriate to climate but using modern building technology continued, following their inception in the 1950s. Local materials and techniques as well as international materials and methods were used. Design decisions were made by informed and capable architects and other building professionals, so that energy requirements were combined well with style considerations. Some climate adaptive designs can contribute to both heating and cooling energy saving, for example the use of insulation or of earth-sheltering. On the other hand even when local climatic conditions create a pleasant degree of comfort out of doors a building can fail to offer comfort to its occupants if its design does not suit the climate.

If it is accepted that the principles of climate adaptive architecture design have their origins in the need to provide comfort in buildings using the natural climate, then it is possible to set out these principles, which may or may not be applicable in any one scenario depending on whether the requirement is to create more heat to provide comfort (as in winter), or to create greater cooling to provide comfort (as in summer). According to Watson and Labs (1992) these principles may be listed thus

- Minimise conductive air flow
- Promote solar gain
- Minimise external air flow
- Minimise infiltration
- Promote earth cooling
- Minimise solar gain
- Promote ventilation
- Promote evaporative cooling
- Promote radiant cooling

Climate adaptive architectural design therefore demands of architects and builders that they take into account climate, orientation, natural light, and other features of the environment in the planning and construction of buildings. It requires a building to be planned as part of its environment, not independent on it. For the users of a building the design team's concentration on climatic and environmental factors means that a building will perform to high standards in the provision of comfort, shelter, and safety, as well as any other cultural needs such as privacy and seclusion.

As far as buildings in a hot climate are concerned, the emphasis should be as far as possible on minimising cooling needs through building design, as this would be less costly than the use of cooling systems, even passive ones. Indeed the attempt to apply passive cooling systems in such a situation would be fruitless as long as the building was not designed for the climate. In this environment using architectural design to minimise the cooling needs of a structure means in effect reducing the solar load and the conductive daytime heat gain through the building's envelope. The aim should be to lessen temperatures inside and to facilitate effective natural ventilation (Givoni, 1994).

Since summers are the main problem in hot regions, we may identify five principle architectural design elements that need attention in relation to the solar load on a building (Olgyay, 1973; Givoni, 1981). These are:

- Building layout
- Orientation
- Window size
- Shading devices
- Building colour

4.2.2.1 Building Layout

The part played by building layout will be affected by whether the building is to be air-conditioned or whether it is to rely on natural ventilation and on whether the climate is hot and dry or hot and humid. Our main interest is in buildings which will not be air-conditioned and which are in hot dry climates.

In such an environment it is important to minimise the heat gain from out of doors so that the interior temperature can be lowered below the outdoor temperature. To this end the building should be relatively compact, its external envelope surface area being as small as possible, and its ventilation rate should be maintained at the minimum compatible with a healthy atmosphere in order to keep to a minimum the heating up of the inside of the building with the hotter outdoor air.

However, many hot dry climates have cool evenings where the temperature drops rapidly below that of the indoor environment. Under these conditions it is important to enhance the cooling rate of the interior as much as possible. This means that ideally, far from being compact, a building should have a spread layout with maximum exposure to the air outside.

The design of the building therefore has to be such that the effective area of the envelope of the building can be changed rapidly so that maximum exposure to the cool evening air is achieved while exposure is minimised through a more compact arrangement when the day is at its hottest.

One way in which this can be done is to design a building such that it has deep and narrow porches indented on its outer surface, so that it presents an envelope of high surface area in the cool evening air. But these indentations may be equipped with shutters or similar devices which, when closed, effectively form part of the façade of the building, thus presenting a more compact envelope during the daytime. This means that the areas within the shutters are, when they are closed, part of the interior of the building and are protected from sources of heat. When the shutters are open, as we have seen, more effective cooling in the cool evening air may take place.

4.2.2.2 Orientation

As far as orientation is concerned in a hot dry climate the factor of most importance is the orientation of the windows, since heat from the sun penetrating through large windows can raise the interior temperature of a building well above that outdoors, causing extreme loss of comfort and increasing the cooling load. The locations of most hot dry areas in the world are such that the greatest penetration of heat from solar radiation is through east-facing and west-facing walls and windows in summer, and south-facing walls and windows in winter (heat from this source may, of course, be welcome in the winter). The effect of indoor solar radiation through walls can to some extent be minimised by the use of reflective colours and by shading by plants, but windows can be more problematic.

The preferred orientation for structures in hot dry conditions must therefore be north-south for the main outer surfaces, in particular for the window, since the high position of the sun in the sky in subtropical zones means that the south-facing windows and wall can be readily shaded in summer by overhangs. Although ventilation in the cool evenings is important, the main orientation consideration in a hot dry climate must be to keep to a minimum the effect of the sun on the building.

4.2.2.3 Window Size

Windows, of course, have functions other than those associated with heat penetration and with ventilation, but these are our concerns here. In comparison to their area, heat gain through windows is much greater in a hot dry climate than through walls or roofs. Even when windows are closed and sun penetration is blocked their small thermal resistance and their design makes them the areas most likely to allow the access of heat into a building.

In hot dry climates windows have traditionally been quite small in order to lessen the overheating which they permit, but in fact large windows may offer some ventilation advantages in such an environment. They can increase the rate of cooling, especially if they allow sufficient cross ventilation, and thus contribute to indoor comfort at night.

When large windows have appropriately designed shutter attachments, these can be adjusted to provide maximum thermal comfort. They can be closed during daytime to minimise heat penetration, but opened at night to allow cooling of the inside of the building.

4.2.2.4 Shading Devices

The part played by shading devices of various kinds in reducing solar gain through windows is very important in hot dry climates. These devices are primarily of two types: fixed devices and adjustable devices. Each type offers a different advantage in certain conditions. Fixed shading devices are set architectural elements of a building and form an important part of its surface area.

Indeed they have often been used as part of the architectural styling of a structure, sometimes to the detriment of their performance in terms of thermal control. In hot areas a horizontal overhang over a south-facing window (assuming it is in the northern hemisphere) can be designed to offer full shading from the sun during the hottest months and to permit a degree of solar penetration during cooler months. As for north-facing windows, vertical fins provide protection from low sun in the morning and the late afternoon. Horizontal overhangs, although not capable of delivering full shading, are most effective for south-facing windows. Full shading for such windows requires a combination arrangement of horizontal overhangs and vertical fins.

Adjustable shading devices can be either internal or external, that is fitted inside or outside the window glazing. External devices may be of several designs – shutters, rotatable fins, horizontal plates, Venetian blinds, canvas awnings, and so on – and of various materials. They can be adjusted by the occupants to block or to admit solar radiation, and those fitted externally may exclude rays before they reach the glazing. Some devices can block radiation reflected from the ground. Because they can be adjusted to admit solar radiation at appropriate seasons adjustable devices are more versatile than fixed shading.

The colour of shading devices makes little difference to the performance they deliver, though dark fittings will absorb and then dissipate most of the sun's rays, while light fittings will act as reflectors. Light coloured devices, however, offer more daylight through reflection and may therefore be preferred by many occupants.

4.2.2.5 Building Colour

The colour of the external wall surfaces and of the roof of a structure are of great importance on its thermal performance, as they affect the impact of the sun on the building and they affect interior temperatures. In some cases the colour may have an influence on decisions about whether it is worthwhile applying passive cooling to a building.

Research has been done by Givoni and Hoffman into the effect of the colour of roofs and walls (1968), though their work was done in a humid climate rather than in a hot dry one. Various materials were used, including lightweight concrete. Such factors as the thickness of roofs affected temperatures, but there proved to be a spectacular difference in the performance of white roofs and coloured roofs, with the white roof surface temperatures during the day being in many cases repeatedly recorded as lower than the temperature of the surrounding air, demonstrating that radiant loss was in fact greater than the solar energy absorbed by the white roofs. The temperatures of coloured roofs were much higher than those of the white roofs.

Tests carried out by Givoni and Hoffman with walls were all conducted with roofs painted white. Again the thickness of walls made a difference to the test results, but again it was shown than white walls were much more effective at maintaining indoor thermal comfort. With walls painted grey indoor maximum temperatures were always above the outdoor temperatures, while with white walls interior temperatures were generally lower than those out of doors during daytime hours.

As has been noted, these tests were conducted in a humid climate; the amount by which the indoor temperature in hot dry regions is lower than the outdoor temperature is much greater.

4.2.3 Passive Cooling

The term 'passive cooling', like 'passive heating' was first coined in the USA, and its usage is fairly new. The first formal use of the word 'passive' in the context of space conditioning was as recent as 1972 (Rogers, 1972), and the expression was adopted to apply to space conditioning systems that are driven primarily by natural events and forces. They may be contrasted with 'active' systems, conventional solar heating and cooling methods which utilise electrical and mechanical means to control indoor thermal conditions.

There have emerged several approaches to passive cooling, but these have not come to the fore as a result of systematic research building on previously accepted knowledge. In some countries climate adaptive architecture design gained ground while little attention was paid consciously to passive cooling because there was insufficient information available. Indeed passive cooling has been called 'the neglected stepsister of passive solar heating' (Cook, 1989, p. 37). The passive cooling techniques, then, have emerged at different stages of development in research and in design practice. Indeed passive cooling is perhaps best understood in the current situation as a series of research fields which concentrate on the basic heat sinks (Roaf & Hancock, 1992).

It has been mentioned earlier about the energy crisis of the 1970s and how this led to an interest in natural renewable energy substitutes for oil and other fuels. Attention was thus directed to solar energy for heating, and gradually awareness of the advantages of natural cooling systems also arose. The cost of electricity, which drives most air conditioning systems, as well as a rise of concern about environmental matters also boosted interest in passive cooling techniques.

In contrast to thermal control approaches involving, for example, air conditioning – an approach that demands only an elementary information base regarding climatic factors – passive cooling requires a complex information base to relate successfully to natural climatic conditions. Enhancing the thermal performance of structures by relating their cooling requirements to natural heat sinks is thus a particularly demanding exercise for building design teams, especially in countries which have traditionally looked to technological means to fulfil their heating and cooling needs.

Unlike passive heating, which utilises only one natural source, the sun, passive cooling involves several bioclimatic phenomena. Nevertheless passive cooling has been more widely practised throughout history than has passive heating. Amongst the phenomena used by passive cooling are the natural heat sinks of the world, which balance the energy inputs from the sun. These are the atmosphere, the sky, the earth itself, and the natural water areas of the world.

The atmosphere transfers heat, for the most part through convection, but it also provides cooling opportunities. Cooling by ventilation into the atmosphere is the commonest and most elementary passive cooling process and is widely used in hot dry climates, where it is much more effective than in humid areas.

The space beyond the earth's atmosphere –we may conventionally call it the sky - is the only available heat sink outside earth, providing the absorption balance of the energy inputs from all sources. Cooling takes place naturally by radiation to this space. The earth itself also acts as a heat sink, though it is not a particularly effective one. It is, however, at least a reliable one. Such natural features as lakes and other water areas can also act as heat transfer mechanisms.

Each of these three cooling possibilities acts differently on a building and these differences must be taken account of in design. To take one example, evaporative cooling is normally channelled or directed through ducts (and thus it is the resource most compatible with mechanical thermal control systems). Using the earth as a heat sink, on the other hand, demands considerable earth contact at least through floors and foundations. Each passive cooling resource relates to a different part of the structure, so that the most successful passive cooling schemes react to all natural heat sinks.

The different passive cooling systems might, then, be classified according to the main natural resource which they utilise. Four major types of system may be identified. These are comfort ventilation, radiant cooling, evaporative cooling, and earth cooling.

4.2.3.1 Comfort Ventilation

Ventilation may seem a clear and straightforward way to offer cooling in most climatic conditions. However, it is not always as simple as that. Cook (1989) writes:

> Ventilative cooling may be as obvious as opening a window. But designing the window or calculating available comfort from a breeze has the difficulty of quantifying an open system within the moving matrix of changeable climate. (p. 34)

Cross-ventilation produces comfort through the provision of high indoor air speeds. Indeed the very movement of air in the inside a building raises the upper limit of the comfort zone in comparison to still air conditions (which is why this cooling technique is sometimes called comfort ventilation) though this tends to be more noticeable in humid conditions when air speed aids sweat evaporation.

There is little point, however, in seeking to use comfort ventilation during the day unless it is possible for a building's occupants to experience thermal comfort indoors at the same temperature as prevails outside, since the inside temperature of a cross-ventilated building keeps closely to the ambient temperature.

Comfort ventilation should be differentiated from nocturnal ventilative cooling because some features of a building such as the thermal conductivity of a structure's interior mass have to be designed differently to make the best of each technique. Nocturnal ventilative cooling is particularly useful in hot dry climates, which have a large diurnal range in temperature, and a relatively low night time temperature. In those conditions it is possible to accumulate the cool night air in the mass of the structure. If winds at night are deemed too low for a sufficient flow of air, this can be aided by fans.

The design of a building, of course, also affects how hot it would be indoors without ventilation, as do other factors such as the amount of solar energy to which it is exposed and its internal heat generation. How hot the interior of a building would be without ventilation determines the effect of the exterior air flow on the indoor diurnal temperature. Some buildings, because of their design, construction, and location, could well be cooler inside than outside, and in such cases ventilation would raise and not lower the interior temperature.

The temperature difference between indoors and outdoors depends to a large extend on the amount of ventilation afforded by the wind speed, since with even fairly gentle winds speeds the indoor temperature tends to approximate to the outside temperature, whether this means adjustment up or down. At night, however, winds speeds tend to be lower, so that there often exists a greater difference between indoor and outdoor temperature if no thermal control method other than ventilation is in operation.

Some conditions and some types of structure, in particular high mass buildings, can lead to the highest indoor temperature being experienced during the evening hours, so that even with constant comfort ventilation the interior of the building is most uncomfortable in the evening.

In conditions when comfort cooling is applied as the main cooling technique, buildings have to be designed so as to maximise air speed and fast cooling of interior space during evening hours. Large but well-shaded windows are therefore advisable, and the building materials should not absorb too much heat during daytime. Light material, such as wood, or lightweight concrete, is recommended. In areas where the natural air speed is too low or the building design militates against high air speed, fans may aid the ventilation process. It should be noted, however, that daytime comfort ventilation and night time ventilative cooling cannot be operated in the same building, since with night time ventilative cooling the structure has to be unventilated during the day to prevent the inside being heated by the hot air.

4.2.3.2 Radiant Cooling

Radiation is not only the way in which the benefits of the sun reach the earth, but also a basic mechanism in maintaining the thermal equilibrium of the planet, with the release of energy into space from the earth. The sky, indeed, offers the ultimate continuous heat sink for maintaining the thermal balance (Roaf & Hancock, 1992).

Any surface exposed to the sky loses heat to it by the emission of long wave radiation and can be regarded as a heat radiator. Although the radiant heat loss takes place day and night, it is only during the night that actual cooling occurs. During the daytime the absorbed solar radiation counteracts the cooling effect of the long wave emission and results in an overall radiant heat gain.

Roofs are generally insulated to minimise heat loss in winter and heat gain in summer. As the radiant loss takes place at the external surface of the roof the insulation minimises the actual cooling that a building can utilise from nocturnal radiation, unless specially designed radiant cooling systems are in operation.

One such system would be a heavy and highly conductive roof (for example, one made of dense concrete) exposed to the sky during the night but insulated externally by means of operable insulation during the day. Such a roof can prove to be highly efficient at losing heat during the night, not only by long wave radiation, but also through convection to the surrounding air. The operable insulation can minimise heat gain from the effect of the sun and from the warmer surrounding air, and the cooled roof can then act as a heat sink and soak up heat penetrating into the structure and generated inside it during the daytime.

One particular radiant cooling system is the 'Skytherm', developed by Hay in 1978. In this system the roof is made of structural steel deck plates, and above the metal deck plastic bags filled with water are placed. Above them in turn insulation panels can be moved mechanically to cover or to expose the water bags. In winter the water bags are exposed to the sun during the day and covered by the insulation panels during at night.

In summer, when cooling is needed, the opposite occurs, with the bags being exposed and cooled during the night and insulated during the daytime. The cooled water bags, being in direct thermal contact with the metal deck, enable the ceiling to act as a cooling element for the space beneath. This has proved, however, to be a main problem with the Skytherm system in relation to the movable insulation, which has been costly and mechanically undependable.

As far as the applicability of radiant cooling is concerned, the roof is normally the only part of a structure that has much exposure to the sky and therefore it is the natural location for a nocturnal radiator. High-mass roofs with operable insulation, either of concrete or with roof ponds, can offer cold collection and storage together. Radiant cooling of this type is therefore effective in providing daytime cooling in almost any location with few clouds at night, whether the climate is generally humid or not, and thus it is suitable for hot dry regions.

4.2.3.3 Evaporative Cooling

A further passive cooling technique is that of evaporative cooling. Outdoor air can be cooled by evaporating water before it is introduced into a building. The air flow can be induced either mechanically or passively; for example by the use of evaporative cooling towers that humidify the ambient air, and this is direct evaporative cooling. However, passive evaporative cooling can also be indirect. The roof can be cooled with a pond and the ceiling transformed into a cooling element, which cools the space beneath by convection and long wave radiation without raising the indoor humidity.
In hot dry regions with a low humidity, as far as comfort is concerned, direct evaporative cooling can be an inexpensive technique which also has physiological advantages. However, the problem of water availability in these regions makes this technique unpractical. Indirect evaporative cooling is more suited to humid conditions.

The use of cooling towers has been mentioned above. Attention might be drawn in particular to two types of cooling tower, one developed by Cunningham and Thompson and the other, an inertial 'shower', developed by Givoni.

- ***The Cunningham and Thompson System***

A passive evaporative air cooling tower attached to a building has been tested by Cunningham and Thompson in Tucson, Arizona, USA. The system consists of a down-draft tower with vertical wetted cellulose pads at the top. Water is distributed at the top of the pads, collected at the bottom in a sump, and recirculated by means of a pump. The tower was attached to a building of about 100 m^2, which was cooled by the air emitting from the tower. The measured performance of the system was very impressive. When the maximum temperature of the outdoor air was 40.6°C and the wet bulb temperature was 21.6°C, the tower exit air temperature was 23.9°C. The corresponding speed of the exit air was 0.75 in/sec.

- ***Inertial Convective/Evaporative 'Shower' Cooling Tower (Givoni)***

Givoni's system was developed while he was a consultant on the cooling of outdoor rest areas for the '92 EXPO in Seville, Spain. However, his system can also be used to cool buildings. With this method fine drops of water, which have a very large surface area, are sprayed vertically downwards from the top of an open shaft; the falling water contains a large volume of air. The water is collected in a small pond at the bottom of the shaft and is pumped back to the shower head so that momentum of the falling water is transmitted to an air stream, creating an inertial air flow down the shaft. The evaporation from the fine drops cools the water and the air in the shaft to a level close to the ambient WBT.

The inertial airflow can be supplemented by wind effect through the use of a wind catcher placed above the shower head. It is not necessary to use fresh water with this method, the same cooling being delivered whatever the water source, so that this approach can be used in hot dry regions where only brackish water is to be found and in desert coastal regions with access to sea water.

Indirect evaporative cooling by roof ponds is another possibility. Instead of using evaporation to humidify and cool the ambient air that is introduced into a building, evaporation can be used to cool the roof of the building by placing a cooled pond over it, so that the structure is cooled by conduction across the roof. This type of indirect evaporate cooling lowers indoor air and radiant temperatures without elevating the indoor vapour content of a building.

As to the type of climate suitable for the application of evaporative cooling, it can be stated that, as the performance of both direct and indirect evaporative cooling depends on the wet bulb temperature, this is the main climatic criterion for their applicability.

The temperature of the humidified air is above the ambient WBT by about 25% of the WBT depression. The interior air temperature in a building cooled by a direct evaporative cooling system is about 2 to 4°C above the temperature of the humidified air, depending on the cooled air flow rate, the thermal quality of the building, and its solar load. By taking account of these factors, the applicability limits for direct evaporative cooling may be gauged. Since indoor air speed can be enhanced in a closed building by the use of fans, indirect evaporative cooling can be applied in places where the WBT is 24°C and the maximum DBT is 44°C.

4.2.3.4 Earth Cooling

Practically every structure has at least one surface in direct conductive contact with the earth. The earth mass under, around, and sometimes even above a building can act in most climatic regions as a natural cooling source, whether passively or actively. But in hot regions the natural temperature of the soil in summer is usually too high for it to serve in this way. However, it is possible by very simple means to lower the earth temperature well below the natural temperature in a given location.

Two methods have been used successfully to lower the earth temperature by shading it while permitting water to evaporate from the surface. These are: covering the soil with a layer of mulch or a similar substance at least 10 cm thick and, in regions with dry summers, irrigating it; and raising the building off the ground to permit water, provided by either summer rains or by irrigation, to evaporate from the shaded soil surface. Once the soil surface temperature in summer is lowered the temperature of the layers below the surface is also reduced.

When the temperature of the soil is low enough it can be used to cool buildings by several means, depending on the type of structure and the climate of the region. A suitable technique in hot dry regions with mild winters, at least for earth-covered structures, would be to utilise the adjoining earth mass to provide direct passive conductive cooling.

4.2.4 Energy Efficiency by Management

Energy savings through management may be described as the organisation and direction of resources to attain cost-effective saving. Several steps can be identified as essential to energy management; these include: measuring how much energy is used, comparing this with previous or standard performance, investigating the possibility of applying energy-saving measures, and observing progress towards intended targets. It should be emphasised that the saving of energy is not an end in itself, but is a means to saving costs and to upholding environmental standards.

It is not only individual occupiers or owners who are interested in energy saving measures. National authorities are also eager to do this, and they are often capable of taking a wider view than an occupier, taking into account not just the immediate cost savings, but also longer-term economic and environmental factors. Indeed the government attitude to cost-effective energy saving is often different from that of the interested individual, something which is generally reflected in building regulations. Thus, for example, regulations may set a minimum heat loss for a structure over a period of 100 years, so that there is not an undue burden on national energy supply over that period, while the interests of the occupier may be much shorter, no longer perhaps than the period of his occupancy (Leach, 1985).

National authorities, of course, have to deal not just with new buildings, but also with structures that are already there, and governments on the whole set national energy conservation targets which can only be attained through modifications to existing buildings. As part of their strategy in achieving these targets governments have attempted to price energy realistically and in such way as the consumer understands that it does not come without cost. With this in mind, most governments have also dropped subsidies on energy and have encouraged energy saving through financial incentives to occupiers to install such energy saving measures as double glazing and insulation.

As far as monitoring the use of energy is concerned, this has often proved problematic, principally because the energy consumption of a building depends to a great extent on the way it is used by its occupants. Occupants therefore need guidance in the best way to achieve and manage energy efficiency.

Compared to non-domestic buildings energy usage in domestic buildings is relatively low. However, monitoring costs and achieving energy efficiency through management is by no means an uncomplicated undertaking. Whether a dwelling is occupied by owners or tenants, there tends to be a change of occupancy every few years, and this has to be taken into account when evaluation or advice is given on energy efficiency. Indeed two different sorts of advice may be required, one associated with the current requirements of the building occupants, and one associated with the type of building and with any energy-related modifications it may undergo over the years.

Although domestic energy consumption forms a considerable proportion of total energy consumption in many countries, attempts to monitor and audit domestic energy usage have been slow to develop. However, in the UK and elsewhere there have been moves to assist domestic consumers through the use of questionnaires and computer analysis of their usage patterns and through predictions about the likely saving potential of various strategies that they might adopt. One difficulty with this is that accuracy demands detailed measurements of domestic space, detailed descriptions of heating systems, etc., and all this is very costly. In relation to this, a 'labelling' system for a domestic building may be operated, whereby such measurements as have been described above might be carried out between occupancies, when a building stands empty, as part of an evaluation survey. Ideally, however, a scheme which avoided the need for surveys of this type would be preferable, as it could be applied without a change of house occupancy.

Energy, of course, can be managed automatically, though in this context it is not always easy to find an understanding of the term 'automatic' which differentiates it in a useful way from any other means. Leach (1985) writes:

> There is some confusion in the terminology used to describe automatic energy management systems. In one sense the simple thermostatic radiator valve is an automatic energy management system because it automatically controls the heat input into a space according to demand. At the other extreme there is the complex and sophisticated electronic computer based system which uses digital data analysis and control to operate the services and other devices in a complex or set of buildings. (p. 97)

Leach comments that by automatic energy management system the latter is usually meant.

There are several ways in which energy management systems can make savings. These include minimising unnecessary use, maximising efficiency, facilitating better operation and maintenance standards, encouraging greater energy awareness and economy, detecting equipment failure, and supplying information for audit (including target achievement). Indeed energy management systems may be configured in such a way as to control and monitor all main energy uses within a building. The incorporation in a system of a means of detecting and indicating equipment malfunction is of particular importance for simple controls in a smaller building, as it will help to reduce the need for complex, and therefore expensive, energy management systems.

As far as the technology of energy management systems is concerned, progress in this has been dominated till now by hardware developments, especially in the area of microelectronics. However, it now seems likely that energy management systems will be more dominated by software than by hardware advances.

Greater energy efficiency, then, can be provided by building management systems which concentrate on more effective and accurate control of plant, and which offer performance-based management information. Monitoring and 'labelling' can be introduced both for smaller dwelling units and for more complex structures, where there is greater potential for savings because of their higher energy costs.

4.2.5 Energy Innovation

Any enterprise intended to conserve energy in buildings must give proper consideration to the place of innovation. Innovative materials, designs, and construction techniques will not succeed if they do not fit in with existing practices. In this context existing practices mean not only established building regulations and standards, but also conventional consumer tastes and the established methods of financing construction. On the other hand, new design or construction ideas will not succeed if those involved in the design and erection of buildings do not adopt them.

It is thus a two-way process: innovations must integrate with what is already there, and building professionals must be prepared, at least in principle, to move away from convention if new concepts offer viable improvement.

That point having been made, it should be recognised that there is a long way between an innovation intended to conserve energy arising as a concept, and its realisation as an available product or as a viable aspect of design featured in buildings.

The practicability of many building design innovations have been increased in recent decades by the rise in construction practices which are in themselves innovate ways of implementation. These include the so-called 'turn-key' construction, fast-track construction management, pre-packaged delivery systems, and so on, all designed to integrate more closely the business of building development. Other new forms of implementation may include initiatives between private and public sectors in the area of utility provision, with simplified billing for the consumer.

Another field for development is that of technical innovation, and this is an area which offers great potential to find solutions to the demands of thermal comfort, including passive and climate adaptive solutions. Ideally such solutions, while in principle universal in concept, are specific to the nature of the energy requirement and the local conditions contributing to the requirement, and they do not involve the imposition of technically complex and expensive systems. We may include a more conservation-conscious use of existing resources, such as recycling, in this category.

Design innovations would include climate adaptive architecture, as discussed above, where the climate of the region and the awareness of the potential for using passive cooling techniques will play a part. But design innovation need not be confined to new structures. A greater emphasis on the informed and imaginative adaptation of existing structures may be required, rather than a readiness to demolish buildings which do not at first seem to be worth retaining. Where design innovations do apply to new build their successful implementation will generally depend on co-operation between several members of the building team.

Changes in attitude, what might be termed social innovation, are also required to assist the application of energy conservation. Indeed they may be considered of prime importance, since the technology and other requirements already exist to apply it. Watson (1979) has summed the point up in this way:

> The phrase that might best summarise the point is that appropriate technology requires a corresponding *appropriate sociology*, if this is what we can call the process of implementing innovative solutions to new energy and environmental quality standards in building design, construction, and use. Just as the environment is the physical model of culture, changes in the way we design the built environment require a corresponding social impetus. (p. 297)

Financial and legal constraints may in fact have to be reconsidered, as they may be counted amongst the social attitudes and practices that require to be changed in order to attain the goal of energy conservation.

4.3 Thermal Analysis of Building Envelope

4.3.1 Introduction

The building envelope can be defined as a physical barrier that separates the indoor space from the external environment. It plays a major role in modifying or preventing the direct effect of climatic variables such as air temperature, humidity, wind, solar radiation, rain, and snow.

The building envelope is usually composed of two major types of materials, opaque (structural and finishing materials), and transparent, (glazing surfaces); translucent materials are some times included in this classification.

The natural phenomena of heat transfer in building fabric basically occur in four ways; by conduction, convection, radiation, and evaporation. The amount of heat transferred by each mechanism varies according to characteristics of the transferring media. However, almost 60-70% of total heat gain/lose is transferred through building fabric (Al-Mujahid, 1995).

4.3.2 The Mechanism of Heat Transfer

Heat flow mechanism is a result of the influence of climate conditions on building materials. Out-door thermal condition expressed mostly by air temperature, solar radiation that followed diurnal and annual cyclic patterns.

Indoors thermal profile in buildings without mechanical control usually follow the outside cyclic pattern but with slight modification resulted from the effect of building fabric. The modification can be shown as a change in amplitude of variation and on the timing of the maximum and minimum temperature.

Typical pattern of heat transfer cycle can be explained as follows; before sunrise, both outdoor air and external surfaces of the building envelope are at their minimum temperature. When sun radiation starts to reach the earth, the air begins to warm up and reach its maximum in the early afternoon. The hot air, in contact with building surfaces cause a rise the fabric temperature, therefore, heat flow start to occur through construction layers into the indoor space.

This effect is almost identical for all surfaces regardless of their position. Solar radiation impinges on building surface adds further elevation in temperature. The position of the surface determines the amount of solar intensity received. This process alters the temperature profile for different building surfaces in different orientation.

Building envelope is composed of multi construction layers. Heat flows into each layer cause an elevation of its temperature. In this process each layer receive less heat thus subject to a smaller temperature rise than the layer externally adjacent to it.

When the external surface reach its maximum capacity of storing temperature it starts to get-red of its temperature, hence cool down. The construction starts to remit the accumulated heat in two directions, in words and outwards, depends on temperature differences, but later the entire flow is outwards to the cold night atmosphere. During this operation, a wave–like cycles of heating and cooling are undergoes daily for building envelope.

The thickness, heat capacity, and thermal conductivity are the main factors responsible for modifying the daily cyclic pattern of heat flow. As thickness and heat capacity of walls increase and thermal conductivity of the materials decreases, the amplitude of internal wave diminishes and the timing of the maximum and minimum is more retarded.

Figure 4.1 A-D illustrates a theoretical graph of the cyclic heat transmission through building fabric and shows the effect of material properties on heat flow pattern.

In part A, a typical cyclic pattern for energy flow through a perfectly conductive wall is shown. Part B shows the modification of the previous energy flow pattern resulted from the thermal mass properties of an assumed equivalent U-value material to the example shown in part A. The effect of thermal mass modifies energy flow pattern by damping down the amplitude of energy flow and increase in time lag of the energy transmission through the wall, i.e. time delay in the maximum and minimum energy flow.

With few exceptions, in practice, the basic constructions employed in dwellings do not of themselves provide sufficient insulating value. It is necessary or desirable in most cases to add a layer of insulation to improve the over-all resistance to energy flow.

Ideally it would be best if this insulating layer could be applied to the building in a manner similar to that of clothing on a person. In this way the insulation would be continuous over the building and its structure would be protected from the extremes of temperature both winter and summer.

Thermal insulation is used to inhabit heat flow through the components of the building envelope. It reduces the over-all rate of energy flow and minimizes high variations in surface temperature. This high variation in surface temperature can cause cracks to wall plaster and also leads to condensation problem.

Figure 4.1 part C shows the impact of introducing insulation layer on energy flow pattern. Significant reduction in the amplitude of energy flow but no time delay in maximum and minimum can be noticed.

The compound effect of thermal mass and insulation is illustrated in part D. The maximum and minimum energy flows (decrement factor) are reduced and their occurrence time is delayed (time lag). The position of insulation materials relative to construction mass has a very significant effect on the time lag and decrement factor.

For hot—arid regions, external insulation perform the best than internal position. Reasons for this, as can be inferred from the mechanism of the heat transfer process, are:

1. Insulation on the outside reduces the energy flow rate into the mass. Less heat will enter the mass in a given time, or, it will take much longer to fill up the thermal storage capacity of the mass.

2. Reduces the heat emission to the inside space and modify the mean radiant temperature to the inner surfaces.

In hot climates, insulation drawback can be resulted from the restriction of heat dissipation from inside to outside. If insulation is on the outside, heat stored can only be dissipated effectively to outside by ventilation and this is difficult in hot arid climate.

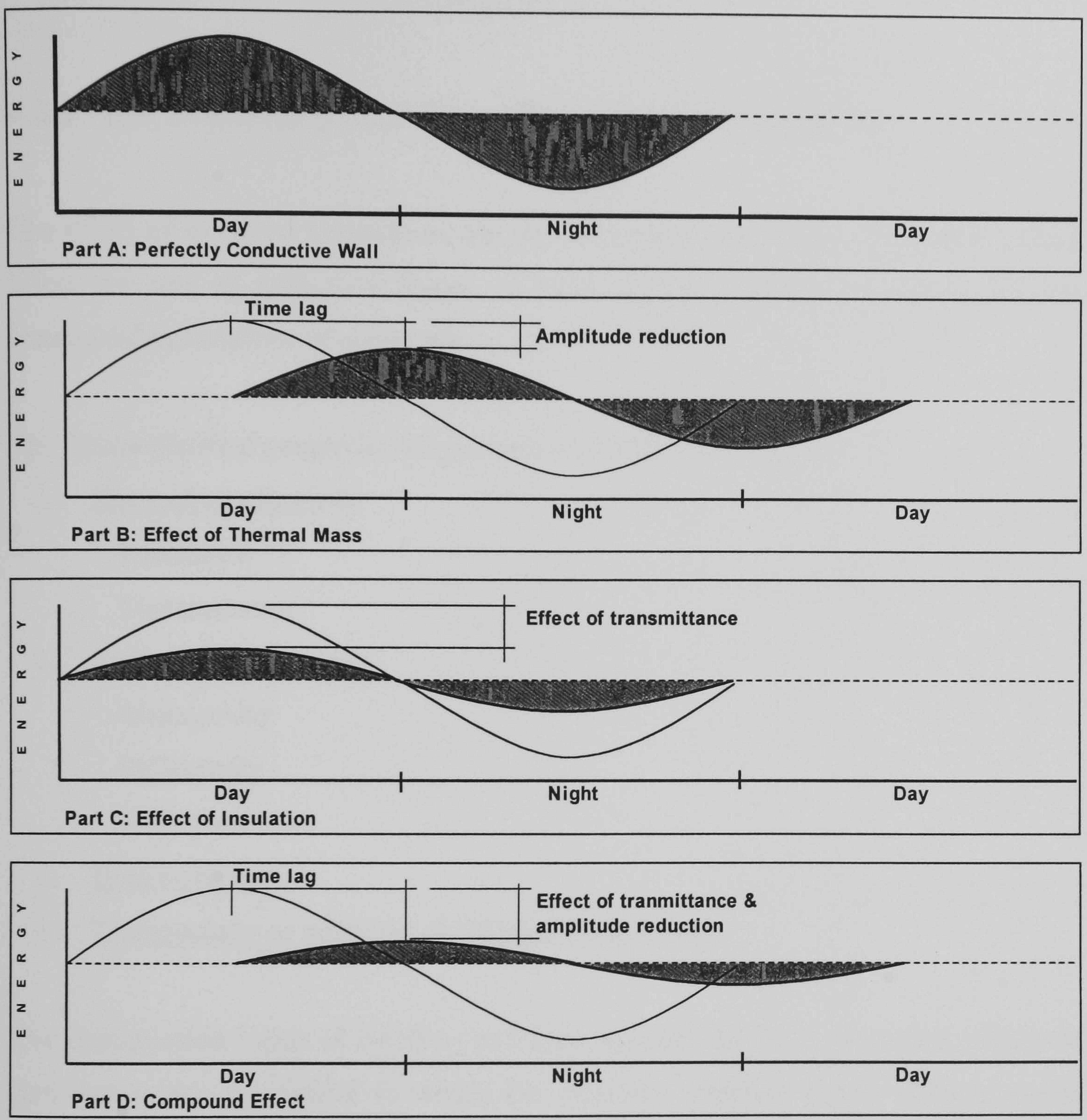


Figure 4. 1: Thermal Performance of the Cyclic Heat Transmission through Building Fabric. Source: Lowis, D., 1979.

The process of heat flow through building fabric represents only one heat path in which the outside climate variables can reach inside space, other heat paths of the same importance which effect indoor temperature are; ventilation, solar gain directly from glazing surfaces, and heat generated within building.

These factors effect indoor condition directly and skip over the modifying effect of the physical barrier of building fabric. However, these sources of heat are manageable and can be controlled and can be minimise.

4.3.3 The Thermophysical Properties of Building Materials

The effect of envelope depends on the thermophysical properties of materials which affect the rate of heat flow in/out of building, hence affect the indoor thermal conditions and comfort of occupants.

The thermophysical properties of materials can be listed as follow:

1. Thermal conductivity
   . Resistance
   . Transmittence
2. Surface characteristics
   . Absorptivity
   . Reflectivity
   . Emissivity
3. Heat capacity
4. Transparency to radiation of different wave length

The transmission value of building envelope depends on these properties, which in turn determines the extend to which the envelope responds the to climatic cyclic pattern. Thermal conductivity is considered to be a major factor that gives the direct physical characteristic of materials; hence it plays a major role in the thermal strategy design decisions. The following is a brief description of some of these properties and their potential effect on thermal transmittance procedure.

4.3.3.1 Thermal Conductivity

Thermal Conductivity is the property of a material that determines the quantity of heat that will be transferred through unit area and thickness in unit time for a unit temperature difference. It is expressed by (λ), in Jm/sm°C = W/m°C. The adopted values for thermal conductivity are based on historical data for broad classification of materials. The λ values in many building materials vary according to their density, porosity, composition, and moisture content. Thermal conduction can be used to describe heat transfer properties of a construction using these expressions:

<u>Thermal Resistively:</u> is the reciprocal of the thermal conductivity ($1/\lambda$). It is expressed by (r), in m°C/W.

$$r = 1/\lambda \quad \ldots\ldots\ldots (\mathrm{m^{o}C/W})$$

<u>Thermal Resistance:</u> is a measure of resistance of heat flow (through unit area) of material of any thickness. It expressed by (R), and given by the following formula:

$$R = L/\lambda \quad \ldots\ldots\ldots (\mathrm{m^{2o}C/W})$$

Where :

L = Thickness .... m

λ = Thermal conductivity .... m°C/W

Thermal resistance of materials depends on the nature, thickness, and disposition of the materials.

<u>Thermal Transmittance (U-value):</u> is the reciprocal of the thermal resistance R , and it determined the rate of heat flow through a given building component. It is termed as U-value, and calculated in $\mathrm{W/m^2k}$.

$$U = 1/\, R_{si} + R_1 + R_2 + \ldots\ldots\ldots + R_a + R_{so}$$

Where:

U = Thermal Transmittance .... W/m°C

R_{si} = Inside surface resistance .... $\mathrm{m^{2o}C/W}$

R_1, R_2= Thermal resistance of structural components .... $\mathrm{m^{2o}C/W}$

R_a = Air space resistance.. $\mathrm{m^{2o}C/W}$

R_{so} = Outside surface resistance.. $\mathrm{m^{2o}C/W}$

The U-value of certain structure is mainly used to determine the rate of heat flow through a given building structure. It is a good indicator of the rate under steady state condition, but the dynamic response should be taken into consideration for an accurate assessment of thermal performance of a building.

4.3.3.2 Heat Capacity and Thermal Storage

Heat capacity of building components denotes the amount of heat required to elevate a unit volume of the structure or a unit area of the surface by one degree. When dealing with volumes, it is termed the volumetric heat capacity of the material and expressed in $J/m^{3o}C$.

The volumetric heat capacity of any material C_v is a product of two major properties of this material, and these are specific heat capacity of material (*c)* J/kg^oC and the density of material (*e*) in kg/m^3. Thus;

$$C_v = e\,c \quad \ldots\ldots\ldots\ldots\ldots\ldots \; J/m^{3o}C$$

Where:

C_v = Volumetric heat capacity ....$J/m^{3o}C$
e = Density ....kg/m^3
c = specific heat capacity ....J/kg^oC

The entire range of specific heat capacity is relatively small. It falls between 480 J/kg^oC–1400 J/kg^oC. The lowest value can be found in materials such as metal and the highest value can be found in wood as a natural material and in insulation as an artificial one.

In contrast, we found the density values of building materials have a wider spectrum. Densities range from 30 kg/m^3 in polyurethane and rise up to 7800 kg/m^3 in metals. Therefore, Heat capacity of any structure is strongly related to its weight. Low weight structure has a low heat capacity and heavy weight or massive structure has a high heat capacity.

4.3.4 Thermal Effect of Building Materials on Indoor Condition

The external envelop influence on the building environment relies on the thermophysical properties of the materials comprise the envelop, their thickness, and positional order in the construction configuration.

This effect is variable according to the nature of cooling strategy adopted inside the building. Buildings operating under natural conditions, not controlled by mechanical cooling, can witness a pronounce change in indoor air temperature and wall surface temperature. Meanwhile, the change may be less in air-conditioned buildings. Materials properties in the later case can determine the amount of cooling or heating load provided by mechanical aids (the capacity of air-conditioning units), thus contribute on the economical efficiency of control system.

Indoor conditions are also influenced by many factors such as direct solar radiation entering the space through glass area, various process of occupants' habituation such as cooking, washing, use of light and electrical equipment. These sources liberate heat inside the space, elevate its temperature and consequently heating indoor temperature and the surrounding surfaces. Building envelope role in this context is to transfer, store, and regulate these heat resources.

The product of thermal conductivity (λ) and the volumetric heat capacity (C_v) of materials determine how much its response usually be to thermal stimulus.

4.3.5 The Effect of Infiltration and Ventilation

Building envelop is also affected by air movement surrounded its environment. Air movement influence occurs through two main forms, infiltration, and purpose ventilation. These two heat paths impose extra load on air conditioning system because outside air entering a space has to recondition to harmonize with the internal environment.

- ***Infiltration***

Infiltration refers to air leakage in fabric or around door and windows that allows air to pass through into space, it is essentially a random occurrence depending upon uncontrollable factors. Structural infiltration can be occurred due to two main reasons; the differential of wind pressure extracted through the structure and due to stack effect phenomena (imbalance between the internal and external air temperature). There are three methods of evaluating infiltration rate and they can be specified as follows:

. Air flow per unit area of building opening
. Air flow per unit length of crack around doors and windows
. Volumetric air change per hour

Infiltration rate around closed window and doors can be calculated after CIBSE equation as follows:

$$Q = C\,(\Delta p)^n$$

Where:

Q = Volume flow rate of air per meter of opening.................... litres/sec
C = Window infiltration coefficient, defined of the volume flow rate of air per unit length of window openings joint at a pressure differential of 1.. N/m^2
Δp = The pressure differential across the window.................... N/m^2
n = Index value depends on the characteristics of the component Involved

Infiltration can be occurred due to two natural phenomena, which are pressure differences in wind and stack effect phenomena.

- ***Ventilation***

Purpose ventilation is the planned movement of air into and out of building. It takes a form of controlled resource that can be known and planned for at the design stage.

Ventilation is needed for enhance the environment inside buildings and it can be either by mechanical or by natural means.

Mechanical ventilation admits the outside fresh air and circulated into space by mechanical means in order to maintain an odour-free and healthy environment. The rate of airflow into space can be expressed by one of the following terms:

- Air change per hour, the number of times per hour that the volumetric air content of space is changed.
- Volumetric rate per square meter.
- Volumetric rate per occupant (litre per second per cubic feet per minute (cfm) per person)

Main planning feature which influence natural ventilation rate is wind speed which mainly effected by the prevailing climate, the height of the building and the size and orientation of openings.

On building scale, natural ventilation can be done by using opening i.e. windows, doors and wind catchers. For hot climate, ventilation usually is undesirable for indoors thermal comfort. Outside air in this area maintain a high temperature most of the time and if allow to enter it will add more thermal load for internal space. So, the aim here is protect rather than obtaining the best ventilation.

One of passive strategy for conserving energy is to block out outdoor air during day time and only let cool air during night time. By doing this, airflow will have a substantial effect on cooling down heat stored in structure fabric.

Rate of recommended ventilation varies according to the rate of oxygen consumption within the space, thus, dependant upon rates of human metabolism, cooking, smoking, odor, and containment production. Table 4.1 illustrates the recommended air changes for minimum requirement.

Occupancy Known		Occupancy unknown	
Type	Air changes (m3/person/s)	Type	Air changes/hour
Homes	0.012	Office	3-8
Schools, theaters	0.014	Engine rooms	4
Factories, shops	0.017-0.028	Garages	5
Hospitals	0.019-0.047	Baths	5-8
		Lavatories	5-10
		Restaurants	5-10
		Cinemas, theaters	5-10
		Kitchens	10-40

Table 4. 1: Recommended air changes. Source: IHVE, 1970.

Thermal load added to spaces due to the controlled ventilation can be calculated by the following equation:

$$Q_v = M \Delta H$$

Where:

Q_v = Load from ventilation...J/s (W)

M = air mass flow...kg/sΔH

ΔH = Difference of specific enthalpy between outside air and inside air condition...J/kg

4.3.6 Heat Gain Calculations

Heat gain experienced by structure fabric can be interrupted to either a cooling load or heating load or both. Makkah's climate as mentioned in chapter 3 is classified as hot and arid. The major concern for comfortable environment in this type of climate is how to overcome the severity of hot weather, thus cooling demand for comfort is essential. Cooling load in buildings is a result of three forms of heat gain resources. These are named as follows:

1. Fabric loads, refers to heat gains passed through building parameter. Heat delivered to space is resulted from a combination of large variable constituents such as external conduction, solar loads, and infiltration. The sum of these loads determine the proper size of cooling system required to offset these load from to space in order to maintain specified indoor design temperature.

2. Internal Loads; refers to load developing inside internal spaces apart from fabric influence. It is mainly a combination of direct loads from pre-known factors such as people, lighting, and equipment. Internal load usually represent to basic load that relatively constant and can be controlled by the behaviour of building occupants.

3. Instantaneous load; is the sum of fabric load and internal loads plus any additional load produced by mechanical system in use.

The calculation for these loads can be giving by the following equations: -

- ***Load from Solar Radiation by Direct Transmission***

The two forms of solar radiation, direct and diffused, are transmitted as a heat gain via the glazing surfaces. The gain from this source can be calculated from the following equation: -

$$Q_D = A_{ig}\, I_D S_f S_c$$

Where: -

Q_D = *Heat transmitted by direct solar radiation* .... W

A_{ig} = *Glazing area\plus frame* .... m^2

I_D = *Peak dierst solar heat gain factor* .... W/m^2

S_f = *Storage load factor*

S_c = *Shading coefficient*

$$Q_d = A_{sg}\, I_d\, S_f\, S_c$$

Where: -

Q_d =*Heat tranmitted by diffused solar radiation*……………W

A_{sg} = *area of shaded glass and frame*…………………………m^2

I_d = *Peak diffuse heat gain factor*

S_c = *Shading coefficient*

From the above equations, the composed effect of solar radiation can be expressed as follows: -

$$Q_{Dd} = A_{ig}\, I_{Dd}\, S_f\, S_c$$

Where: -

Q_{Dd} = *Aggregate heat transmitted by solar radiation*……..W

A_{ig} = *Area of glass and frames*……………………………………m^2

I_{Dd} = *Direct and diffused peack solar heat gain*…………….W/m^2

Direct and diffused peak solar gain is a constant usually obtained from published values for solar radiation on different common types of glass with different orientation and tilting. Storage load factor is taken from (0.0- 1.0) depend on solar altitude and time.

- ***Heat Gain from Solar Radiation through Construction***

Solar radiation also transmitted as a heat gain by construction through windows' fabrics by conduction. The effect of this media can be given by the following equation: -

$$Q_w = A_{wf}\, U_w\, (t_o - t_i)$$

Where :-

Q_w = *Heat gain by conduction through windows*……………W

A_{wf} = *Area of window plus frame*…………………………………m^2

U_w = *U-value of window* .... W/m^{2o}C
T_o = *Outdoor air temperature* .... ^{o}C
T_i = *Indoor air temperature* .... ^{o}C

- ***Heat Gain Load through Building Fabric via Conduction***

Heat gain through opaque surfaces from the combined effect of solar radiation and outdoor air temperature can be given by the standard equation of heat transmission as follows: -

$$Q_f = A_f U_f (t_{eo} - t_i)$$

Where :-

Q_f = *heat transmitted through fabric by conduction* .... W
A_f = *Area of fabric* .... m^2
U_f = *U-value of building fabric* .... W/m^{2o}C
T_{eo} = *Solar-air temperature* .... ^{o}C
T_i = *Indoor air temperature* .... ^{o}C

Solar-air temperature is a hypothetical temperature of the combined effects of solar and airs temperature.

- ***Internal Heat Gain Load***

This source of load comprises the following internal sources that despatch heat into indoor spaces: -

1. Heat Gain Load by People

This is an internal heat source that is generated and dissipated to space by the process of metabolic of human body in sensible and latent heat forms. Heat dissipation form human body can be occurred by one of the following ways:

- . By radiation to surrounding surfaces
- . By convection to surrounding air
- . By moisture evaporation and respiration to the surrounding air

For healthy individuals, the metabolic rate is a dependant on many factors of human nature, i.e. age, sex, activity, and temperature differences between body skin and the surrounding air.

2. <u>Heat Gain Load from Lightning and Equipment</u>

It consists of heat gain from installed lighting system and equipment in use. The process of computing this load is depending on types of illumination fittings, equipment power, and operational time. Third of overall sensible heat gains can be commonly resulted from this source according to operation schedules. Energy conservation plans usually fail when this factor is but underestimation. The data needed for calculation are customarily obtained from technical specification provided by manufacturers which is precisely manifest the amount of electrical input and the equivalent wattage transferred to direct heat.

The calculation procedure of this source is carried out with respect to the following thermal phenomena. The heat emission during the operation of the electrical light fittings and equipment is mainly radiant and must be absorbed by the structure and the surroundings and then re-emitted as a convection heat before becoming a components of space heat gains, hence, converting to system load.

Building structure, therefore, has a specific role to play in this context and its contribution, positive or negative, to this heat source comes from the storage capacity of this structure. The storage load factor, which is involved in calculation, depends entirely upon the specific weight of the structure, operation schedule for lighting and equipment, and the synchronised A/C operation schedule. It should be noted here that lighting fittings could convey as much as 100% of its heat to the surrounding space if they left in direct exposure to the space. While, this high percentage can be decreased to be 35% if fittings recessed in the ceiling and connected to active ventilation system.

Chapter 5

The Survey Research

Chapter 5

THE SURVEY RESEARCH

Investigating the Existing Apartment Buildings in Makkah

5.1 Introduction

This research concentrates on the local home environment, this environment is not something that can be characterized in simple terms, but is a complex area with many diverse aspects. The closer the researcher can get to the heart of the problem, the better will be the understanding of space, behaviour, qualities, and problematic aspects of the environment.

Energy behaviour in existing apartment buildings in Makkah, requires a strategy that incorporate a mixture of methodologies for data collection and data analysis.

The research into the energy behaviour pattern for local apartment buildings involves the integration of two major approaches. These approaches are practical and theoretical.

These two research approaches are necessary to comprehend and to evaluate the real situation. The practical approaches the issue through factual information collected from the field and the theoretical simulates the situation theoretically using an advance computer program for energy analysis.

This chapter will review contemporary research methodologies and will introduce the methodology adopted for this study. The chapter will also provide a detailed description of the procedures followed in the field survey, which were survey aims, survey design and preparation, method of data collection, and survey organisation and execution.

Finally, the analysis of the survey outcome will be given in relation to all the factors involved in the determination of energy requirements for the existing situation, and a picture will be presented about behavioural, thermal, and spatial identity that characterises the existing apartment buildings.

5.2 Overview of Research Methodology

Fundamentally, social research involves a constant interplay between observation and explanation, collection of further facts to test the explanation, a refinement of explanation, and so on (de Vaus, 1996).

There are two common types of research approach usually applied in the social science. These types are the quantitative and the qualitative approaches.

The key factor influencing which of those two methods to select is the nature and environment of the research, i.e. whether the research is empirical, experimental, etc. These methods are designed to facilitate different research needs and fulfil the need to establish a rational and systematic way of approaching and exploring the problems under investigation. They also aid in achieving research goals and objectives.

The criterion by which to judge each approach for any type of study is the suitability and reliability of data gathered and analysed following that particular approach. This data will be expected to support a complete set of explanations, inferences and predictions for the research issue. Furthermore, fundamental decisions may be built on that basis. Therefore, the right methodology is crucial for successful results.

Social science researchers have introduced many definitions and descriptions of qualitative and quantitative methodology. The following account will briefly highlight the merits of each.

5.2.1 Quantitative Approach

Semantically this term is clearly connected to quantities and numbers and indeed the quantitative approach mainly applies where the research has to deal with a large numbers of cases under limited and controlled numbers of variables.

Ragin (1994) sees this method as a strategy of establishing relationships out of different variables in order to make a certain definition of covariation. This method usually requires a large number, under a disciplined sampling system, of participants' cases and many statistical tests and indicators to reach solid conclusions. It also requires standardisation in measurements to overcome the diversity of response in variables that may exist when dealing with life subjects (Patton, 1990).

5.2.2 Qualitative Approach

This approach is a way of collecting data through in-depth investigations. The intensive examination of the targeted subjects is the essential technique used in this method of extracting research data.

The qualitative approach has been considered as a natural method of research. It is based on a live and direct interaction between the researcher and his data sources. The qualitative approach is also considered to be a highly flexible a method in that its data collection tools can be modified according to respondent circumstances.

This approach mainly utilises the interview technique, which is thought to be more interactive, objective and precise for open-type questions. A great level of freedom can be achieved in expressing the ideas through this method of data collection. The respondent has the privilege to record his thought without being guided by certain questions and pre-set answers. It is only the time and the resources factors which make this technique some how difficult to apply. The application can be limited to few representative respondents such as authority and decision-makers.

5.3 Method Adopted for the Research

This research is devoted to the study of dynamic phenomena, namely the energy, behaviour, and characteristics of apartment occupants under specific social, cultural, and economical conditions.

To reach the subjects concerned and build a dialogue with them in order to extract factual information is a task affected by many factors. Among these factors is the importance of privacy for local families, which necessitates a special tool for handling data collection. This acts as an obstacle lessening the chances for long and in-depth investigation as a method in this particular research.

Another important factor is that the research requires relatively large samples to be approached in order to reach reliable conclusions valid for the existing situation, and in order that these conclusions can be generalised and applied to other samples with similar properties. This requirement suggests that this research should be quantitative rather than qualitative

The administration of the survey, the diversity of educational background of the respondents, and the time frame required to handle such large samples are other factors that indicate the quantitative approach.

The qualitative methodology seeks to provide insight into the problem addressed, and this relies on contextual, in-depth, detailed data that require lengthy open-ended interviews. The interpretation of the results in this type of research depends a great deal on personal judgement that might overestimate or underestimate the situation. By contrast, the quantitative method approaches problems statistically through a concise pre-structured data collection tool. By using standardised statistical tests, the respondents' characteristics can be expressed and quantified numerically in more reliable and fixed indicators. The quantitative method seems to be more practical and logical for the purposes of this study, and therefore it has been adopted as the research methodology.

Two distinct strategies for data collection in this research have been combined: data collection through field surveys, and data collection through case studies.

Field survey is an essential requirement and is the most common strategy in handling research. This strategy seeks to collect information on a wide base for samples that share common properties, features, and problems and are subjected to similar circumstances. The field survey strategy targets achieving a generalisation of the results rather than specifying an individual result. The process can be lengthy and time-consuming, especially if a large-scale survey has to be undertaken. The process is also dependent on the availability of proper financial resources.

The primary data gathering techniques for this strategy are interviews and questionnaires. However, the former will be impractical for many reasons, which include time and financing limitations. The latter, therefore, has been adopted here to be a major tool for data gathering.

Case studies for the purpose of this research aim for more realistic descriptions that can be integrated with the results from the survey. They have been employed to investigate in further detail a limited number of apartments where they can be used as explicit and illustrative examples from the wider sample.

Moreover, in this strategy, the researcher will have a chance to perform some site measurements and examine some variables that are beyond the reach of the survey strategy. Also the small numbers that usually characterise the use of the case studies enable the researcher to observe closely, and to conduct direct interviews with occupants, to increase interaction.

5.4 The Field Survey Aims and Objectives

The field survey aims to collect data from the actual location of the research. March (1988) insists that a survey is not synonymous with a particular technique of collecting information. The distinguishing features of surveys are the form of data collection and the method of analysis. The ultimate goal of the survey is to gain some reliable knowledge about a situation that, at present, is not the subject of such knowledge. This is done in order to identify, understand, and solve particular problems associated with the situation.

The situation we are concerned with here deals with the identification of the characteristics of energy performance patterns in existing apartment buildings in Makkah. The principal objectives of the field survey are the following:

- To identify the thermal performance of apartment buildings stock.
- To identify occupants' behaviour influencing building energy issues.
- To identify energy requirements in apartment buildings and patterns of domestic energy consumption.
- To identify socio-economic problems rooted in thermal and energy building aspects.

If these objectives are achieved, the phenomena under study will be visible and more readily accessible for further investigation aimed at dealing with deficiencies.

5.5 Survey Design and Framework

The fieldwork survey was planned and conducted by the researcher in Makkah, Saudi Arabia, from June 1998 to September 1998. During this period all data were collected according to a pre-planned framework designed to fit in with the time available.

Having decided to adopt a field survey for the research, the researcher had to follow a systematic procedure to set this part of the work in process. The field surveys were characterised by a structured set of data in the form of variables collected for a defined set of samples by a defined tool of data collection. The intention was that each of the participating cases would eventually find its attribute on each variable and the researcher would end up with a structured and complete set of data that could be an important source of information.

In designing the field survey the researcher bore the following factors in mind:

- The scope of the survey
- The survey sampling
- The determination of the case studies.

5.5.1 The Scope of the Survey

The fieldwork survey covered apartment buildings in Makkah, a type of building which represents the vast majority of dwelling houses in the city. Because of the topography of Makkah, where is flat land is very scarce, apartment buildings form 70%-80% of the total residential buildings. The rest of the accommodation building types are units in the form of two-storey villas built in the new neighbourhoods.
The scope of this survey is also limited to the middle-income group whose monthly income falls within the range of 2000 SR – 4000 SR. This group represents 40% of the total.

No restriction was imposed on the selection of building age, apartment size, and family size. In general a large percentage of existing buildings (56%) are considered to be new since they have been built within the last 10 years. Apartment size and family size are two factors beyond selection control and they were left without pre-determination. The field survey covered some of the major districts in the city where the population density is high and where the districts share similar economic standards and type of built environment.

5.5.2 The Survey Sampling

Sampling is the process of selecting the subjects to be approached. Ideally it would be preferable to collect information about everyone in the group under investigation. But when the group is too large the process will be prohibitively impractical, time-consuming, and very costly. The alternative is to select a sample from the major group in such a way that their responses and characteristics reflect those of the group from which they are drawn. This procedure is more convenient and time-saving to researchers as they have the flexibility to control and define their sample rather than survey everyone.

A representative sample is one which accurately reflects its group, and what constitutes a suitable representative sample in any one research study depends mainly on the nature of the research problem. From the statistical point of view, the larger the sample size is the more representative cases can be obtained. However, the survey sample in this research was strongly affected by the time and resources available to the researcher; hence a relatively small sample was chosen.

The survey body in this research was the apartment buildings sector in Makkah. At the time of the survey there were 289,994 registered members on the electricity company residential list. This list included all types of housing, i.e. apartments units and villa type units. The accurate total number of apartment units was not available, but if we take into consideration that the apartment buildings represent 70%-80% of the total residential buildings then the approximate number of apartment units might have been around 217,496 (75%). It is very obvious that this number is a large sampling frame. To obtain a proportional sample size out of this large frame was a difficult task, taking into consideration the limitations mentioned earlier.

The major factor to look after when designing sample size is the degree of accuracy required by the sample. For the level of accuracy, a decision has to be taken about how much error the researcher is prepared to tolerate.

Table 5.1 lists the sample size required for various sampling errors. The points to be observed from this table are as follows. When dealing with small samples any small increase in sample size can lead to a substantial increase in accuracy. On the other hand, only a very slight reduction in sampling error can be achieved with a large increase in the sample size. In fact in order to reduce sampling error by half we need to increase sample size by up to four times. This imposes an extra cost and takes up extra time which, beyond a certain point, will not add further information.

In other words, the payoff in terms of accuracy would not be worthwhile in terms of information gain and the cost in time and money.

Sampling Error %	Sample Size
1.0	10 000
2.0	2 500
3.0	1 100
4.0	625
5.0	400
6.0	277
7.0	204
9.0	123
10	100

Table 5.1: Sample Sizes Required for Various Sampling Errors. Source: de Vaus, D., 1996.

It is difficult to apply certain techniques to determine sample size. If we can decide upon the degree of precision needed, we must also bear in mind how people are going to respond to survey questions. The problem is we often lack this kind of information.

One safe approach is to determine size on the basis of the variables in which there is likely to be greatest diversity within the samples, and also on how we intend to analyse the results.

In practice a key determinant of sample size is the need to look separately at different subgroups and make sure that the sample is sufficiently large and contains sufficient numbers for the purpose of comparison. Hoinville states that the rule of thumb in this position is to ensure that the smallest subgroup has at least 50 to 100 cases.

Sample size should be a compromise between three important factors: the desired accuracy, time, and cost. Of course, sample size should ensure sufficient numbers for meaningful analysis.

Taking the above considerations in our account, the sample size for this survey has been determined at 600. This size was very small if compared to the actual sampling frame, but it was reasonably adequate if considering time and resources factors.

The selection for the sample representatives was random but subjected to the considerations mentioned above (see the section headed 'The Scope of the Survey'.

5.5.3 The Determination of the Case Studies

In-depth investigation for typical apartment models was required to configure the information produced by the field survey. This demand could not be accomplished without the adoption of the case studies approach.

A sample of 8 cases was chosen to be under direct investigation. Each case represented a unique situation with a different set of variables dictated by location, size, and orientation. The aim of this investigation is to establish detailed measurements for assessing different environmental aspects as well as aspects of the behaviour of occupants.

The selection process of the case studies based was on the basic criteria of creating homogenous and representative samples. However, the following parameters also directed the selection decision:

- Availability and accessibility. This criterion was a crucial factor in the determination and selection of the cases. For privacy reasons, it was very difficult to find available places to take measurements without disturbing the family and special preparations had to be made in order to secure these units for investigation.

- Appropriateness. This criterion refers to the harmony between the selected cases in terms of physical configuration of the apartments, the socio-economic standard of the occupants, and orientation.

This discussion will be continued later when a detailed description of these cases will be given in the section on case studies analysis.

5.6 Data Collection Tools

In social research and in other scientific disciplines, there are many tools, also termed as methods, instruments, and techniques, to be followed for data generation and collection. These tools are mainly concerned with making the problem in hand more researchable and clearer.

Survey is the technical term that usually comprises the research tools and tends to describe the form of data collection methodology.

Appropriateness, validity and reliability are three essential factors to look after when designing or selecting tools for data collection. The well-known techniques for data collection comprise the following; questionnaires, observation, lab experiments, and field experiments. Too often, techniques are selected according to the nature of the problem and the facts required from the field to tackle this problem with adequate accuracy. As far as this research is concerned, the following tools has been adopted for the study:

- The Questionnaires
- The field measurements
- Direct observation and personal interview

This triangulation is thought to be the most convenient methodology for data collection as it covers all the data resources for this research. Standardised data obtain from occupants via questionnaires and more elaboration will be attained by personal observation and interview and then more in-depth detailed can be obtained by field measurements.

5.6.1 The Questionnaires

The questionnaire is one of the important and widely used instruments at the disposal of the researcher. It is a favoured by many in the field of social research as it offers one of the simplest ways of gathering information and too often, the questionnaire function as a measurement.

This type of data collecting tool is a highly structured and allows the investigators to assemble a set of data against a consistent suit of questions and variables for each respondent involved. The target is to collect data of different nature and this can be given by question content. Question content can be classified to four distinct types: behaviour, believes, attitude and attributes, (Dillman, 1978)

The questionnaire design involves thinking ahead about the research problem and it reflects both theoretical thinking and an understanding data analysis. The research questions usually focus on the phenomena the research is trying to describe and explore.

There are two types of questions usually employed in any questionnaires: open questions and closed questions. A closed question is one which the respondents are offered a choice of alternative replies. Open or free-response questions are not followed by any kind of choice and the answer has left completely open to the respondents to write. The free-response questions are often easy to ask and allow a great deal of freedom to respondents to express them self. However, it is difficult to answer, and even more difficult to analyse. On the opposite, closed type questions are quantifiable, time saver, and straightforward.

The choice of open or closed questions depends on many factors such as the question content, respondent motivation, method of administration, type of respondents, and the amount of time allocated for the survey.

Although that there is no right or wrong approach in selecting the type of question, the closed type question, some times termed as forced-choice, have been adopted for this questionnaire over the open type questions. The reasons behind the selection are that the closed type questions are quick to answer, easy to code, and need no skilled interviewers for demonstration. Moreover, this type of questions gives all respondents an equal chance to answer without depending on how talkative or representative the respondent might be as it limited the choices in pre-developed forced-choice questions.

As far as this study is concerned, sets of closed type questions have been developed in order to collect factual information on the apartment buildings and their occupants with regards to apartment physical sides, indoor environment, occupants life, costumes and behaviours.

The questions are developed to meet the goal from this survey, which is to know as much as possible about this type of housing stock and specifically the issues of thermal performance and energy behaviour.

The questionnaire for this study has been developed with a frequent consultation with Dr. Robin Humphery in Social Science Department. The basic consideration was to produce a simple and concise type of questions that can be easily understood taking in mind the respondents' cultural and intellectual background.

An Arabic version of this questionnaire has been produced, piloted, and reviewed for further amendments by many colleagues in the College of Engineering and Islamic Architecture at Umm Al-Qura University. Copies of these (English and Arabic) questionnaires are included in Appendix I.

5.6.2 Field Measurements

A field measurement is one form of the observational instruments where it represents the most basic and most direct method of obtaining data. The researcher or the observer design and execute an observation plan in order to establish a data record for the phenomena under investigation

The technique of observation is used frequently in behavioural research where the researcher aimed to examine a specific pattern, typically for performance and behaviours. Normally, this type of technique is conducted in the natural setting associated with the issues under examination where the variables are measured in a true context. Doing field measurements or observing real life is not an easy task to carry out especially when people are involved. This is one of the obstacles that frequently faced the researchers; another obstacles for this technique are high cost, long time, and low controls over variables.

As far as this study is concerned, field measurements and the direct observation facilitate the way to the study and assess closely the environmental impact on indoors daily life. It also aims to monitor the interaction between the activities of people to the space, energy and out door environment and assess how these activities may influenced by different physical and behavioural elements.

Field measurement can be seen as a complementary tool that works in integration to the wider scope of the questionnaire tool. These measurements have been designed to generate some facts about typical examples from the surveyed units which will be treated as a detailed case studies.

The information needed is exclusive and comprises measurements for indoor temperature, and measurements on infiltration rate inside the apartments. Also observations on energy behavioural of the occupants are considered.

5.6.3 Observation by Personal Interview

Interview is a major research tool that brings the research face-to-face with the subjects concerned with the investigation. The interview is a term that describes an open oral dialogue where the researcher can have more control and better demonstration on the questions and the respondents has more freedom on answers.

This technique can lead to an understanding and record much more information that cannot be obtained by the pre-mentioned techniques due some socio-cultural obstacles.

The interview can be classified into three major categories: standardised open-ended interview, the informal conversational interview, and general interview (Patton, 1990).

In the context of this study, the interview is considered to be a secondary and a complementary source that can be employed wherever applicable. Data collected by interview takes a form of informal discussion with parties involved in the topic of this study. These parties include professional staff, authorities, and ordinary residents.

Although there was no pre-schedule interviews because of the limited time frame for the survey, however, many discussions have been casually held and information obtained is often extremely worthwhile as it comes spontaneous and without a pre-impression. An example of simple statement has been said by Mr. F. Sultan (apartments' resident) is:

> "Our country is very hot and the A/Cs are great blessing for this generation. However, I don't like them, they cause me some medical difficulties."

This observation reveals the tolerance developed by an older generation against the local climate. This tolerance has elevated the comfort zone for these people to a degree that can be satisfied without the aid of A/C.

5.7 Field Work Organisation and Execution

The major field survey for this study has been carried out in Makkah, Saudi Arabia in the summer of 1998 for three months started from June 1998 to August 1998. The summer period has been chosen due to the nature of this period where the temperature is at its highest levels and the platform for data collation is ideal. The survey had to go through three major stages, which are:

- Design the survey
- Preparation of the survey
- Executing the survey

5.7.1 Design the Survey

The strategy of the design is focused on gathering an adequate amount of practical data that can be used to satisfy the research objective that investigating thermal characteristics and energy conservation in apartment buildings in Makkah.

The information needed to accomplish this strategy has to examine this type of housing stock in its macro context (represented by large group) as well as in its micro context (represented by selected case studies).

The information is collected from the large group via the questionnaires. Direct measurements and observation are employed to collect detailed information about the selected case studies.

The questionnaire was carried out on the apartment buildings, which is the main body of this survey. The information to be collected from these units is mainly concerned with physical properties of apartments, thermal properties and user reaction, energy behaviour of the occupants, and occupants' consciousness towards energy issue. More elaboration on questionnaires' contents is shown in Chapter 6.

The measurement scheme has been set for getting an in-depth view for the internal environment of the apartment. Therefore, a small sample of eight cases has been chosen as typical prototype apartments to host these measurements. The same information which required from the questionnaire is also executed in this sample. Further, in-site thermal measurements were undertaken in these apartments.

The survey, according to the pre-mentioned setting, has to go in two separate directions in order to be accomplished within its time frame. Data collection via questionnaire has to be performed in synchronisation with the measurement survey to make control on time and resources.

5.7.2 The Preparation and the Executing the Fieldwork

The preparation for the Fieldwork had to go through many stages before the actual commencement of the fieldwork. The first stage was setting the platform for the administrative work that usually proceeds the field survey by few months. This work comprises the applying for the approval from the scholarship sponsor represented by Saudi Arabia Cultural Office and Umm Al-Qura University in Makkah. Upon granting the approval, the second stage is to establish the communication required for data collection with the different governmental authorities and private sectors that involve in the survey subject. Because the questionnaire was the major tool in this survey which necessitate a direct contact and visit to people homes, permission has to be issued from the official authority before it could be possible to carry on with any field survey. This permission is needed for security reason specially when taking into consideration the closed and conservative nature of the local society.

After securing these demands for the two stages mentioned above, the technical work and actual execution of the survey is started from this point. Time was very short and the administrative procedures made it even shorter, whereas, the tasks are many and have to be covered under the available time. Therefore, further assistance has been arranged to help the researcher in taking control over the survey tasks. This assistance came from employing five university students from the Collage of Engineering and Islamic Architecture in Umm Al-Qura University.

The students were assigned for distributing, demonstrating, and handling the questionnaires. They were issued identification cards with an official letter that state the purpose of the survey and asking for co-operation in filling the questionnaires.

Makkah City is divided into 22 administrative sectors or neighbourhoods which surrounded the Holy Mosque in radial planning form. These neighbourhoods vary in population densities according to their approximate location to the Holy Mosque. Also they vary in building types as you find more villas in the recent developed neighbourhood at the city edges while more apartment buildings are found in the neighbourhoods close to the Holy Mosque. Neighbourhoods surrounded the Holy Mosque have been excluded from the survey as they have irregular occupancy pattern resulted from the pilgrimage and visitors seasonal activity. 14 neighbourhoods, which exemplify the concentration of the vast majority of apartment buildings, have been selected for the survey (Table 5.2 & figure 5.1).

Surveyors' Name	Neighborhoods	Questionnaires' Serial No.
M. Eaid	Al-Azzaizieh – Al-Awali	1-100
M. Mumenah	Jaroual – Al-Seteen – Batah Qurish	101-230
K. Khodair	Al-Hijra – Al-Rosifa – Al-Haje	231-360
H. Qurashi	Gasalah – Al-Mabeda – Al-Adel	361-500
A. Ataibi	Al-zaher – Al-Nozha – AlHindawiah	501-600

Table 5. 2: Questionnaires Survey; Area Selection and Distribution Scheme

The selection criteria for the buildings to be surveyed have taking into consideration the following factors:

- Only apartment buildings are to be surveyed
- Unify the selection according to building statues wherever possible
- Maximum apartment units to be surveyed in each building are three (ground, middle, and top floor samples) to guarantee maximum sample coverage
- Middle-income group is the main target to approach in this survey. This factor can be assessed externally by observing building condition, whereas luxurious looking buildings are to be avoided.
- No restriction on building age
- No restriction on building materials
- No restriction on building size
- Cover most possible building orientations

Neighborhood Name and Location

1. Al- Mabeda
2. Al- Azizieh
3. Al- Hijera
4. Al- Awali
5. Batha Quraish
6. Jarooual & Al- Hindawia
7. Al- Zaher
8. Al- Nozha
9. Al- Seteen
10. Al- Rosifa
11. Al- Haj
12. Al- Adil
13. Al- Gasalah

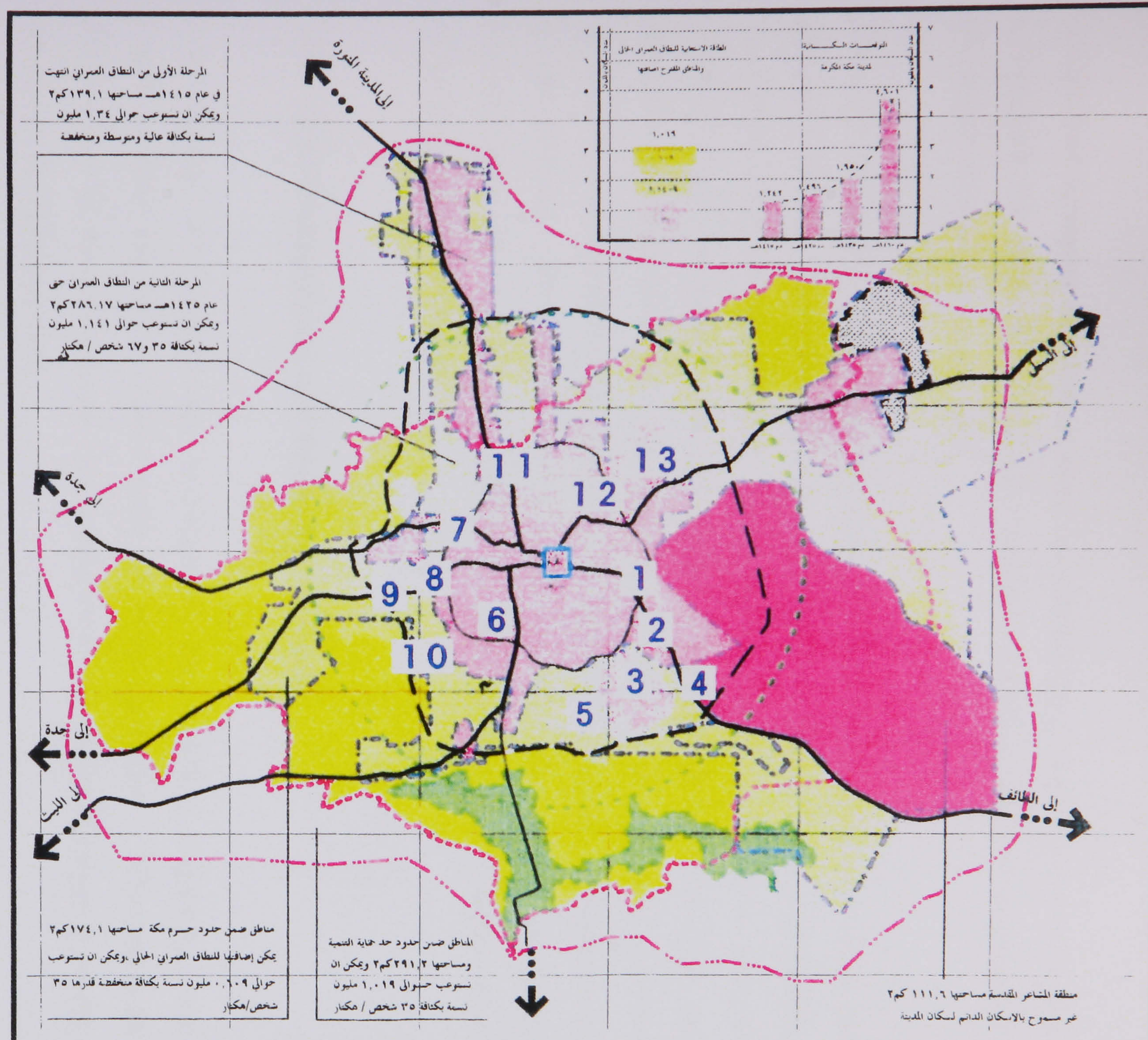


Figure 5. 1:
Makkah City. Diagramatic divisions of Makkah's districts shows the locations of the neighborhoods selected for the survey in relation to the Holy Mosque.

All the field surveyors were trained about the questionnaires' contents, how and when to approach the respondents, and how to mark problems related to respondents' rejection or incorrect or missing data.

The other part of the survey (the measurement survey) has been carried out by the researcher directly. The difficulties of this part arise from the provision of apartments in order to make the measurements. This matter has taken some time to resolve. However, Eight co-operative apartment holders who thankfully agreed to install the measurement equipment inside their dwellings. The privacy and time are two appreciably important factors that hinder, to a certain limits, the proper completion of the measurement. Nevertheless, the information gathered was adequate enough to give the image the researcher is looking for (more details of the measurement procedure are given in Chapter 7).

5.7.3 Data Management and Method of Analysis

Field surveys' data management is concerned with handling, classifying, and processing these data and to make it ready for analysis procedure. With regards to data obtained by the questionnaires, the management plan set for this stage is mainly focused on the following steps:

- Revision of the completed questionnaires and elimination of the incorrect and the missing data
- Recording the respondents' answers in each individual form according to pre-determined questionnaire coding system
- Electronic tabulation for variables on spreadsheets
- Setting these electronic tables in the environment of the statistical package program SPSS for the analysis stage.
- Finally, Proceed with the questionnaire data analysis and extracting the results.

This procedure has been systematically performed and partially completed during the field by the aid of the field surveyors (first part that comprise revision and recording the answers) and the remaining part was accomplished afterwards.

The data obtained via measurements were downloaded from the data logger equipment electronically tabulated on spreadsheet, classified for each individual case, and the information are produced in graphical form. A descriptive analysis for the results has been carried out extensively.

Chapter 6

The Questionnaire Survey

Chapter 6

THE QUESTIONNAIRE SURVEY

The Questionnaire Survey Data Analysis

6.1 Introduction

The aim of this part of the survey was to build up an image of energy and thermal features characterising apartment buildings in this investigation. Clearly the occupants of these apartments are a major primary source of information, and the field survey was based on self-administrated occupant questionnaires in order to make use of this source.

Examining the social lives of families and the way that they customise their lifestyle is a very difficult task, especially in such a conservative environment. Even with high response feedback, the process of generating a solid conclusion will always be attended with uncertainty.

Such uncertainty as exists in this survey would result from the attitudes of respondents. While many respondents would have given due care and thought to their responses, it may be that some were concerned to deal with the matter quickly or evenly. Perhaps, to give the responses that they the researcher wished to receive as a way of showing courtesy which is very common in social customs. There must, therefore, remain some small element of uncertainty about the survey results. These factors are very crucial and might effect the information in any field survey. For this reason, the questionnaire was designed with simplicity in mind and with the minimum number of multiple-choice questions. It also takes into consideration the educational background and the age of the respondents, which might affect the quality of the answers.

The output of this survey has been classified in such a way that all the aspects of building energy issues are covered. The major subjects of this analysis can be listed thus:

- The physical configuration of the apartments
- Electrical appliances and usage patterns
- Occupant/apartment interaction
- Energy usage behaviour and occupants' incomes
- Occupants' awareness of the energy conservation issue.

The survey targeted a sample of 600 apartment holders covering most of the parts of the city. The response rate was 90.3% (542 responded). The rest of the questionnaires were excluded due to missing and incorrect data. The information gathered through these questionnaires has been electronically tabulated and processed by the means of the computer program SPSS. The results of the survey were charted and the analysis is discussed below according to the above classification

6.2 The Physical Configuration of the Apartments

The part of the questionnaire designed to collect information about apartment configuration was based on questions about ownership, years of occupation, apartment location, family size, size of apartment (number of rooms, and the orientation of the apartment). The characteristics of the apartment building will be shown as follows:

- ***Ownership Pattern***

89% (486 respondents) of the survey sample were tenants and the remaining percentage of 10.3% (56 respondents) owned their apartments, as can be seen in Figure 6.1.

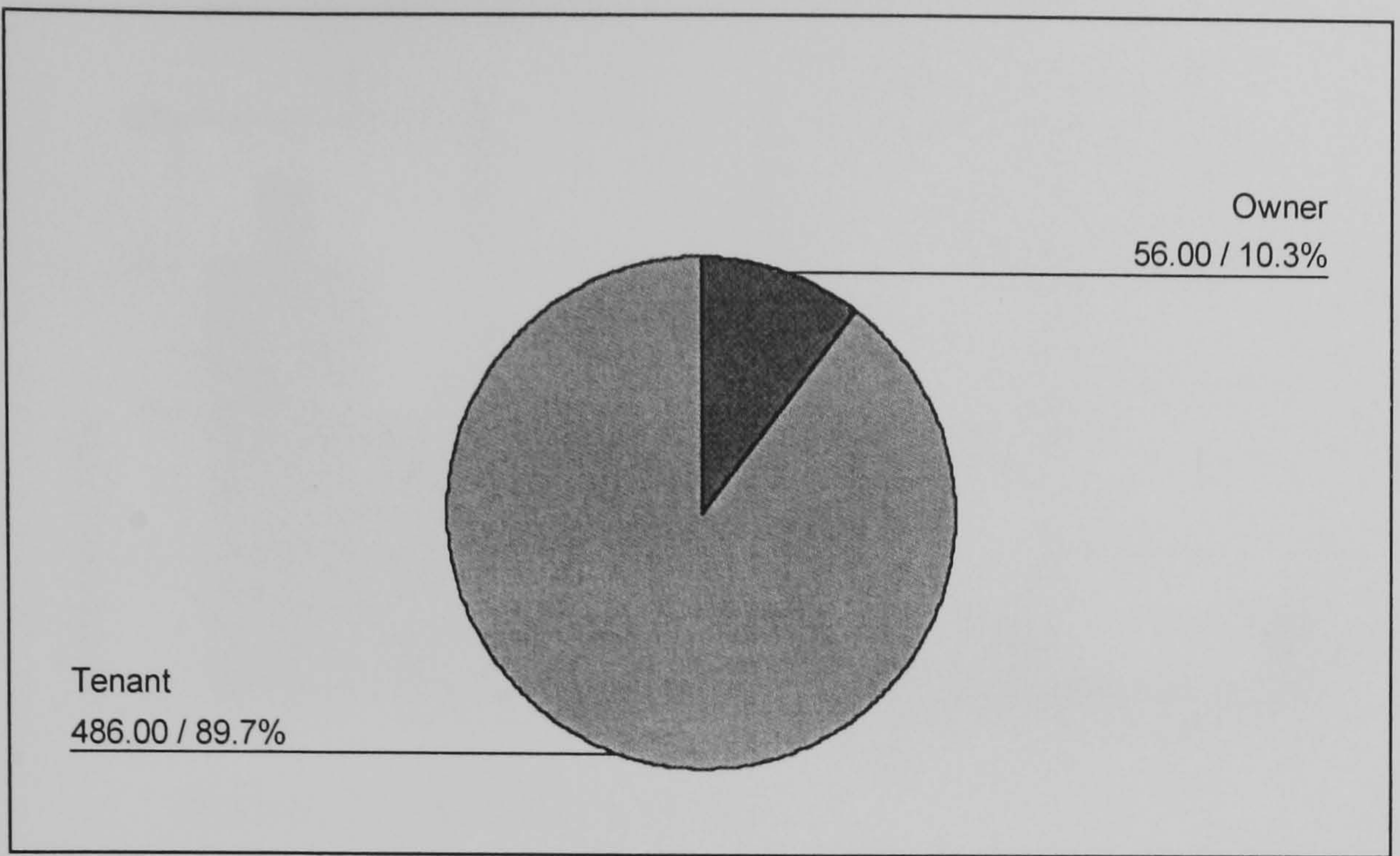


Figure 6. 1: Ownership/ Tenant Pattern

Ownership of apartments in Makkah is very limited, and those respondents who owned the apartments were in fact owners of the whole building. It is a rare situation that apartments are owned individually in Saudi Arabia.

The fact that most householders are tenants may have a negative effect on any potential apartment upgrade even if the householder should desire it. For example, applying saving energy measures in this context would depend on the decision of the owner, and this may not be in line with the wishes of the tenant. This means that improvements are hard to achieve in this context..

- ***Occupancy Pattern***

Number of occupancy years for the survey sample are illustrated by Figure 6.2. Occupancy periods can be classified into four main categories: from 1-5 years, 5-10 years, 10-15 years, and 15-20 years. The vast majority of respondents (54%) fall into the first category, 30% are in the second category, 9% in the third category, and 7% in the last category.

Saudi tenants prefer to remain in one place as long as it still fulfils their needs. These needs are totally governed by family size in relation to the spaces available. Moving homes regularly is not a custom, especially for large families.

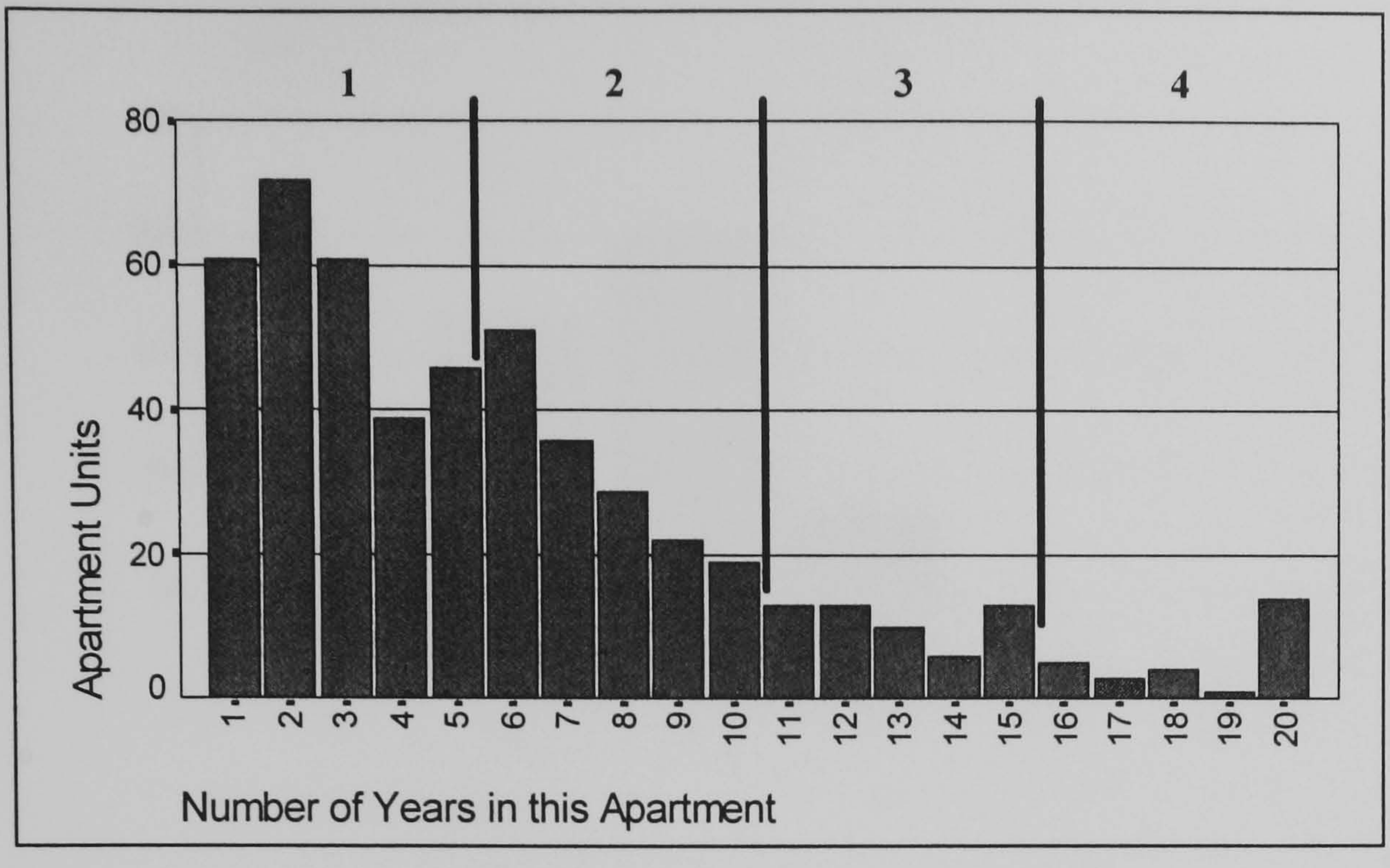


Figure 6. 2: Occupancy Period Pattern

In view of this the high percentage in the first category indicates that most of the apartments involved in the survey were comparatively new, rather than that the majority of the respondents displayed a different residence pattern (in terms of years in the apartment) from most Saudi occupants. The average for living years in one apartment is 5-8 years. People are always looking for new buildings to rent as a priority, thus the skew in the first category indicates a state of these buildings which are mostly newly built. The percentage of the last category indicates the ownership properties for those respondents.

- ***Apartment Size Pattern***

Apartment sizes vary according to the number of rooms in each apartment. The number of rooms varies from three to eight. The average room size in local apartments is $25m^2$, and 30% of the total area is allocated for support functions and circulation. Therefore, apartments areas based on this would range from $100m^2$ (a small apartment) to $250m^2$ (a large apartment). The survey shows that of 40% live in a five-room apartment, 30% live in a four-room apartment, 15% live in six-room apartment, 9% live in a small three-room apartment, and only 6% live in a large apartment with seven or eight rooms. Figure 6.3 shows the above classification of apartment sizes.

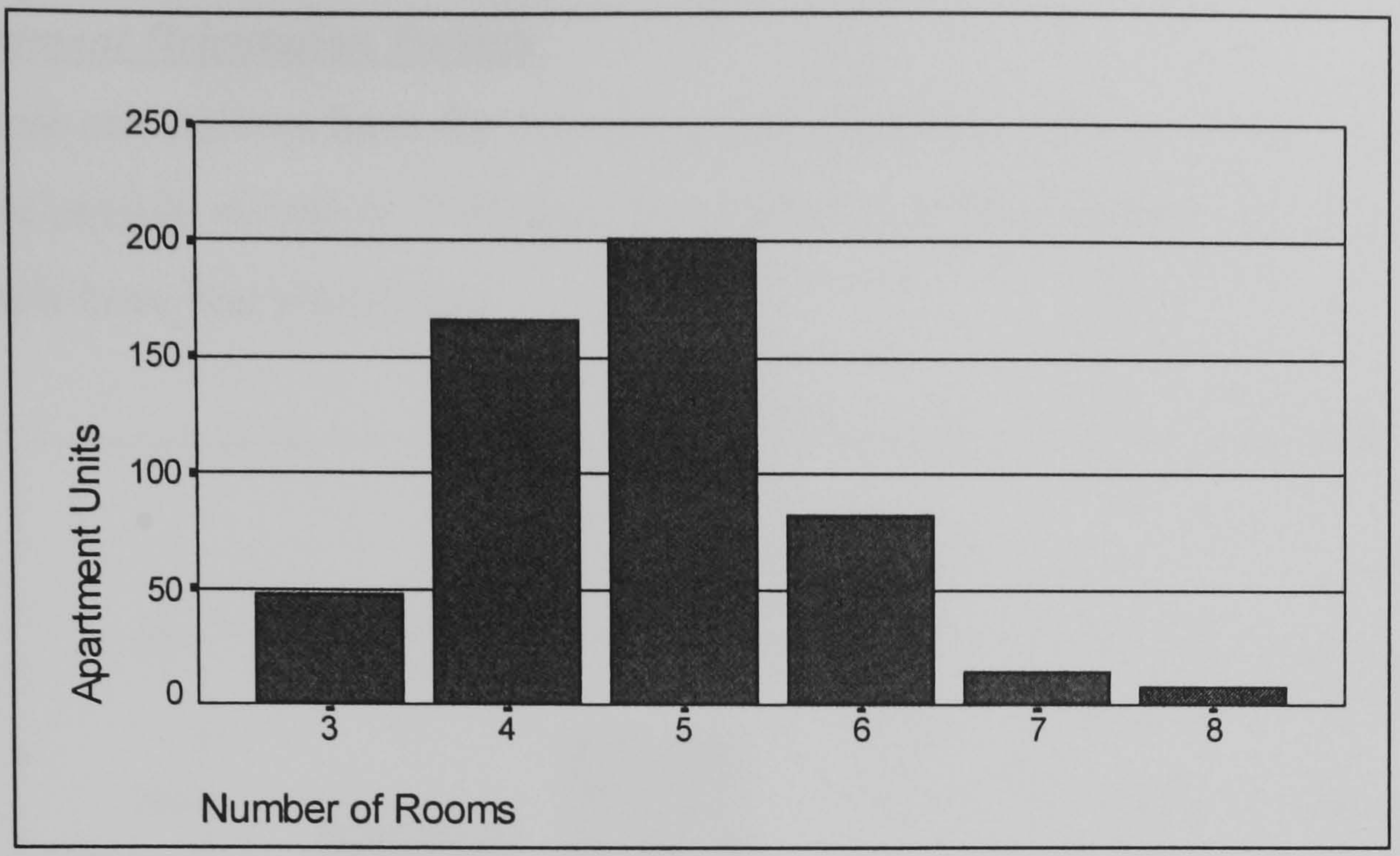


Figure 6. 3: Apartment's' Size Pattern

- ***Family Size Pattern***

Family size pattern in the survey sample covers all the possible family size groups. It ranges from a small family composed of a couple up to a large family composed of 10 members. Saudi families are usually large and the family size usually ranges from five to seven members. The distribution pattern of the family members in the survey is illustrated in Figure 6.4. Family size can be classified into three main groups: the first group is the small family (2-4 members), the second group is the average family (5-7 members), and third group is the large family (8-10 members). The three groups in respective order form 32%, 58%, and 10% of the total.

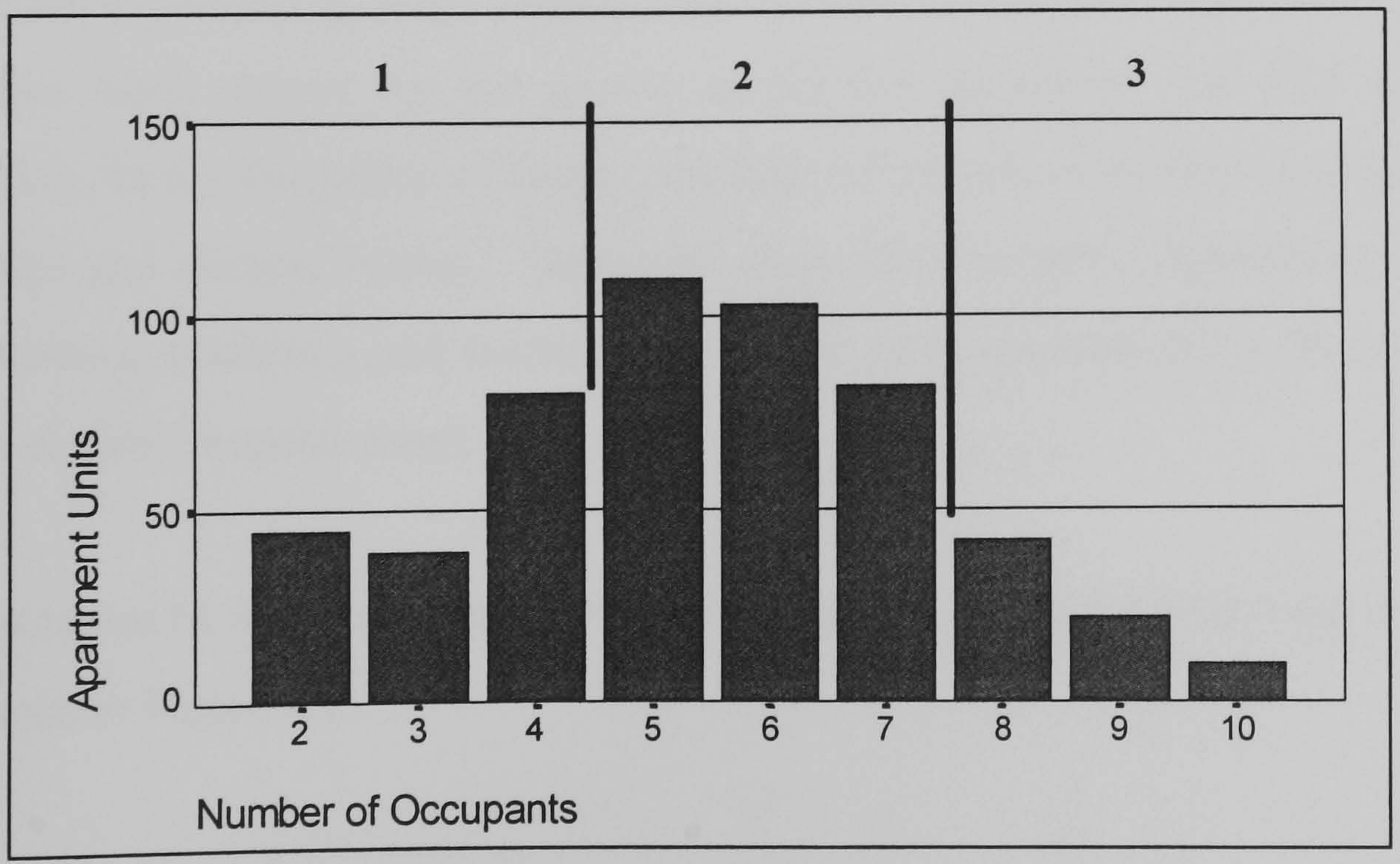


Figure 6. 4: Family Size Pattern

- ***Apartment Orientation Pattern***

Apartment orientations have the following classifications: 32% of the survey sample have one outside elevation, 44% have two, 20% have three facades, and only 4% of the sample have four elevations.

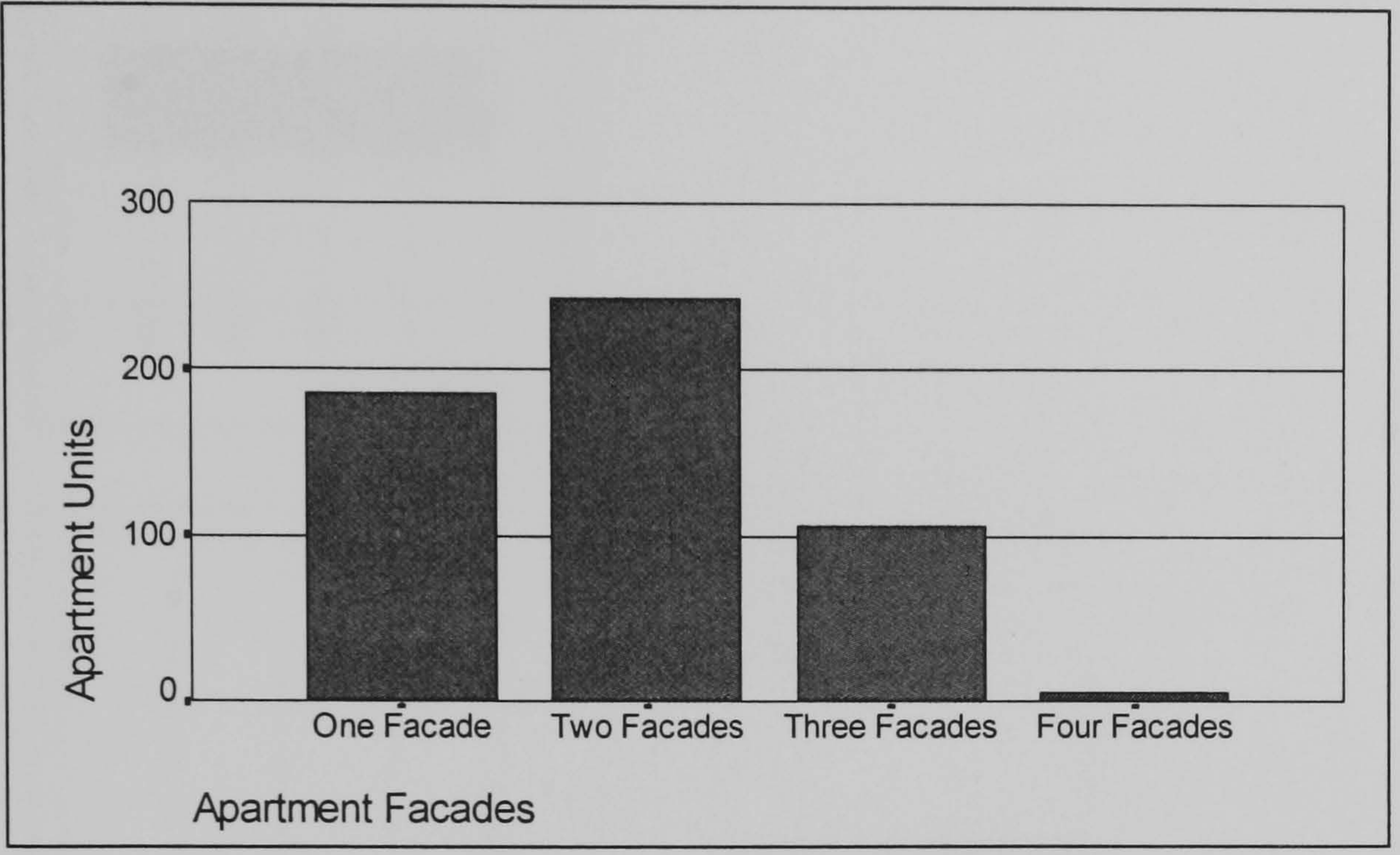


Figure 6. 5: Apartments' Facade Pattern

6.3 Electrical Appliances and Usage Patterns

The domestic electrical appliances surveyed in this section of the questionnaire are as follows: air conditioning units, ceiling fans, electric ovens, and microwaves. These units have been chosen for the survey inside the apartments for their common distribution, heavy frequency of usage, and high consumption demand (especially for A/Cs units and electric ovens). There are some other domestic appliances, such as irons, washing machines, and kettles, which have been excluded from the above list because of their irregular usage.

The possession of these units inside the survey samples takes the following pattern as can be seen in Figure 6.6.

Figure 6. 6: Possession Profile of Electrical Appliances

- ***Occupants Response to Artificial Light***

Respondent attitude towards the use of artificial light during day period has been sought and the responses are charted in Figure 6.7. The results show that 11% of the respondents never turn on their lights during day time, 74% do sometimes use artificial light at day time, and a significant proportion, 15% always keep their lights on.

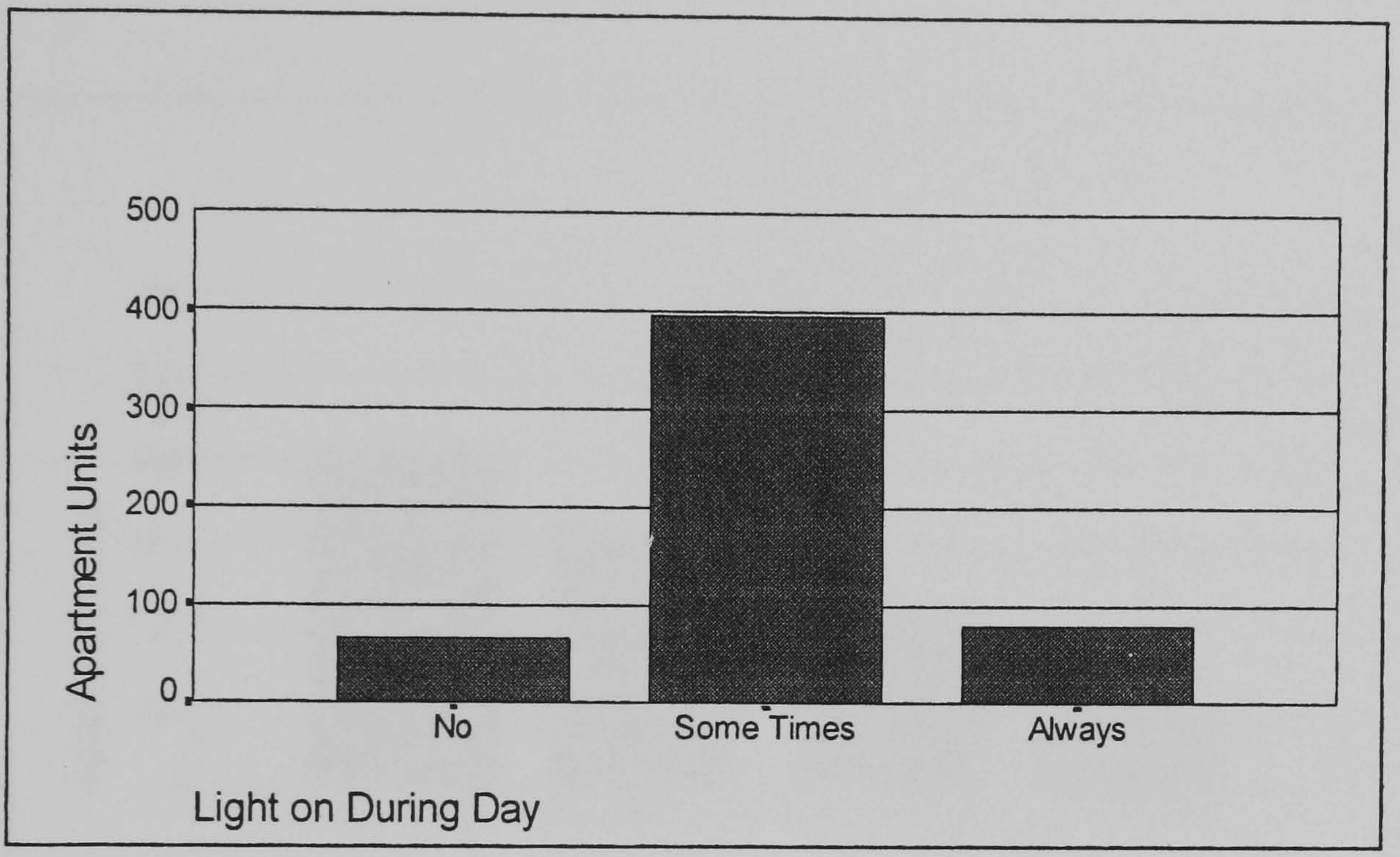


Figure 6. 7: Occupants' Attitude towards Artificial Light

- ***Artificial Light Daily Usage Pattern***

In theory, the intensity of natural light is immense during daytime in an apartment and there is no reason for any artificial light to be used. In practice only a low percentage of occupants apply this theory and the vast majority have another attitude. Because of the heat associated with direct natural light penetrating windows, and also for some other reasons will be explained later, occupants tend to keep their heavy curtains closed, which degrades the quality of natural light and increases the need for artificial light. The daily use of artificial light is classified into four periods as follows:

- Night-time and daytime
- From dawn to midnight
- From noon to midnight
- From sunset to dawn.

The responses show that 39% fall in the first category, 30% fall in the second, 22% fall in the third and 9% fall in the fourth category. The usage pattern of artificial light is not consistent among the survey sample and the high percentage response in the first category indicates this irregularity (Figure 6.8). The 24-hour use of artificial light is an extreme situation that might or might not represent a high addition to electricity consumption. It clearly shows the extravagant usage of light source from the vast majority of survey sample (39%).

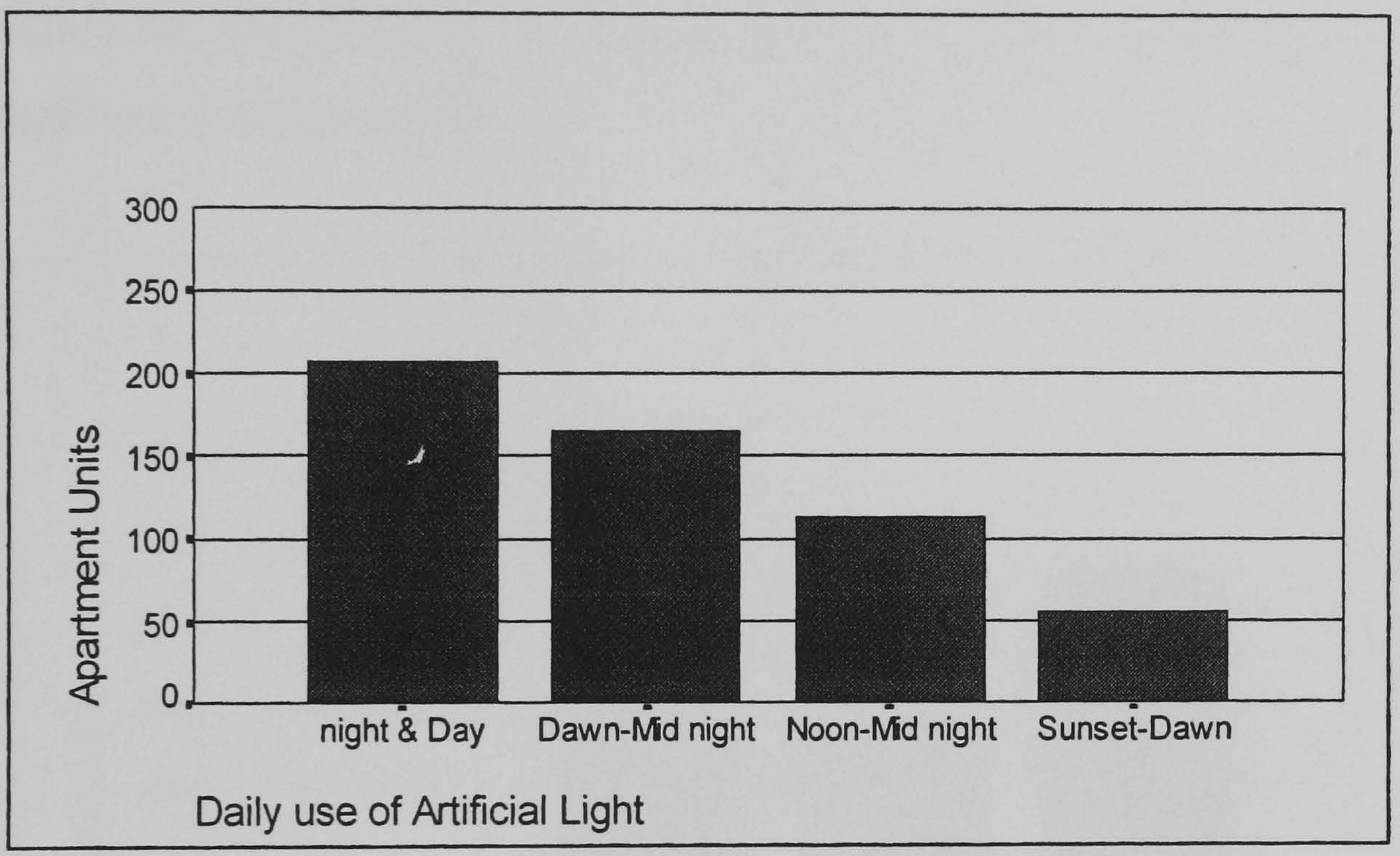


Figure 6.8: Daily Pattern for using Artificial Light

A third of the survey sample (30%) also shows some careless usage as they limited their use to the period where artificial light becomes unnecessarily most of this period (from dawn to midnight). In other words, the use of artificial light within this group extends to 18 hours a day.

A considerable percentage of 22% have confirmed the need of using artificial light during part of the day (noon to midnight) and only 9% have limited their use to night-time.

It should be noted that the uses of artificial light indicated here is exclusive and covers any light might turned on for any reason in any of the zones of the apartment.

- ***Living-room Occupancy Pattern***

The living zone is the most actively used space inside the apartment in that it is in regular use during the day and hosts most of the family activities. The pattern that has been constructed from the survey for the occupancy of this zone is illustrated in Figure 6.9. The prevalent daily occupation period, represented by 43% of the total survey respondents, was almost 18 hours (morning – midnight).

This pattern was virtually invariable within families, especially when taking into consideration the multi-purpose function of the internal space, something that is very well recognised in Saudi society.

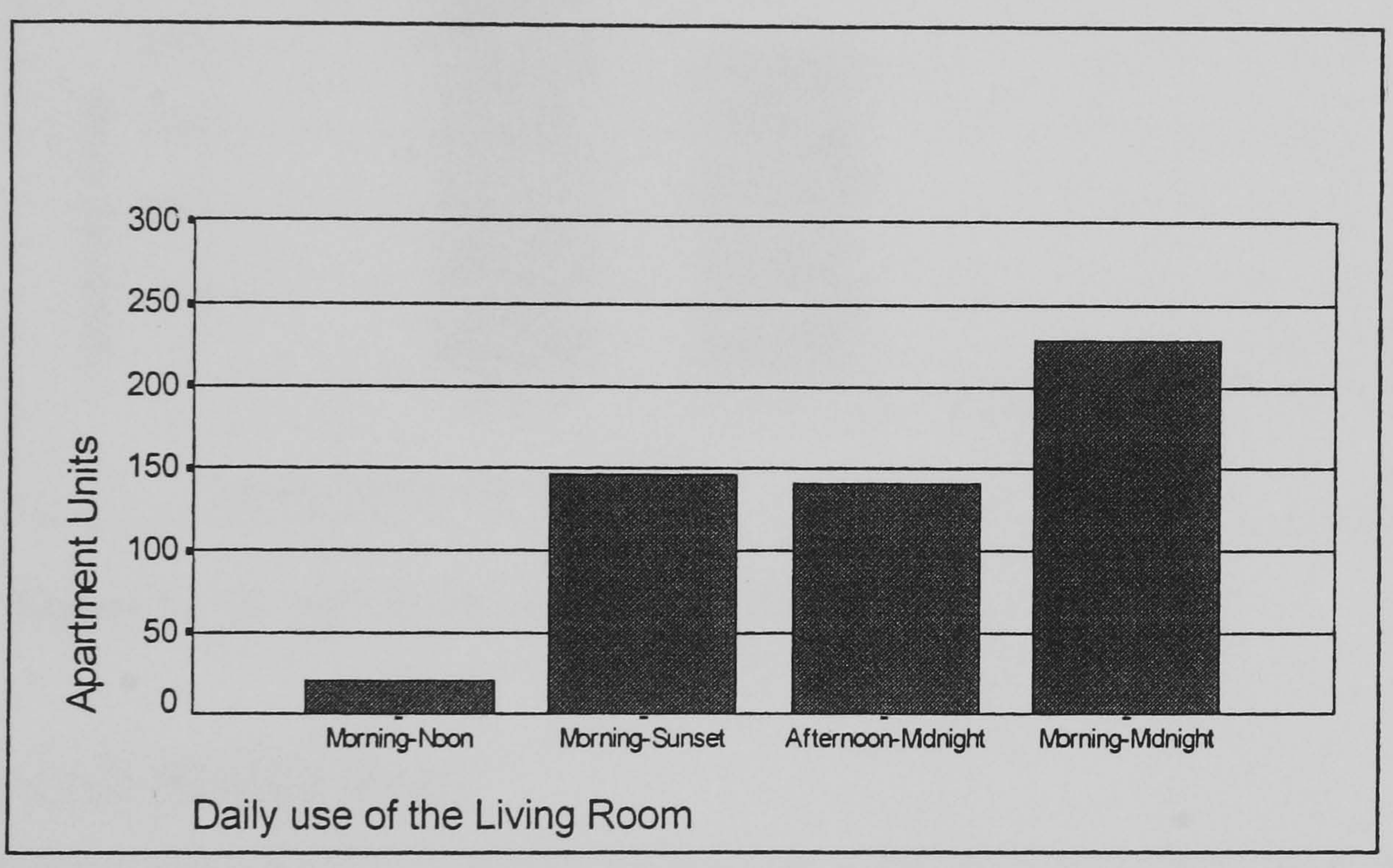


Figure 6. 9: Occupation Pattern for the Living Room

The pattern of occupancy for the living rooms usually accommodates many daily life activities such as a family gathering, entertainment, dining, and sometimes sleeping.

A percentage of 27% was returned by two groups of respondents that occupied the living room for 12 hours, the difference between these groups being only in their occupation periods. The 12 hours' occupation ran from morning to sunset for one group, and from afternoon to midnight for the other group. The fourth group (3%) occupied the room for only 6 hours (morning to noon).

- ***Air Conditioning Demand Pattern***

The yearly demand for the use of air conditioning systems has been extracted from the respondents' replies. 65% considered the need for air conditioning systems to cover all the year. The respondents who limited the need for air conditioning to during the summer months are only 37%, with as little as 8% needing air conditioning in certain other months of the year (Figure 6.10).

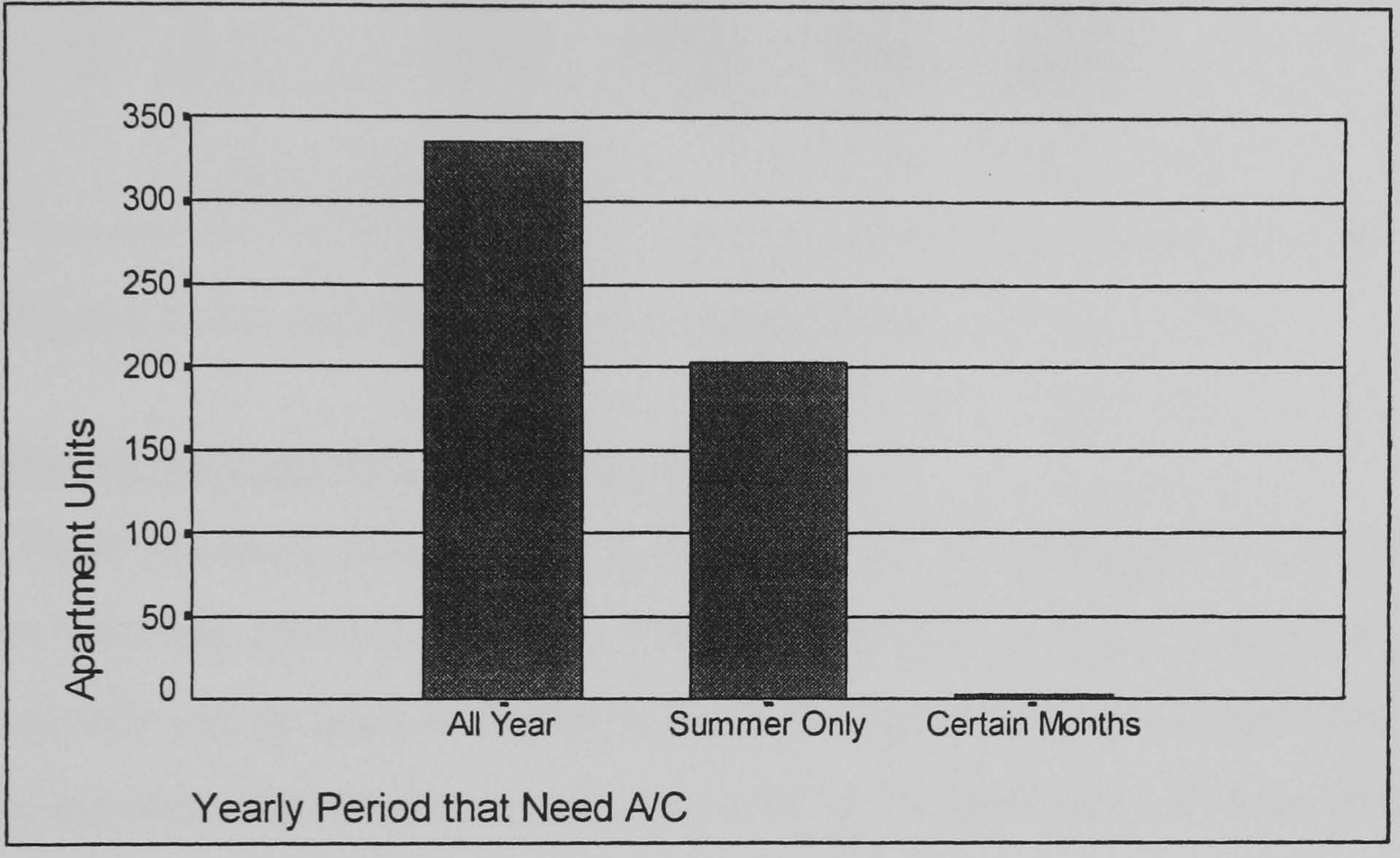


Figure 6. 10: A/C Demand Pattern Profile

- ***A/Cs Daily Working Hours***

The classifications of daily working hours of air conditioning systems as revealed by the questionnaire are from 1-6 hours, 6-12 hours, 12-18 hours, and for 24 hours. The response percentages are 8%, 22%, 52%, and 18% respectively. These ratios can be seen in Figure 6.11. More than half of the survey sample (52%) use their A/Cs for 12-18 hours daily which infers that the main purpose of A/Cs is not to offset the peak thermal load but it become a daily life necessity. This percentage also indicates that most of the apartments are not performing well thermal wise and the comfort inside these units can not be achieved without the aid of A/C units and for most of the day period. 18% (a considerable ratio) use their A/Cs for all the day long which may indicate, beside the pre-mentioned reason, the good economic situation for this group and the relative low cost of electricity..

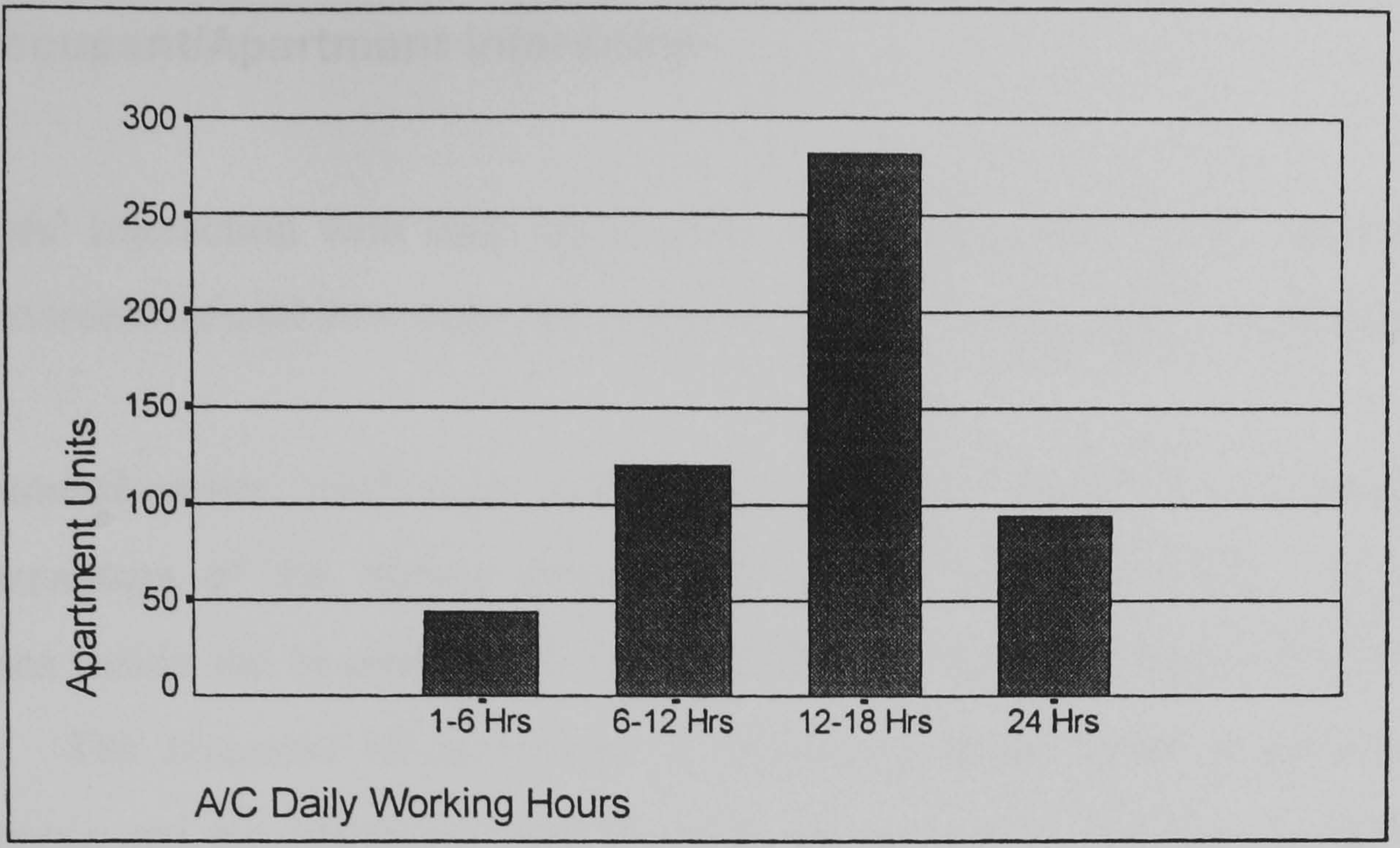


Figure 6. 11: A/C Operational Hours Profile

- ***Number of A/Cs usually Work Together***

Usually there are more than one air conditioning unit working together as occupants use more than one space at the same time. The pattern of using more than one unit simultaneously can be seen in Figure 6.12. 9% of the respondents used only one air conditioning unit, 46% used to operate two units at the same time, 27% operated three units, 12% operated four units and 6% operated five units. Almost half of the survey sample operated two air conditioning units at the same time and this may indicate that the use of two spaces is frequent and very common. The occupation of three spaces simultaneously is also common but with a lower percentage.

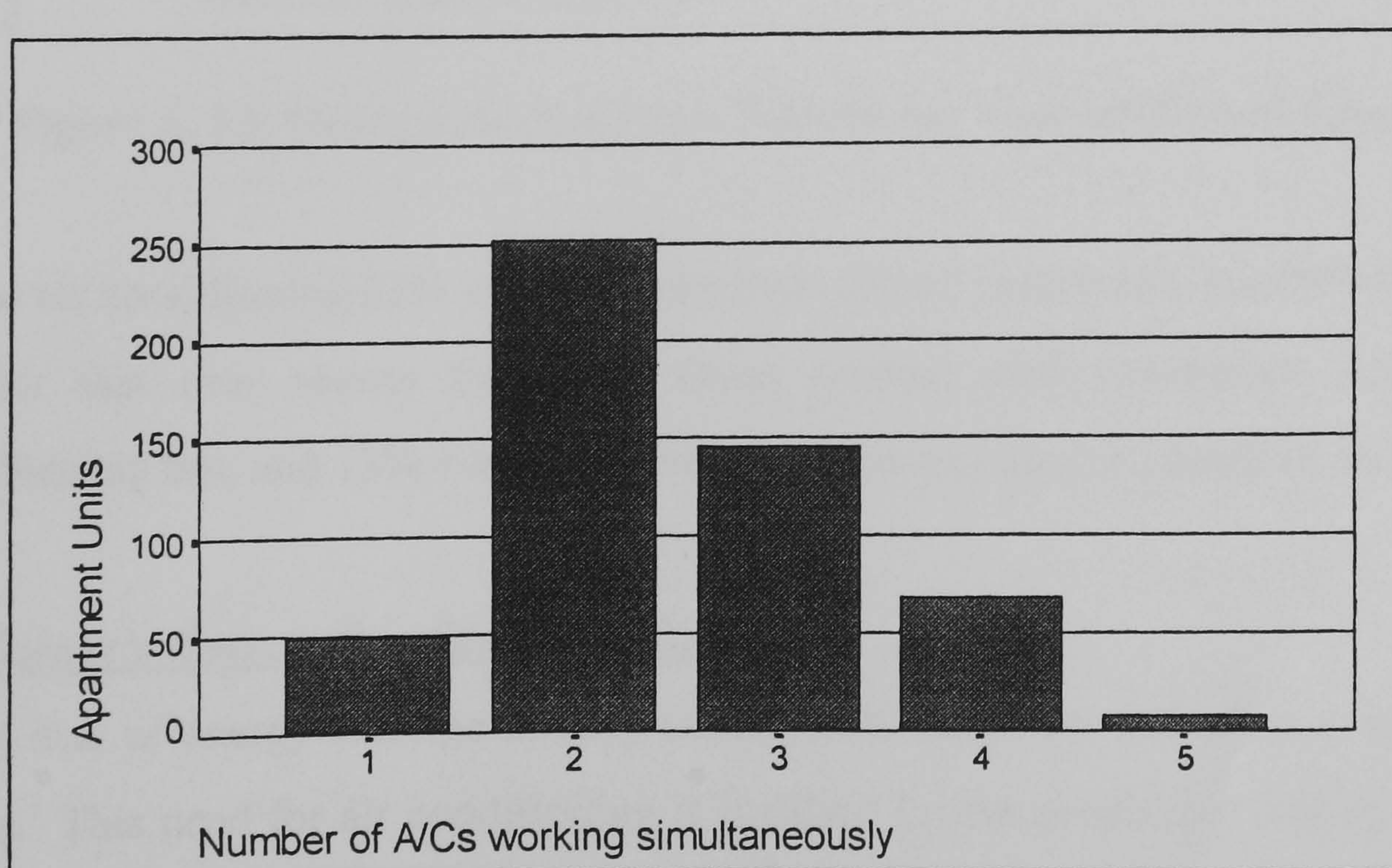


Figure 6. 12: A/Cs Simultaneous Working Pattern

6.4 Occupant/Apartment Interaction

Occupants' interaction with their apartments can be described in the terms of their living environment and how they feel regarding spatial quality and thermal quality.

As mentioned earlier, mechanical cooling is a necessity almost all year round and a high percentage of the survey groups have pointed out this need. In general, conditions inside the apartment are uncomfortable without the relief of mechanical cooling. The response of occupants to situations where there is no use of air conditioning and the effect of room location on occupant's feeling of comfort are illustrated in Figure 6.13.

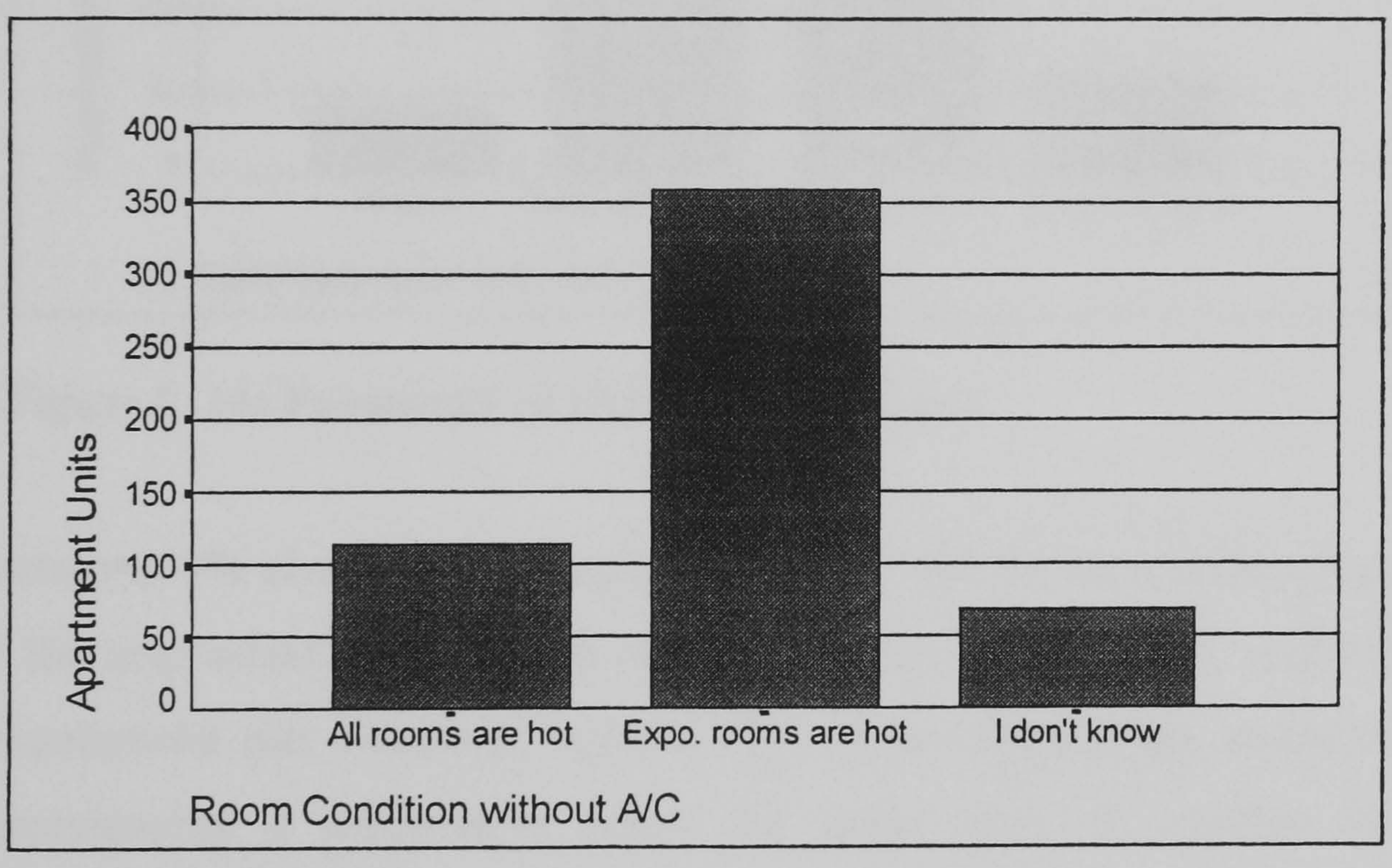


Figure 6. 13: Occupants Response Pattern for Unconditioned Spaces

Without air conditioning 22% of the respondents felt all rooms are uncomfortably hot, 65% felt that only rooms that have direct contact with conditions outside are uncomfortably hot, and 13% were not sure about this and gave no positive answer.

- ***<u>Occupant's Overcooling Sensation Pattern</u>***

A great deal of energy wastage usually occurs with the heavy use of air conditioning systems. This need for air conditioning is justified by hot conditions that exist inside the apartment most of the time. But there are some periods where this need becomes very little, so that the unnecessary consumption of energy can be a consequence of using the air conditioning. One situation where air conditioning can be turned off is when the temperature drops to an uncomfortably cold level. This does sometimes happen, and the occupants' response to how frequently they felt uncomfortably cold when air conditioning was in use is charted in Figure 6.14.

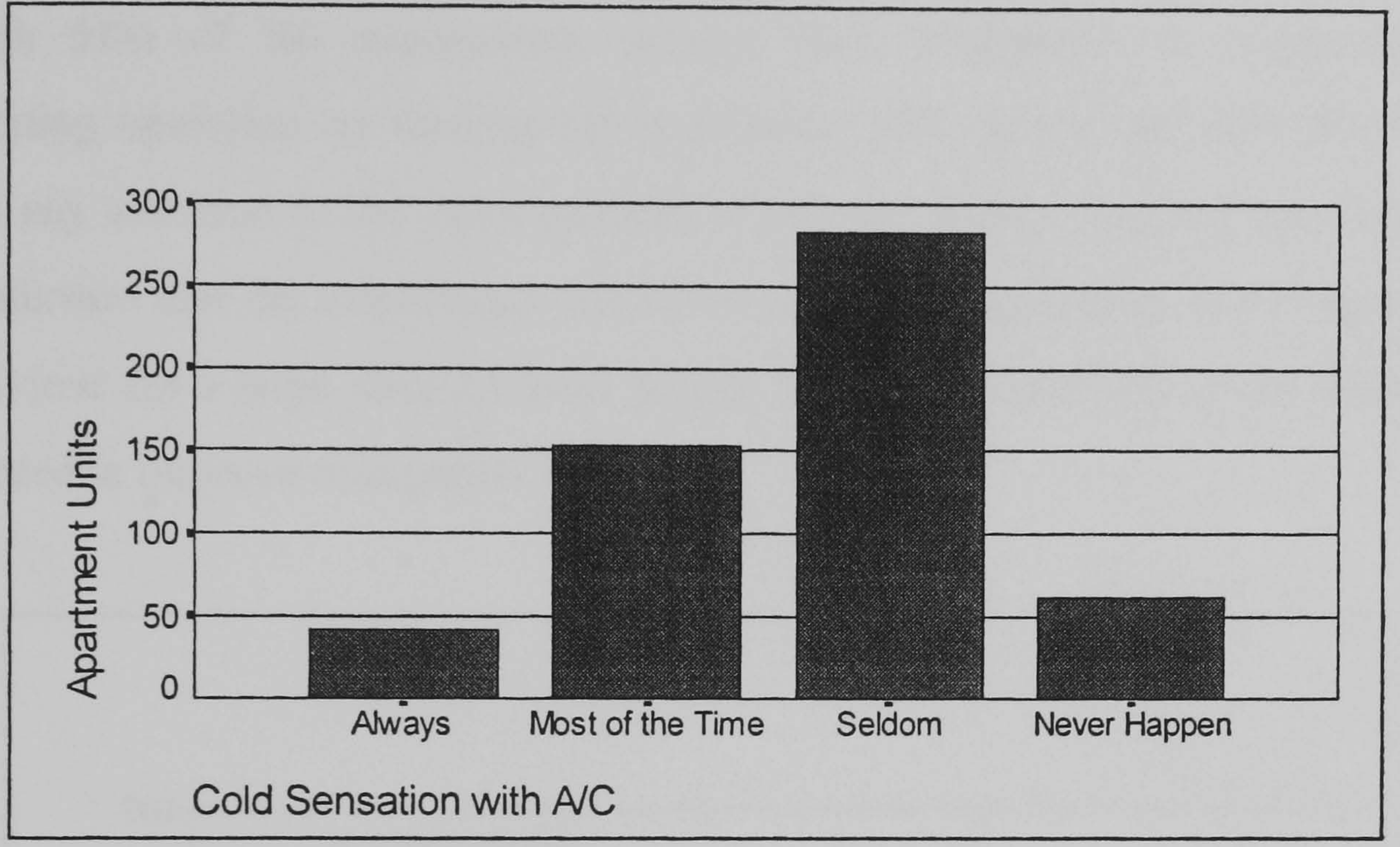


Figure 6. 14: Frequency of Over-cold Sensation

A percentage of 9% always felt uncomfortably cold when the air conditioning was on, 28% of the respondents did so most of the time, 52% occasionally, and 11% have never experienced this situation. Almost 37% of the respondents, aware that they were experiencing a temperature below the lower limit of comfort zone, felt uncomfortably cold. In this situation the air conditioning, if still in use, will be working out-side the economy level and action should be taken to save this waste of energy.

- ***Occupant's Reaction to Overcooling Sensation***

The action taken on this is another indicator to the attitude of occupants towards the conservation of energy. Figure 6.15 shows that almost half of the survey sample (49%) responded positively by turning off the air conditioning as a reaction, 39% reacted to this situation by the use of heavy covers, and 12% did not react at all.

The common types of air conditioning units in the existing buildings are window-mounted units. These units are not so sophisticated as some other types in terms of thermostat settings, and for this reason the control of the unit is often difficult for some respondents, so that usually people simply use the off/on switch to control the temperature.

Although 51% of all respondents showed their awareness of unnecessary air conditioning operation by turning off their units, still mostly the half (49%) acted without any attention to the consequences of this on energy consumption rate. This point indicates that the extravagant use of air conditioning systems is a common type of behaviour for a large slice of local people in Makkah, and this issue needs to be highlighted to improve occupants' awareness.

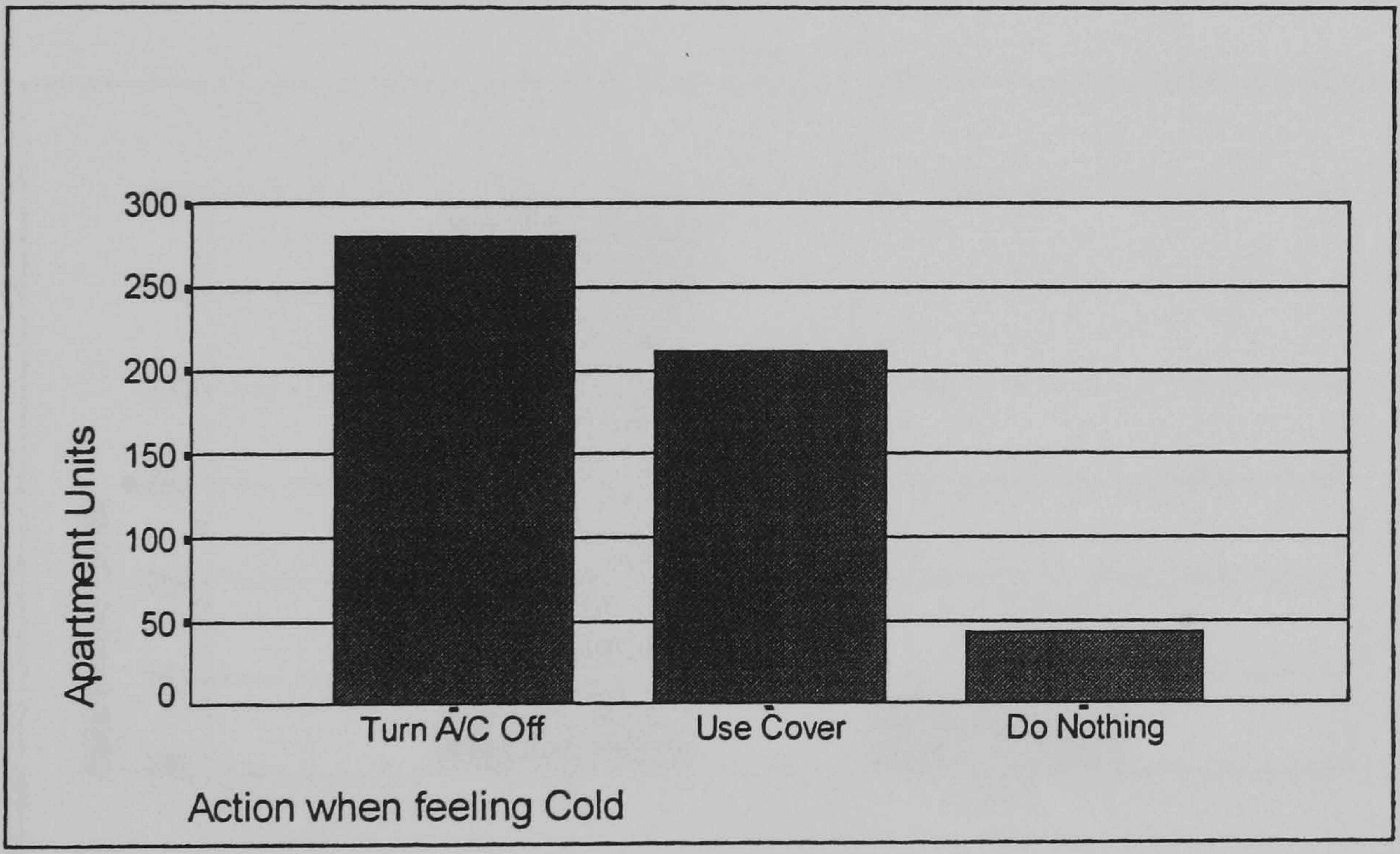


Figure 6. 15: Occupants Reaction towards Over-cold Sensation

6.5 Energy Usage Behaviour and Occupants' Incomes

In this set of questions, the intention was focused on recognising the attitude and the background of the occupants towards the relevant issues of energy. Window openings play a substantial role in indoor conditions as well as in domestic energy requirements. Questions were therefore formulated in such way that a useful understanding of the interaction between windows and occupants could be revealed from the answers.

The occupants first indicated whether their windows were fitted out with curtains or not. The positive responses were 73% and 27% responded negatively. The expectation was that 100% would say they had curtains, but the return of 27% indicates that some units do not have proper curtained protection on their windows. This is an extraordinary matter from the social point of view, where the issue of privacy is of great importance. Whatever the 27% response means, it cannot mean that there is no opaque covering of any kind over windows. From the point of view of social requirements there simply must be a cover for windows, even of wooden mesh, in order to fulfil privacy needs.. The return of 27% must mean that this percentage of respondents did not consider the covering to be a curtain (Figure 6.16).

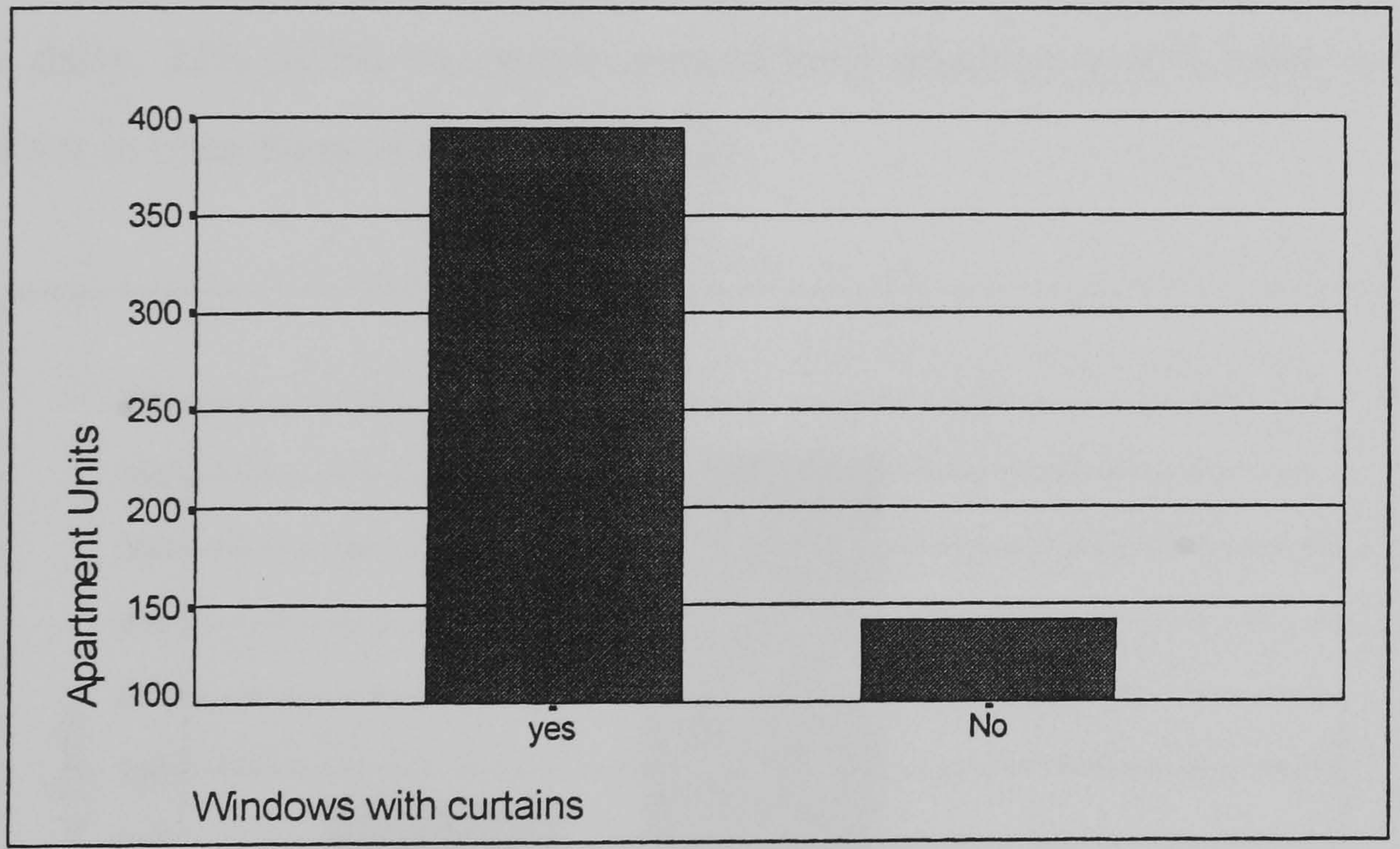


Figure 6. 16: Curtains Provision Pattern

- ***Occupant's Reason for Using Curtains***

The main reasons behind fitting curtains from the occupants' point of view were firstly, to block out the sun's radiation and the strong daylight (this reason was supported by 66% of the total respondents), secondly for privacy reasons (the respondents under this category are 30%), and lastly, for decoration purposes (4% think this should be the main reason for having curtains) (Figure 6.17).

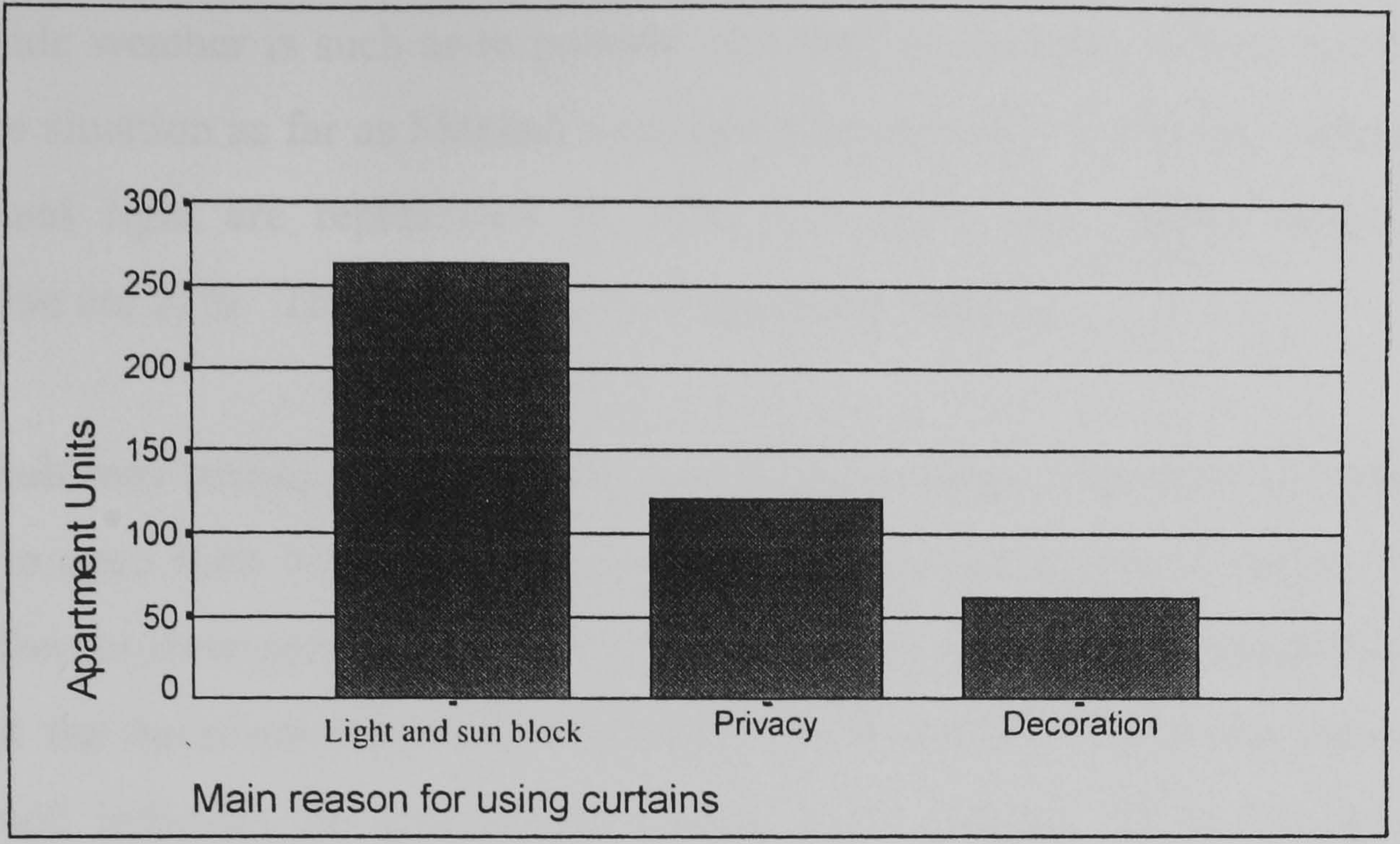


Figure 6. 17: Reasons for using Curtains on Windows

- ***Frequency of Opening the Windows***

As far as the practice of opening windows is concerned, 12% had them open most of the time daily, 22% of the occupants opened their windows a few times daily, and 66% did not to open them at all (Figure 6.18).

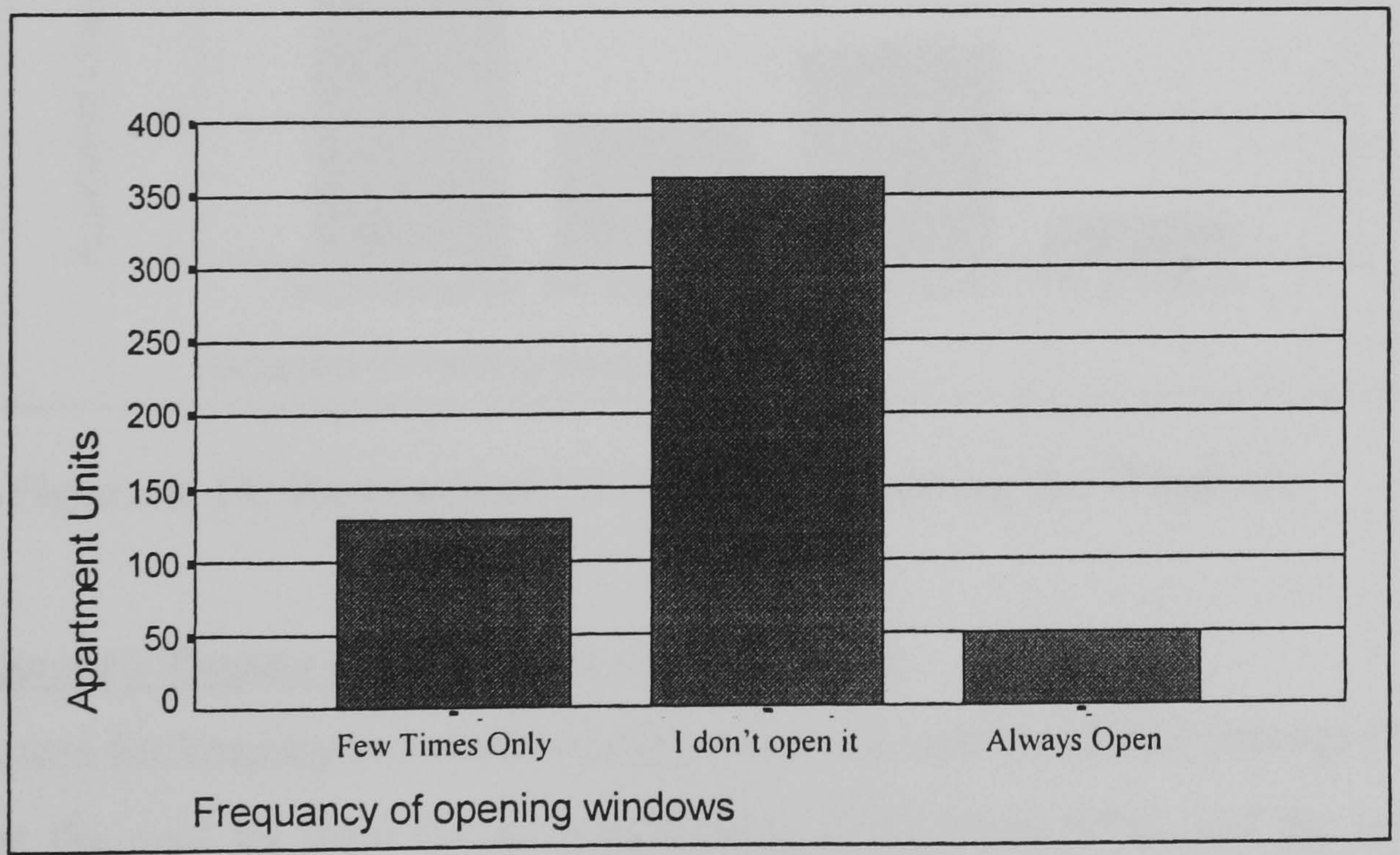


Figure 6. 18: The Habitual Frequency of Opining the Windows

- ***Occupant's Reason behind Opening the Windows***

This pattern of activity is controlled by many factors, and the respondents who responded positively did not always open their window. Some opened them only if the outside weather is such as to provide cool fresh air to enjoy (57%) and this is a very rare situation as far as Makkah's climate is concerned. Those who opened them for natural light are represented by 18%, and those who opened them natural ventilation are 22%. The remaining 3% chose all the reasons.

This result may perhaps appear a little odd, in that a large proportion of respondents appear to open their windows primarily for one particular reason or another, a small proportion for three reasons, but none for two! However, this can be explained by the fact that the questionnaire asked respondents to be specific about one main reason which will indicates the spontaneous attitude, or to indicate 'all of the above' (the reasons) (Figure 6.19).

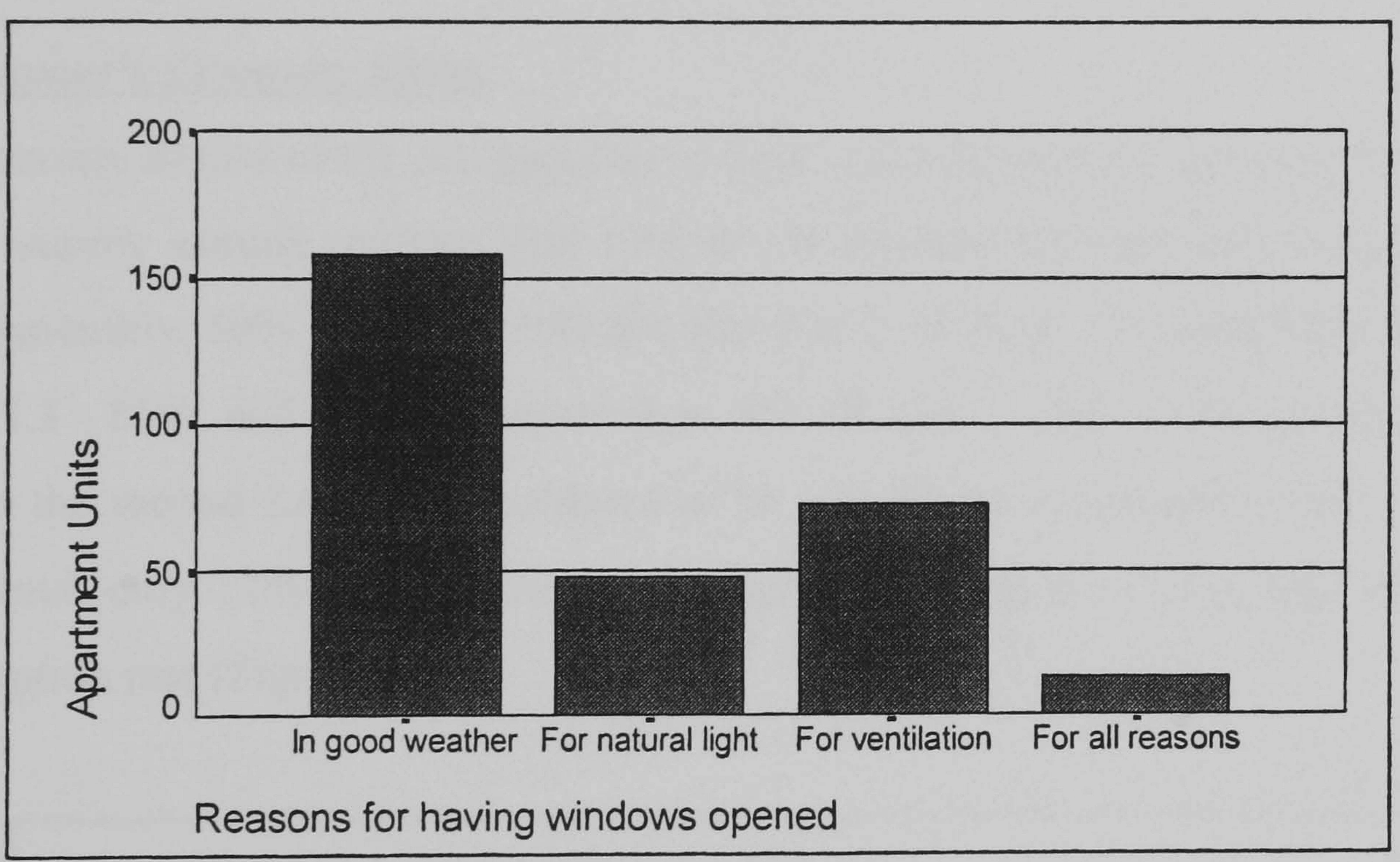


Figure 6. 19: Respondents' Reasons for Opening the Windows

- ***<u>Occupant's Reason behind Closing the Windows</u>***

The reasons for keeping the windows closed are: hot weather (31%), privacy (13%), to conserve the cool air from the air conditioning (5%), noise (2%), and the remaining respondents (49%) chose all the reasons. Once again respondents were asked either to be specific about one main reason, or to indicate all reasons (Figure 6.20).

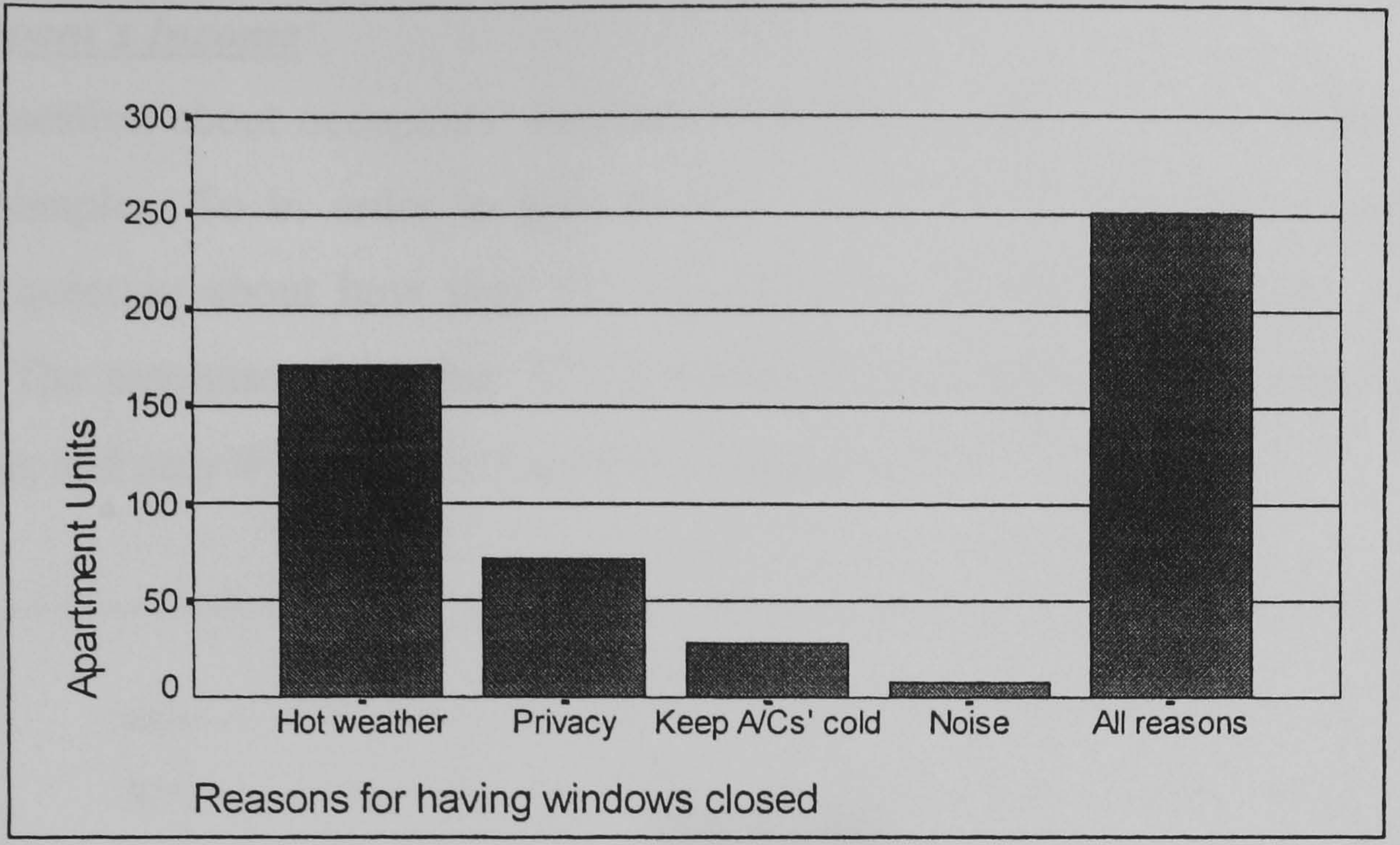


Figure 6. 20: Respondents' Reasons for Keeping Windows Closed

- ***Occupant's Economy Status***

The economy statues of the occupants have been indirectly tested. The electricity bills for the survey sample indicate that 12% of all respondents paid less than 100 SR (£16.7) monthly, 50% paid from 100-200 SR (£16.7 - £33.3), 26% paid from 200-300 SR (£33.3 - £50), and 12% paid more than 300 SR (£50). Half of the survey sample fell into the second category, considered to be a moderate consumption rate. On the other hand, only 12% fell into the last category, considered to be a high electrical consumption rate (Figure 6.21)..

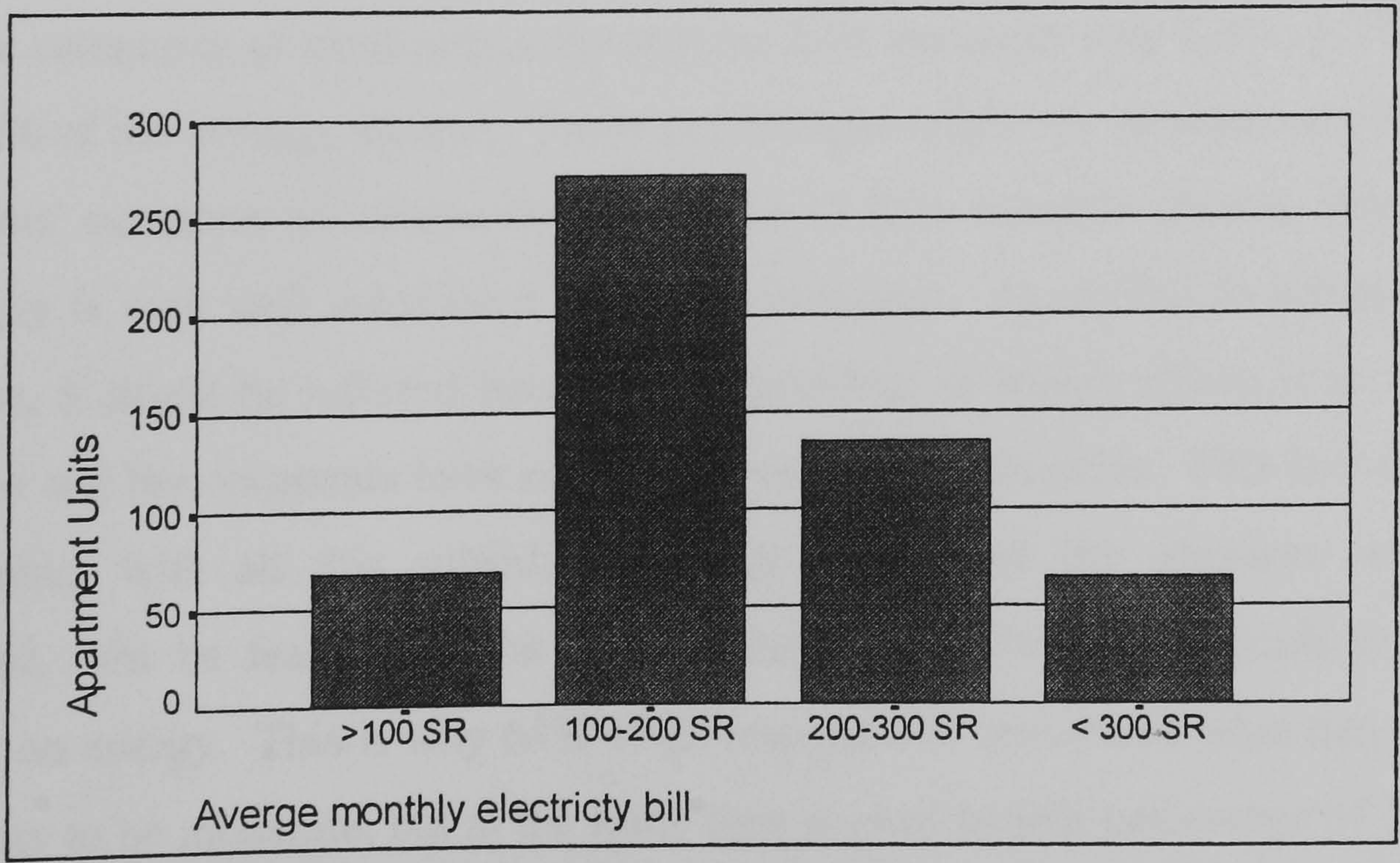


Figure 6. 21: Occupants' Spending for Electricity Service

• ***Occupant's Income***

Direct question about occupants' incomes is neither possible nor acceptable for the survey sample. So in order to gain an idea about the income of respondents an indirect question about how they felt regarding the electricity bills they paid was asked. The response show that 32% considered them high, 64% considered them moderate, and only 4% consider them low (Figure 6.22).

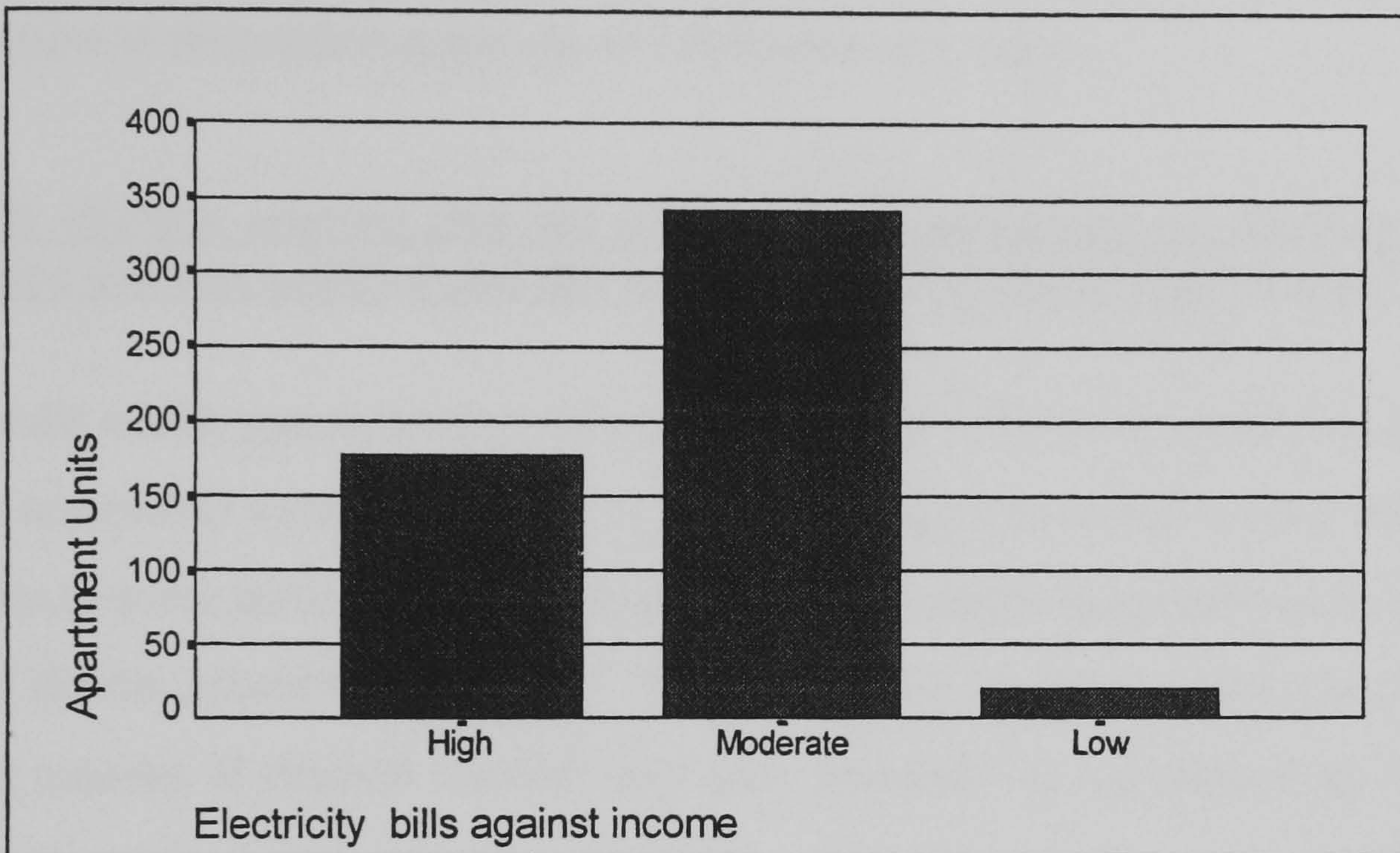


Figure 6. 22: Occupants' Reaction towards Electricity Bill

If we consider the monthly income rate for individuals in Saudi Arabia at the time of the survey to have been approximately 3500SR (£583) for the middle income group, then the categories of electricity consumption bills represent only 2.9%, 5.7%, 8.6%, and 8.6% of the average income. These percentages might not represent any stress on occupants' economic situations in comparison to their monthly income, because the electricity is very well subsidised by the Government. According to pre-mentioned situation, it might be inferred here that the problem of energy prices is an artificial situation and the occupants have no problem regarding this point. This is true for the time being, with all this subsidy to energy prices, but the situation, which we predicted, will be feasible in the near future if the government decide to lift the subsidy on energy. This is why 64% of all respondents considered what they paid for electricity to be moderate, but at the same time a considerable percentage of 32% still considered this as high. This indicates that their income is lower than the standard.

For those of low income, the situation was unacceptable even with the subsidy plan, but for most of the survey portion they found no problem in the prices. This fact led us to an important observation, namely that the issue of energy conservation is of no concern to people as long as people are satisfied with the subsidy arrangement. The crisis may arise if, in the future, the government cancels its subsidy. For the time being the cost of electricity as it is now does not represent a motive for local people to conserve, rationalise, and manage properly their needs. On the contrary, it might be an incentive to their extravagant use of this source of energy.

For this average amount that the occupants of apartments in Makkah pay for electricity, are they satisfied and thermally comfortable inside their houses?

The results of the questionnaire survey indicate that 57% have responded positively and the rest (43%) were not satisfied with the cooling performance in their apartments, often due to some restrictions being imposed on air conditioning working hours by the head of the household (Figure 6.23). This means that the former group is convinced that the amount of thermal comfort they gain internally in comparison to what they pay for electricity is satisfactorily, the later group may tolerate some uncomfortable periods for more economical saving and what they pay is not enough to achieve a comfortable environment.

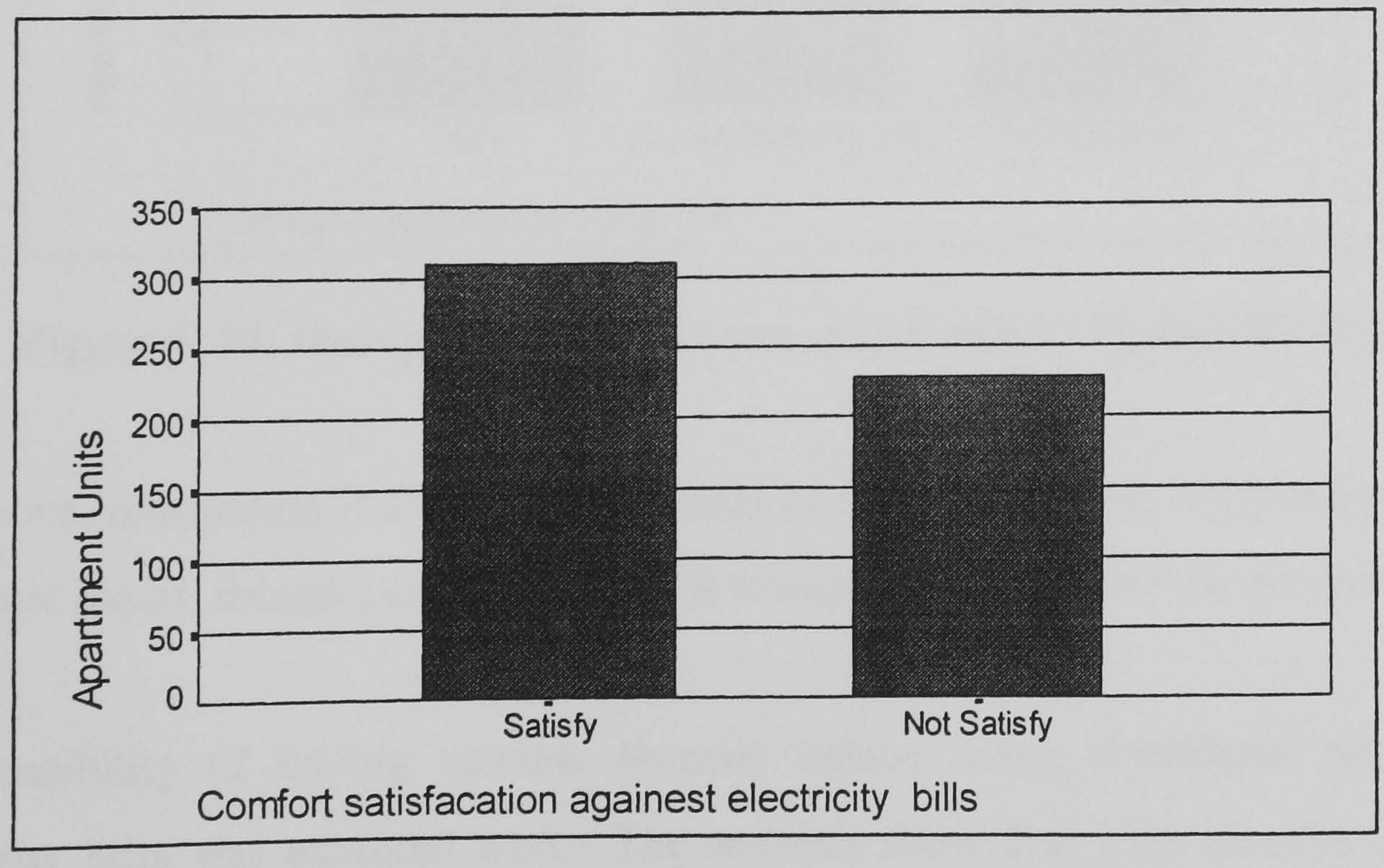


Figure 6. 23: Occupants' Thermal Satisfaction against Electricity Bills

It was very clear to all of the participants in this survey that the most of their electricity consumption went on air conditioning. The responses to the question about which equipment contributes most to electricity consumption were almost 100% agreed on this.

6.6 Occupants' Awareness of the Energy Conservation Issue

Occupants' awareness of their electricity consumption against their thermal comfort has been questioned. A percentage of 39% would keep their apartments thermally comfortable whatever the consumption was, 44% indicated that they would monitor their consumption and not let things get out of control, and 17% were not sure (Figure 6.24).

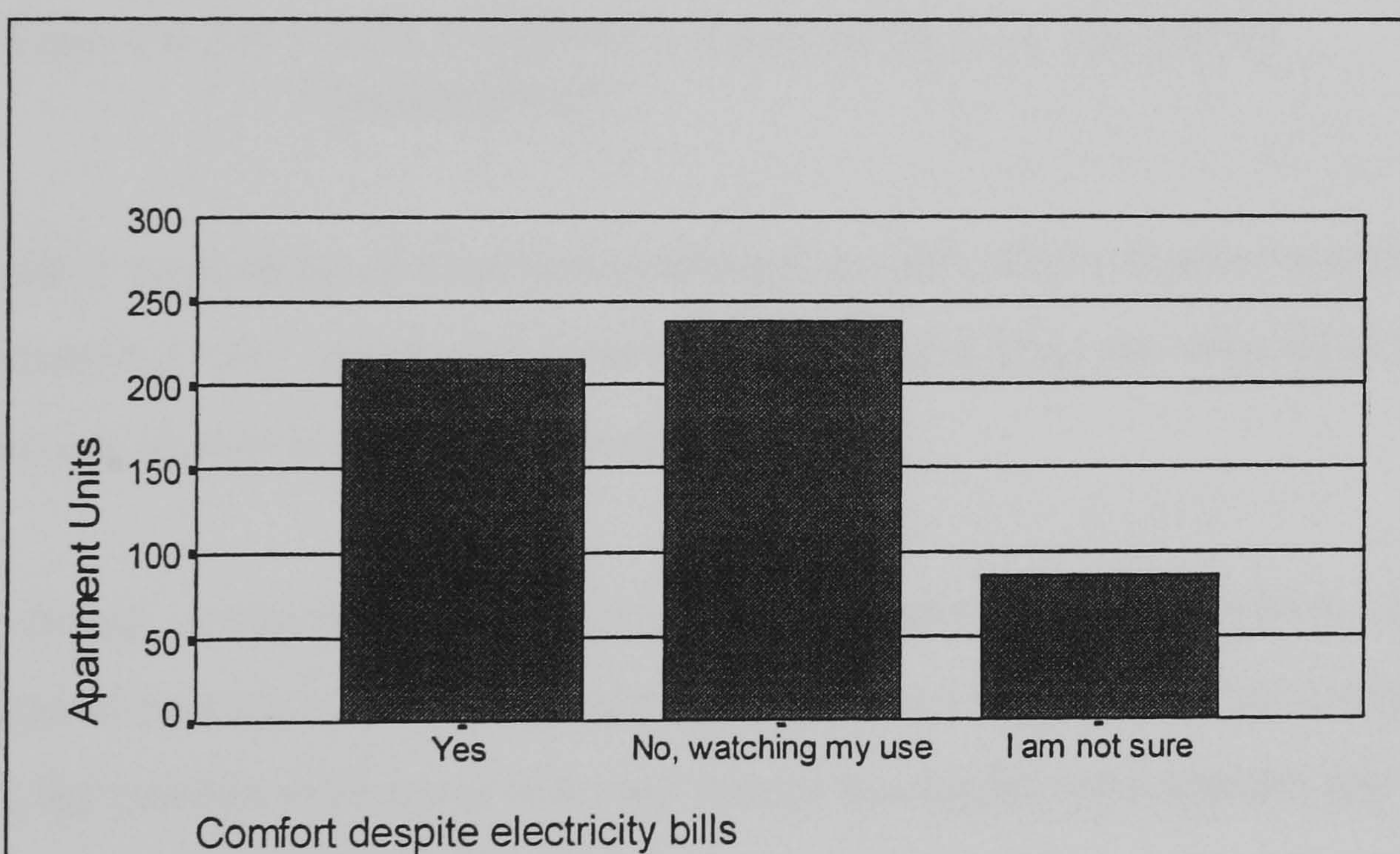


Figure 6. 24: Occupants' Attitude towards Comfort against Economy.

The above information indicates a good ratio of public awareness and concern about economic issues, though people might need to improve their indoor environments.

The possibility of having suitable thermal indoor living conditions and proper electricity bills was explored next. The answers show that 11% thought that they could achieve this by good management of their life style, 29% thought that they could do this but only for some time, and 60% thought that it was impossible to balance the equation (Figure 6.25).

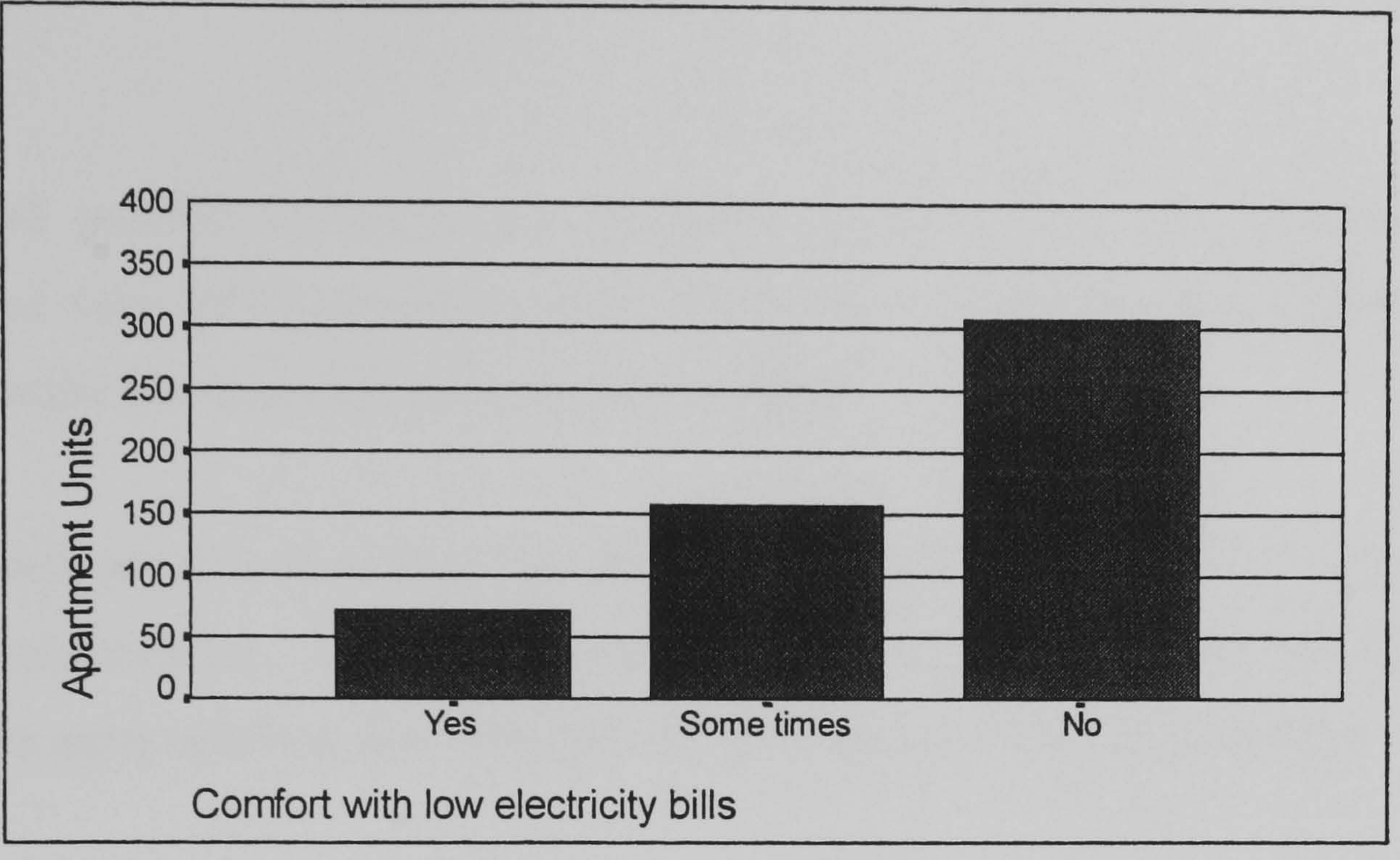


Figure 6. 25: Could Comfort be Achieved by Low Electricity Consumption?.

The positive association of electrical consumption with active thermal comfort inside the apartment is very strong and it seems that, at least from the respondent point of view, the one cannot exist in the absence of the other.

Energy saving measures could be common-sense behaviour that could be picked up and practised instinctively. What might the response of people be to the application of some of the passive techniques that may reduce electricity consumption and yield, at the same time, a comfortable temperature?

The first possible technique would be to control the usage of mechanical devices. A percentage of 5% thought that doing this would have no effect whatever, because they would be uncomfortable. These people are not persuaded of the value of such a step. 47% thought that this step would have a limited effect on electricity consumption, and 48% thought that this step would have a significant effect.

The second possible technique was to reduce the number of occupied rooms inside the apartment. The responses were: 5% did not think this to be of any use, 51% thought it would be quite effective, and 44% believed that this act would have a significant effect.

The third possible technique was to protect windows from sun radiation. The responses were: 20% responded negatively, 69% think it would be quite effective, and 11% thought that it would have a significant effect.

The fourth possible technique was to use controlled night ventilation to cool the interior environment. The responses were: 27% responded negatively, 48% thought it would be quite effective, and 25% think that it would have a significant effect.

The fifth technique was to guarantee the airtightness of the spaces in order to minimise air infiltration. The responses were: 28% did not think it is effective, 54% thought it is quite effective, and 17% thought that it would be significantly effective (Figure 6.26).

Figure 6.26: Passive Energy Saving Measures Background

Occupants practical awareness towards the above mentioned measures has been directly tested by forwarding the following questions:

- **Have the apartment holders deliberately tried to apply these techniques in their daily activity?**

27% responded positively and indicated that they have applied all of these techniques in order to save energy. A large proportion of respondents, 61%, applied these techniques partially, and thus showed that they have some awareness of conservation issues. The rest of the sample (12%) responded negatively, and they seemed unaware of the techniques involved (Figure 6.27).

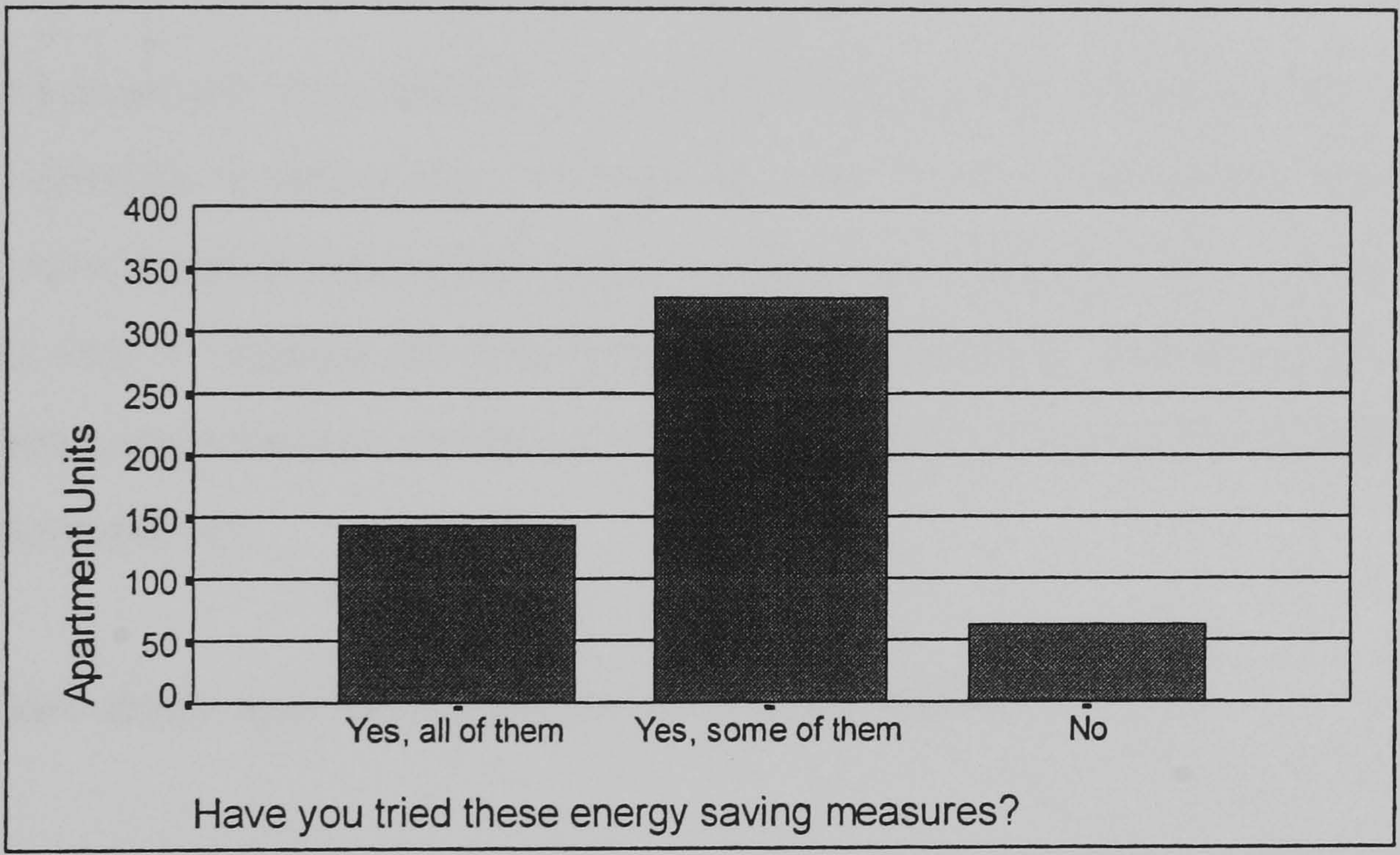


Figure 6. 27: Occupants Practical Tendency to Energy Saving Measures

- **Do public know about insulation materials and its potential effect?**

48% of the total who responded had an idea about these materials from commercial advertisement and through public information media. The respondents who did not have any idea about insulation materials was 33%. This figure is a considerable one, which indicates the lack of interest from the occupants with regard to this subject. The rest of the respondents (19%) were not sure about their information or had confused information (Figure 6.28).

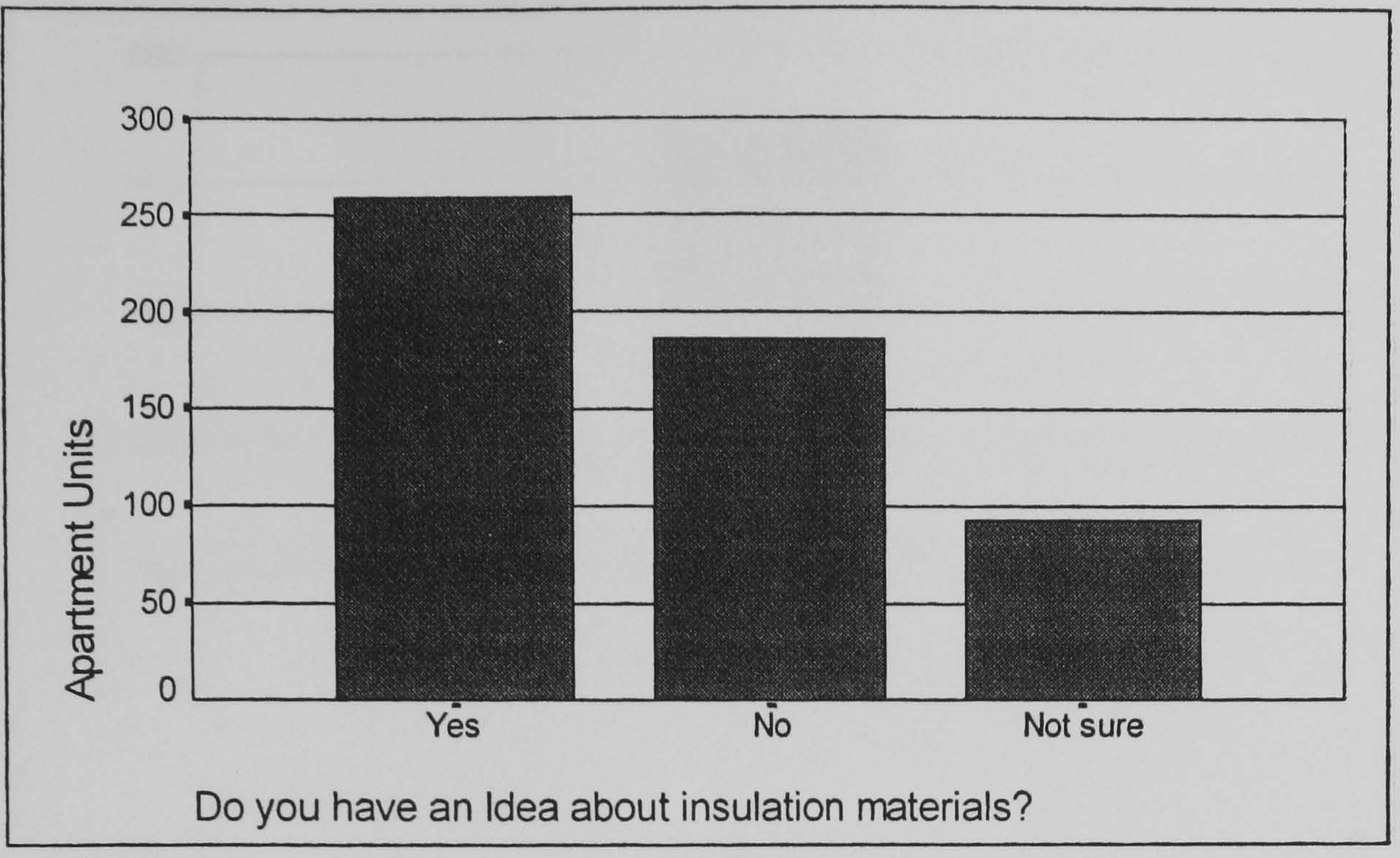


Figure 6. 28: Occupant's Awareness about Insulation Materials

Technical issues are often difficult to comprehend and digest, especially for people of simple education backgrounds. In Makkah most of the local people usually lose interest once a matter becomes technical and hard to understand. To overcome these obstacles and to increase the awareness of energy concerns as a national target, a simple and comprehensive campaign should be planned to spread the knowledge in a straightforward way.

- **But how many apartments are there with insulation?**

The answers to this question show that only 8% of the total sample stated that they lived in apartments with insulation, 85% said they did not, and 7% did not know. This is means that the vast majority of apartment buildings are not insulated (Figure 6.29).

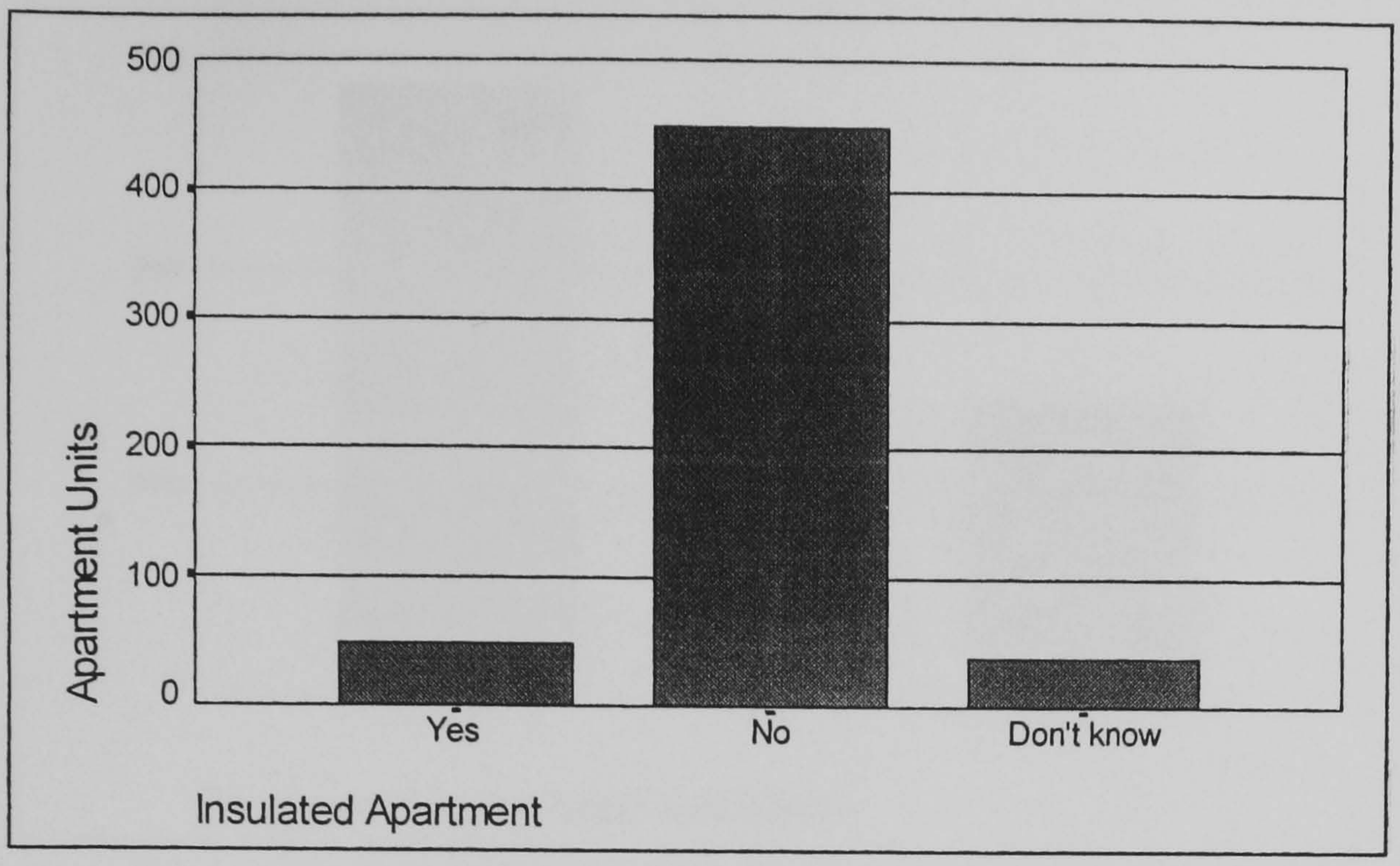


Figure 6. 29: Insulated Apartment Profile

For those who have an insulated apartment, **do they experience better indoor conditions than an apartment with no insulation?**

Among the 15% referred to above, made up of those who had an insulated apartment and those who did not know whether they had one or not, 7% (of the overall total) thought that the situation was better in an insulated apartment, 5% thought it was not, and 3% thought that there was no difference.

- **What people feel if they have been offered an insulated apartment. Would they move and leave their existing one?**

This question reveals the householders' attitude towards a new situation that might or might not improve their thermal indoor conditions and save them some money. Also it exhibits people's attitude towards moving house.

The responses to this question demonstrate the following attitudes. 54% stated they would move to an insulated apartment, 17% responded that they would not move because this not a matter important enough to cause them to move to another home. The rest of the sample (29%) also responded that they would not move because they doubted whether the new situation would have any advantage over the existing state of affairs (Figure 6.30).

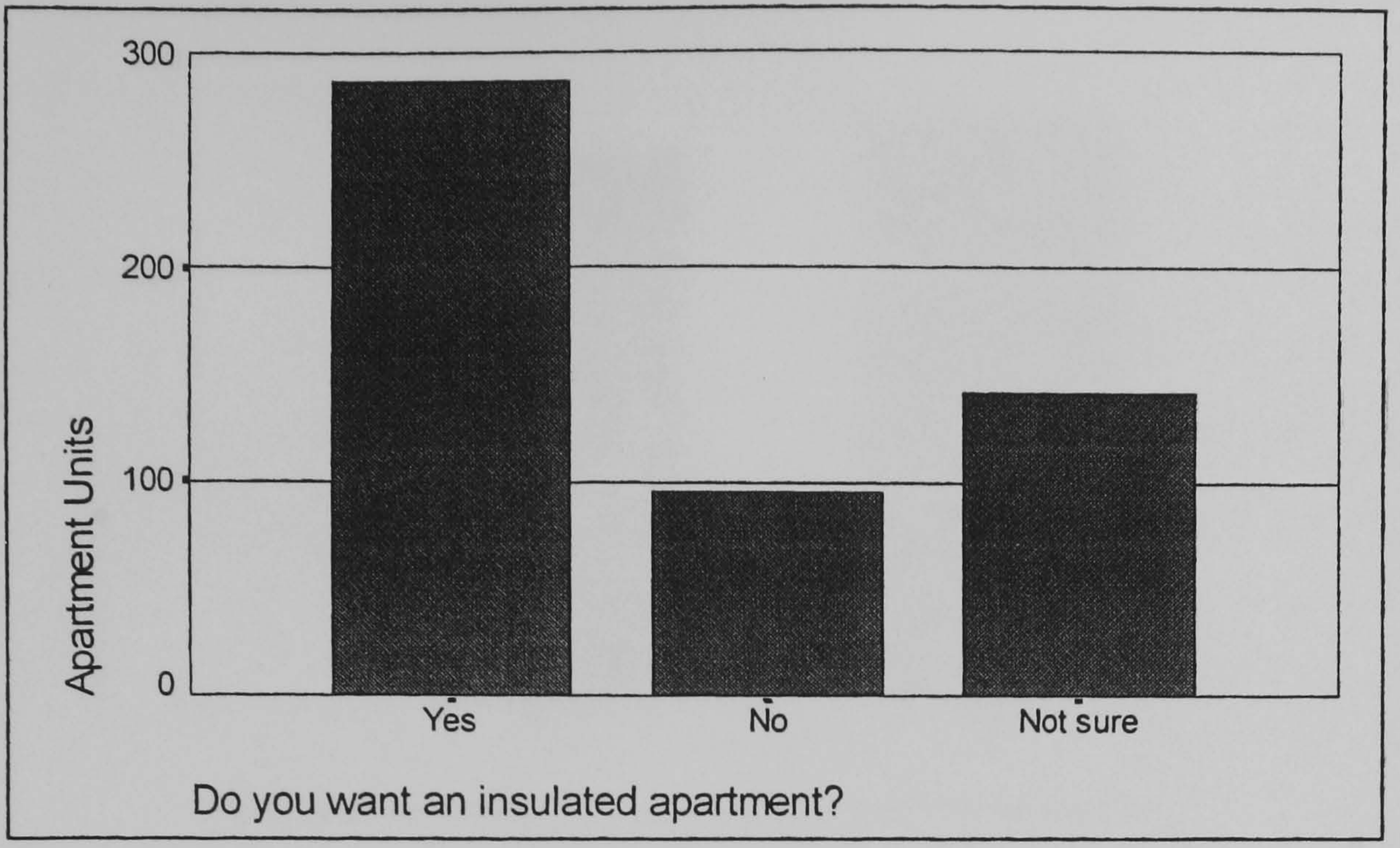


Figure 6. 30: Occupants Reaction towards Moving to a new Situation

The total for those who would refuse the change is 46% and of those who would accept the change it is 54%. The fact that these proportions are almost equal highlights the fact that the desire for new and improved indoor conditions is still surrounded with much fear and uncertainty.

- **Assuming that people own their own houses, would they act positively if they were asked to refit their apartments with insulation?**

This question touches upon the degree of willingness amongst people to apply and follow any proposed amendments in building rules and regulations.

Once again, an equal response was noted. 49% responded with Yes and 51% responded with No. These two opposing standpoints indicate that there is a long way ahead for advocates of energy conservation before they can achieve their ultimate target (Figure 6.31).

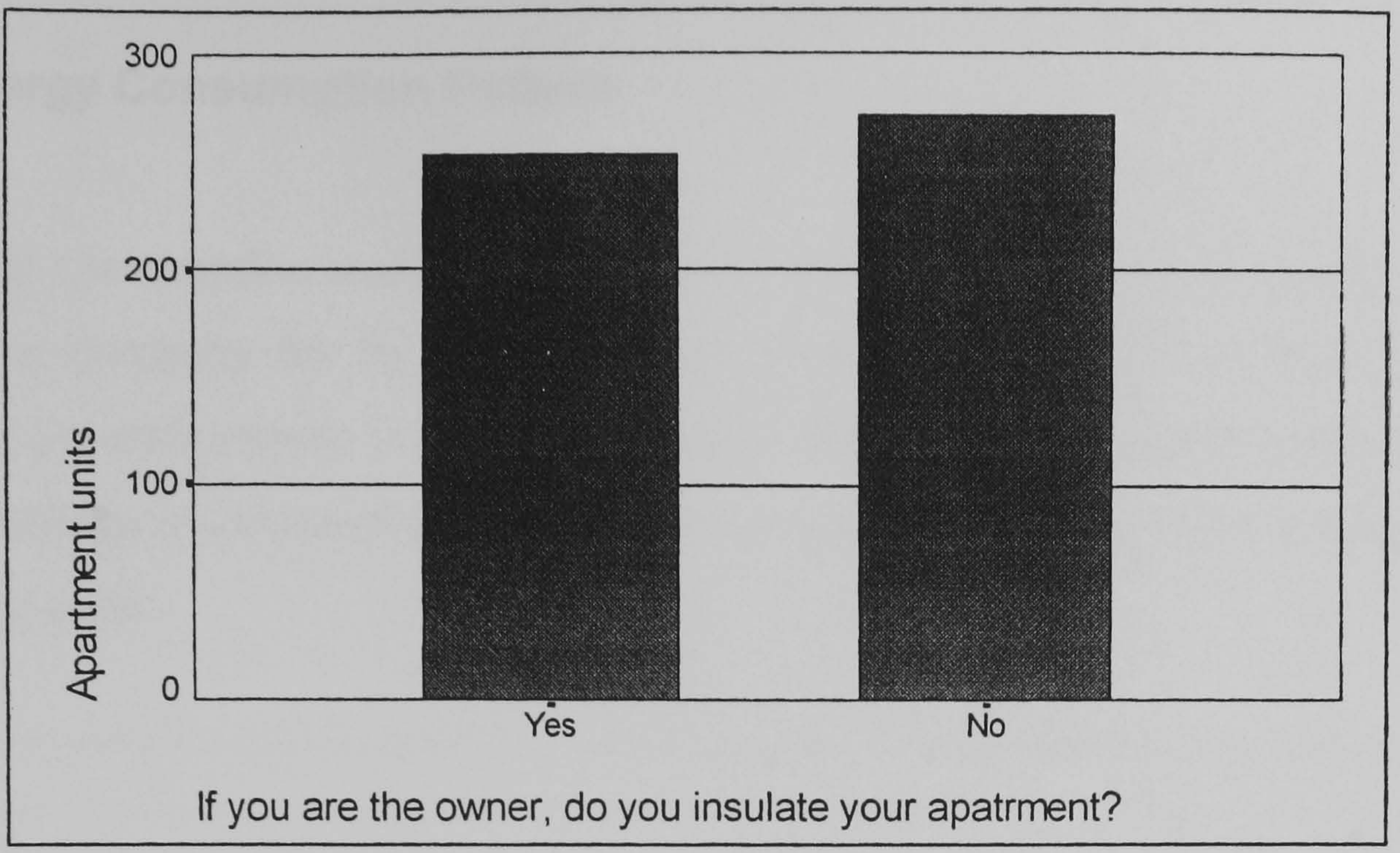


Figure 6. 31: Occupants Reaction towards Building Improvement

Finally, what are the reasons behind the objections for those who responded negatively? The process of installing insulation materials in existing building is quite an expensive operation. This opinion was supported by 70% of this 'No' group. The second reason for not fitting insulation in existing apartments was that the operation is destructive and causes great disruption to occupants. 15% of the 'No' group express this concern. The remaining proportion of 15% said No because they were not quite positive about the effectiveness of insulation and they needed more information and study to reach a positive decision (Figure 6.32).

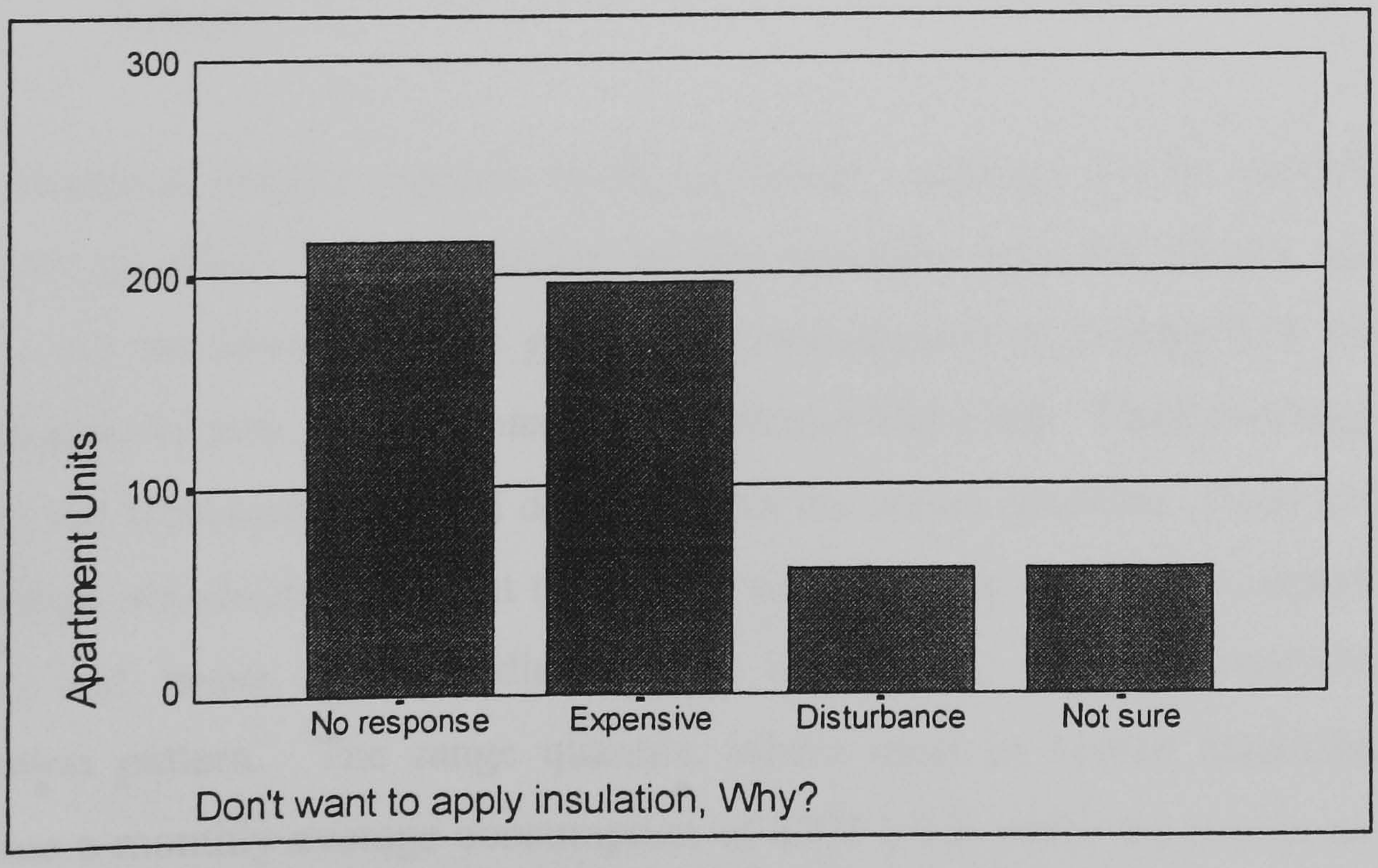


Figure 6. 32: Obstacles Facing Building Improvement

6.7 Energy Consumption Pattern

Electricity consumption readings for one year (1997-98) have been obtained from the Electricity Company for the survey sample. The readings of the 12 months were averaged for each sample in order to recognize the pattern of monthly consumption. These readings are illustrated in Figure 6.33 as electricity consumption is graphed in ascending order.

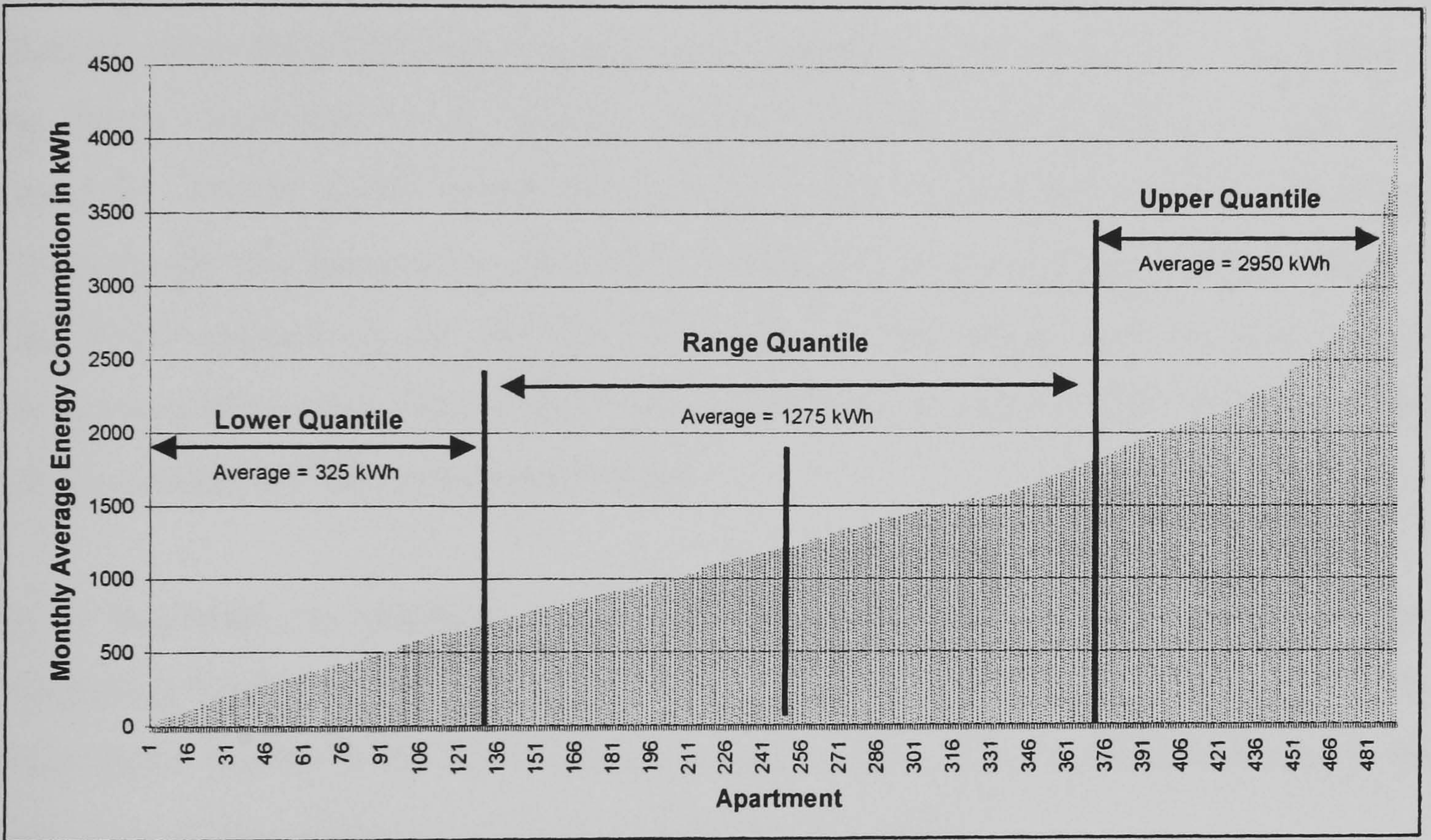


Figure 6. 33: Monthly Average Energy Consumption Profile for the Survey Sample

The consumption pattern inferred by the electricity readings can be classified into three major quantiles: lower quantiles, middle quantiles (quantile range), and upper quantiles. In the lower quantile group, the consumption is average 325 kWh, the minimum goes to zero, and the maximum is around 650 kWh. These readings in this group are not representatives and do not reflect the actual situation. They have very low readings, which indicates that these units somehow are not fully occupied during the year, and hence these reading cannot be counted on for establishing the consumption pattern. The range quantile, where most of survey respondents are hosted, has a monthly average consumption of 1275 kWh while the minimum is 650 kWh and the maximum is 1900 kWh. The upper quantile represents the higher consumption pattern, its monthly average is 2950 kWh, the minimum is 1900 kWh, and the maximum exceeds 4000 kWh. This group has a relatively high consumption rate and could be attributed either to the size of the apartment, large family size, or good economy statues.

The major characteristic that can be noticed from the above figure is that the consumption has no regular pattern, hence no solid picture can be established for the domestic electricity consumption. This type of diverse consumption pattern has been formed as a result of several social factors that characterized Makkah's families. Among these factors are the unsystematic occupancy patterns that differ from family to family according to the holiday periods, summer, spring, *Ramdan*, and *Hajj* holidays. People usually spend their holiday in other places that may be cooler than Makkah and this reduces the electricity consumption rates for these months. Most of the lower quantile group and the first group of the range quantile have a light occupancy which may refer to this reason. Nevertheless, other groups show the effect of the summer by high consumption rates.

It is important to establish a reference value for monthly consumption in the apartment buildings out of these profiles. This value is to be used to validate the simulation results in the forth-coming analysis, hence give an indication about the accuracy of the simulation program adopted for this study.

In order to do this the following scenario has been adopted; the lower quantile has been omitted from the calculation for its impracticality and only the range and the upper quantiles have been considered. The monthly average consumption for the range quantile is 1275 kWh and for the upper quantile is 2950 kWh. Monthly Consumption Reference Value for the Questionnaire (MCRVQ) is 2113 kWh ((1275+2950)/2). This MCRVQ is the most practical value that can be inferred from this information and can be used to indicate the monthly consumption rate in practice.

The survey sample is a homogeneous. Therefore, an averaging the overall monthly consumption of all samples has been established and represented on monthly basis in order to have an idea about the annual distribution profile for energy consumption, (Figure 6.34).

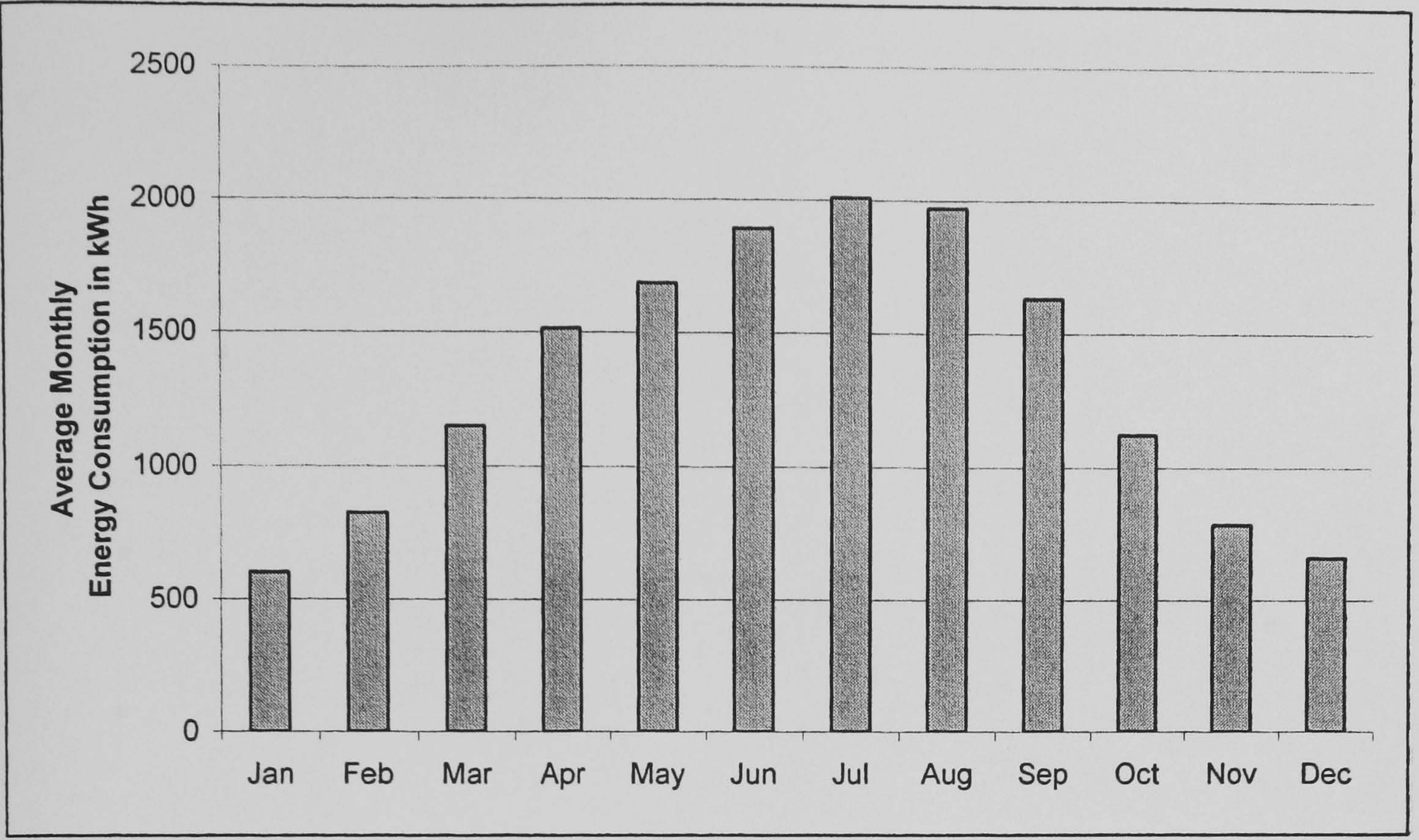


Figure 6. 34: Average Monthly Energy Consumption Profile

Three major periods can be recognized in connection with consumption rate, first one represents high consumption period in summer months (Jun, July, and August). The peak can be seen in July with a consumption rate of 2020 kWh. The second period is a relatively moderate one and it represented by the months of April, May, September, and October. The consumption rate for this period is between 1500- 1700 kWh. The third period indicate the months with lower consumption represented by January, February, November, and December. The consumption for this period is between 700 – 800 kWh.

The aim of introducing the above profile for the existing apartment buildings is to recognize the following; firstly, to know the impact of the monthly climatic situation, secondly, to know the impact of the occupancy pattern. More energy consumed in summer months, normally, because of the high temperature profiles. This is the ultimate situation of the year that should be taken into consideration from an early design stage. Occupancy pattern through out the year is a difficult task to determine among the families for the pre-mentioned reasons.

Chapter 7

The Measurement Survey

Chapter 7

The Measurements Survey Data Analysis

(Data Analysis of the Selected Case Studies)

7.1 Introduction

Field studies have always been a realistic ground for conducting research and observing phenomena. Investigations through case studies are a frequent mode of applied research in all disciplines and fields. It is but one of several ways of doing science research. Other ways include experiments, surveys, histories, and the analysis of archival information (Robert, 1994).

The case study as a research methodology is a technique that is mainly used when 'what' or 'why' questions are being asked. What is going on in real situations (descriptive approach) and why this happening (explanatory approach) usually are two fundamental questions that the case study seeks to answer.

Investigating the thermal behaviour of apartment buildings is a topic that needs descriptions as well as explanations, and it is a very complex topic, where many interrelated factors are involved. Accurate explanations require observations that build upon facts.

It is neither practical nor reliable to generate factual information from a remote site, and it is furthermore necessary to be in close proximity to problems to achieve accurate results. With this in mind, case studies have been adopted here in order to investigate the contemporary phenomenon within its real-life context, and to yield a solid body of information to be tested against different theories.

The aim of this stage of the fieldwork undertaken by the researcher was to monitor closely the built environment of apartment buildings and the influential factors characterising their existing thermal performance. These buildings are generally envelope-dominated and their energy use is subject to the weather. Because they have less stringent lighting requirements, relatively low equipment loads, and greater surface-to-volume ratio, buildings are less influenced by internal loads if rational attitudes have been practised, and therefore more influenced by the climate where there no control can be applied on this natural factor. Nevertheless, the behaviour of the occupants and their socio-economic status are still critical issues for energy analysis and can not be under-estimated by no means.

This part of the fieldwork attempted to formulate the characteristics of thermal performance and energy process occurring inside the individual exemplar apartment, which it was intended would lead to a better understanding of the energy requirements for this type of residential stock.

Sets of eight apartments, which represent most of the variable configurations in apartment buildings stock, were inspected. These apartments were selected according to their vertical locations, floor area distributions, and geographical orientations. Social restrictions, e.g. privacy, inaccessibility, public awareness, and the limitations of the survey time made it difficult to enlarge the number of apartments under direct investigation. However, more data have been collected from a larger sample, 600 participants, in the questionnaire survey.

Method of analysis concentrated on describing the thermal integrity of building envelopes, the current patterns of residence behaviour, and cooling, lighting, and equipment characteristics.

7.2 Description of the Case Studies

Except for other types of residential dwelling units, i.e. single family detached and semi-detached villas, apartment buildings in the Makkah area are physically almost the same. They are commonly low-rise buildings. Residents are of the middle income group, and they have much the same average number of occupants. Moreover, they are all surrounded by similar microclimate conditions.

All the residents of the apartments were tenants and not owners, and this helped to close any gaps of discrepancy in life style that might have been present if other residential types had been taken in consideration. The case studies have been selected from three buildings in different locations, taking into consideration the need to study apartments of diverse geographical orientation and vertical position in order to build a representative sample out of these cases.

The physical characteristics of the case studies are presented in Table 7.1. The set of apartments is classified according to their vertical locations, embodying all possible arrangements, i.e. top, middle, and ground floor, and also maintaining the four-geographical orientation as can be seen in Figure 7.1.

Due to the lack of choice factors dictated by social obstacles, and the size and number of rooms in each apartment, were identified as the only available random elements. However, they still represented the average size of typical Saudi apartments. Furthermore the number of occupants in the case studies was generally within the average size of typical Saudi family, i.e. 2-6 persons. The internal layouts of the case studies are shown in Figure 7.2.

Cases 2 and 6 are located on the top floor and are entirely exposed to sun radiation. The roof construction is insulated with 5cm polyurethane foam board in Case 2, while Case 6 has no thermal insulation. Cases 1, 4, 7, and 8 are located on the middle floor. Except for Case 4, which has an insulated envelope, the cases are similar in construction. Cases 3 and 5 represent ground floor apartments. The materials available on the local market have strongly influenced the construction system of the modern housing stock within the last 20 years. Reinforced concrete has dominated the construction industry as a primary material, along with other locally produced materials for building fenestration, i.e. concrete, and clay blocks and bricks.

Location	Case	Number of Occupants	Floor Area m^2	Outside Wall Area m^2	Glazing Area m^2
Top floor	Case 2	7	147	108	12
	Case 6	5	108	113	18
Middle Floor	Case 1		147	108	12
	Case 4	5	190	123	17.5
	Case 7	7	165	108	17
	Case 8	8	165	108	17
Ground Floor	Case 3	6	136	108	14.5
	Case 5	6	108	113	16

Table 7.1: Physical Description of the Case Studies.

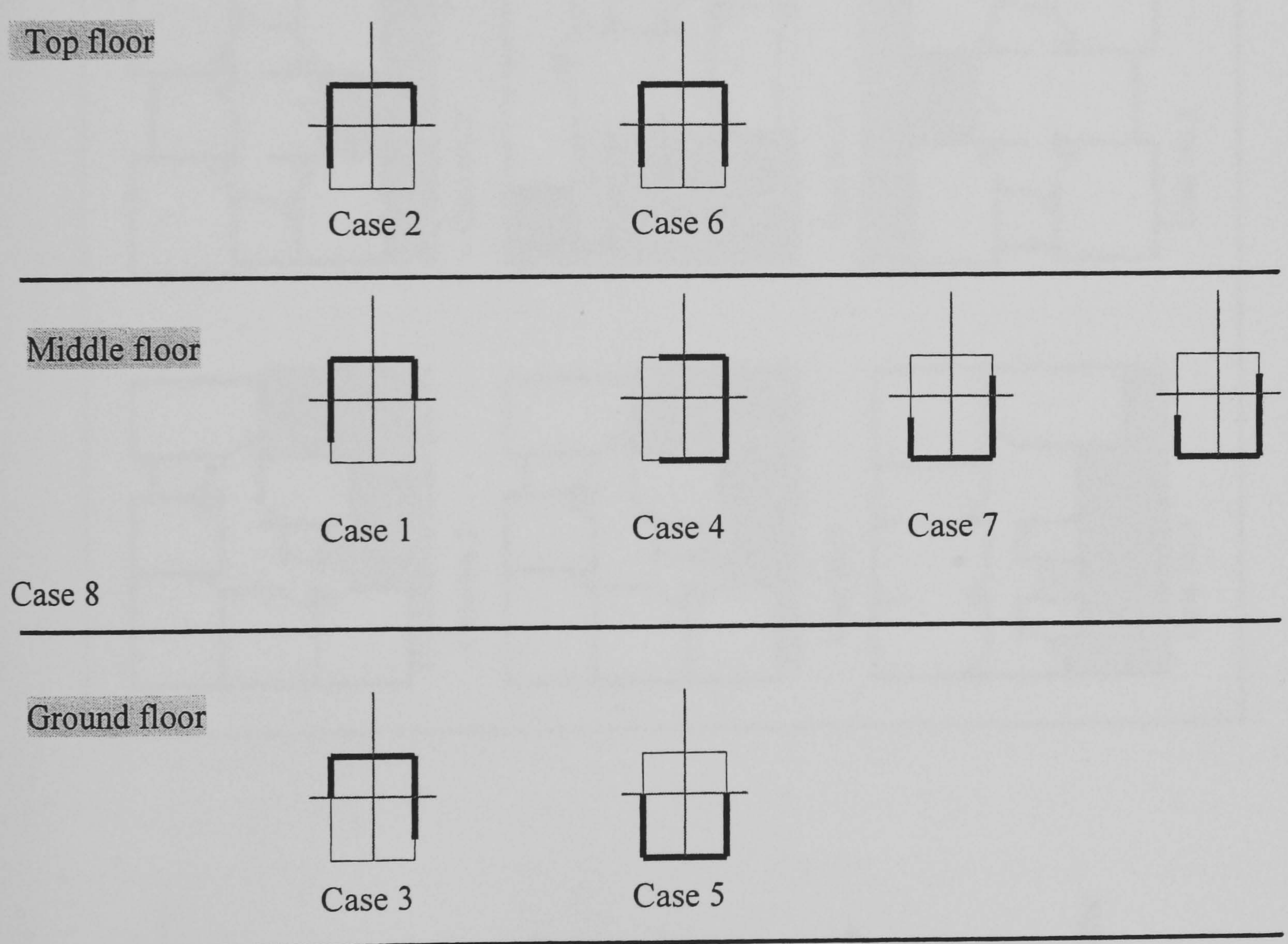


Figure 7.1: Physical Orientation for the Case Studies

The Case Studies

1. Top Floor Apartments
- Case No.2
- Case No.6

2. Middle Floor Apartments
- Case No.1
- Case No.4
- Case No.7 & 8

3. Ground Floor Apartments
- Case No.3
- Case No.5

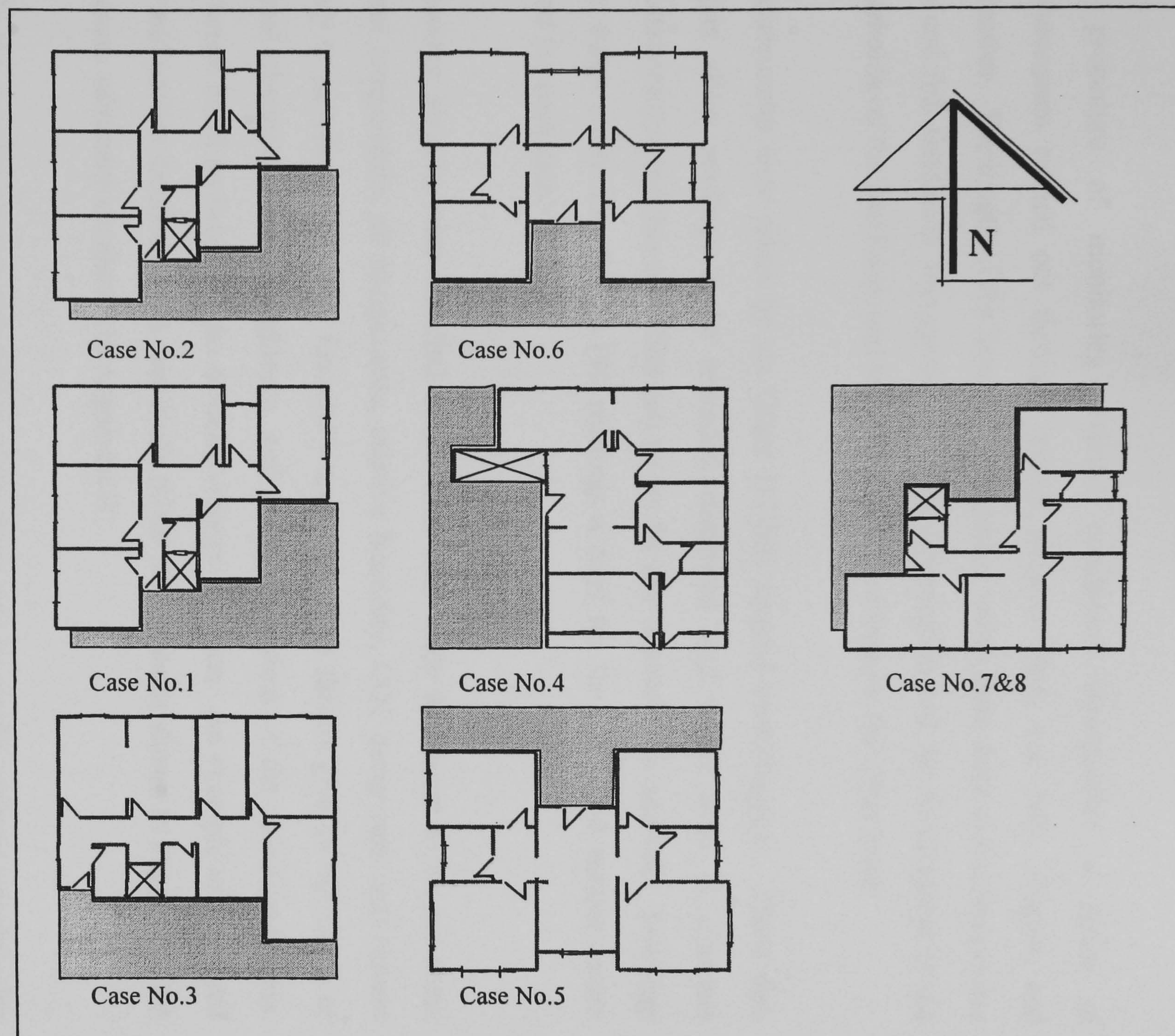


Figure 7. 2: Physical Configuration for the Case Studies

7.3 Measurements and Data Handling Procedure

The procedure of monitoring internal conditions incorporates a series of measurements carried out through typical summer days, e.g. July, August, and September. The length of the measurement period varies from three to five successive days and this limitation was governed by the cooperation and the involvement of the households on the one hand, and the insufficiency of time on the other hand.

Measurements were taken by six Grant (12-bit) squirrel meter/loggers. These data loggers allow readings to be recorded, displayed, and stored from 11 channels simultaneously, and this operation can be set for any desired time intervals. Readings were taken every 15 minutes (96 readings a day) for the permitted measurements period for each case.

Measuring sensors were installed inside each case study apartment to record mean radiant temperature, air temperature, relative humidity, CO2 decay rate, and current supply to air-condition units. Generally speaking, these factors give an indication of thermal characteristics, air tightness, and energy behaviour of the monitored cases, and hence build an image of the domestic energy situation. An example of measured data and probes locations for a case study (Case No.1) can be shown in Figure 7.3, the rest cases summary are shown in Appendix II.

While the logging process was taking place there was no predetermined schedule for any internal activity or use of time inside the study apartments, and the collected data is a genuine expression of the existing daily life situation. Although the logging period was not long, the data recorded is still significant and informative.

Except for CO2 decay rate and air condition current readings, which met with some obstacles, all other readings were taking in very precise manner. Electrical wiring systems hindered the air conditioning current reading attempts in some cases, and the custom of leaving doors open also hindered the attempts at monitoring the CO2 decay rate in other cases. Only one room, in Case 3, was left without measurement due to privacy reasons. The difference between MRT measurements and air temperature was slight especially in the air-conditioned zones. Therefore, air temperature measurements have been taken for expressing the indoor situation as illustrated in the following part of this chapter.

Besides the information collected from direct measurements there were interviews with the households regarding their utilization pattern of energy and their personal comments. The interview covered many points such as electrical domestic appliances in each apartment, air conditioning units, family members, activities, economy status, and comfort/discomfort sensations.

The electricity consumption rate for each apartment in kWh was obtained from the Electricity Company for 12 consecutive months for year 1998-1999.

Data has been downloaded from the loggers, tabulated, and graphed accordingly. These graphs illustrate the interaction between the measured factors in such a way that the rules of each factor can clearly be established. Graphs have been drawn on a 24-hour time scale for all measured spaces (see Appendix II).

DATA RECORD SHEET

Case no. : Three

Apartment Reference: Mr. S. M.

Date of record:

Start Logging : 2 Aug. 1998

End Logging : 8 Aug 1998

Logging Details:

Probe No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1		1			
2		3			
3		2			
4		4			
5		2			* A/C current
6					
7		4			* CO2 probe
8					
9		2			* RH %
10		4			* RH%

Building Details :

Location : Ground Floor Apartment

Construction :

1- Reinforced concrete frame structure
2- Hollow ceramic block for the envelope covered with sand cement rendering
3- Single glazing windows with aluminum frame

Notes :

. Three adults + Three Children
. All windows are with curtains
. Window type A/C units are fitted in all rooms
. Living room has a daily occupancy of 16 hours
. No A/C in the Living space
. The living space is centrally located and has no outside surfaces

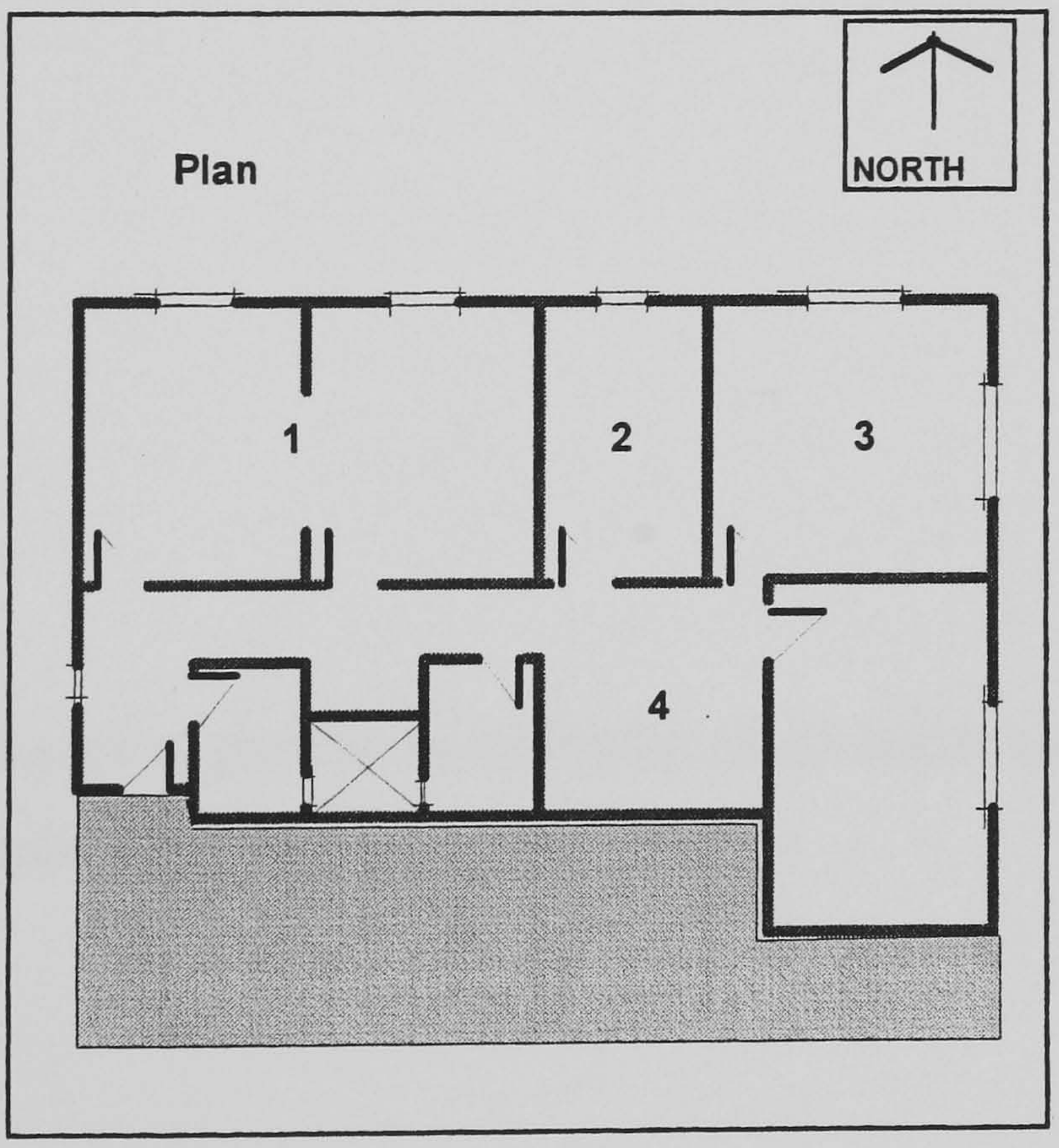


Figure 7.3:
Typical Data Record, Measurement Types and Locations for the Case Studies (Case No.3).

7.4 Quality of Indoor Thermal Condition

Indoor thermal conditions can be described in terms of indoor air temperature and relative humidity level, which in turn are functions of more complicated system of heat transfer mechanism, e.g. heat transfer through building fabrics and heat generated internally by people, equipment, and lightning.

As far as human responses to the indoors thermal environment are concerned, an individual single factor cannot explain the phenomena independently. In fact it is the combined effect of all these factors mentioned above that can produce a realistic evaluation of the physical context. Moreover, the influence of any factor depends on the levels of the other factors.

The measurements, which have been taken to monitor indoor situation, can be listed as following:

- Air temperature
- Relative humidity
- CO2 decay rate
- Air conditioning current.

The last two parameters have been assigned to provide an indication about indoor air infiltration rate and energy usage for cooling purposes.

7.4.1 Air Temperature

Air temperature is the simplest practical index of cold or warmth under ordinary room conditions. It is usually a result of heat accumulation developed or generated in space. Its use as a single indicator of a comfortable thermal environment is limited, especially when sweating from human bodies occurs or when high-power radiant sources are present. Therefore, air temperature alone does not represent a reliable measure of human reaction to warmth and cold, and hence cannot be taken as a comfort scale without considering the other measurements.

The measurement of air temperature is relatively straightforward provided that the effects of thermal radiation between the sensor and surrounding surfaces are limited. Since the measurements are taken as thermal observations, the description of each measure in each case will only pave the way for comparison between different buildings.

It has been noticed from the analysis that the indoor air temperature profiles for the case studies are characterized by steadiness and homogeneity. Without mechanical modifiers there is no sharp drop or sharp rise in temperature of great significance. Indoor conditions have developed a phenomenon similar to a thermal oven, where heat is distributed evenly inside the space, and this can be clearly observed in unconditioned space, especially in Case 1. Case 1 represents an unoccupied apartment where no mechanical cooling is in process. This case serves to establish background knowledge of extreme situations.

It can be seen from Figure 7.4 that the daily air temperatures inside the apartment rooms range from 35°C to 37°C, regardless of room orientation, location, and the period of the day. The outside dry bulb temperature is very steady for this time of the year, and there is no big diurnal and nocturnal fluctuation. This causes a heat balance situation occurring inside this unit, were there is no time for the building envelope to cool down and start to heat up again. The temperature recorded in this case represent a pure face load of the heat gain that are imposed on the parameter areas, and no other internal load has been considered due to unavailability.

It has been noticed that room orientation has a negligible influence on temperature levels and the difference between north-, east-, and west-oriented rooms is tiny. Obviously internal conditions are very uncomfortable in this situation, being only 3°C to 5°C lower than the outside temperature.

The temperature profile is more interactive in Case 2. The maximum temperature is 36°C and the minimum is 32°C in unoccupied rooms, and this similar to Case 1. For a heavily occupied room, the temperature follows the operational pattern of the air conditioning. It ranges from 22°C to 30°C when the air conditioning is off. Although this apartment is situated on the top floor with its roof exposed to direct solar radiation, the temperature ranges do not show excessive rise as expected. This is might be related to the insulation layer on the top of this roof. The corridor has a steady temperature line of 33°C. Room.3, which is used as a kitchen, has a relatively high temperature though the air conditioning unit is on. Figure 7.5 illustrates the temperature profile for Case 2 for one typical day.

Case 3 is a ground floor apartment and the temperature profile in this case has relatively lower readings. The maximum temperature recorded here is 34°C inside the unoccupied room. The temperature inside occupied rooms with air conditioning reaches a maximum of 30°C when the air conditioning is off and goes as low as 21°C for the coldest period of air conditioning operation hours. The thermal profile of this case can be seen in Figure 7.6.

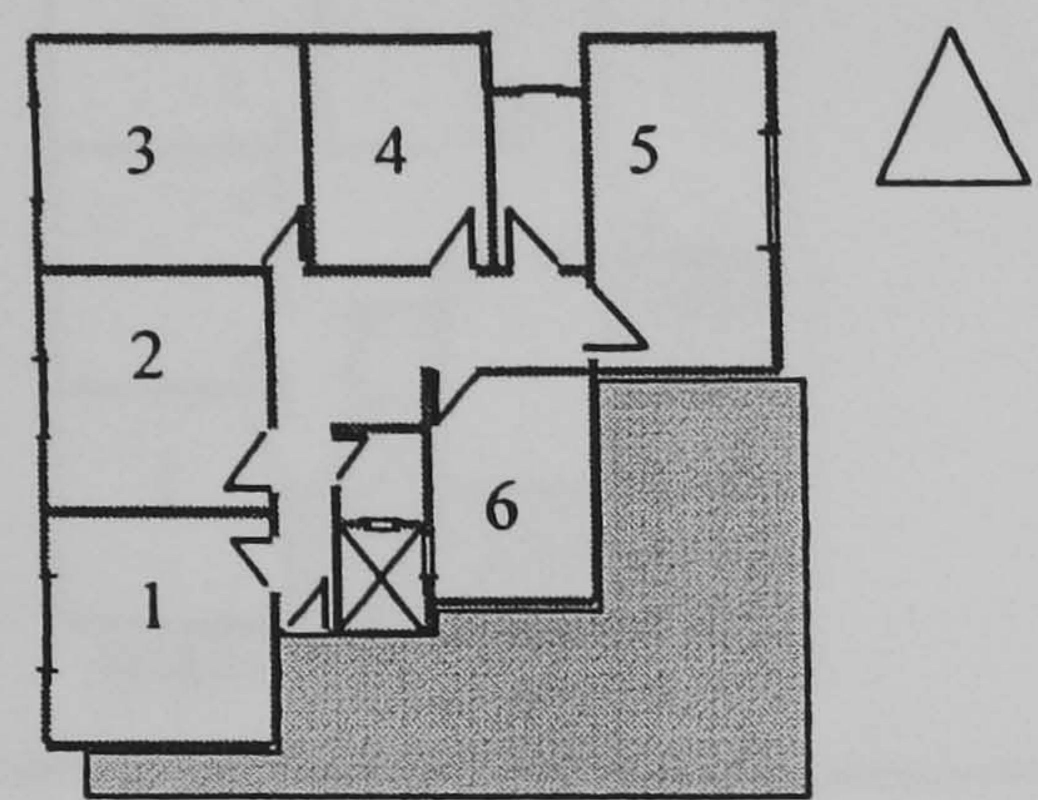
The thermal conditions inside Case 4 are illustrated in Figure 7.7. The overall conditions also fall outside moderate parameters. The main distinguishing feature of this case in comparison to the other cases is the insulated envelope. But this seems to be a disadvantage rather being an advantage, and the recorded temperature is 36°C for most of the rooms. Inside the occupied room, and with air conditioning on, the minimum is 26°C and this could be due to thermostat setting.

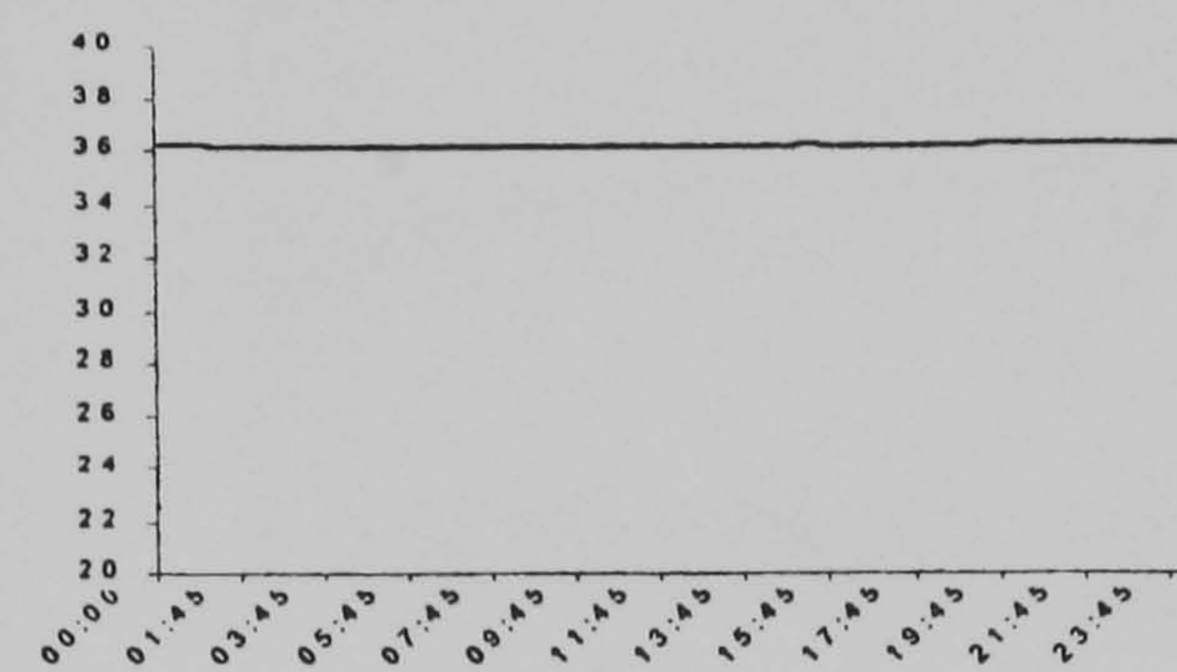
The temperature profiles in Case 5 are similar to other cases. However, rooms 6, 5, and 3 have the highest temperature respectively. Temperatures range from 34°C to 36°C without the effect of air conditioning. The rest of the rooms vary according to air conditioning thermostat setting. Eventually, the maximum temperature it reaches inside these rooms with the air conditioning off is 34°C. The construction of the apartment in Case 5 is traditional fired red bricks, and this material seems to perform well thermally. On the other hand, this case shows high a temperature profile due to the high rate of infiltration from some traditional windows. (Figure 7.8)

In Case 6, the top floor apartment in the same building as Case 5, new readings of high temperature have been recorded. Rooms 4, 5, and 6 have temperatures of 37°C and 38°C, the highest among the case studies. This apartment has no roof insulation and also has high infiltration rate from uncontrolled openings. Rooms 1, 2, and 3 are a few degrees lower than the other spaces, and the temperature in these rooms, as can be seen in Figure 7.9, ranges from 28°C to 36°C.

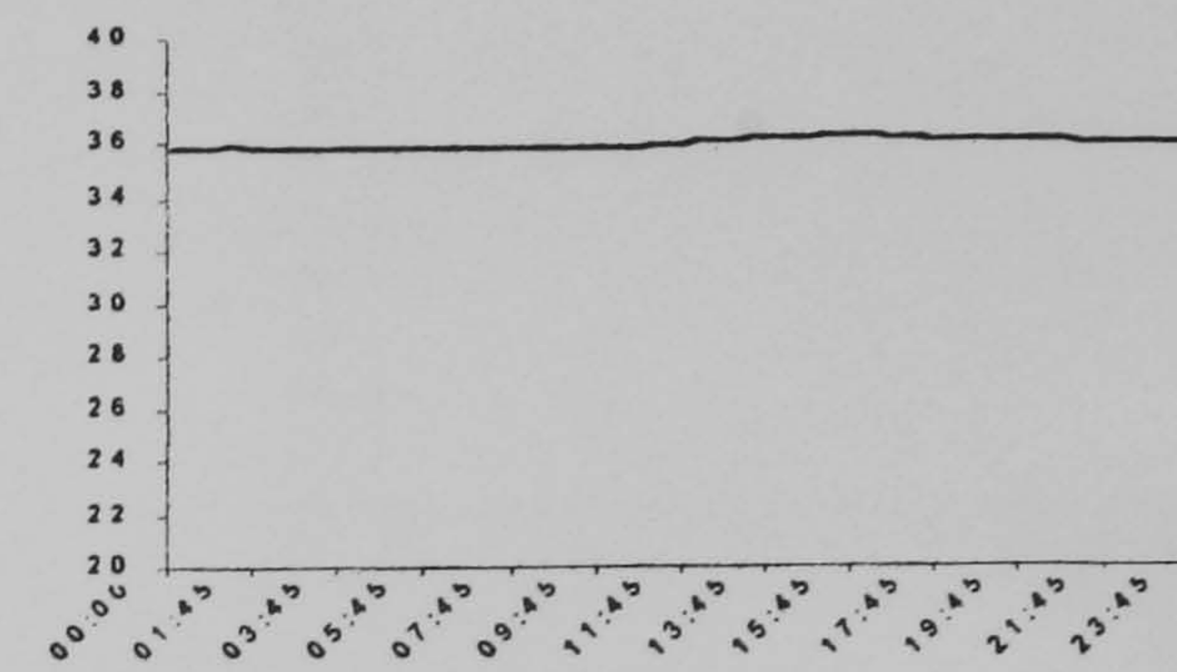
Cases 7 and 8 are the moderate cases. Due to the frequent usage pattern of air conditioning and the relatively good sealing of openings, the average temperature inside these apartments is 27°C and 28°C respectively. The highest temperature in Case 7 is 32°C, while the highest in Case.8 is 35°C. Both of these temperatures have been recorded in room.5, used as a kitchen. The temperature profiles of these cases are shown in Figures 7.10 & 7.11.

Case No.1
Temperature Profile

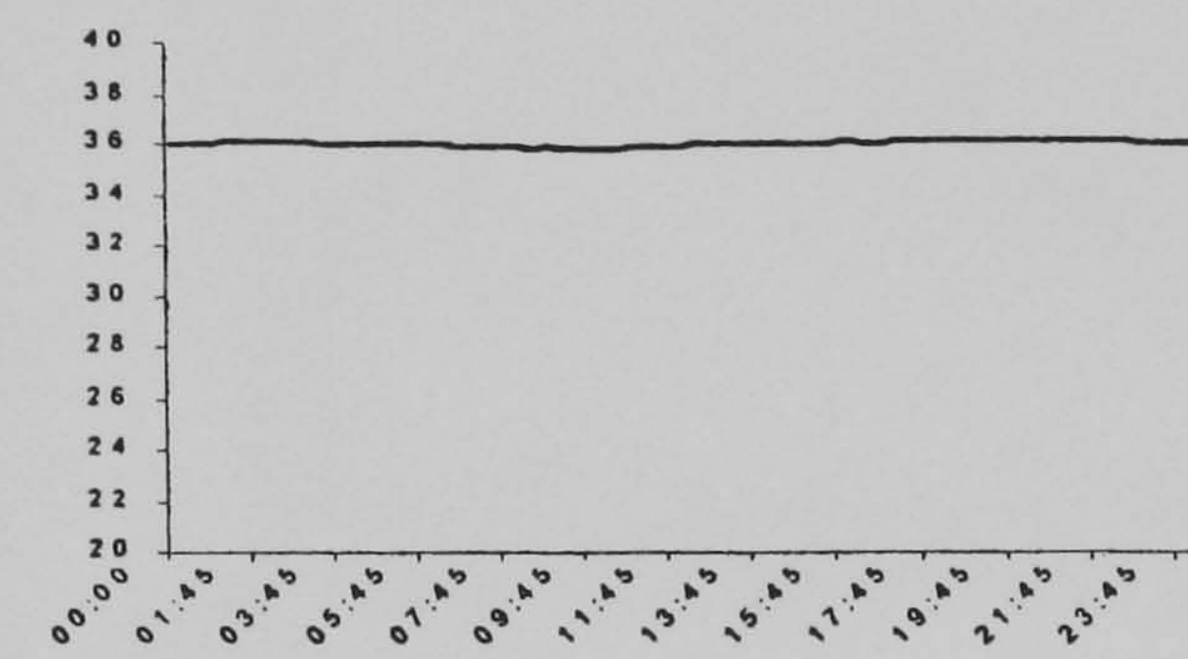




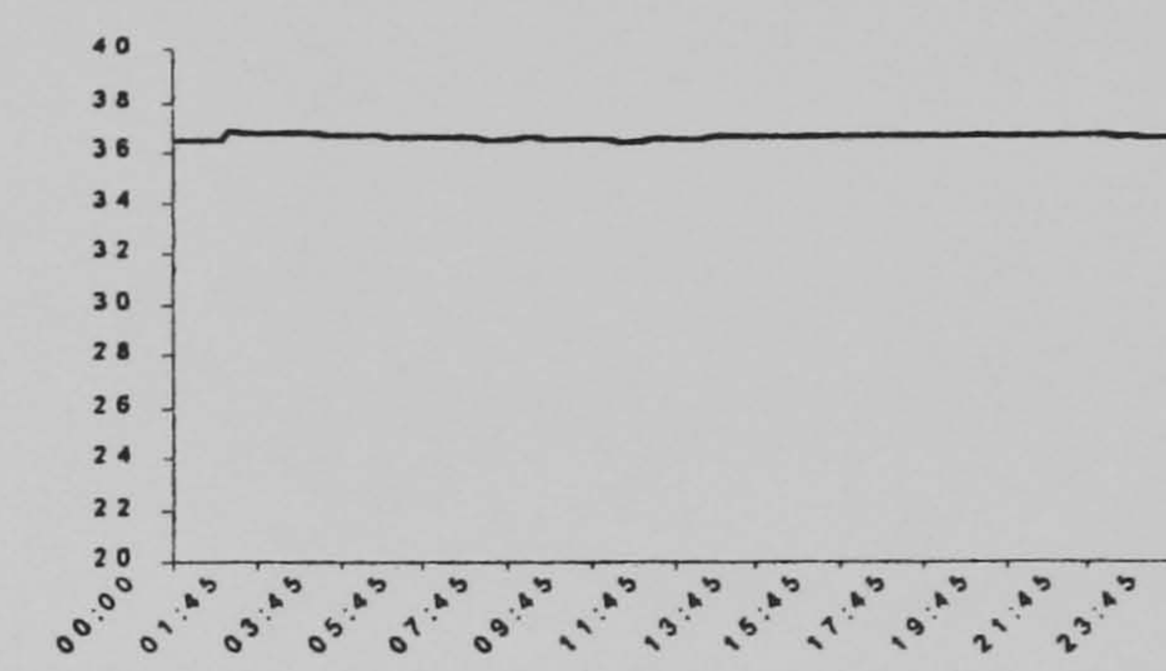
Room No.1



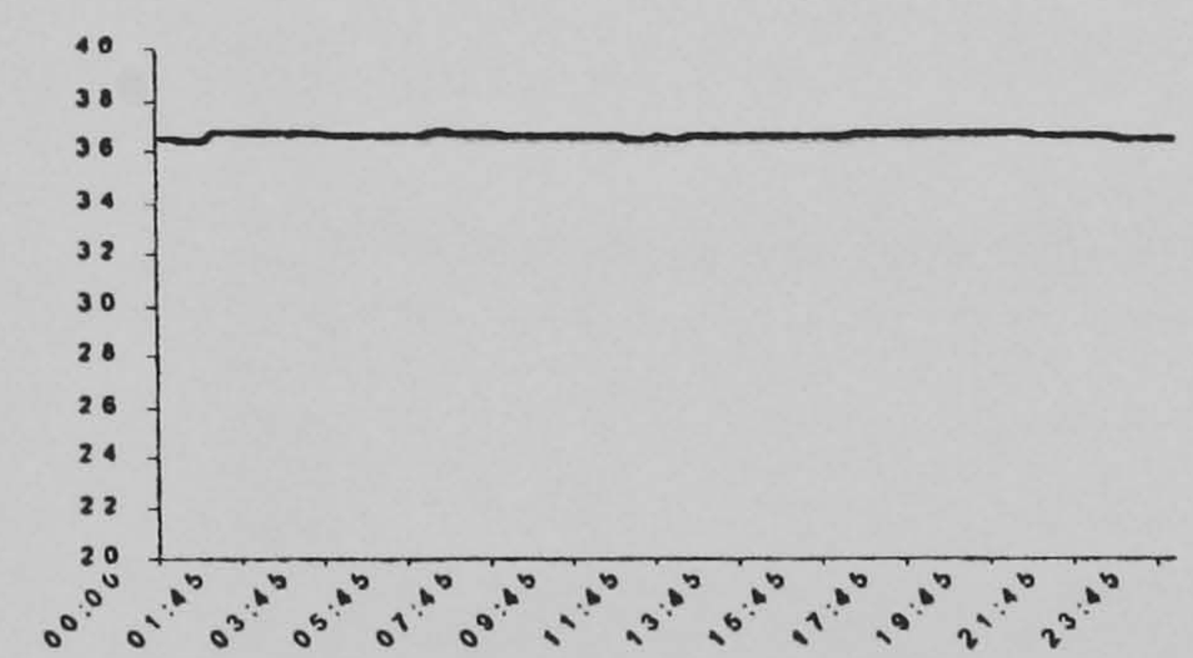
Room No.2



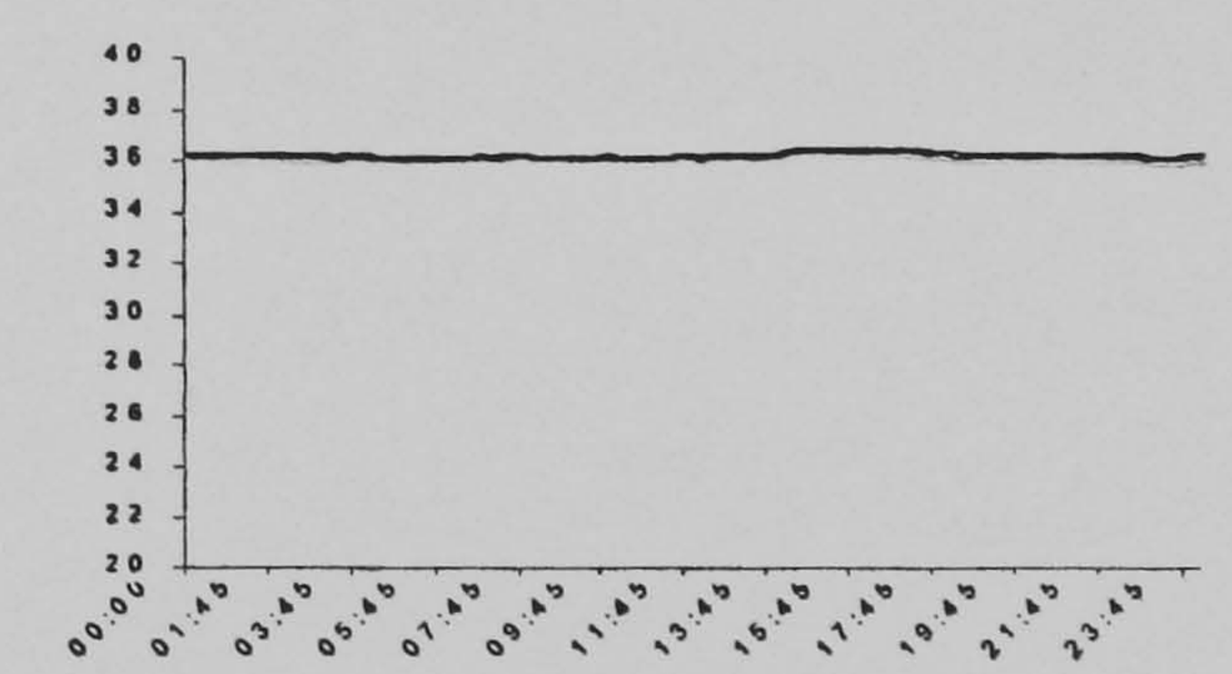
Room No.3



Room No.4



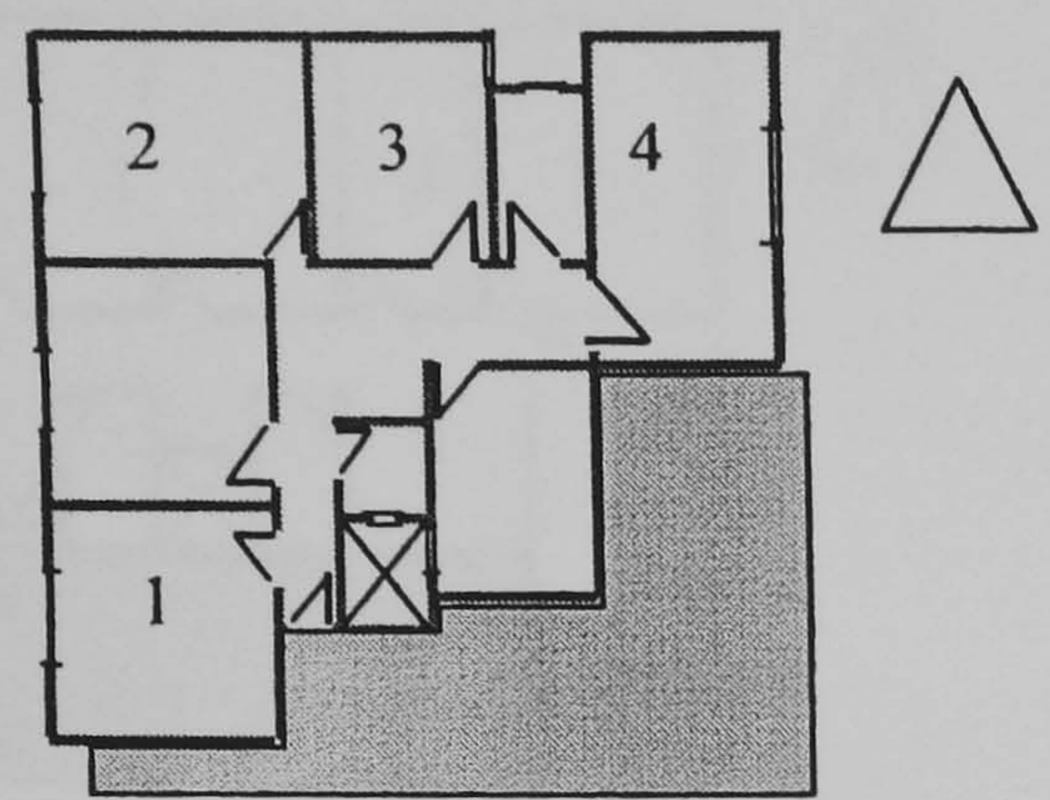
Room No.5



Room No.6

Figure 7. 4:
Typical Indoor Temperature Profile for Case No.1

Case No. 2
Temperature Profile



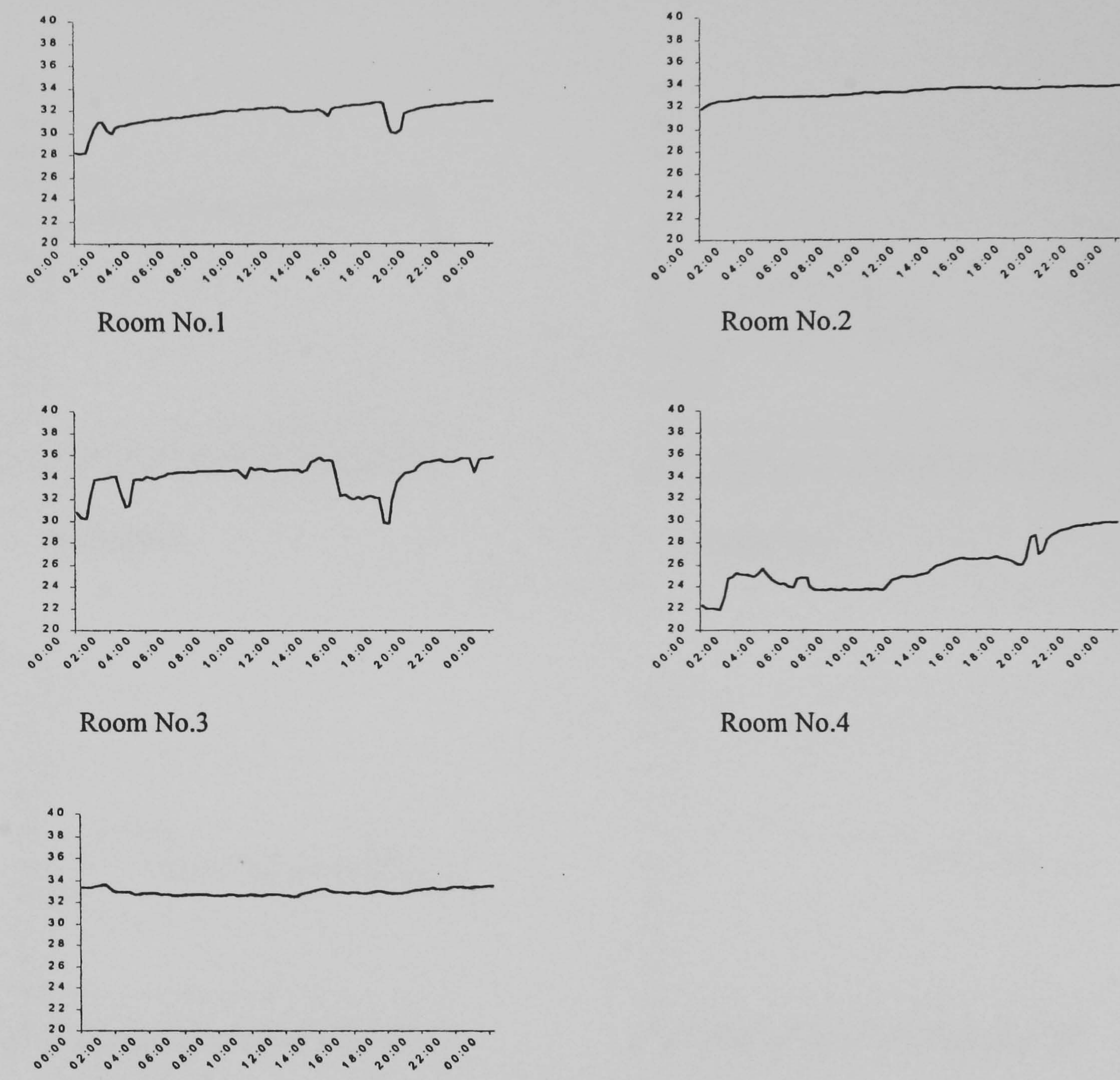
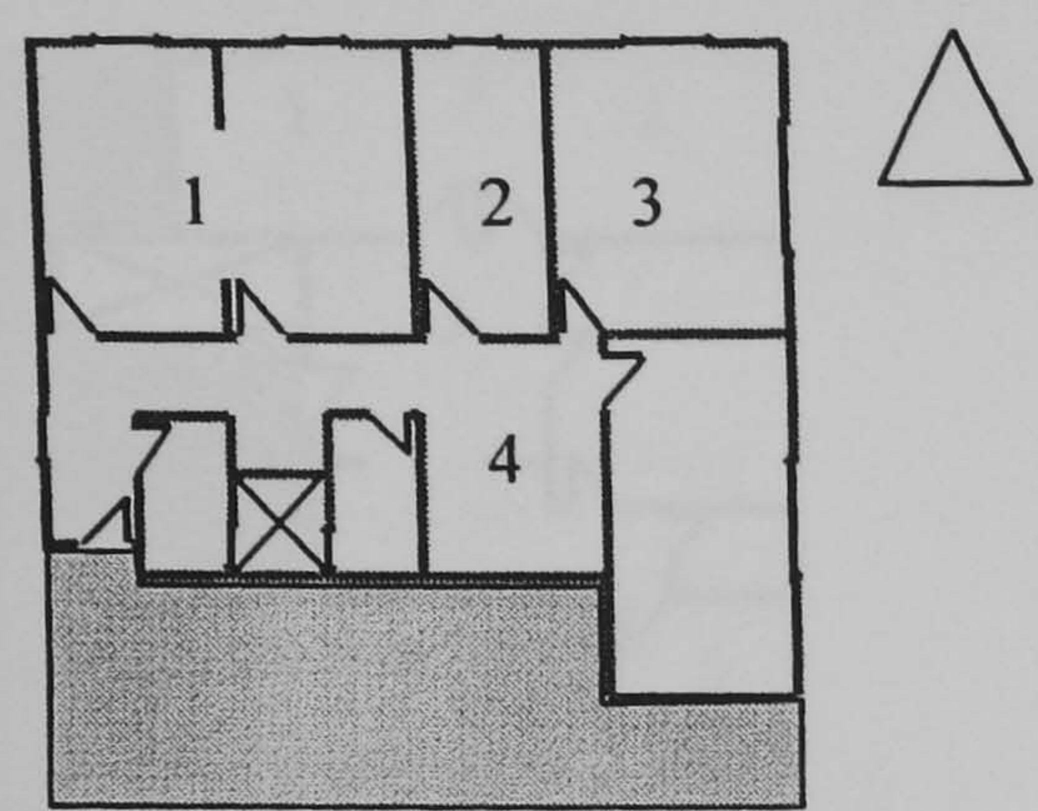


Figure 7. 5:
Indoor Temperature Profile for Case No. 2

Case No. 3
Temperature Profile



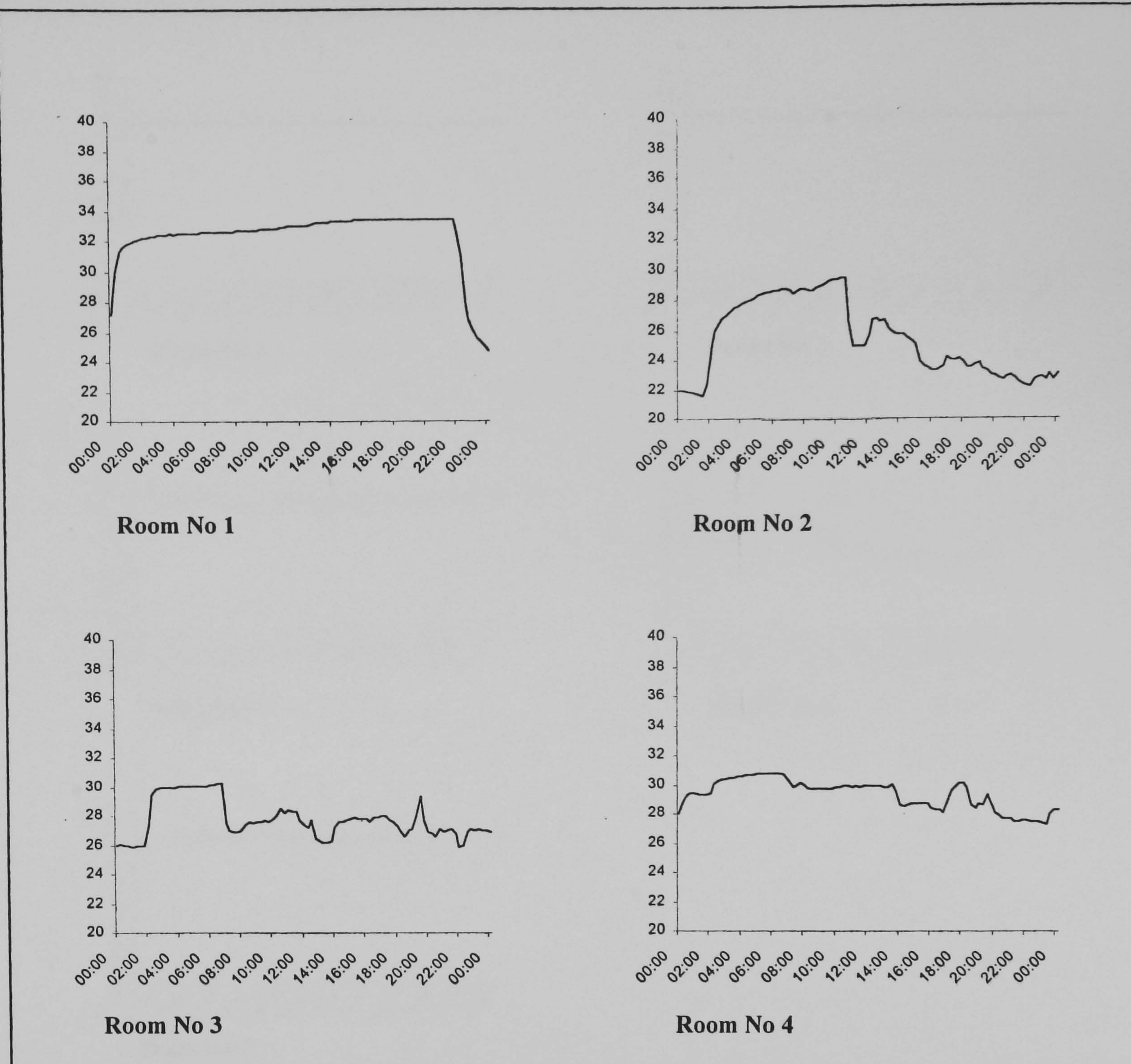
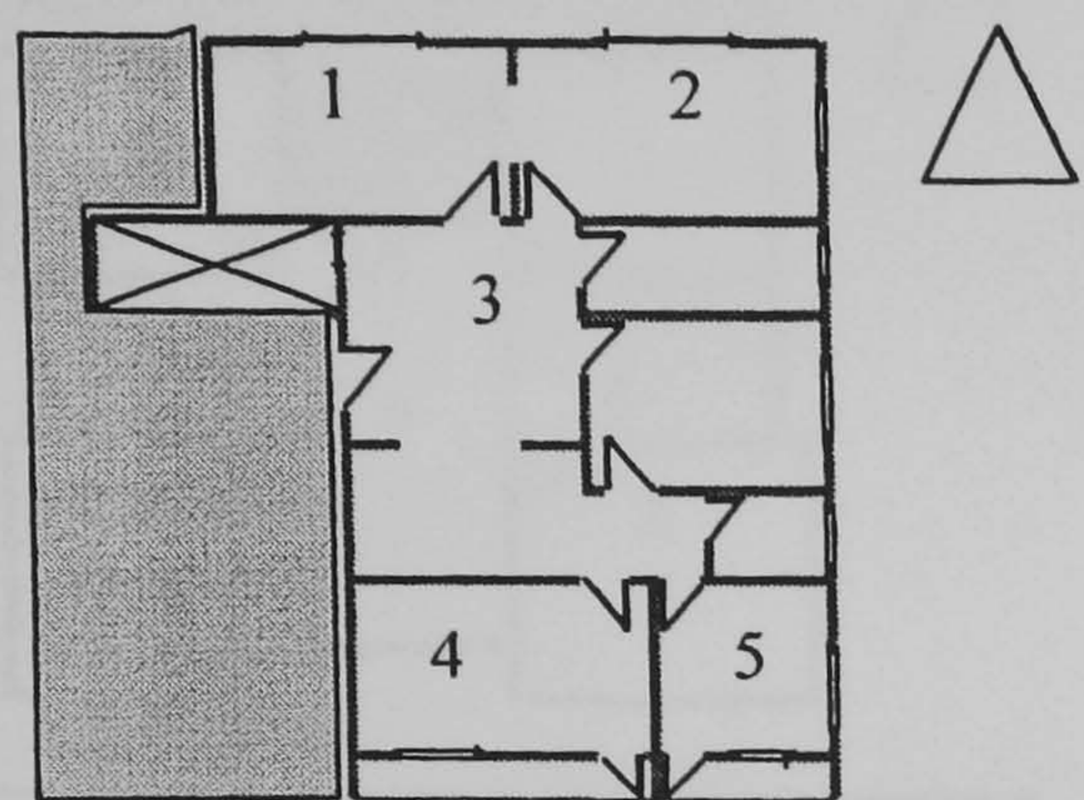
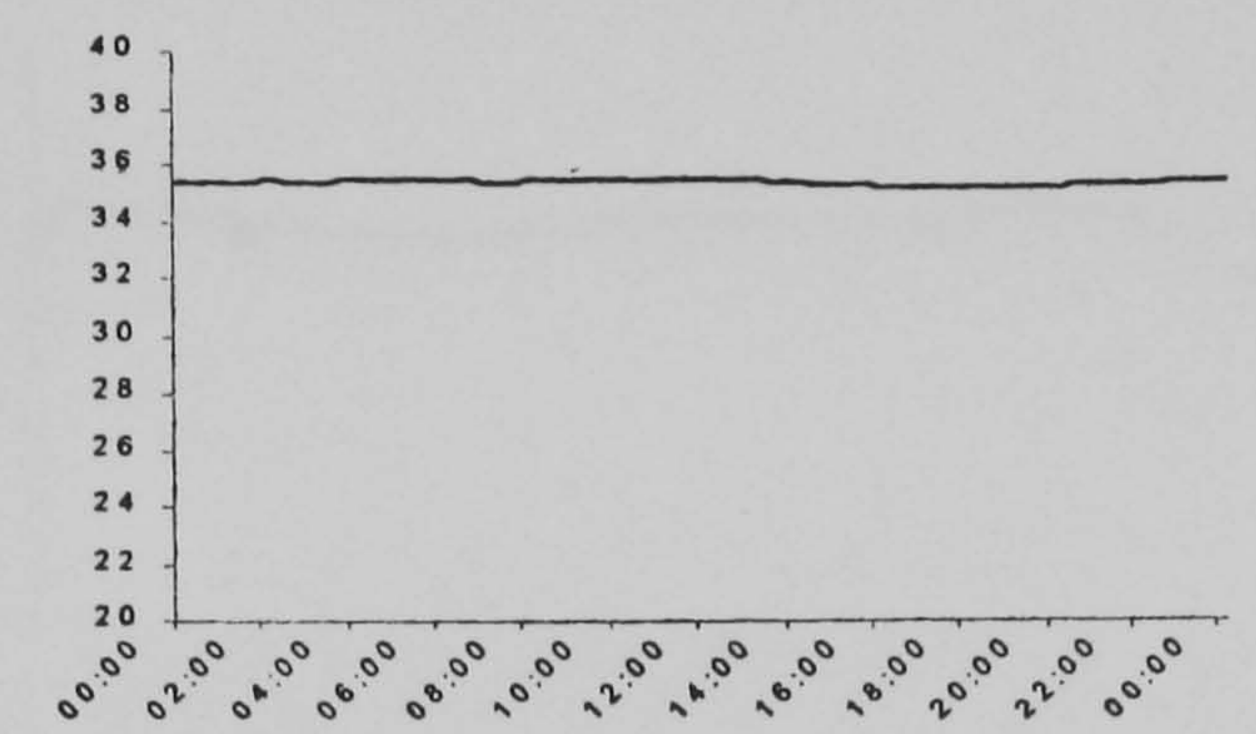


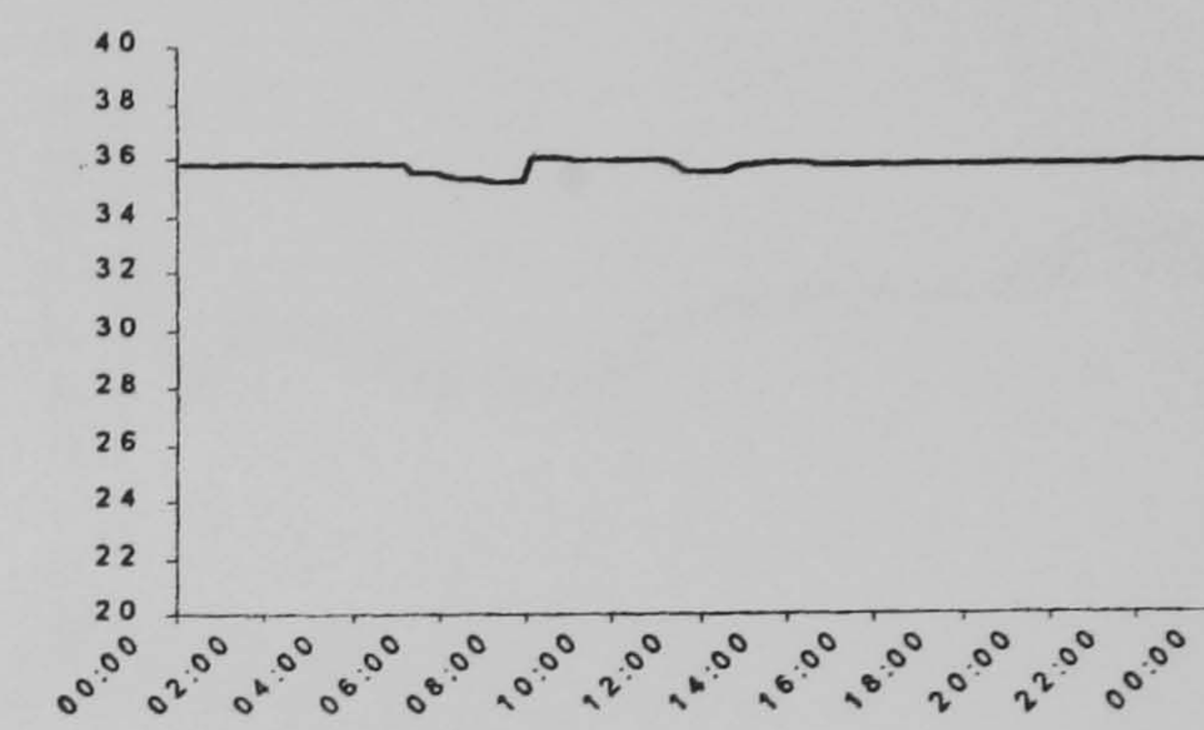
Figure 7. 6:
Indoor Temperature Profile for
Case No.3

Case No.4
Temperature Profile

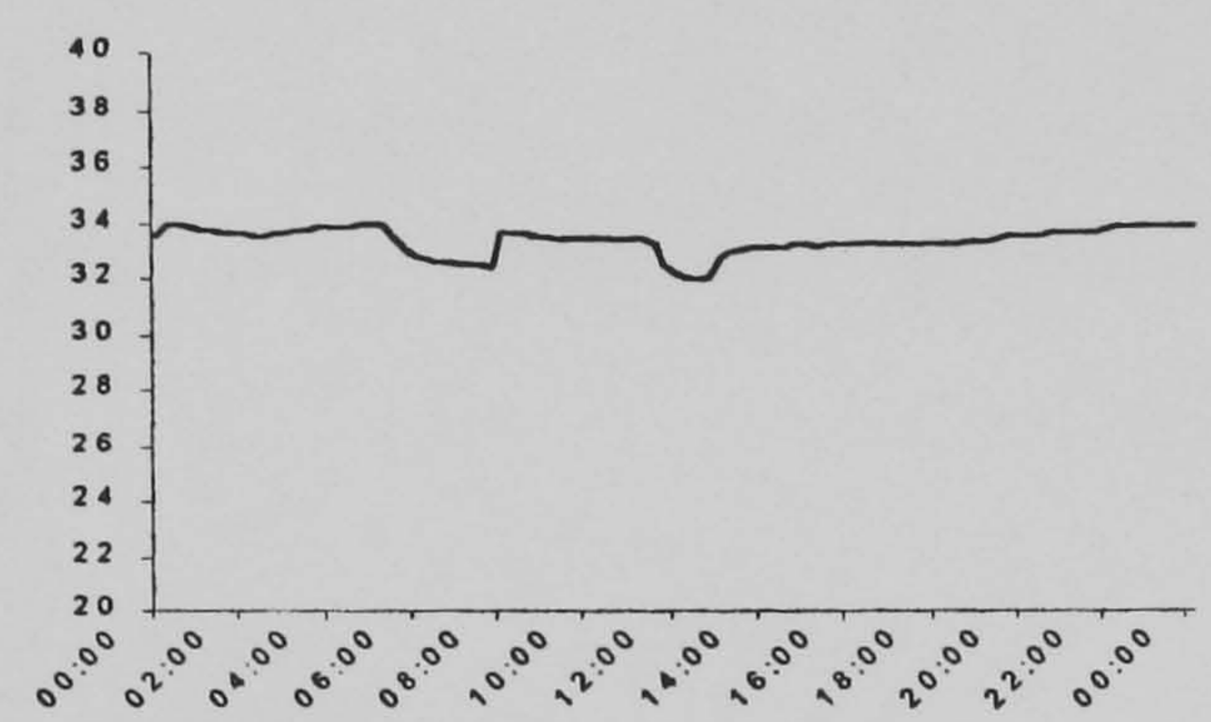




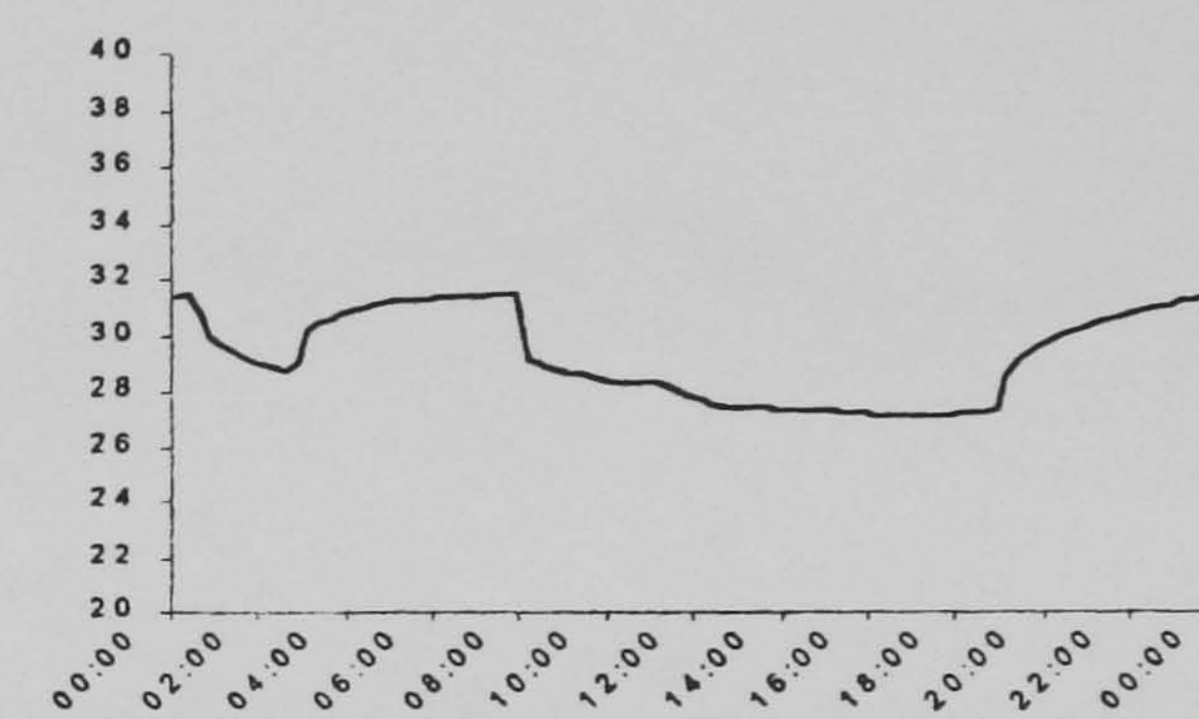
Room No.1



Room No.2



Room No.3



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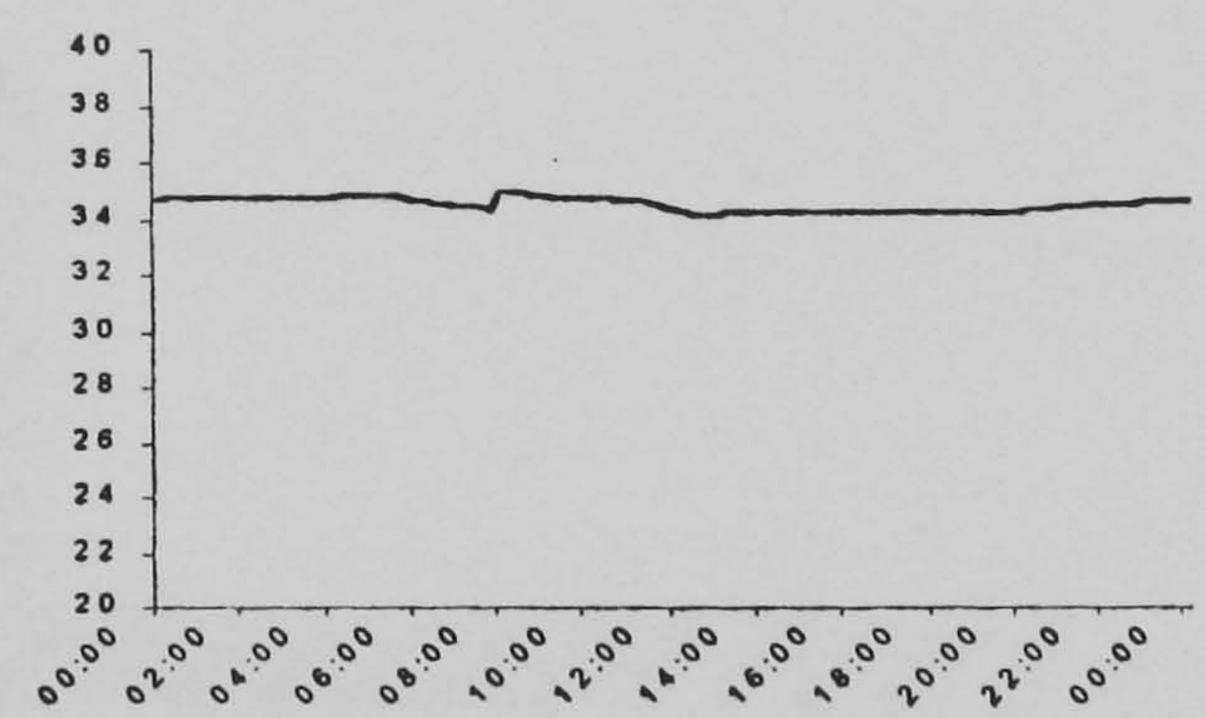
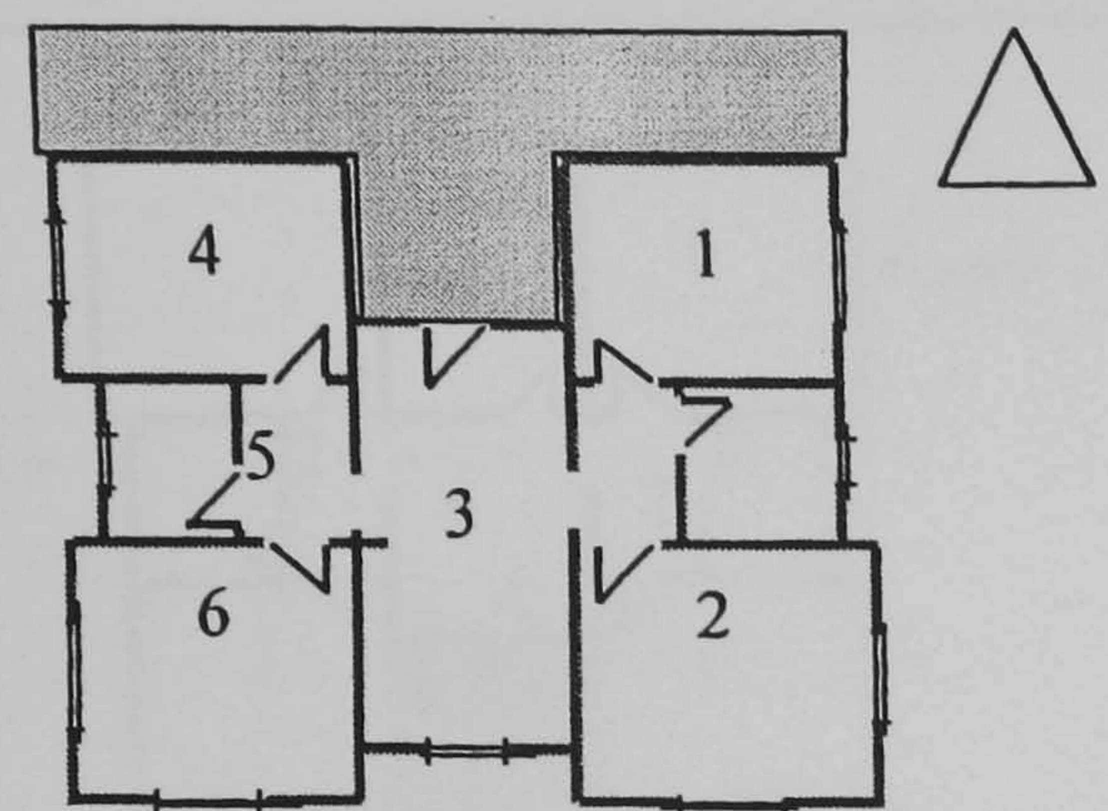


Room No.5

Figure 7. 7:
Indoor Temperature Profile for
Case No. 4

Case No. 5
Temperature Profile



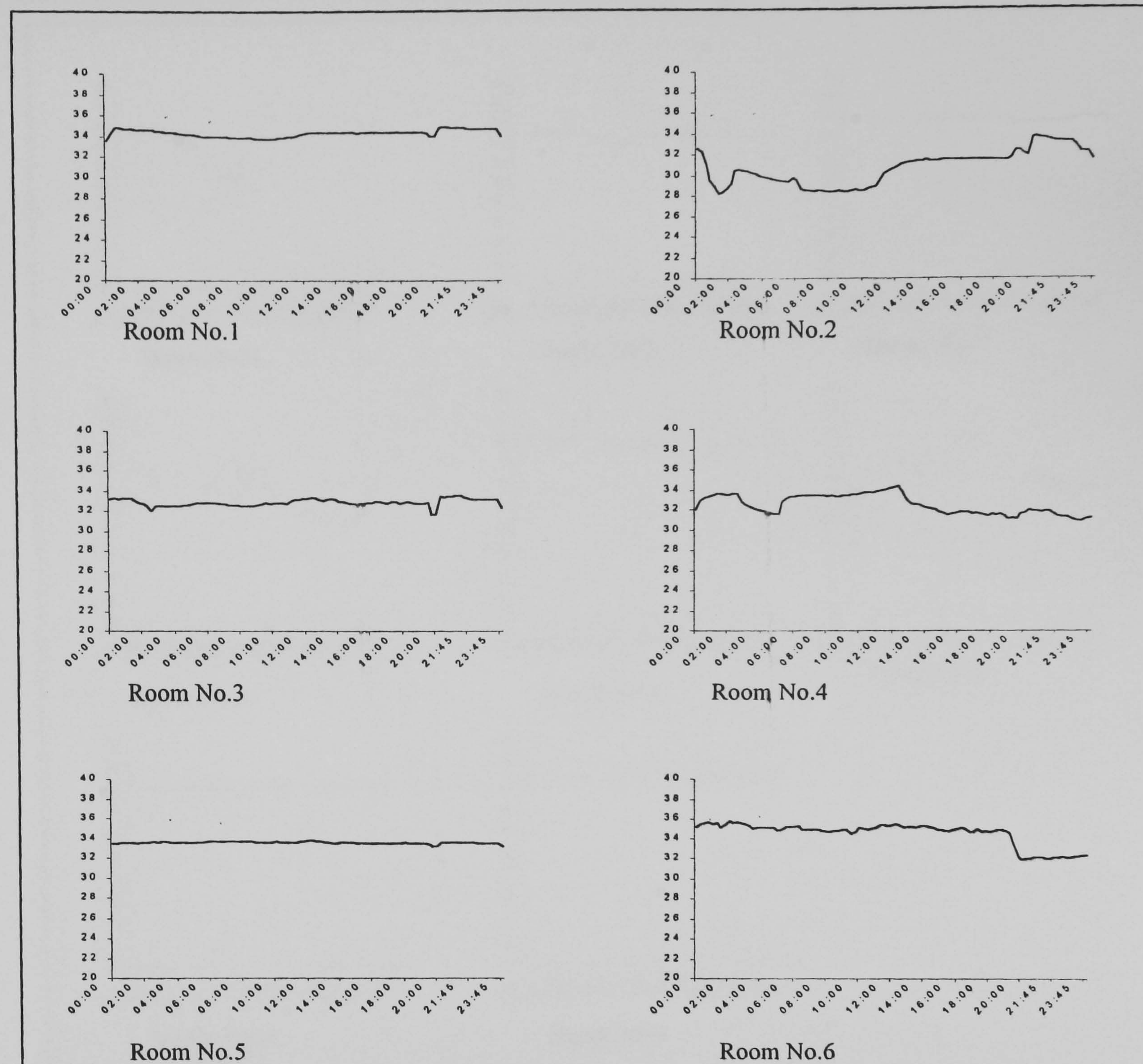
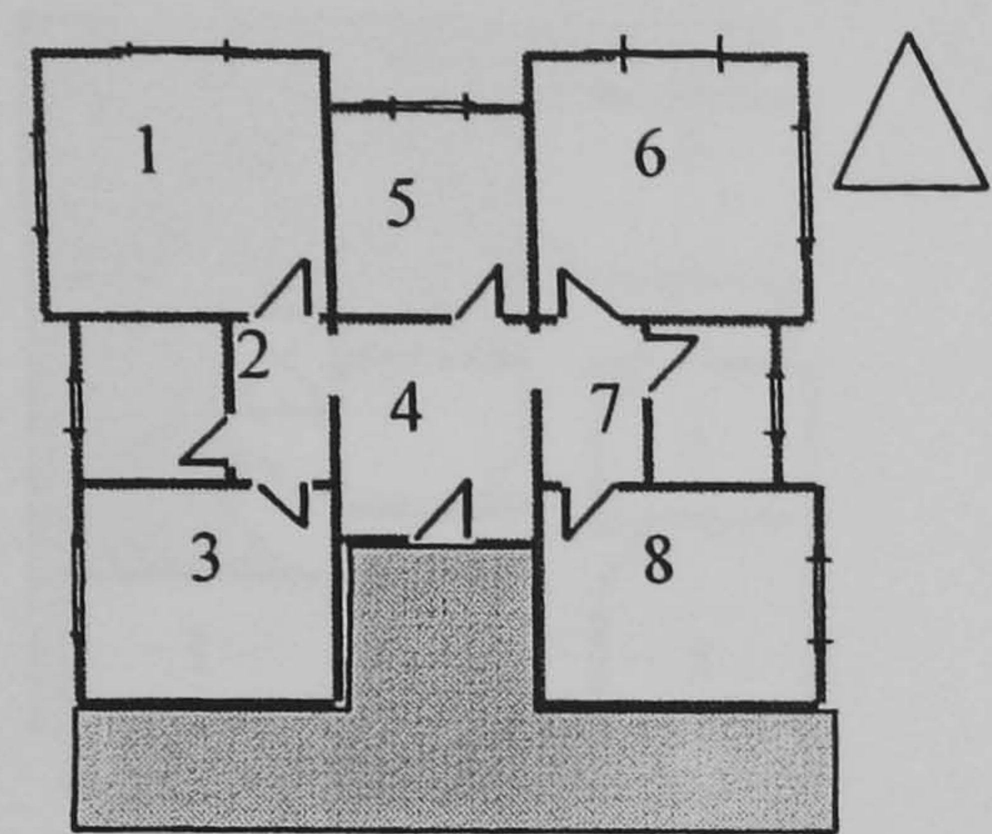


Figure 7. 8:
Indoor Temperature Profile for Case No.5

Case No. 6
Temperature Profile



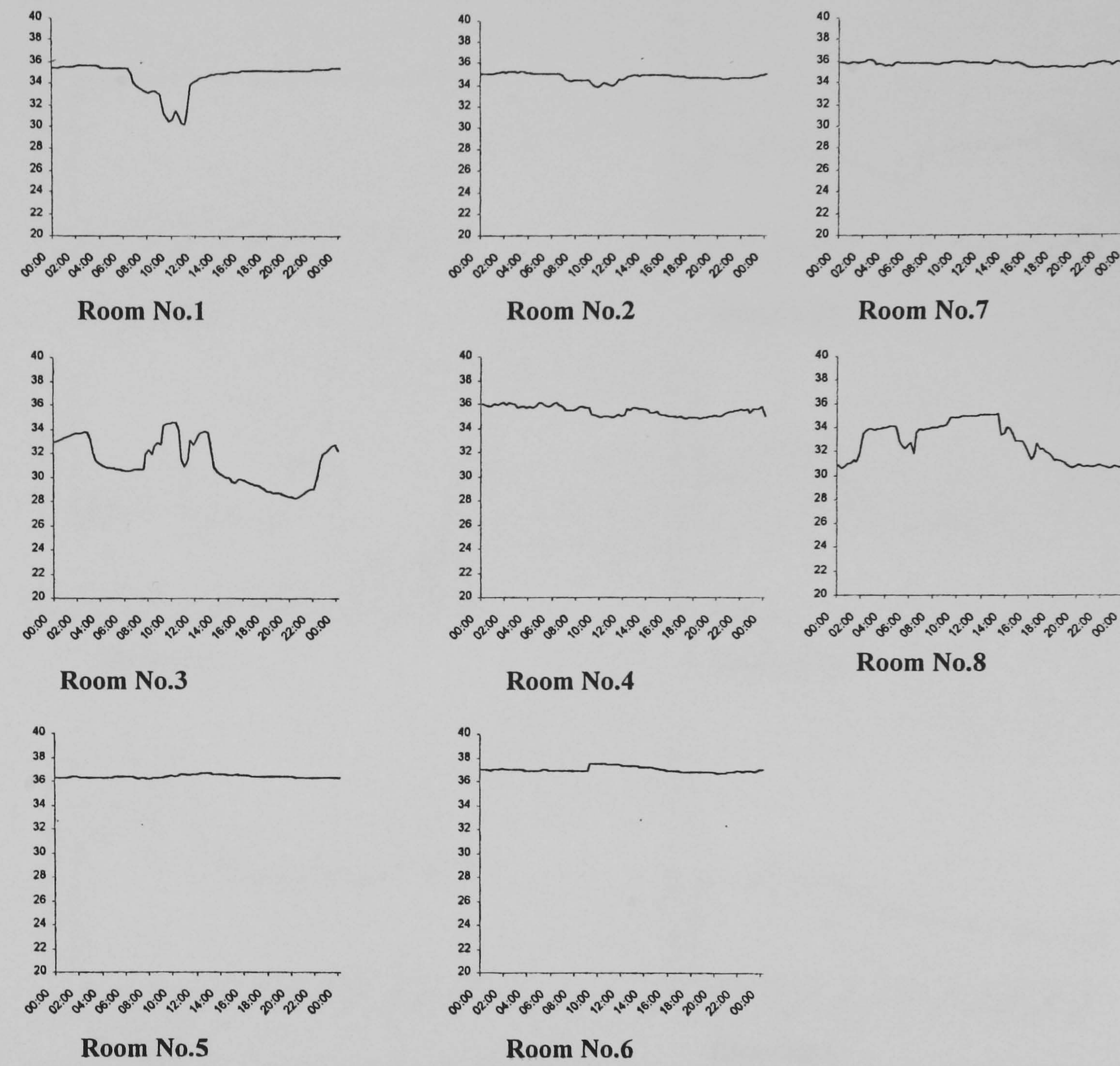
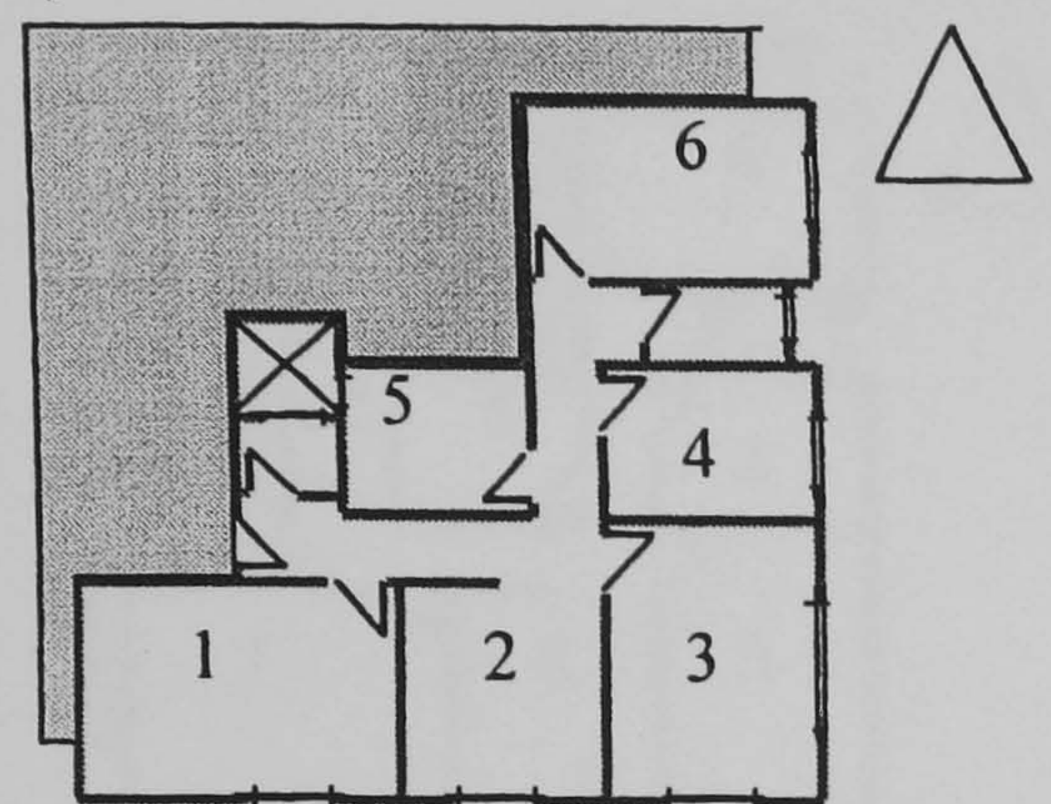


Figure 7. 9:
Indoor Temperature Profile for Case No.6

Case No.7
Temperature Profile



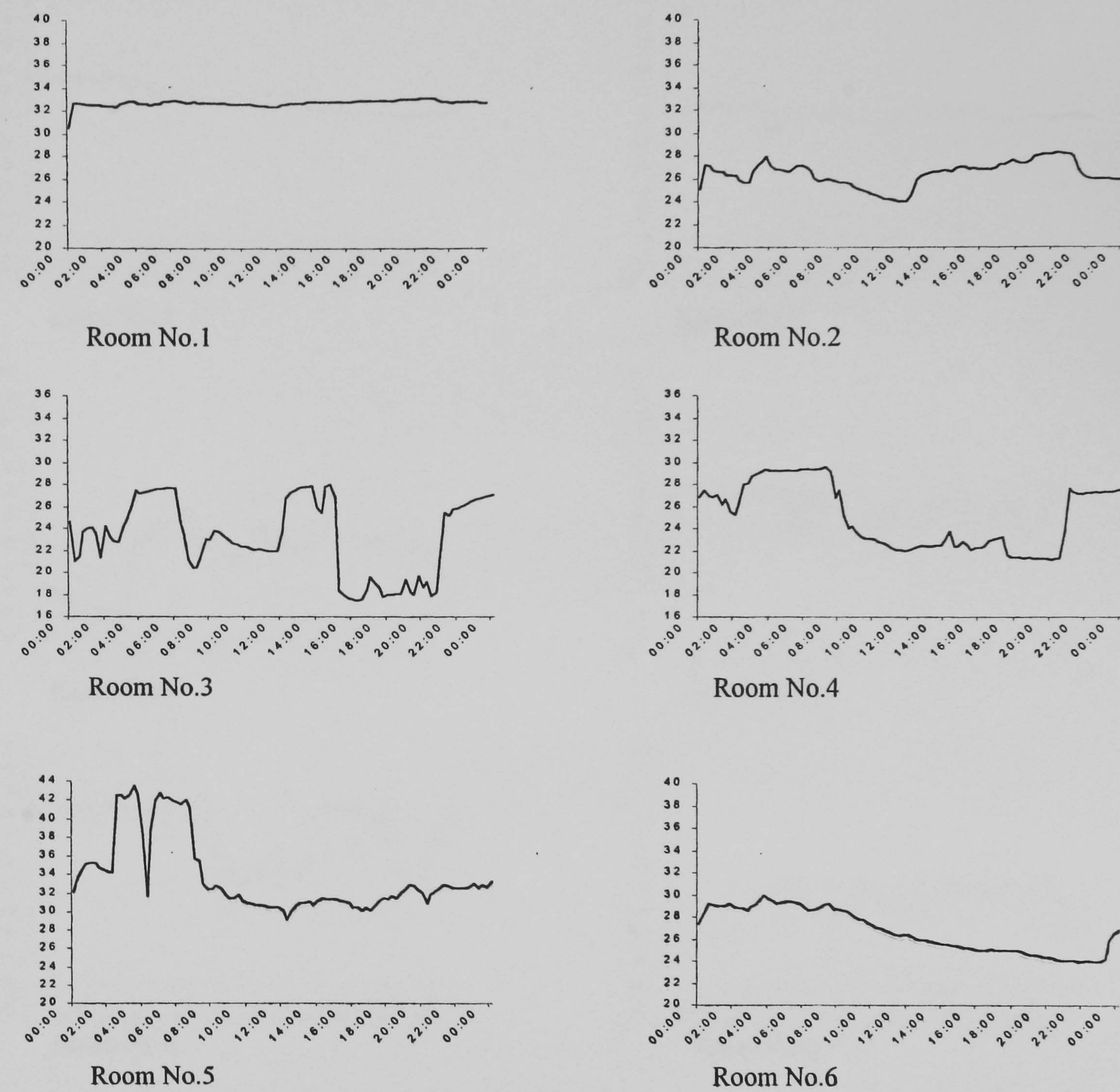
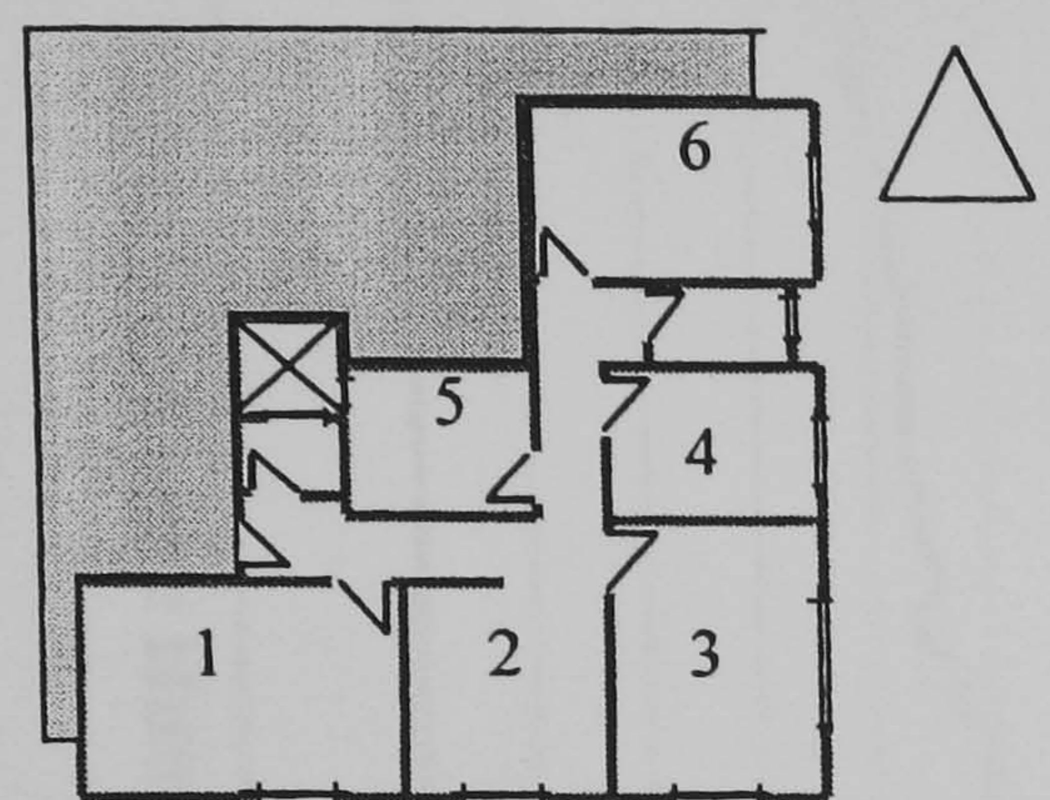


Figure 7. 10:
Indoor Temperature Profile for Case No.7

Case No.8
Temperature Profile



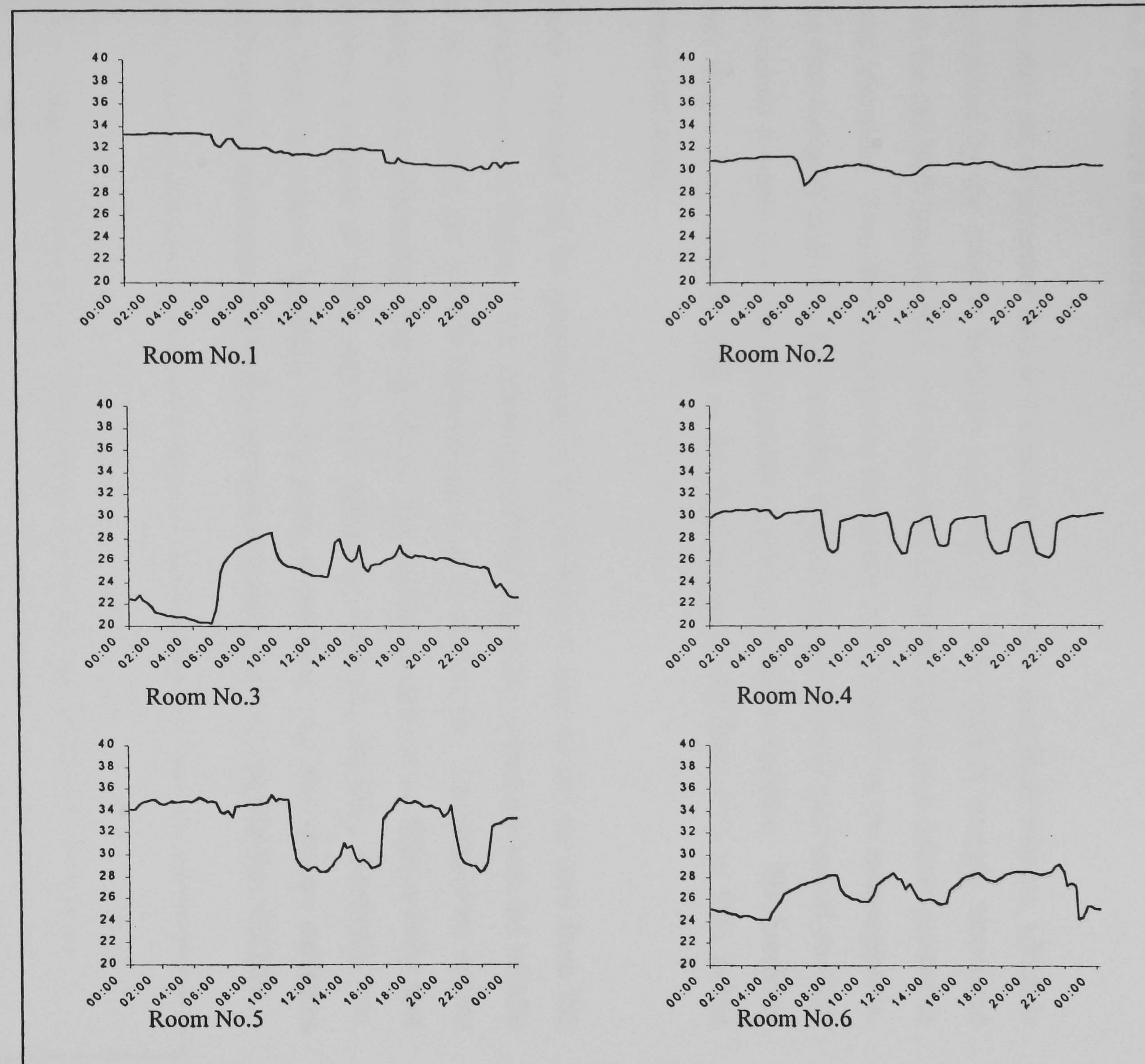


Figure 7. 11:
Indoor Temperature Profile for Case No.8

7.4.2 Relative Humidity

The other set of recorded data is the percentage of water in still air indoors, which is represented by the relative humidity scale RH %. This scale is strongly associated with the dry bulb temperature, and very much influenced by indoor activity related to water moisture. Two major categories have been established from the measurements. The first category indicates the humidity level in the presence of mechanical cooling, the second denotes the level of humidity in a normal indoor situation. The humidity level ranges from 60% to 75% in the first category, and from 40% to 55% in the second category.

These readings can be generalized in all the case studies as can be seen from the example case in Figure 7.12. Minimum relative humidity occurs towards the middle of the day when the outside temperature is at its maximum. The maximum occurs during air conditioning working hours, and during the period of daily activity that involve a release of water vapor into space, i.e. cooking, sleeping, exercising, etc. The level of relative humidity is dry most of the time, and this dryness enhances cooling via evaporation and makes dry heat relatively more acceptable than wet heat.

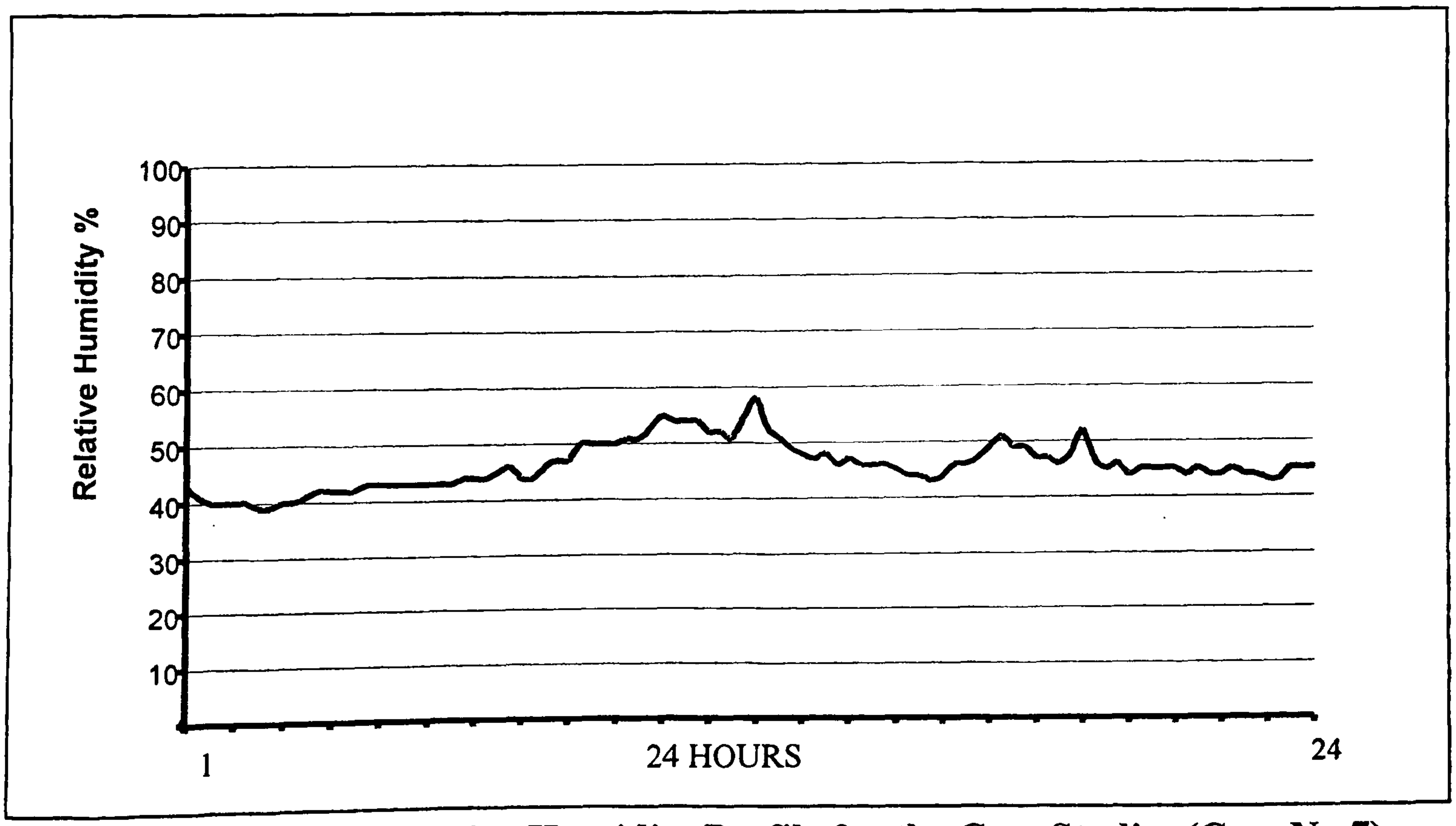


Figure 7.12: Typical Relative Humidity Profile for the Case Studies (Case No.7)

7.4.3 CO2 Decay Rate (Infiltration Assessment)

Ventilation (purpose ventilation and infiltration) plays an important role in maintaining air quality in buildings. It is needed to satisfy the metabolic requirements of occupants and dilute and disperse occupant-generated pollutants. Ventilation also contributes significantly to energy demands, especially at times in which cooling and heating are needed. Therefore a conflict can arise between increasing ventilation to reduce pollutant and cooling loads and reducing ventilation in order to minimize cooling and heating loss and reduce discomfort.

As far as the case studies are concerned, the major source of ventilation can be through leakage of the building envelope (infiltration). From personal observations, the issue of infiltration was not recognized by most of the occupants. Most of the cases were not airtight, which played a major part in degrading the thermal performance and increasing the discomfort level as well as increasing energy demands within these cases.

Air leakage in these units commonly occurs from many sources, which include doors, windows, exhaust fans, and the permeability of opaque fabrics.

In order to assess the infiltration rate, the CO2 decay rate method was used to investigate the air tightness in certain apartments (Warren, 1982). The instrument used was a Horiba APBA-200E infrared analyzer. However, it was not sensitive enough to absorb CO2 concentration from some cases due to the large volume of space.

The calculated output from the successfully measured cases shows that an infiltration rate between 0.75-2 air changes per hour is common in these apartments. Windows are closed all of the time in these cases and the infiltration comes from leakage and doors which are sometimes left open. The measured cases were Cases 1, 3, and 4 and a typical profile of these measurements can be seen in Figure 7.13.

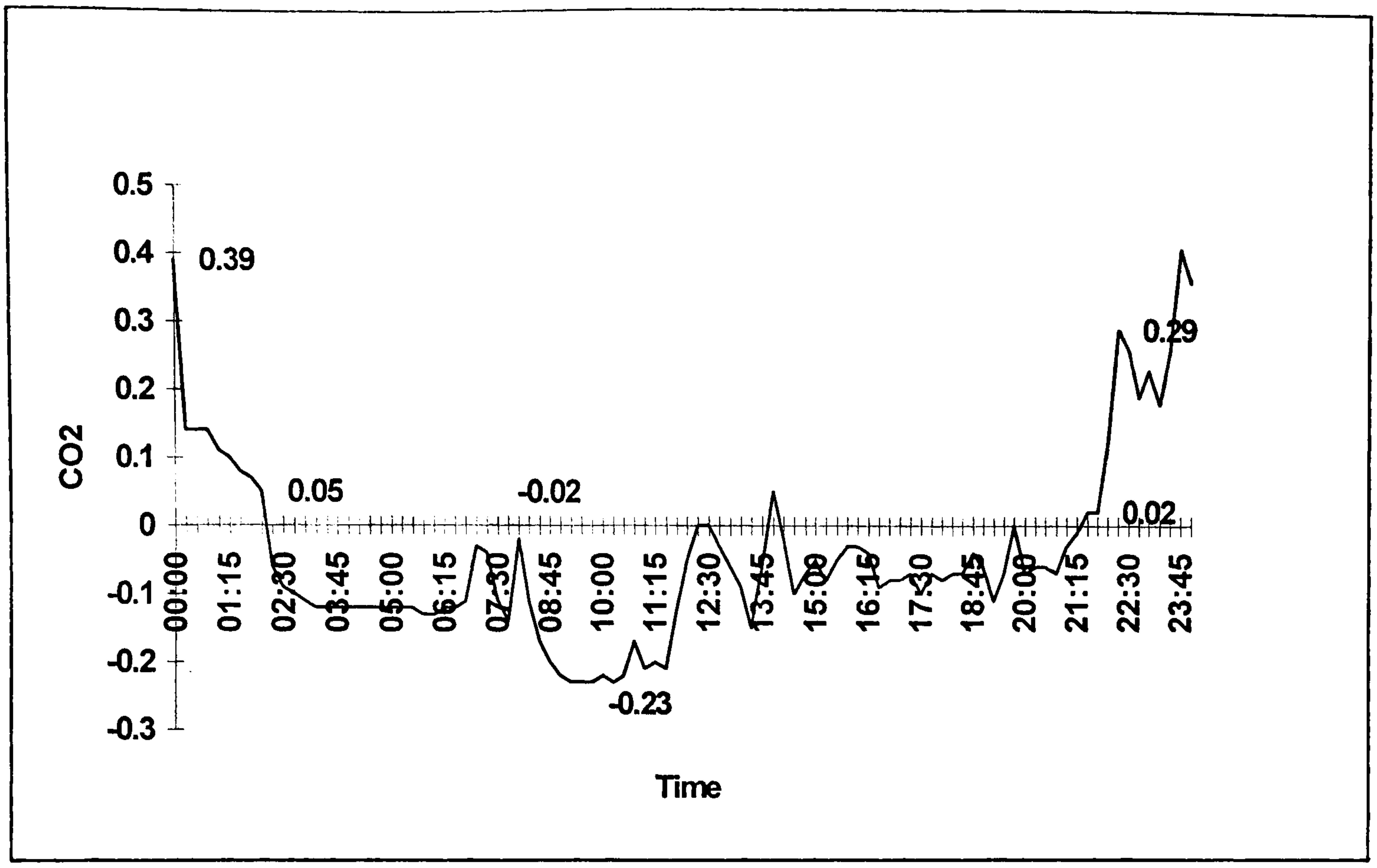


Figure 7. 13: Typical Measured CO2 Decay Rate Profile (Case No.3)

7.4.4 Observation of Air Conditioning Operational Patterns.

Volt clamps were connected to data loggers in order to monitor the operational hours of the air conditioning units. During operation the voltmeter indicates the time and period of switching the air conditioning on and off.

Not all the cases were managed due to hidden wiring systems. However, the monitored cases were Cases 2, 3, 7, and 8.

The operational pattern derived from the analysis of these cases shows inconsistency and irregularity in using the air conditioning units. It depends greatly upon the behaviour of the occupants, the space utilization habits, and is sometimes influenced by economic considerations. It seems that the occupants are always motivated by their needs to stay relatively cool, wherever they move inside the apartment. The traditional concept of multi-use spaces usually eases the movement, and makes the spaces more adaptable to different daily activities.

The trend of using air conditioning is coupled with space occupation. People tolerate high temperatures for only a short time, and after that air conditioning becomes a necessity. The average operation total is 12, 16, 12 and 10 hours daily respectively for the most occupied rooms in the monitored cases.

7.5 Energy Consumption Pattern

Energy consumption profiles for the case studies have been established on the base of the electrical records that obtained from the Electricity Company. These profiles represent good indicators for energy behaviour inside each case especially when configure this information with the pre-mentioned measurements of the internal environment.

The monthly average consumption is varies from case to case and can be classified into three main classes (high, middle, and low). This variety in consumption is associated with the variety of the physical configuration and family soci-economy structure that characterise each case.

In the first class of the high consumption, relatively high in comparison with other cases but not high by the standard official brackets (first brackets in this scale, see chapter 1), is recorded for Cases No.2, 7, and 8 with monthly average readings above 2000 kWh. Case No. 2 has an average of 2456 kWh (17 kWh/m^2) while the consumption for the two other cases are 2366 kWh (14 kWh/m^2) and 2230 kWh (14 kWh/m^2) in respective order.

These cases, interestingly, share the same building and also share similar circumstances with regards to apartments' sizes as well as family size. The occupants of these apartments have reported the extensive use of A/C and the importance of being comfortable despite the excepted high electricity bill. They also stated that the operation hours of the A/Cs could extend to 24 hours in most of the time especially in the summer months. Artificial lights also have long operational hours regardless the time and they are basically used as a major light source even during the daytime.

Cases in second class are fall in consumption rang from 1000 kWh to 2000 kWh and characterised as a middle class. These cases are 3, 4, and 5 and the consumption for each case is 1871 kWh (14 kWh/m^2), 1666 kWh (15 kWh/m^2), and 1293 kWh (12 kWh/m^2) respectively. The respondents of these cases stated that they always try to control their demands from the A/C and any aspects work direct relation with electricity as an essential attitude in their life style.

Temperature measurements for these apartments showed relatively uncomfortable readings in unoccupied and, some time, in occupied spaces. However, this indoor environment, in general, is acceptable for the occupants, especially in Case No. 4 and 5, and they rarely feel uncomfortable. This response has been attributed to the tolerance the occupants have developed to accept relatively higher temperature as a part of psychological adaptation to certain temperature profile.

Of course, not all the occupants are interviewed and they might have a different response from the above-mentioned statement. However, the head of the family, the main interviewer, responded according to adopted family strategy.

The lower monthly average consumption (less than 1000 kWh) is recorded by Case No. 6 with total consumption of 908 kWh (8 kWh/m^2). This low consumption is attributed to the low consumption rate recorded during January till April, which also indicate an absence period for this family during these months. However, the same explanation as the mentioned in the second class might be drawn to this class. Moreover, the measured temperature are at its highest readings among the other cases and the occupants in this case seem to use less A/Cs in their rooms due to a pure economical reasons.

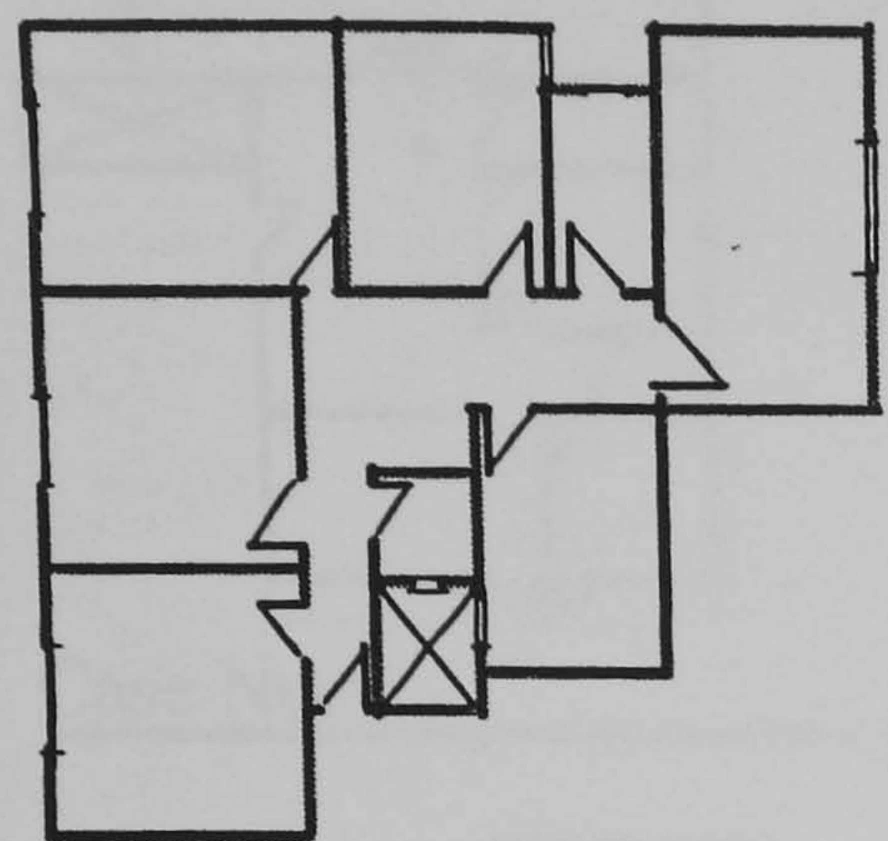
To establish Monthly Consumption Reference Value for the Measured samples (MCRVM), once again, out of the three classes of the pre-mentioned consumption types only the first class (the high consumption cases) and the second class (the middle consumption cases) are considered in this calculation. The third class is omitted for its lower consumption value.

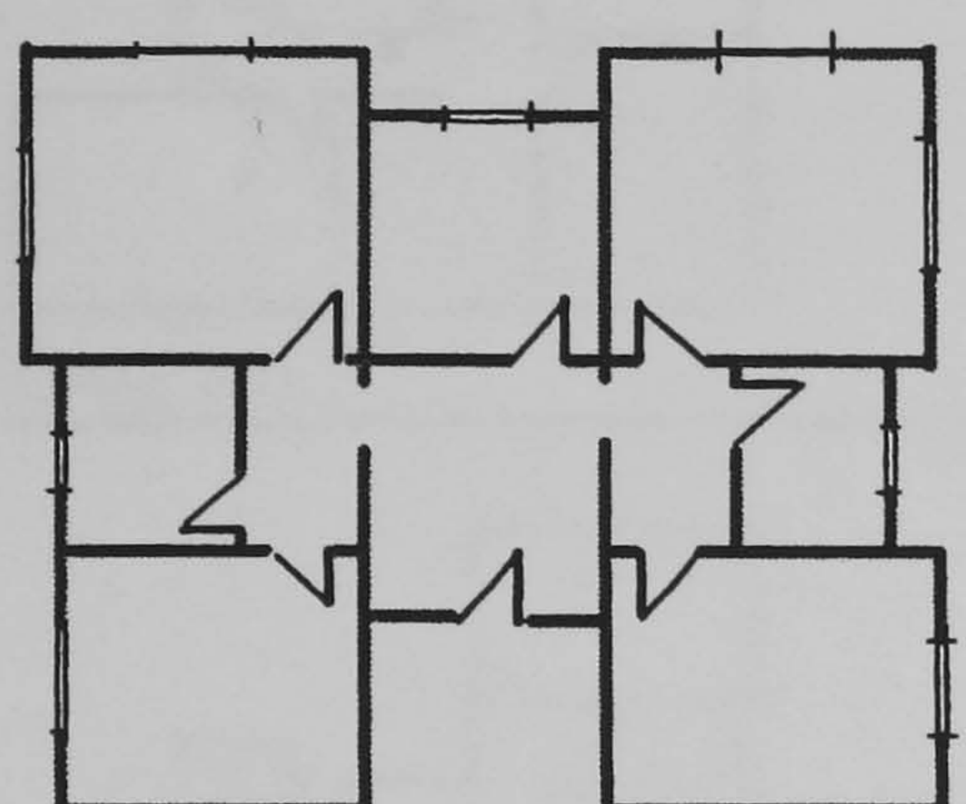
The monthly average consumption in the first class is 2350 kWh and in the second class is 1610 kWh. Therefore, the MCRVM is 1980 kWh ((2350 kWh+1610 kWh)/2). This value will be used in connection with the MCRVQ (2113 kWh, Chapter 6) to validate the predicted consumption value for the simulation analysis. These two values are integrated as they are obtained through the field survey of the large sample group and complemented by the detailed sample that represented by the different case studies. They have a very good agreement as the difference between these two values is only about 6% (133 kWh).

MCRVQ and MCRVM are averaged in order to produce the Monthly Consumption Reference Value (MCRV) that will be used in comparison with the predicted consumption value of the simulation stage. Therefore, the MCRV for typical apartment unit in Makkah is 2047 kWh. It is very difficult to establish the exact consumption rate, but this value is the most practical rate and will be used, with good creditability, hereafter as actual monthly energy consumption rate in apartment building as it is resulted from the data supplied by the field survey of this study.

According to this MCRV, the annual consumption rate in the apartment buildings in Makkah, Western Province of Saudi Arabia is 24564 kWh (MCRV*12). The equivalent consumption rate for apartment buildings in the Eastern Province of Saudi Arabia has been given as 20000 kWh (Said, 1994). This part of the country is located on the coastal line of the Arabian Gulf and the prevailed climate is much humid and more moderate than Makkah climate.

Energy consumption profiles for the case studies can be seen in Figures 7.14-7.16, where yearly total and monthly readings is depicted. Case No.8 has recorded the highest monthly electrical consumption with 4900 kWh in the month of July. This reading is considered to be a high reading for an apartment and it falls into the second brackets of the electricity price list where in this brackets, a fine of 0.05 SR is imposed for every extra kWh consumed above the 4000 kWh line.


Case No.2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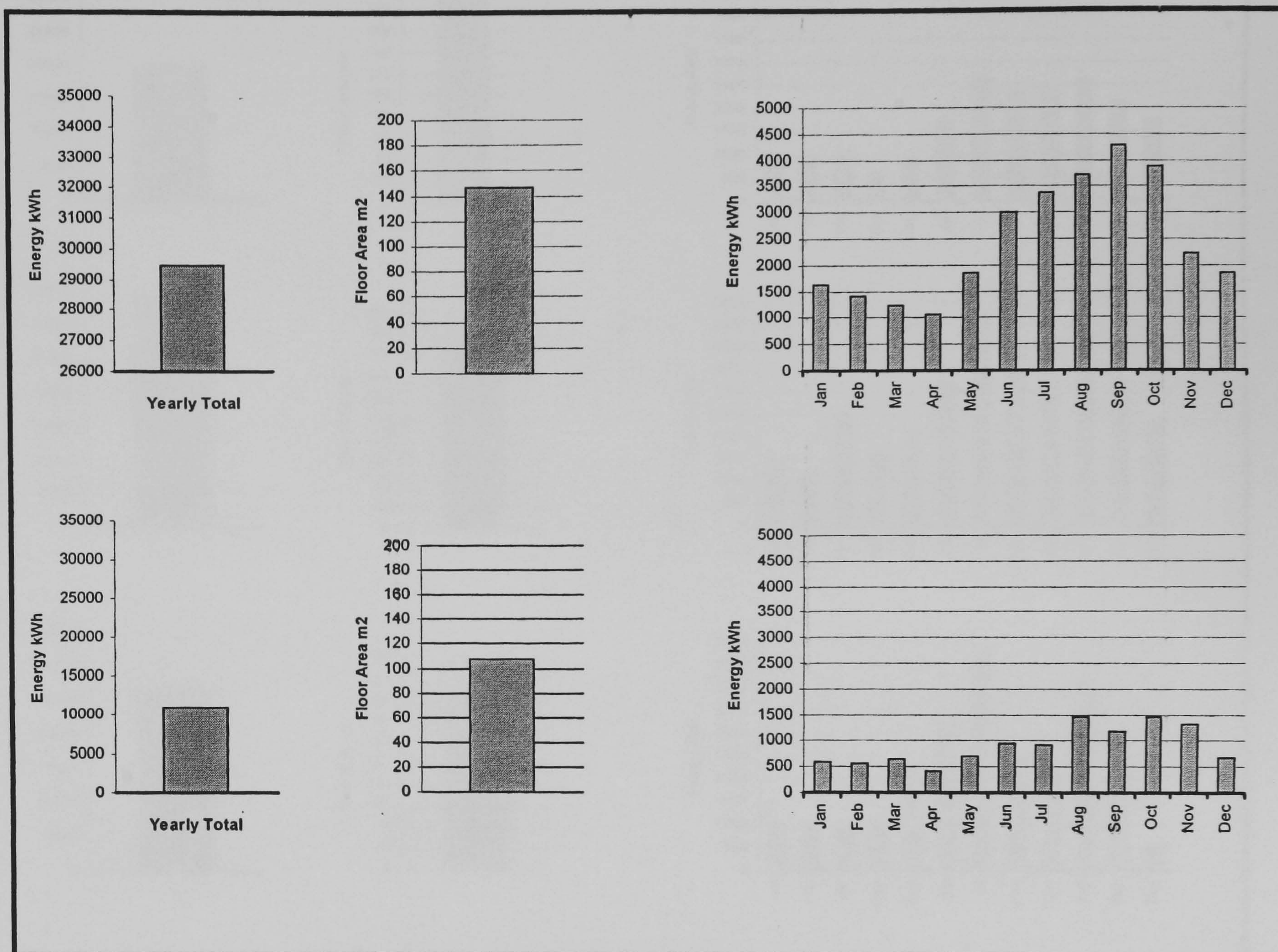
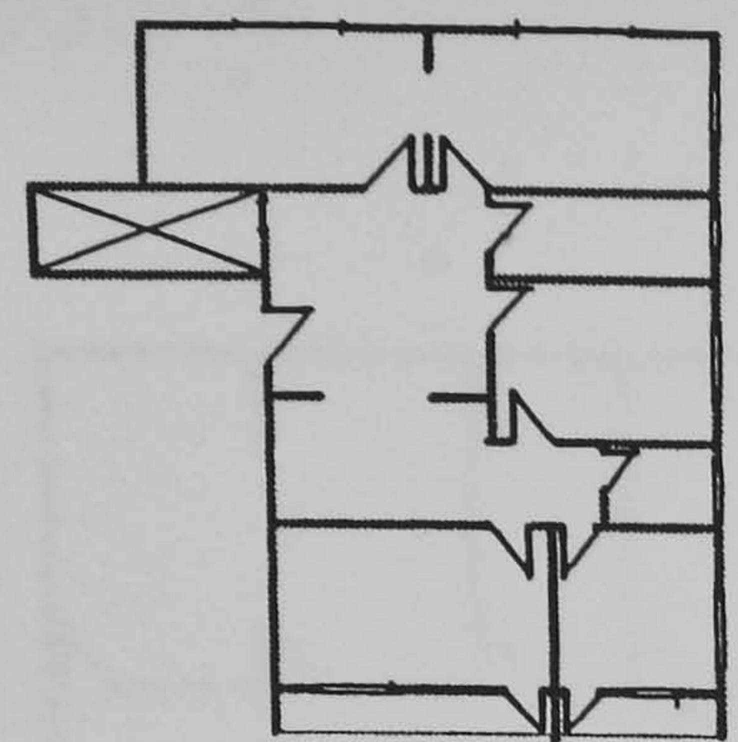
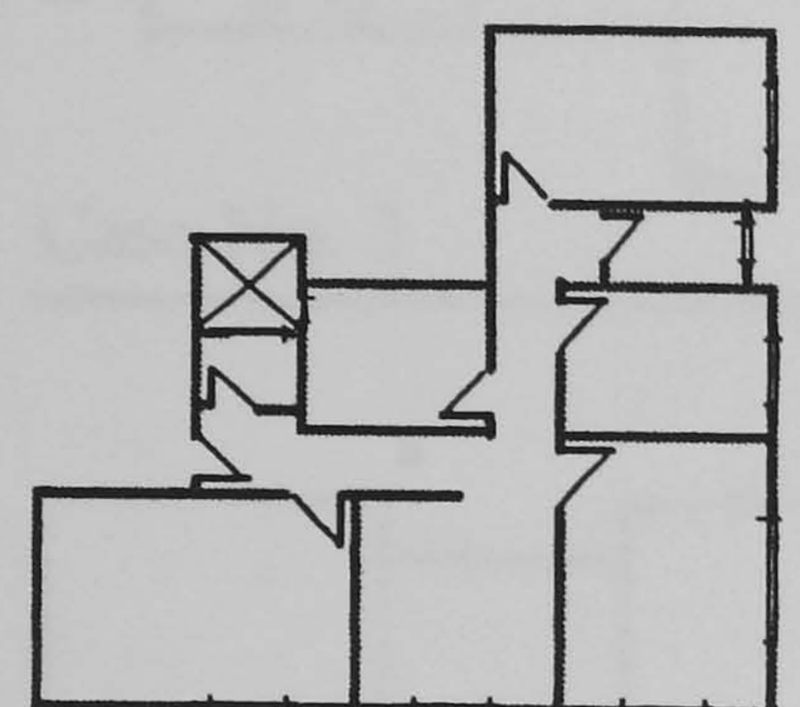


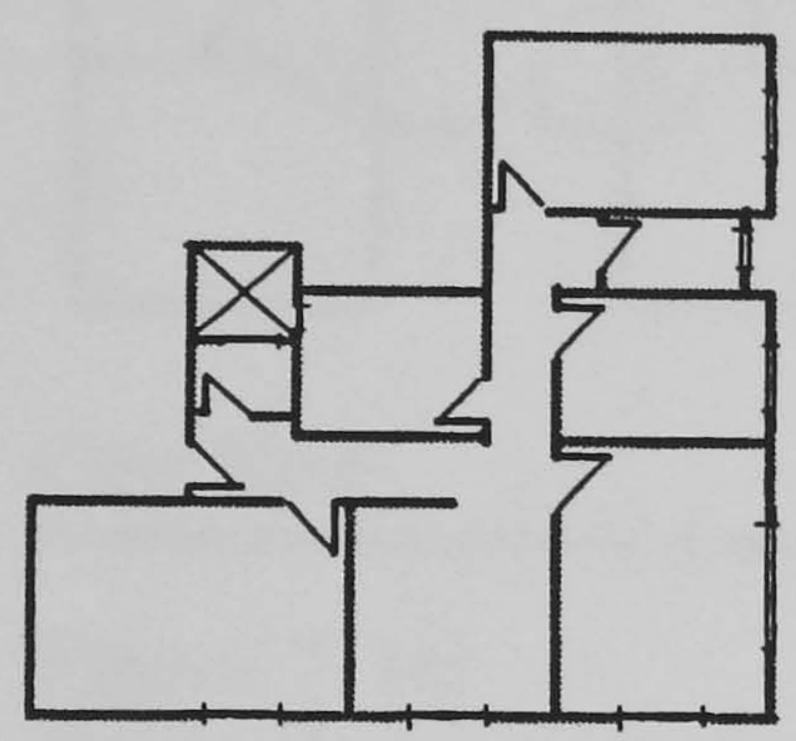
Figure 7. 14: Energy Consumption Pattern for Top Floor Apartments



Case No.4



Case No.7



Case No.8

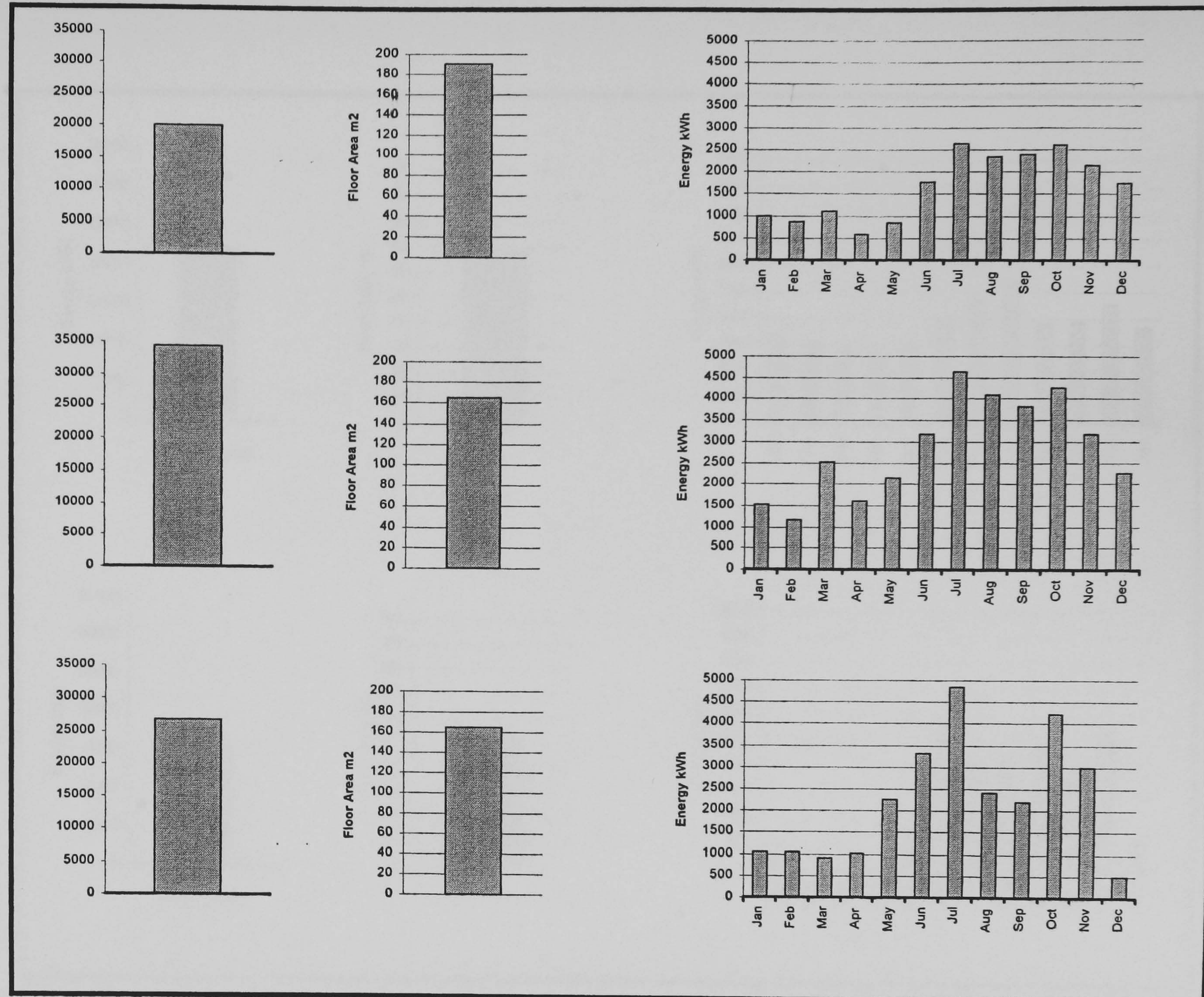
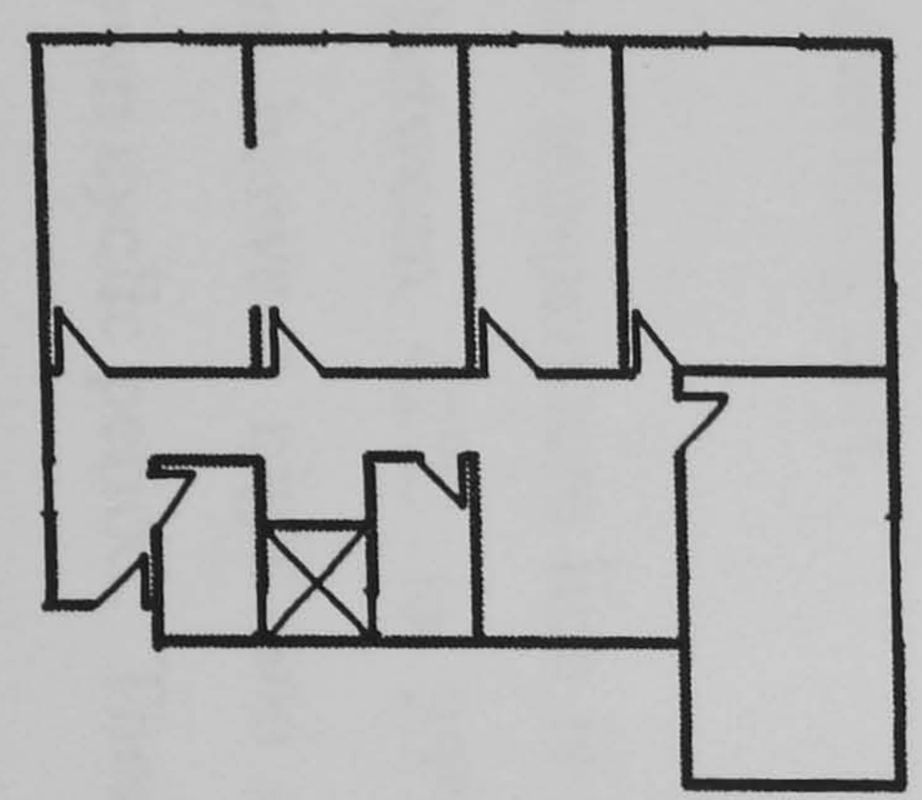
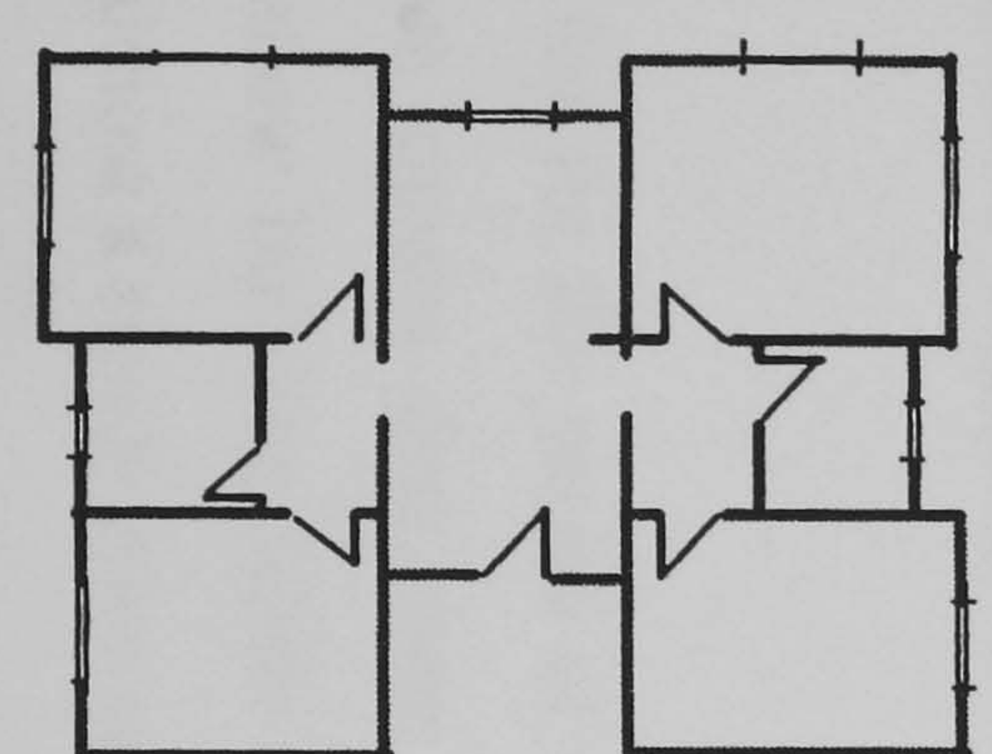


Figure 7. 15:
Energy Consumption Pattern for Middle Floor Apartments



Case No. 3



Case No.6

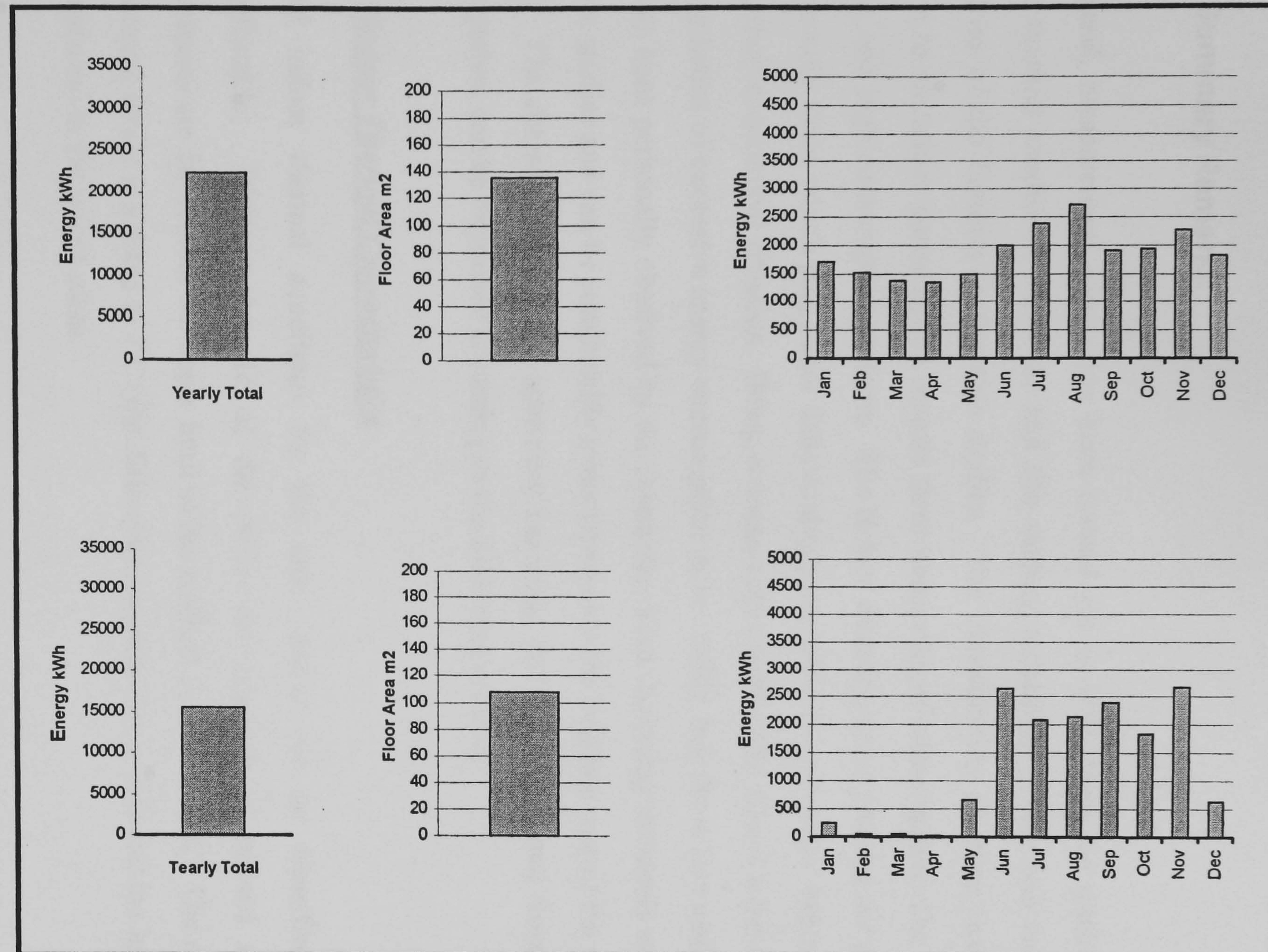


Figure 7. 16:
Energy Consumption Pattern for Ground Floor Apartments

7.6 Summary Remarks

In general, measurement survey has been carried out to investigate the quality of indoor thermal conditions under the real life varying occupancy pattern and various life styles of the families in the case studies. The classification of these cases in relation to electricity consumption reveals three categories of consumption: The low, middle, and high consumption patterns. The factors dictating these patterns are many but normally those which play major determining parts relate to occupants' behaviour and to their economical situation. Being economically comfortable allows a family to develop habits of excessive energy consumption more readily than those less well-off. This has been personally observed by the researcher from the living standards within the case studies and can be comfortably generalised over the building type of the same nature. The characteristics of the apartment buildings that can be inferred from this investigation, can be expressed according to the following context:

- ***Indoor Thermal Characteristics***

Overall indoor thermal conditions for the case studies can be classified as uncomfortable. Without the aid of the A/Cs, the majority of normal room temperatures are far beyond the upper limit of the comfort zone, i.e. 26°C. The effect of structural fabric is limited to 7°C (the difference between the outside and the indoor temperatures) in the worse cases.

There is no significant difference that can be noticed among the cases, regardless of the differences in their construction material, vertical location, and orientation. Also, the difference in temperature is small between the unoccupied rooms in each case. This finding reveal that the prevailing climate condition is dominates the situation inside the dwelling unit.

The outdoor temperature line is almost flat for the period of the year (summer). It averages between 42°C to 39°C, which means that there is no big swing in temperature between night and day to allow building fabric to undergo its normal cooling down cyclic period. Therefore, almost a steady state condition is to be found, with the indoor temperature remaining steady if no air conditioning aid has been provided. Indoor occupancy and usual daily life activities contribute in pushing the temperature profile further as continuous generation of heat is always in progress.

Cases 7 and 8 have the lowest temperatures as a whole, which may be attributed to the extensive use of air conditioning in most of the rooms, and the open doors inside the unit. This highlights the importance of cooling down the heat accessed through building fabric, so that the possibility of a dynamic cycle of heat transmission is realised. In unoccupied and unconditioned rooms, the accumulation of heat matches the temperature profile almost everywhere in the apartment.

Insulation materials, naturally, delay outside heat transfer and keep the inside wall surface mean radiant temperature (MRT) to its minimum for longer periods, and by this means the effect of insulation upon human comfort can be experienced. But if heat accumulates inside and there is no means of ventilation for this heat, then insulation works in reverse and traps the heat for a longer period and further elevation for the indoor temperature can occur. This situation is clearly shown in Case 3.

- ***<u>Occupants Behavioural Characteristics</u>***

The indoor atmosphere in all case study apartments is uncomfortable without mechanical aids, this can be seen in figures 7.4- 7.11. In these figures, the occupancy of any rooms is always associated with A/C operation, while the unoccupied rooms, where no A/Cs are in operation, temperature profiles go far above the comfort line. Air conditioning operational patterns and daily occupancy patterns are not regular for most apartment spaces. Intermittent air conditioning operation is common both in the occupied and the non-occupied periods. The function of multi-purpose rooms encourages occupants to move to the most comfortable area inside the apartment according to the time of day. The space customarily recognised by the occupants to be coolest dictates where they go.

It should be mentioned here that this movement does not come about as a planned action but rather occurs more as something casual and spontaneous. It is applied and reported more by the occupants in Case No.5 and 6. It must of course be recognised that the occupancy of room is generally dictated by its function, and is systematically and connected to daily life activities, e.g. bedroom normal occupation hours is between 11pm to 6am.

One of the major problems observed in most of the cases is the uncontrolled infiltration rate. This problem is underestimated due to the lack of awareness about its potential influence on indoor environment. Although direct leakage can not be found in the functional rooms, where it is reasonably dealt with around windows' openings, the major sources of air leakage are A/C openings and toilet ventilation openings.

The internal circulation links between the zones some times enhance this infiltration to the air conditioned spaces, as moving through corridors and between the zones invites the leakage of cooled air out of the rooms and substitutes it with some hot air coming from the unconditioned adjacent zones. This kind of infiltration deteriorates the A/C-enhanced indoor environment significantly as hot air infiltrate to indoor spaces at high rate, and hence more loads on A/Cs system is imposed.

Artificial light is essential for most of the cases. The usage pattern for this source in daytime is not regular and does not follow a logical pattern, as most respondents replied that they often need to switch the lights on during the day time. Natural light is mainly blocked by heavy curtains in most of the cases.

The curtains do not totally block this source of light but it substantially degrade its quality. In the gloom usually caused by this blockage artificial light is always the ready alternative. Thus most of occupants depend heavily on this source and most of the time they use it unnecessary. Usually there is no calculation made for actual lighting intensity demands for internal zones, and often higher intensity light sources are misused, so that there is a considerable waste in energy due to this simple action.

In conclusion, almost all the existing apartments share the same thermal characteristics as they all are uncomfortably hot and the need for air conditioning is inevitable. The current constructions have a limited effect in acting as thermal barriers to the outdoor temperature. Methods and techniques to upgrade its performance should be further investigated theoretically and empirically.

With reference to energy consumption pattern, it is very obvious that these patterns are mainly steered by occupants' customarily life style, economical status, and cultural and educational background. Almost all of these factors are beyond the research investigation capability due to the very closed nature of Saudi families. Therefore, it is very difficult to assure a certain pattern of indoor activities. However, of the adopting ideal occupancy patterns, according to observations gathered from the field survey would not be far a way from the reality.

The field survey investigation has established the MCRV (2047 kWh) that can be used as a benchmark for energy consumption rate for apartment buildings in the locality of Makkah.

Chapter 8

Thermal Performance Analysis (The Simulation)

Chapter 8

THERMAL PERFORMANCE ANALYSIS

The Simulation

8.1 Introduction

The thermal analysis of buildings has been an essential demand since the energy conservation issue has come to the surface. During the past years, increasing research on building-related subjects has focused attention on the quality of building thermal performance, indoor environment, and energy consumption rates.

Buildings represent a certain complexity in relation to building materials, systems, occupants, and the surroundings. Therefore, the interaction of these factors imposes a difficult task on designers if they are to produce an inhabitable, healthy, and energy-independent environment.

Before computers came into the process, designers traditionally employed a wide range of analytical methods to ensure at least the minimum requirement of performance satisfaction. These methods comprised both simple and complicated manual calculation and some rule-of-thumb measures.

Traditional ways, however, do not always guarantee good results and the complex nature of the buildings is often overlooked due the limited capability associated with these design methods. The final products, therefore, are matters of uncertainty, especially when buildings exist as an idea on paper and the shortcomings in design only become visible after the construction.

Computer technology has meant a big revolution almost in every field of life. In architecture and building technology, computers have allowed designers to produce virtual buildings, try a number of alternatives, predict performance, and enhance decisions before executing the buildings in reality. They also provide the means to develop and test complementary techniques which, while preserving the dynamic properties of building behaviour, are simple to use and so overcome many of the problems associated with large system implementation, management and operation (Markus, 1984).

This chapter aims to shed the light on thermal analysis techniques and the technique adopted for this study. It also explains the methodology of the data analysis and the configuration of the simulation model constructed for this study.

8.2 Methods for Building Energy Analysis

The methods of studying energy behaviour of the buildings are various. Each has its technical and operational principles, and its assumptions and limitations.

In order to adopt a proper technique for any analysis process, a review of modelling techniques and simulation theories has to be obtained. From thermal point of view, a building is a complex network of thermal resistance factors linking different parts and presenting conductive, connective, radiative and heat storage phenomena.

Thermal modelling techniques are determined by the manner in which the network is treated mathematically. Different techniques are launched from the same basic equations, namely that of energy conservation for the building zone, that describe the storage and flow of heat in and through building elements. The main differences between one technique and another lie in the overall approach to the problem and the assumptions made along the way (Rousseau, 1993).

Energy analysis packages usually consist of two major models. The first is the building model that accounts for the thermal performance of the building envelope and interior loads. The second is the HVAC system model that accounts for the fluid dynamic and thermodynamic processes taking place in the various system elements.

Building models usually make use of one of the following methods in their calculation structure, based on load calculation concepts:

- Steady State
  - Transfer function method
  - Weighting factor method
  - Admittance method
- Numerical
- Electrical analogue

8.2.1 Steady State

Steady state denotes a heat flow situation where no account of the dynamic effect of time has been given. This method is used simply to calculate the rate of heat transmission through the building fabric and the total heat gain/loss load in and out of the building spaces, and it has no mechanism for the accurate calculation of the effects of solar gains, casual gains, long-wave radiation exchanges, and plant operation strategies.

Models that follow this method typically address only fabric heat flow, under special boundary conditions, and not building energy. Typical inadequacies include the omission of any consideration of the dynamic response of buildings, an inability to deal realistically with many of the energy flows occurring within buildings, and an inability to effect the correct relationship between building fabric and installed plant operation.

In consequence this method is being supplanted by dynamic theories and will play a diminishing role even at an early design stage, where as well as accuracy problem, its ability to provide even indicative results may be seriously questioned (Busch, 1996).

There are three commonly known methods that based mainly on the steady state calculation method and enhanced by more complex formulations to satisfy the purpose of each method. These methods are transfer function method, weighting factor method, and admittance method.

8.2.1.1 Transfer Function Method

This approach has been developed by ASHRAE, where an integral form of the energy conservation equation is solved for each building element and the space air mass. With this method the response factor account for thermal storage effect has been given for each element. These response factors are derived beforehand from the solution of transient one-dimensional heat conduction equations for specific multi-layered construction and specific indoor and outdoor temperature.

The heat extraction rate required to maintain the specified indoor temperature is obtained from the heat balance for the indoor air mass. One drawback of this method is that new response factors must be found before any new composition of building materials can be used in any multi-layered construction. Another disadvantage is that the method aims at finding heat extraction or addition rates required from a HVAC system to maintain a given indoor air temperature, and not at finding the correct indoor air temperature given the system operation. An appropriate design tool must, however, accommodate any composition of building materials and must also calculate the correct indoor air temperature (Mitalas, 1972).

8.2.1.2 Weighting Factor Method

The method makes use of two types of transfer function. The first group relates the space energy loads to instantaneous heat gains and the second group relates room temperature to the net energy load of the room.

These two types of transfer function are used sequentially, together with information of the HVAC system, to determine the room temperature and correct heat extraction rate. However, there still is a reservation about this method as ASHRAE has noted that errors can be introduced when large deviations in room temperature occur, since the technique is based on linear mathematics and quite sensitive to initial assumptions.

Such large variations in indoor air temperature often occur in buildings, especially where the system is operated intermittently, and should therefore be properly addressed (ASHRAE, 1989).

8.2.1.3 Admittance Method

The admittance procedure is a technique for estimating energy transfers and temperature changes under steady cyclic conditions. It was developed by Danter and Loundon at the Building Research Station in 1970. It shows that when environment temperature is used to quantify the radiant and the convective interchanges within a space, the response of the building surfaces to energy cycles can be determined by the admittance factor, decrement factor, and surface factor. By using the 24-hours frequency values for these factors, a practical manual solution for the calculation of internal gain in buildings can be obtained (Milbank, 1978).

8.2.2 Numerical

With the advent of powerful computing systems many problems of varying complexity can be solved by numerical means. Two main numerical techniques exist: finite difference and finite element. The former is the technique most commonly applied to the problem of building energy. This method uses several nodes to represent each layer in each building element as well as the space air mass. The differential equations describing mass, momentum and energy conservation is solved at each node to determine the correct temperatures.

Although this technique represents a very rigorous treatment of the building, the methods involved require vast computational resources, restricting its use to mainframe computers or workstations.

8.2.3 Electrical Analogue

The analogy that exists between electrical flow and heat flow has led to the construction of electrical analogue devices useful in the study of complex heat flow phenomena. This technique is useful as a research tool, allowing long-term simulations to be completed in a short elapsed time.

Electrical analogue methods essentially solve the same equations as those used in finite difference techniques but make use of electrical circuits to visualise the building network. This usually gives a very good physical feel for the problem in hand.

In this method, each element is represented by capacitor and a resistance while heat gains and losses are represented by sources and sinks. In the same models, groups of building elements are lumped together with hardly any loss in accuracy and this reduces the size of the network. Well-established electrical circuits theory is employed to obtain solutions for temperatures in the different nodes in the circuits. In this way even the passive performance of a building may be simulated in an efficient manner. By rearranging the same equations, accurate loads can be calculated for a given indoor air temperature (Rousseau and Mathews, 1993).

8.3 The Nature of the Design Tools

Ever since the need for better shelters with that requires low energy has increased, the associated need for better understanding and evaluation has risen as well. The performance of the building, its HVAC system and its control cannot be easily described, and there is a need for a systematic approach and design tool, therefore, in order to design for energy efficiency. In the interaction of the building the HAVC system is a subject of crucial importance.

Most of traditional design tools are based on load calculation procedure. The procedure fixes an indoor air temperature at design set point, which may vary from hour to hour during the day. From this, heating or cooling loads are calculated for given outdoor air and internal load conditions. Instantaneous space heat loss or gain is calculated and an attempt is usually made to account for the delay effect of radiation and thermal storage in building structure.

The concept of load calculation usually overlooks four major considerations that may adversely affect the accuracy in this technique. However, these considerations are essential in any successful design tool and can be listed as follows:

1. The way that thermal storage is handled
2. The shortage of information on the passive building performance
3. The fixed set-point value for indoor air temperature
4. System performance is not properly addressed

With regard to thermal storage, two of the most widely accepted load calculation methods are the ASHRAE transfer function method and the CIBS admittance method, mentioned above. Field measurements undertaken by the UK Building Service Research and Information Association and also by Tuddenham (1983) have however pointed to rather large inaccuracies in these methods. It would seem that both of these tend to underestimate the effect of thermal storage, resulting in a predicted peak load 25% higher than actual loads. This inaccuracy can result in over-sizing the system with its associated undesirable effects.

There is no allowance made for the calculation of passive indoor temperature (i.e. when no environmental control is provided), which plays a crucial role in the performance of both building and HAVC system. It is very important to be able to calculate the actual indoor air temperature as well as the temperature of building structure when the environmental control system is not operating. Variation in the space temperature through intermittent operation of the HAVC system is a promising energy saving device.

In cool outdoor nights, air may be fed into the building through either natural or mechanical ventilation to cool the building down. The temperature will drift towards the value determined by the passive performance. The thermal storage capacity of the building may then be used to reduce heat the extraction rate required from the system during the day.

The exact temperatures are important parameters to be accounted for in the design tool. They will determine the actual reduction or increase in the heat extraction rate required from the system (Lomas, 1992).

In theory, by fixing the indoor air temperature at specified set-point most of the calculation procedures assume an ideal controller action. In practice however, the controller will hardly ever ensure a constant air temperature. Actual loads can vary considerably from those obtained from fixed air temperature load calculation once the indoor air temperature differs from that initially assumed. Therefore, real-life controller action should be simulated for more accurate design tools.

Load calculation procedures do not properly address the performance of the HAVC system and do not account for its energy requirements, which can be a matter of a large energy saving. Studies have shown that energy saving can be increased by as much as 50% when considering the performance of the HAVC system. Design for energy efficiency should not concentrate on loads alone but it has to be part of a more integrated approach (Amor, 1993; Amre, 1995).

A consultant engineer of 25 years' experience has formulated the situation this way:

> It is my firm believe that, for us to build the buildings that we must have, we will have to fully integrate all building components and systems. It is certainly not acceptable to think of the HAVC system as something added on to the building to make it liveable. All things, animate and inanimate, that make up a building are part of the building system. Consequently, a change in one can affect the others. It is interaction that we must fully understand if we are going to achieve a truly sustainable society (Holite, 1993).

8.4 Simulation Techniques and Approaches

The existing building energy prediction tools can be classified into the following two main groups:

1. Energy Analysis Programs
2. System Simulation Programs

The nature of this classification recognises the potential influence on the accuracy, applicability to practical problems and the time these programs take to perform calculations. The fundamental difference between these approaches is that system simulation tools are aimed at predicting the real-life operation of the system as opposed to the ideal operation which is the concern of energy analysis tools.

8.4.1 Energy Analysis Tools

These programs usually attempt to find an answer for a given question, such as 'What will energy consumption of the system be?' They predict the energy consumption under a given building data, a specific type of HAVC system and a desired space condition to be maintained at all times.

The prediction runs under an ideal controller, with all equipment operating at the ideal conditions. The advantage of this approach is that it usually requires less input, and the calculations also require less computer running time since operating conditions need not to be found but are specified in advance. In the real world however, the system hardly ever operates according to the design specifications. This puts rather severe limitations on the applicability of these programs in predicting real building energy consumption and aiding in the commissioning of new systems and in retrofit projects. Examples of these programs are: BLAST developed by the U.S. Army Construction Engineering Research Laboratory and University of Illinois, DOE-2 developed at the Lawrence Berkeley Laboratory, ESP developed by Strathclyde University, HAP E-20 developed by Carrier, and TAS originally developed by

Amazon Energy in the U.K. and now supported by Environmental Design Solution Limited (Gough, 1986; Birdsall, 1990; LE PECQ, 1992; Lawrie, 1992).

8.4.2 System Simulation Tools

These programs have been developed to find an answer to question such as, 'What are the real indoor air conditions, system-operating points and energy consumption?'

Energy simulation programs therefore attempt to predict the real performance with given building data, the system layout, the detailed component characteristics and control schedules. The advantages of this approach are that designs can be properly evaluated and control strategies can be tuned beforehand to obtain the optimum performance for the complete integrated system.

This approach is also ideal for retrofit studies since, once the old system has been simulated successfully, components can be replaced in the simulation and the effect of each replacement on the indoor environment and energy consumption can be determined almost instantly.

A potentially serious limitation of this approach is that it can require a substantially larger amount of input data and computer time depending on the specific program. Examples of system simulation programs are APCHE, CABARETS, HAVC-DYNAMIC (Irving, 1986; Ogard, 1988).

8.5 Energy Analysis Methodology Adopted for the Study

8.5.1 Aim of Simulation

Currently the most powerful technique available for the analysis and design of complex systems (like buildings) is computer modelling and simulation. Modelling is the art of developing a model which faithfully represents a complex system.

Simulation is the process of using the model to analyse and predict the behaviour of the real system. It is the indispensable prediction technique in the field of building energy design and system configuration.

Simulation aims to complement the visualisation obtained by the field survey for the existing situation of the apartment buildings. Building performance appraisal in terms of energy and other influencing environmental factors is a major target of this stage.

It is also aim from the simulation to produce a theoretical description for the different thermal behaviour of building components and building users in order to recognise the merits and diagnose the defects within the specified residential context (IEA, 1995).

In practice, uncertainties usually surround the effectiveness of the application of any thermal upgrading measures. This subject has been brought up by many respondents of the questionnaire survey. Therefore, simulation also aims to evaluate effectiveness of applying certain energy saving measures, assess their potential effects on energy performance, and reveal some of their uncertainties.

8.5.2 Selecting Simulation Tools

Among the various energy analysis tools, specific criteria have to be set for the selection of a proper device that can fulfil the aim of this study. The criteria for adopting the energy analysis tool selected take account of the following considerations suggested by Wiltsher & Wright (1987):

- Credibility
- Performance Assessment Capability
- Ease of Use
- Resources

Credibility can be defined by how closely the simulation results gained by any adopted program correspond to reality. This correspondence is usually judged under the following terms:

- Recognition and acceptance by the modelling community
- Extent of participation in validation exercise
- Technical appraisal of the program

The Performance Assessment Capability of programs can be judged by the extent of assessment in relation to design aspects, programs' features in presenting problems and the application of the program to sample design cases.

Ease of use comprises all user-program interaction aspects, which involve user-friendly interface, user support, documentation quality, and modification and development of the program. Resources are assessed in the following terms:

- Manpower required to set up and to run simulation
- Hardware and equipment requirement
- Simulations run times

Broadly speaking, these are the major guidelines that provide the base for the selection procedure. Although that they all have been given the same importance weight, the resources factors have been very crucial in final decision.

Three computer programs, among many programs looked at in the primary evaluation list, have been selected for final consideration. These programs are BLAST, DOE-2, and ESP (Table 8.1).

Program Name	Calculation Method	Developer & Origin	Status
BLAST (Building Load Analysis and System Thermodynamics)	Response Factor	DMIE – University of Illinois – U.S.A.	Public Domain
DOE-2	Response Factor	SRG – Lawrence Berkeley Laboratory (LBL) – U.S.A.	Public Domain
ESP (Environmental System Performance)	Finite Difference	ESRU – University of Strathclyde – U.K.	Public Domain

Table 8.1: Simulation Programs under Evaluation

The programs are widely recognized by energy analysts worldwide and they have been in use extensively since the seventies. They all are capable of handling a detailed simulation on an hour-by-hour basis with very reasonable agreement to the actual measured condition. The International Energy Agency (IEA) has put these programs with another 14 programs in a comprehensive empirical validation and concluded that they perform reasonably reliably and efficiently (IEA, 1994).

BLAST is a set of computer programs for predicting heating and cooling energy consumption in buildings, and analysing energy costs. BLAST has been supported by the US Department of Defense (DOD).

DOE-2 is a public domain system that performs an hour-by-hour simulation of a building's energy use and energy cost given a description of the building's climate, architecture, materials, operating schedule and HVAC equipment. DOE-2 is widely used in the United States and 42 other countries to design energy-efficient buildings, to analyse the impact of new technologies and to develop energy conservation standard. DOE-2 has been a basic component of the ASHRAE efforts to produce and upgrade building design standards and handbooks (LBL, 1981; Hong, 1999; VIT, 1999).

ESP is a public domain transient energy simulation system capable of modelling the energy and mass flows within combined building and plant systems. ESP-r is the

European Reference building simulation program, it allows designers to assess the manner in which actual weather pattern, the interaction of occupants, design parameters changes, and control system effect energy requirements and environmental states (Clarke, 1983; Clarke, 1985).

DOE-2 and ESP have been recognized and integrated into COMBINE. COMBINE (COmputer Models for the Building INdustry in Europe) is a major research project within JOULE program of the European Commission's Directorate General XII for Science, Research and Development. It seeks to develop an operational computer-based Integrated Building Design System (IBDS). COMBINE began in 1990 and ended in 1995. There are two integrated system developed in COMBINE. The first system is for architectural practice, which integrates more than ten design tools into an Intergraph-based architectural CAD system. The second system is for HVAC design. It is an AutoCAD based HVAC CAD system, which integrates Superlink for lighting design, TSB13, ESP-r and DOE-2 for detailed thermal simulation, VENT for duct sizing, cost evaluator, HVAC components database, DocLinks for document management (Augenbroe, 1992; Hong, 1999).

The three above-mentioned programs are suitable for facilitating the needs of the research. However, DOE-2 has been selected as an analysis tool for this research for the following reasons:

- DOE-2 is available in PC versions that work under windows environment, which is more suitable for the researcher's available resources.
- DOE-2 is user-friendly program and there are several versions that utilize the DOE-2 calculating core and provide a graphical user interface to prepare input and browse results. ESP-r employ SUN workstations and Silicon Graphics.
- DOE-2 is a simulation program well known to the research community in the Kingdom of Saudi Arabia, hence, analysis procedure and the output simulation results will be more readily comprehendible and appreciated.
- Cost and training time on DOE-2 is relatively lower. Also data input procedure and the running time are more flexible and faster.

8.5.3 Simulation Strategy

Retrofitting involves making considerable changes to existing buildings. These changes aim to rectify existing defects, improving building standards and increase or modify the capabilities of a building's use. Although residential retrofitting usually cannot be justified by energy savings alone, techniques and practice with energy savings potential are worth considering when retrofitting residential structure. The range of energy saving measures involving retrofitting of residential buildings is significant. Energy saving improvements can be made to the building envelope, the building services and to the occupant's behaviour within the building.

The research aims to investigate the potential improvement by retrofitting existing building envelope. Retrofitting strategy for the building façade follows two major approaches:

1. Comprehensive approach, leaving existing fabric unchanged and considers adding second skin for the whole building.
2. Separate measures approach, applying certain energy saving measures on separate basis, i.e. modifying building fabric performance by insulation and elevating windows efficiency by shading openings.

Double skin façade is a system where two layers of construction materials are separated a significant amount of air space. The outer layer provides a weather shield that protects the inner layer from climate factors. The air space between is normally used for two different purposes: space for HVAC systems (ventilation) or a space for louvers that act as movable shading devices. The air space acts as an insulation layer between the out side and inside (Gartner, 2001).

Double skin technology has been well introduced with glass skin (external glass curtain) situated in front of the external wall. It is already a common feature of architectural competitions in Europe; but there are still relatively few buildings in which they have actually been realized, and there is still little experience of their behaviour in operation (Oesterle, *etal*, 1999).

This technique has been in operation in temperate climate as a sound design option to improve efficiency in the retrofit of existing buildings. However, this trend is still questionable from biophysically and psycho-culturally point of view when interpreted as exemplars of sustainable architecture (Diprose & Robertson, 2001). The applicability of such technique in hot arid, where glazing surfaces represent a crucial constructional and thermal element climate, has not been well recognized yet.

This issue usually involves high–tech treatments, vast range of resources and computer controlled automation, which elevate the complexity for the application of this strategy and make it beyond the reach of any retrofit scheme with limited resources.

Adding second layer using non-glazing materials is a feasible alternative but not a practical one. Cost, daylight quality, aesthetical appearance, and natural view are factors to be greatly affected by such technique, which make it architecturally and socially unacceptable alternative.

Adopting the approach of testing the effect of certain energy measures as a retrofit strategy is more suitable to the realm of practical solutions. Due to the expenses involved, retrofitting might take many stages for a single building, moreover the huge existing buildings that need to be retrofitted.

Knowing the individual effect of certain energy measure would give more ground for the application of this measure alone or with connection to some other measures. For these reasons the research has adopted the investigation of different energy saving measures in separate rather than following the comprehensive retrofitting approach mentioned earlier

Simulation has been carried out employing VisualDOE2.5 as major analysis tool. VisualDOE2.5 is a powerful Windows based, graphic interface to the energy analysis program DOE-2.1. This graphic interface has enabled the users to simulate and predict the performance of their buildings in quick and easy process.

Moreover, VisualDOE2.5 is a user-friendly program with an easy data-input procedure, flexible data customisation, and has an extensive output reports (ELEY, 1997). The strategy adopted for the simulation is in three phases as follows:

Phase one is concerned with the simulation of an existing situation that can be found under actual apartment buildings condition. This phase aims to identify the thermal properties of different building components and to recognize their implications on energy consumption pattern with regards to comfortable indoor environments.

Phase two explores the effectiveness of specified energy saving measures and their potential reflection on energy consumption and the indoor environment.

Phase three deals with the impact of the occupants as a major internal driving force in energy performance issue and address the economic issues behind potential upgrading.

The execution of this strategy takes the form of sequential program runs for the proposed model. This procedure requires a certain data protocol before the actual simulation process can be completed. This protocol concerns the following points:

- Building the study model under the program mode.
- Creating different files for different base cases to be subjected for simulation.
- Feeding the program with building data.
- Feeding the program with system data
- Scheduling the activities for occupants and equipment.
- Preparing the weather file
- Total revisions
- Run and extracting results.

The results are then, to be converted into spreadsheet format in order to prepare them for analysis.

8.5.4 Analysis Scope

The scope of the analysis is very broad if we consider the technical ability provided by the simulation program (VisualDOE2.5). Huge amount of information can be retrieved in single program run and this imposes a risk of being overwhelmed by unnecessary and irrelevant information. Therefore, limits have to set to direct the scope of the analysis in a definitive path.

The research aims to approach the problem of identifying the thermal characteristics of existing apartment buildings as whole unit and deal with them in a way resembling as closely as possible the real situation. Therefore, the analysis takes a comprehensive approach rather than a detailed one, and features the following hierarchy in its description of the thermal performance:

1. Level one, the performance of the whole building (aim to compare the performance of the constructional systems)
2. Level two, the performance of inter-building vertical levels (aim to evaluate the performance according to vertical location)
3. Level three, the performance of inter-apartment zones (aim to evaluate the effect of the orientations and occupants behaviour) (Figure 8.1).

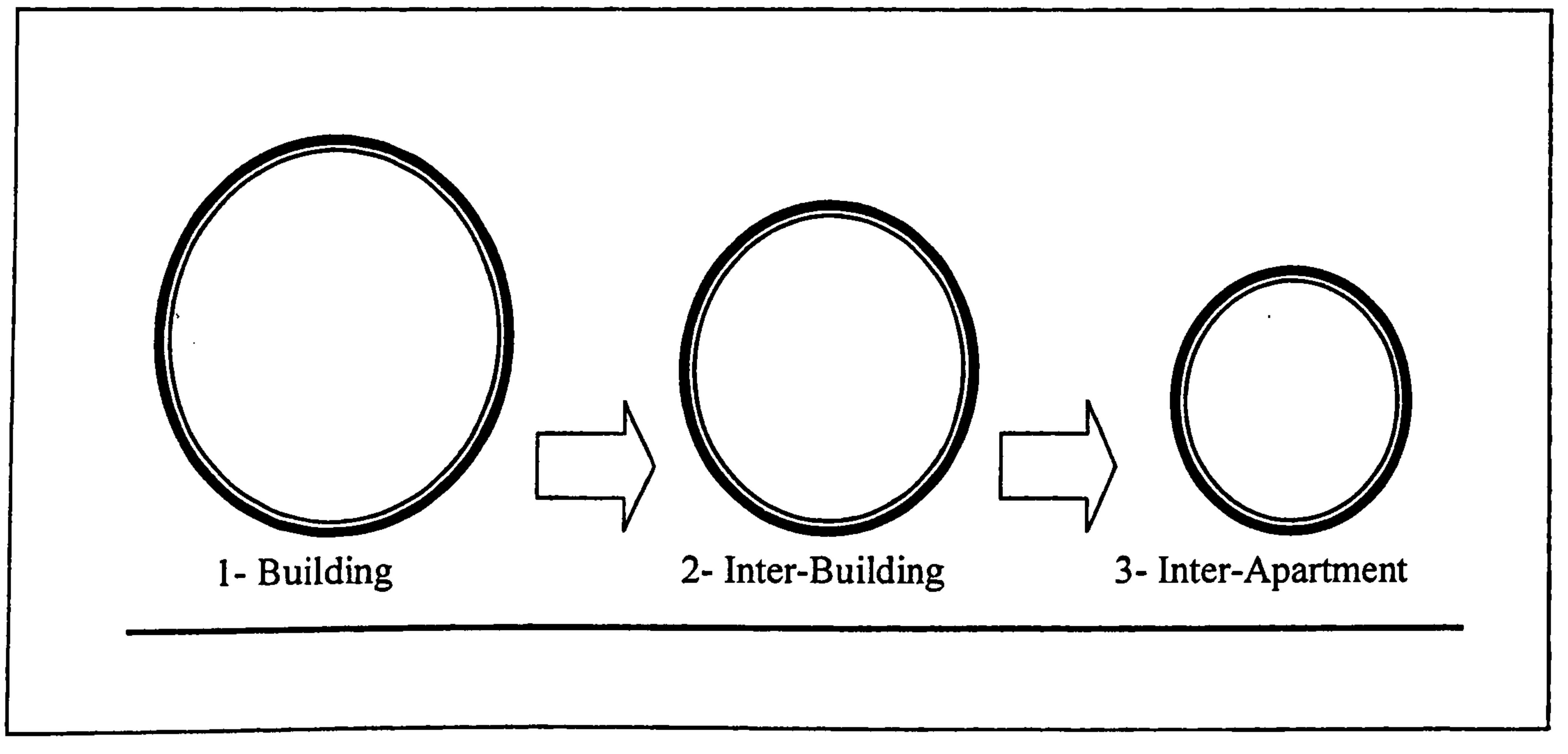


Figure 8.1: Analysis Hierarchy

The analysis mainly targets the amount of heat gain load introduced by different physical and natural components of buildings, the percentage of the contribution from each component, and their implications on cooling load and energy consumption. It also aims to acquire some knowledge about the potential benefits of energy saving measures and their economic effects on the existing situation.

8.6 Construction of Simulation Model

A simulation model can be defined as a model that contains a description of the behaviour of a process. It is a tool that can be used to study the consequences of the different parameters or different process configuration. There are two main types of simulation models. There are continuous simulation model in which, the state of the objects are modelled as a function of time and change according to that function. The other type is a discrete event simulation model, in which the changes in the model occur as a result of events, such as incoming order. Most simulation models that describe production process are discrete event simulation models.

In order to build a simulation model, the first task to be considered is to define the questions that the model should answer. Based on these questions, the appropriate level of detail and scope for the model must be decided. The model must be built to include all the relevant factors affecting the process.

The simulation model in this study is mainly based on an existing process and is aimed at exploring the current behaviour of apartment buildings under fixed socio-cultural and climatic circumstances. Therefore, performance data in close relevance to the existing situation must be collected and used as an integral part of the modelling.

The process of outlining the structure of the model and defining the data needed for simulation is based on the information gathered and inferred from the survey analysis in Chapter 7. This data represent facts about different aspects of the problem and can be comfortably utilised as a foundation for the simulation model. To establish this model, the following data construction articles have to be satisfied:

8.6.1 Geometrical Configuration

The common modelling construction in energy prediction studies rely on a single-zone test unit. These studies, for the purpose of reducing time and cost of simulation, usually consider a building as a single-zone that did not have internal partition walls and, presumably, served with a central mechanical system. In certain conditions, e.g. open office building, this assumption usually fulfil the need and match the problem in reality but in some cases, e.g. housing and apartment buildings, the assumption of modelling a building as one single zone might be unrealistic.

In housing stock in Saudi Arabia, there are two major types of buildings, i.e. detached houses and apartment building. These types are completely different in concept, size, ownership, and internal arrangement. The only thing in common is that they are all served mechanically by separate A/C units that installed in each function zone, e.g. window type and split unit. Central mechanical systems are rare and usually used in high-income family houses.

For practicality, the simulation model adopted in this study is a prototype that represents the common apartment layout that found in large part of this kind of housing stock.

The simulation model illustrated in Figure 8.2 has been set for this study. In this configuration, four zones that represent typical basic functions are introduced. These zones are Guest Zone, Bed Zone, Kitchen Zone, and Living Zone. Each of these zones is located in the outer rim of the apartment unit with one and two exposed facades to the outer climate. There are three internal zones also situated between the major zones.

This reference apartment will be used as a base case for simulation procedure and should reveal information about the potential thermal behaviour of such units in the local environment.

The configuration of the simulation model also takes into account different vertical locations for the base case; these levels exemplify ground, middle, and top floor conditions.

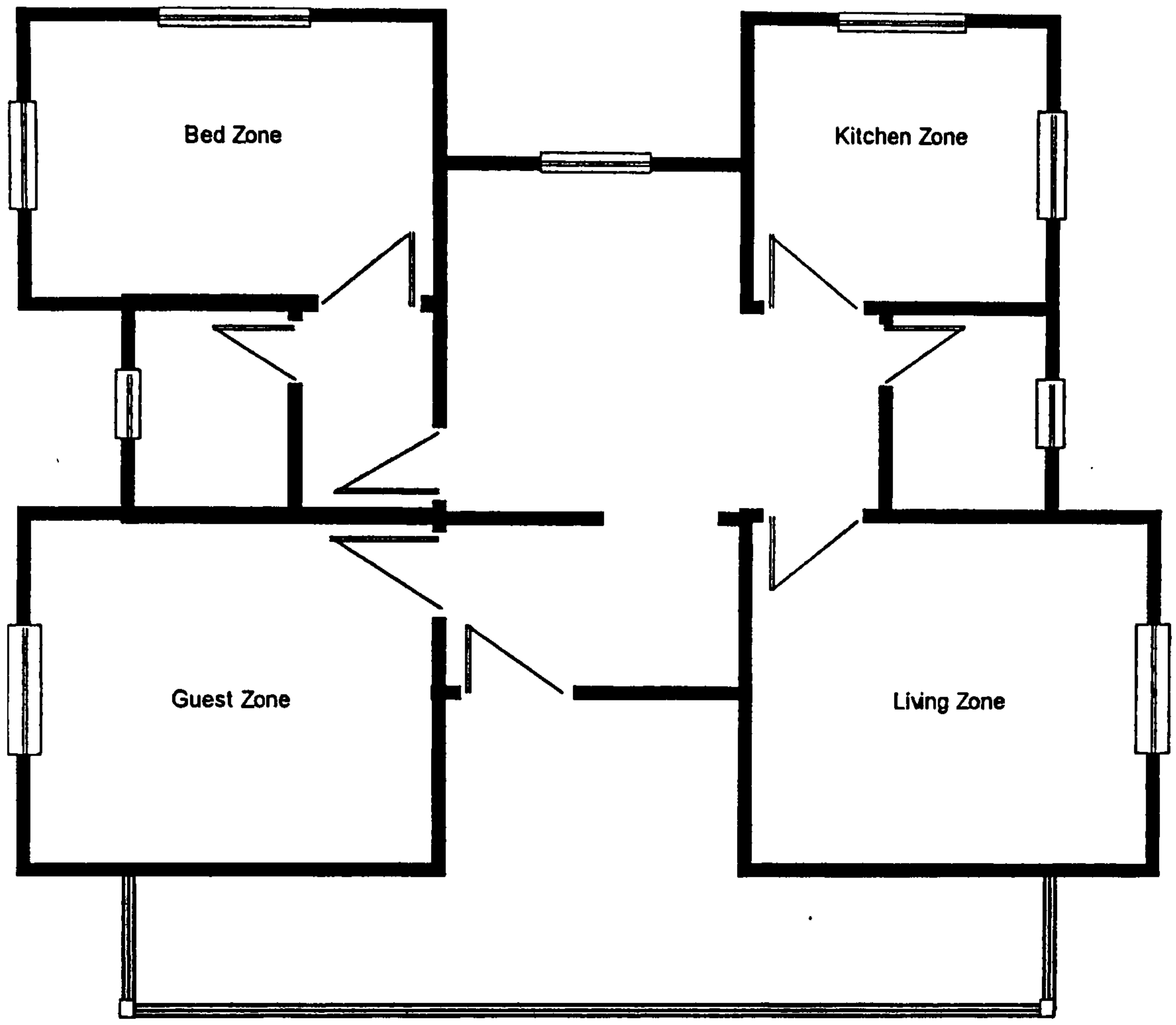


Figure 8.2: Apartment Model Adopted for Simulation

8.6.2 Material Composition

The differentiation given to the base cases in the simulation process mainly applies to the different materials that each base case is constructed from. The building materials under investigation are the popular materials that usually exist in local market. The simulation cases have been named after the kind of construction materials that involved in the evaluation process.

These construction materials are tabulated in Table 8.2 and the property and the composition of each type of construction is illustrated in Figure 8.3.

Simulation Case	Building Material	U-Value W/m²°C
Construction No.1	Hollow Clay Block	1.887
Construction No.2	Hollow Concrete Block	2.564
Construction No.3	Solid Concert Block	2.778
Construction No.4	Red-Fired Clay Brick	2.083

Table 8.2: Types of Construction under Simulation

The Simulation starts with identifying the thermal behaviour of the base case constructions in the first stage, than move to identify the enhancement for these constructions in the second stage. The enhancement in the construction employs insulation materials as a heat delay factor that may help in improving the overall thermal performance of the constructions.

Thermal Retrofit of existing buildings is a process that is highly dependent on the existing building form and practicality of the suggested retrofit measures. Meanwhile many retrofit scenarios can be proposed to upgrade the thermal performance of existing building, only few would be suitable and acceptable within a given social and environmental context, i.e. the case of Makkah.

The retrofit strategies that can be part of upgrading process, in practice, can be comprised of the following enhancements of building envelope:

- Enhancing the thermal performance of the opaque building surfaces by:
  - Installing insulation materials
  - Putting building fabrics under shade
- Enhancing transparent building openings by
  - Shading the openings
  - Using advance glazing systems

The criteria of the selection for which one of the above strategies is more realistic for application in practice is based on the following major factors: low cost, ease of application, acceptance to social conception, and compatibility to current building roles and regulations.

Adding insulation and shading the openings are the two well known, straightforward, and simple strategies for direct application.

Shading the entire building envelope is a strategy that will reduce direct solar energy striking the façade. This strategy is very effective for high angle solar radiation but has limited impact when the sun is lower in the sky. In this study whole façade shading was not considered.

Approximately 25% of the heat gain into the dwellings can be attributed to direct solar gain, via the window elements. Limiting the direct solar gain is an important strategy in reducing the cooling loads. The solar gain can be limited by using reflective glazing systems or by externally shading the window opening.

The most effective glazing system can reduce solar gain by 70 %, whilst window shading, by preventing solar radiation striking the window, can reduce solar gain by 90%.

As the measures considered in this thesis are aimed at the retrofit market in Saudi Arabia, and must observe the social conditions prevalent there. Entering dwellings to undertake window replacement would be extremely difficult. Hence the strategy of window shading was adopted and not the replacement of the windows with high performance systems.

In Saudi Arabia, there are wide varieties of resistive insulating materials available for use in building construction. These materials take the form of boards, blankets, foams, and loose fills. The most popular among these materials is the rigid format that can be found in a variety of sizes and thickness, which suites many applications depending on the design.

The common materials includes polystyrene-expanded and extruded, cellular glass, polyurethane, fibreglass, vermiculite cork, and rock wool. The procedure of selecting the proper insulation materials usually balances between the properties of the insulation materials, the cost, and the thermal performance for these different types.

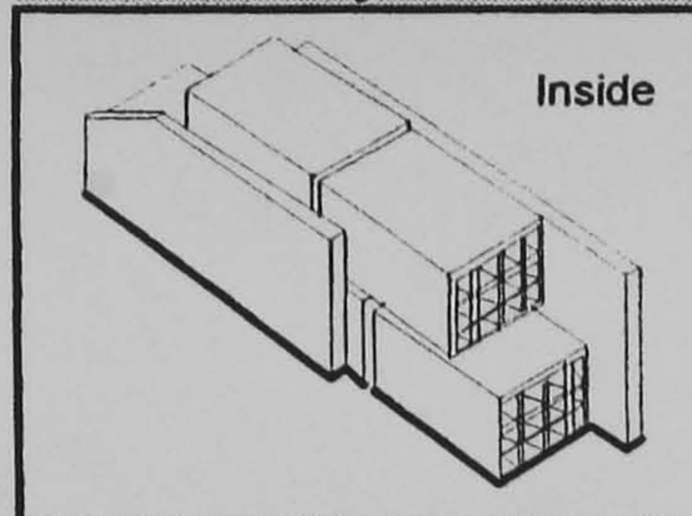
The performance of the insulation materials vary according to their physical properties that comprise thermal resistance, compressive strength, durability, vapour resistance, and fire resistance. Other criteria consider the cost, availability in local market, ease of installation and ease of maintenance.

In this study, the polyurethane boards have been chosen as thermal modification to the base cases due to its popularity, competitively low price, ease of installation, and availability in different form, size and quality. Exterior insulation provides practical enhancement to the building fabric without disturbing the occupants and without destroying the buildings, the polyurethane board has this potentiality and it is suitably fit for this purpose.

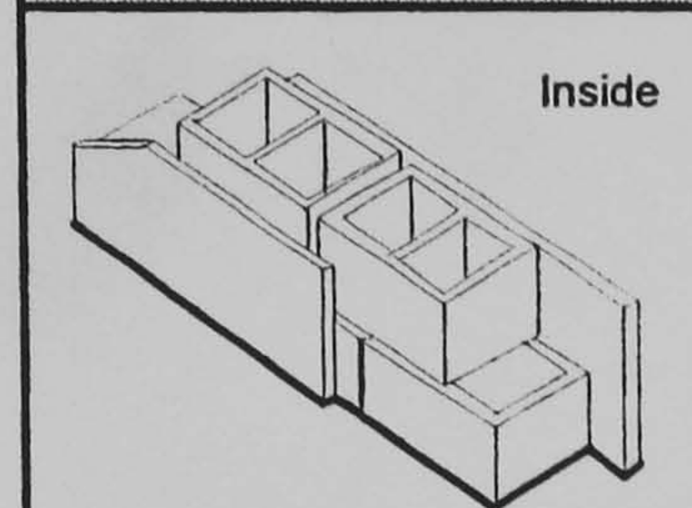
In a recent study by Bojic (2002) who investigated the use of insulation to reduce cooling loads in high rise residential buildings in Hong Kong, showed that 50 mm of insulation was the most cost effective solution, insulation beyond 50mm lead to insignificant further reductions in the maximum cooling load demand. In the hot humid climate of Hong Kong, insulation reduced the cooling load by some 10%, this lower saving reflects the amount of cooling load required to achieve latent cooling.

Tawfik (1993) also concluded that in Saudi Arabia, insulation thickness greater than 50 mm was not economically justifiable.

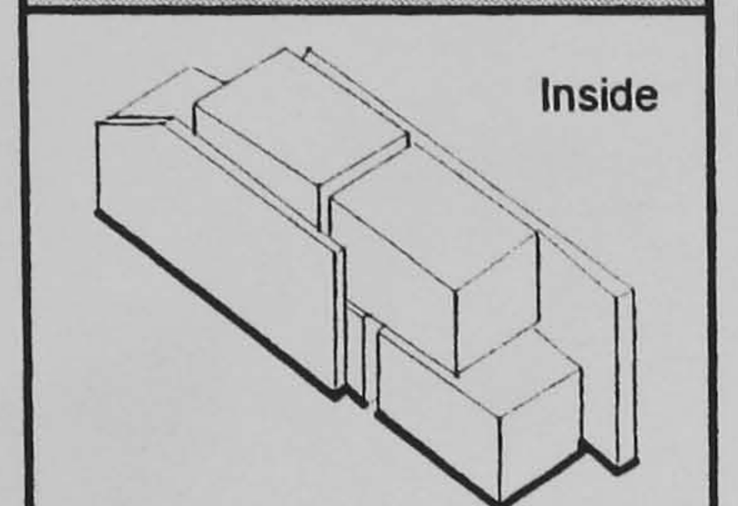
Basic Wall Systems



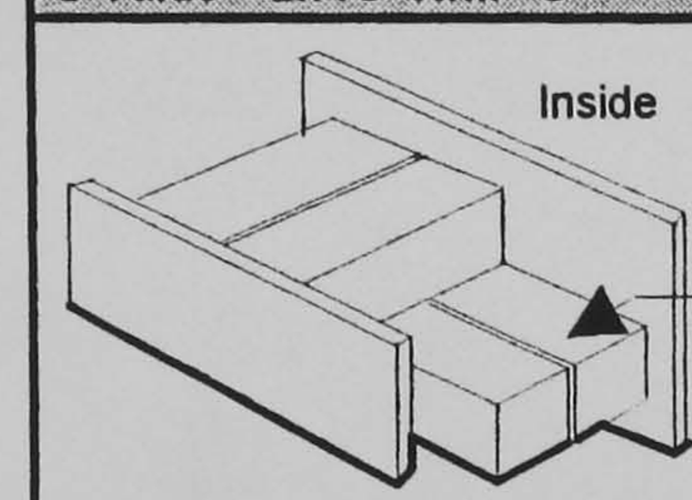
U-Value = 1.887 W/m²°C



U-Value = 2.564 W/m²°C



U-Value = 2.778 W/m²°C



U-Value = 2.083 W/m²°C

1 - Hollow Clay Tile (HCT)

Description :	R-Value m^2°C/W	Thickness mm	Conductivity W/m°C	Density kg/m³	Specific Heat J/kg°C
1. Cement 2.54cm Plaster W/Sand	0.04	25	0.72	1858	837
2. Clay Tile, Hollow 20.3cm	0.33	203	0.62	1121	837
3. Polyurethane, Expanded 5cm	2.21	25	0.02	24	1590
4. Cement 2.54cm Plaster W/Sand	0.04	50	0.72	1858	837

2- Hollow Concrete Masonary Units (HCMU)

Description :	R-Value m^2°C/W	Thickness mm	Conductivity W/m°C	Density kg/m³	Specific Heat J/kg°C
1. Cement 2.54cm Plaster W/Sand	0.04	25	0.72	1858	837
2. CMU Heavy Wt. 20cm Hollow	0.19	203	1.05	1105	837
3. Polyurethane, Expanded 5cm	2.21	25	0.02	24	1590
4. Cement 2.54cm Plaster W/Sand	0.04	50	0.72	1858	837

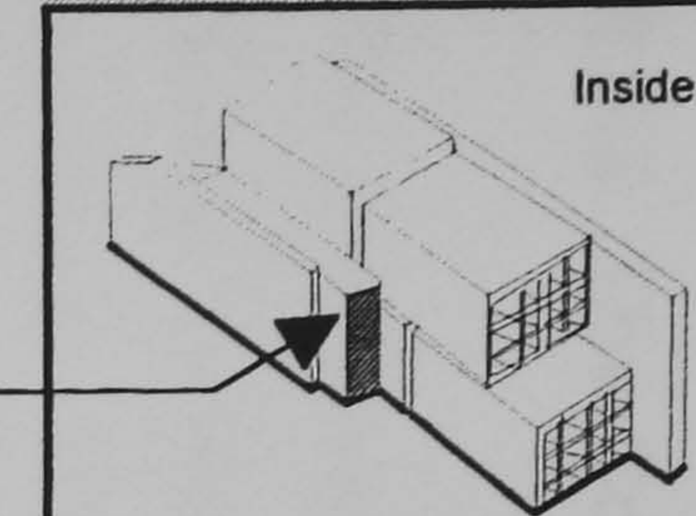
3- Solid Concrete Masonary Units (SCMU)

Description :	R-Value m^2°C/W	Thickness mm	Conductivity W/m°C	Density kg/m³	Specific Heat J/kg°C
1. Cement 2.54cm Plaster W/Sand	0.04	25	0.72	1858	837
2. CMU Heavy Wt.20cm Conc. Filled	0.16	203	1.31	2243	837
3. Polyurethane, Expanded 5cm	2.21	25	0.02	24	1590
4. Cement 2.54cm Plaster W/Sand	0.04	50	0.72	1858	837

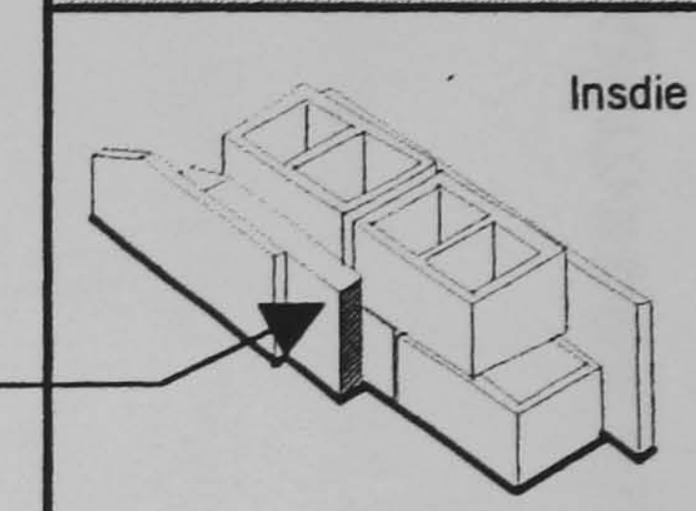
4- Red Clay Brick Units (RCBU)

Description :	R-Value m^2°C/W	Thickness mm	Conductivity W/m°C	Density kg/m³	Specific Heat J/kg°C
1. Cement 2.54cm Plaster W/Sand	0.04	25	0.72	1858	837
2. Brick 10cm Common	0.14	102	0.72	1922	837
3. Brick 10cm Common	0.14	102	0.72	1922	837
3". Polyurethane, Expanded 5cm	2.21	25	0.02	24	1590
4. Brick 10cm Common	0.14	102	0.72	1922	837
5. Cement 2.54cm Plaster W/Sand	0.04	25	0.72	1858	837

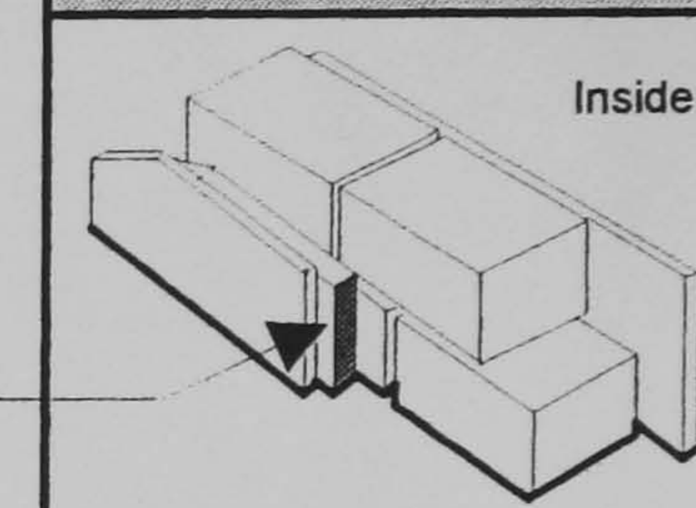
Insulated Systems



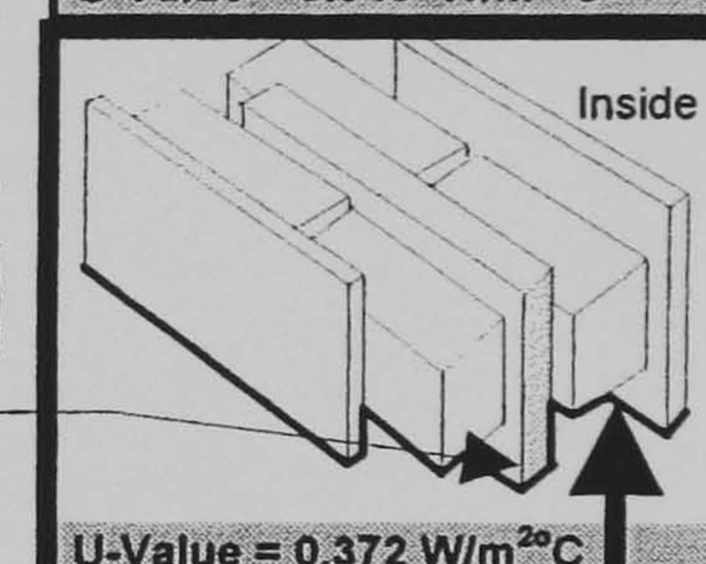
U-Value = 0.365 W/m²°C



U-Value = 0.495 W/m²°C



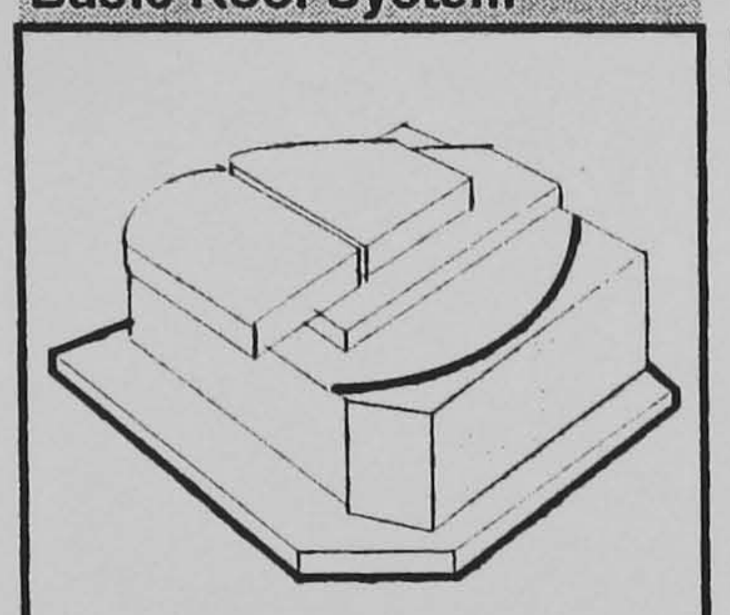
U-Value = 0.546 W/m²°C



U-Value = 0.372 W/m²°C

* The fourth insulated system is a theoretical wall type with insulation sandwiched between two masonry layers.

Basic Roof System

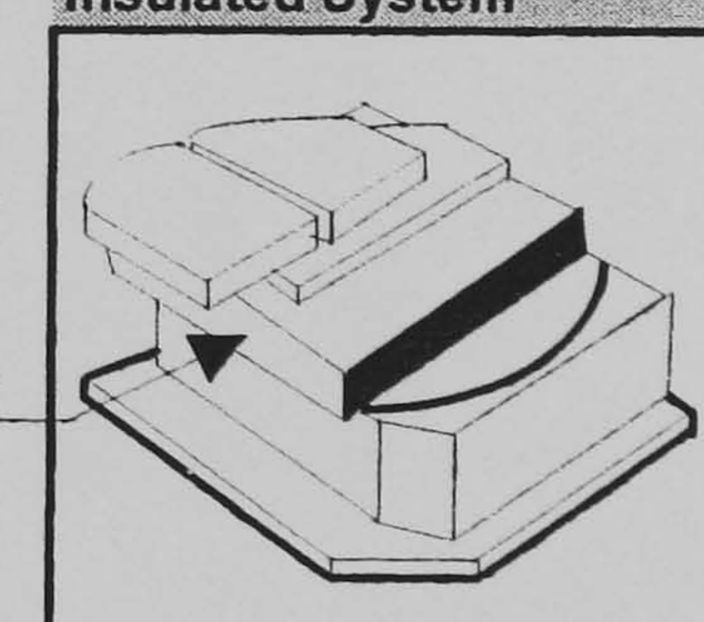


U-Value = 1.613 W/m²°C

R.C. Slab Floor

Description :	R-Value m^2°C/W	Thickness mm	Conductivity W/m°C	Density kg/m³	Specific Heat J/kg°C
1. Clay Tile, Paver	0.01	10	1.8	1922	837
2. Cement, 2.54cm Morter	0.04	25	0.72	1858	837
3. Roof Insulation, 5.1cm	0.98	51	0.05	256	837
4. Medium Wt 15.2 R.C. Slab	0.42	152	0.35	1281	837

Insulated System



U-Value = 0.625 W/m²°C

Figure 8.3: Construction Configuration Systems used in Simulation

8.6.3 The Configuration of the Proposed Shading Device

The simulation process aims to investigate the thermal effect of solar radiation through window openings and to suggest a solution to reduce this effect to its minimum. The practical strategy usually used to control the thermal effect of this source on building interior comes through the application of shading devices around building's openings.

Generally speaking, there are three types of shading device that help in obstructing different radiation angles. These types are horizontal, vertical, and eggcrate shading devices. Each of these elements creates a special pattern of shading mask over the opening. The configuration of the shading devices adopted for simulation considered two major elements usually found in any shading device, which are horizontal and vertical projections. Horizontal projection cast a segmental shading mask on the opening and the vertical projection creates a radial shading mask (Figure 8.4). The combined effect of these two elements enhances the overall shading quality around the openings and significantly interrupts and reduces the amount of the imposed solar radiation.

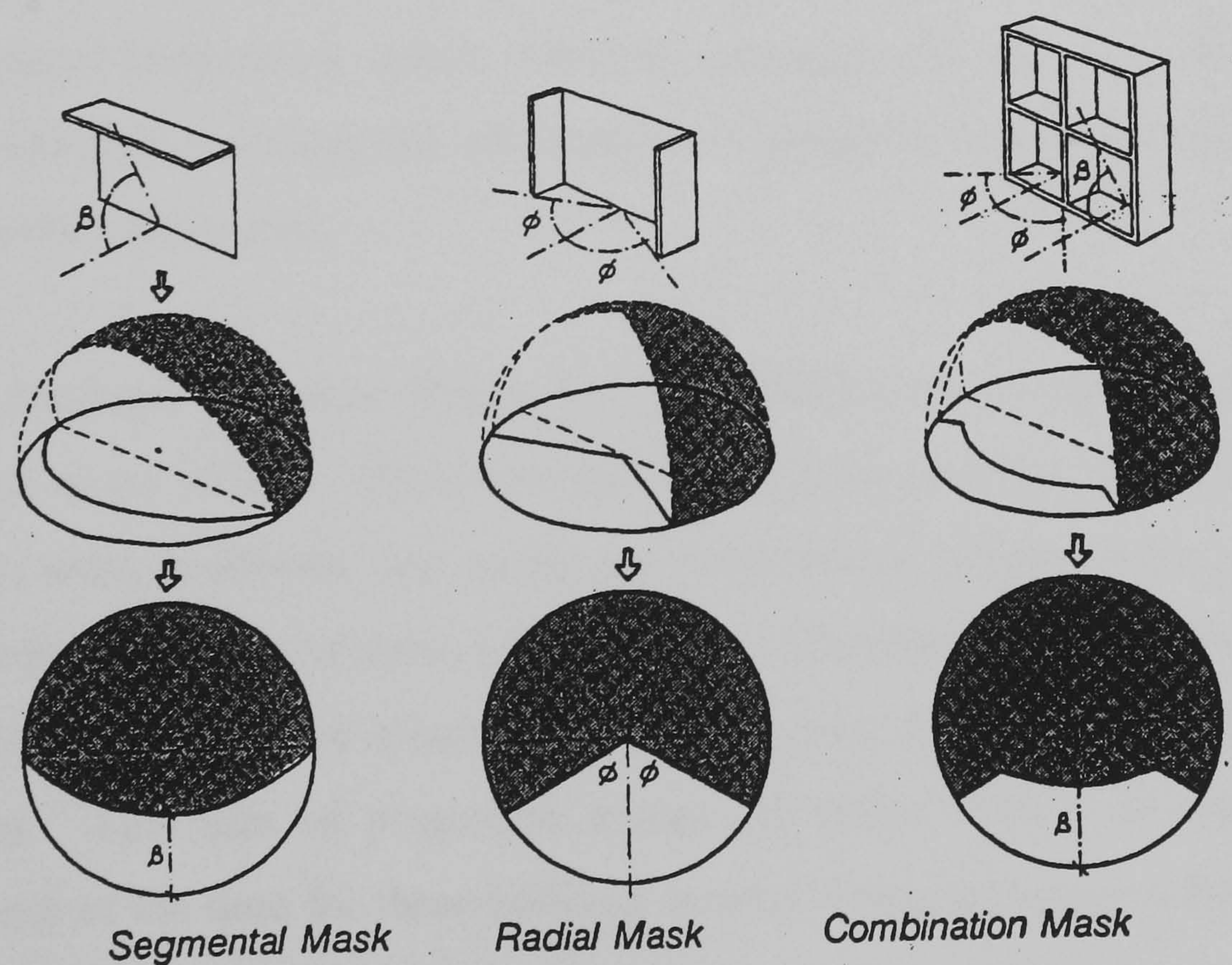


Figure 8.4: Types of the Shading Devices in Relation to Shading Masks.
Source: Olgyay, V., 1973.

For practical considerations, these two elements have been chosen as a shading device because they compose a simple portable frame that can be easily designed, manufactured and installed in existing situation. The combination of these two elements is also consider the aesthetic value of the buildings, as they are visually acceptable and could be made out of from any durable, climatic resistance, lightweight, and colourful materials such as the PVC or Glass Reinforced Concrete (GRC). Horizontal projection above the window can intercept the high summer sun and does not block any view, vertical projection blocks low angle sun radiation. The eggcrate shading device type is a complicated form that combines horizontal and vertical elements in multiple numbers and in different tilting angles. Although it has an advantage over the simple combination of horizontal and vertical element, it is difficult to consider in practice for cost and manufacturing reasons.

The simulation will consider this configuration as an upgrading to the existing situation and will investigate the potential effect for this modification on building thermal characteristics and on energy consumption.

In order to determine the effective size of the horizontal and vertical projection, a Utzinger (1981) method has been followed. This method is a simple technique that requires some information about window openings and the site latitude to be superimposed over the nomgraph developed by Utzinger in order to determine the size of the effective projections.

Following Utzinger technique (Figure 8.5), the effective length of the shading device is suggested to be 360mm. However, this length gives insufficient depth of shadow on the east, west, south-east, and south-west orientations, which are the most critical building facades in terms of fallen solar intensity. Therefore, a 500mm horizontal and vertical projections has been adopted in order maximise the depth of shadow on these orientations. This size of projection makes the fallen shadow covers the entire opening most of the time for these building facades, hence guarantee a full protection from heat gain by solar radiation.

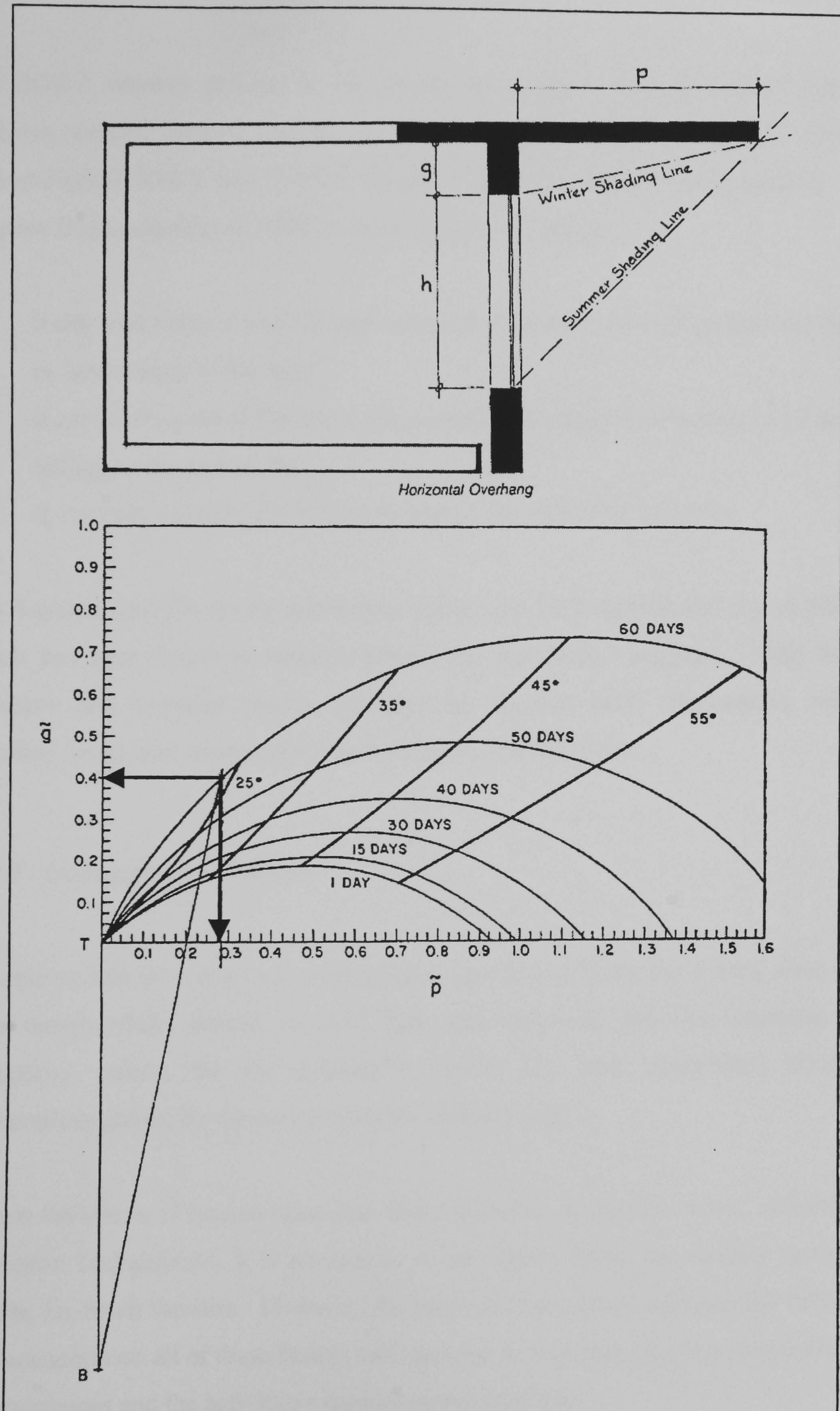


Figure 8.5: Nomograph of Sizing Overhangs. Source: Utiznger, 1981

8.6.4 Weather data

The DOE-2 weather process in the simulation program (VisualDOE2.5) supports different weather method format, e.g. TRY (Test Reference Year), TMT (Typical Meteorological Year), and WYEC (Weather year foe Energy Computation). The program is also capable of fulfilling other tasks for example:

- It can read either a weather tape or a packed weather file and produce an hour by hour listing of the data.
- It can read a packed file and replace yearly user-selected variables, i.e. it can do editing to the packed file.
- It can read a packed file and produce a yearly statistical summary.

The Weather data file set for simulation utilises the TRY data for the city of Makkah which has been found in weather library for the DOE-2 program. This data is inclusive and contains hourly readings for dry-wet bulb temperature, relative humidity, wind, and normal direct and diffused solar insulation.

8.6.5 Occupancy schedule

Occupancy rate is a vital task in simulation process as it has the control over many other energy-related aspects, i.e. A/C, light, and equipment operation schedules. The occupancy pattern for the simulation model has been established from the observations gained by the survey analysis (Chapter 6 & 7).

Due to the nature of human behaviour that influenced by specific social, cultural, and economic backgrounds, it is unrealistic to be certain about one unified occupancy pattern for Saudi families. However, the proposed occupancy schedule has taken into the consideration all of these factors and has tried to resemble, as close as possible, the circumstances and the activities excepted in the daily life.

The many operating schedules are correlated, and are in very respect enabled and disabled by the occupancy pattern and the number of occupants for each individual zone. These schedules control the simulation runs and insures that all environmental circumstances are represented for this model, in order to get a positive evaluation for the performance under the desired conditions.

The typical schedules set for the simulation model is illustrated in Figure 8.6 and are as follows:

- System Schedule: introduces the daily and seasonally operation hours of A/Cs, the thermostat settings, and outdoor/indoor design conditions.
- Lighting schedule: introduces the daily operation schedule, as well as light density required by each zone in W/m^2.
- Equipment schedule: introduces the daily operation hours and equipment density required by different zones in W/m^2.
- Ventilation schedule: introduces the daily amount of ventilation required in each zone and the appropriate time.

The schedules operate the same for the entire year and the consideration for holiday's period has not been made. In Saudi culture, families are often spend their holidays away. However, in practice the middle income families can not afford to do this option and they usually spend their holiday in their homes. The simulation schedules have taken this point as a prevailing situation among the cases under investigation and have built all the occupancy schedules in connection to this assumption.

The equipment items have been assumed on the base of the basic essential equipment that usually possessed by typical households. These comprise Cooker, refrigerator, washing machine, TV set, and audio set etc. Ventilation is set to 0.75 ach/h for all functional zones in the simulation. This value is matched with the measurement survey of the case studies (Chapter 7). In practice, natural and mechanical types of ventilation are not commonly recognized, it is only the infiltration that may form the only type of un-deliberate ventilation.

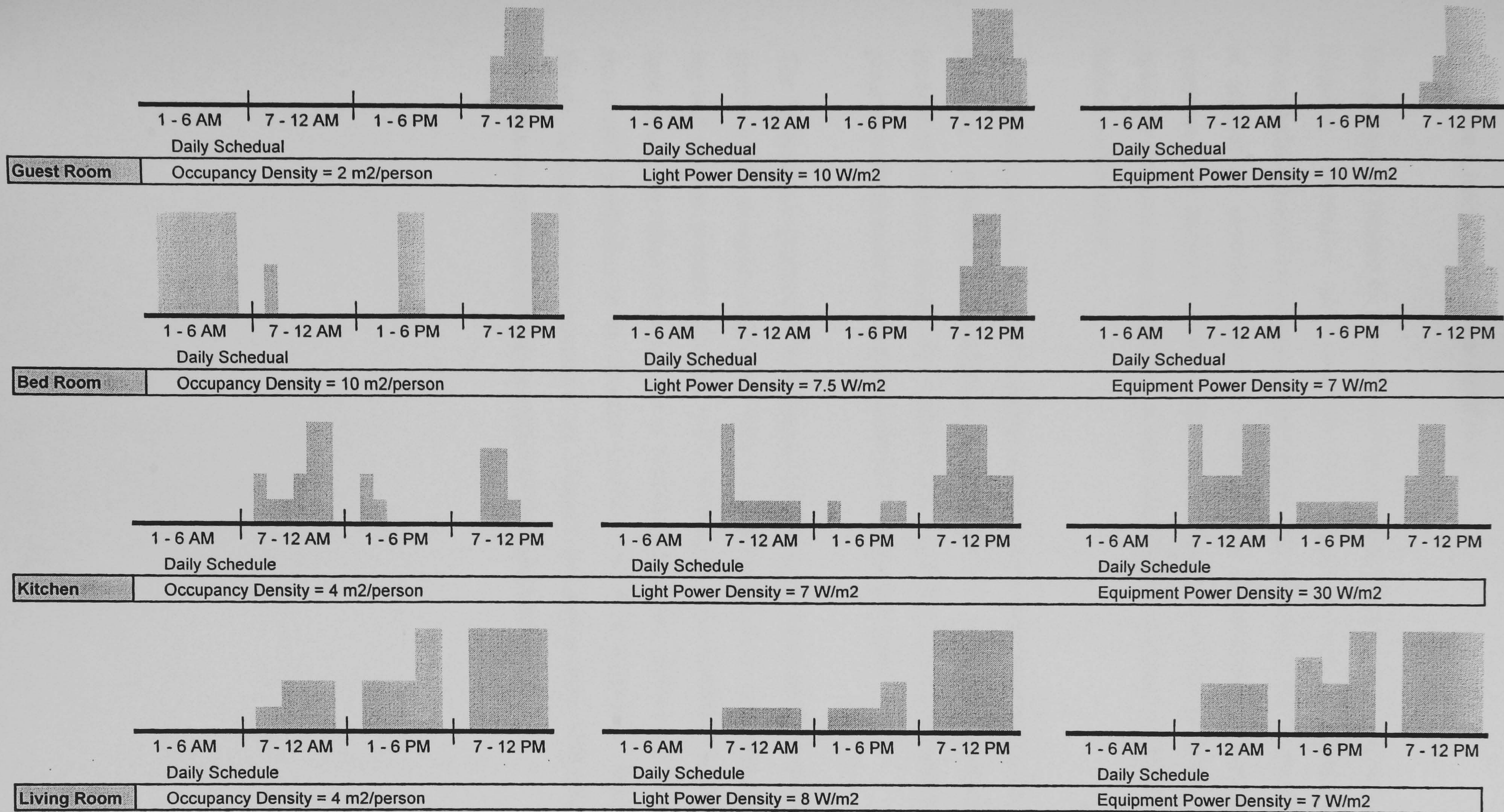


Figure 8. 6: Simulation Scheduales

8.7 The Limitation of the Analysis

The analysis is limited by the extent of the detailed information required to explore the situation. However, micro-analysis with respect to heat transmission behaviour through the consecutive constructional layers is not the aim of this research. This kind of analysis is essential, however, when special development in specific building components is targeted. But, for the practical purpose of this research, all building components have been looked at as one integrated system that, together, creates the indoor environment.

The simulation has also been bounded to the facilities that provided by the simulation program. Although the calculation engine of DOE-2 is capable of simulating every aspects of building energy performance, this capability is not well matched the host programs which build an interface to DOE-2 calculation core.

The limitation experienced with VisualDOE2.5 is its insensitivity to show a detailed profile of the dynamic impact on indoor hourly temperature resulting from the time lag and storage property of construction materials. This limitation hinders the close look inside the effect of properties of building materials. However, it does not effect the overall prediction of the thermal behaviour of these materials. Such these fine details, as these are not essential to the research analysis and they will not, eventually, affect the readings and the interpretation of the simulation results.

Chapter 9

The Simulation Results Analysis

Chapter 9

THE SIMULATION RESULTS ANALYSIS

9.1 Introduction

One of the important features of simulation process is to visualize the complicated nature of buildings' thermal behaviour. Various building components are involved daily in cyclic interaction with climatological parameters. The resultant of this interaction eventually determines the image of the thermal environment in these buildings.

The object of this chapter is to evaluate the thermal performance of the apartment under different types of conventional construction and to recognize the influence of different components on heat gain and energy consumption. Also this chapter intends to indicate the potential place of improvement and the practical strategies to be applied. In practice, it has been noticed that people cannot do without A/C most of the time and the indoor thermal environment usually falls outside the comfort zone defined by the range of 20°C - 26°C. All construction types have been investigated to assess the quality of indoor air temperature under the given datum. The discussion of this assessment will be based on the following categories of simulation out-put results:

- Heat Gain Loads
- System Loads
- Economic Considerations

These parameters basically are the major issues in thermal analysis that can lead to better understanding, hence better design, and to upgrading solutions associated with this issue.

9.2 Thermal Characteristics of Indoor Environments

The characterization of the indoor thermal environment is usually judged by the air temperature profile of the living spaces. The temperature indicator, though it is a simple form of assessment, represents the direct relationship between indoor thermal quality and the associated human sensation of these criteria. The simulation processes were based on a given occupants schedule which considers a comfortable thermostat setting for A/C systems during occupancy hours as described in Chapter 8. This consideration was required to assure the optimum situation for A/C operation based on the concluding remarks of the fieldwork survey. A/C systems have been in operation whenever the spaces are in use and shut off whenever they are vacant.

Very slight differences in indoor monthly average temperature have been perceived from the run reports, which suggest that construction type has a low impact on indoor air temperature. The typical monthly average temperature profile is illustrated in Figure 9.1. Within building boundaries there is no difference in temperature profile that can be noticed with regard to apartment vertical location. Among the apartment zones, the kitchen zone has the highest temperature profile in the twelve months. This zone exceeds comfort level by temperature difference up to 13°C, in the summer time. Even in cool periods, the kitchen temperature still falls outside the comfort level by 6°C- 8°C. The high temperature in this zone is due to the heat generated from the activities and the effect of A/C is even limited with the presence of heat generation sources.

The guest zone temperature profile is not far from comfort level. Variable of 5°C represents the maximum in the hottest month (July). Meanwhile, this difference diminished to almost nothing in the colder period of the year. The living zone and the bed zone are 2°C beyond the line of 26°C in the hot period. They are thermally sustainable. Unlike the situation in the kitchen zone, the capacity of the cooling load conveyed by the proposed system and its operational hours are just right for these functions. Temperature profiles tend to stay within the thermostat set points for A/C systems (26°C) and this condition has been achieved for most of year time in the bed and living zones. Meanwhile, the guest zone is slightly above this temperature in summer time and this may relate to the light occupancy pattern for this zone. The kitchen zone failed to meet the set temperature due to high heat gain loads and to insufficient cooling capacity offered by the proposed systems. Also, the daily operational hours of A/C system for these zones might not have been enough to offset the heat accumulated. The indoor temperature in this zone is too high for human comfort even in cold months, and this indicates how active this zone in terms of energy consumption. To enable comparison of the performance of A/C systems in each zone, Figure 9.2 shows the number of hours that have not been met by systems. Bearing in mind that we have fixed the cooling capacity for all systems to resemble the real situation, the system deficiency in each zone varies considerably due to zone function and occupancy pattern.

In a cool moderate period, the systems seem to be working adequately in all zones except the kitchen zone. Summer time shows the differences clearly. The bedroom system has been adequate for this zone due to its daily operational time that activates the A/C outside the hot period. The A/C system in the living zone has a deficiency of 22 hours as a maximum in the month of July and this deficiency has raised the average temperature for this zone by 2°C above the thermostat setting. It is not a big deficit in the system and this result shows the appropriateness of system/occupancy pattern configuration for this zone.

The guest zone's A/C system maximum deficiency is limited to 27 hours in July, which produces approximately the same effect on temperature as in the living zone. This is does not indicate that the cooling capacity for this zone is adequate, which might be the case. It rather reflects the light occupancy schedule for this zone and the period of the day (night time occupancy) when A/C is usually needed. The kitchen zone is 66 hours under cold and never meets the thermostat set point at any time in the year. Either a higher cooling capacity system is needed to balance thermal loads in this zone, or minimizing heat gain generated and circulated in this space. The situation is more likely to be the same in all types of construction and for this reason only one typical pattern of system deficiency has been illustrated in Figure 9.2.

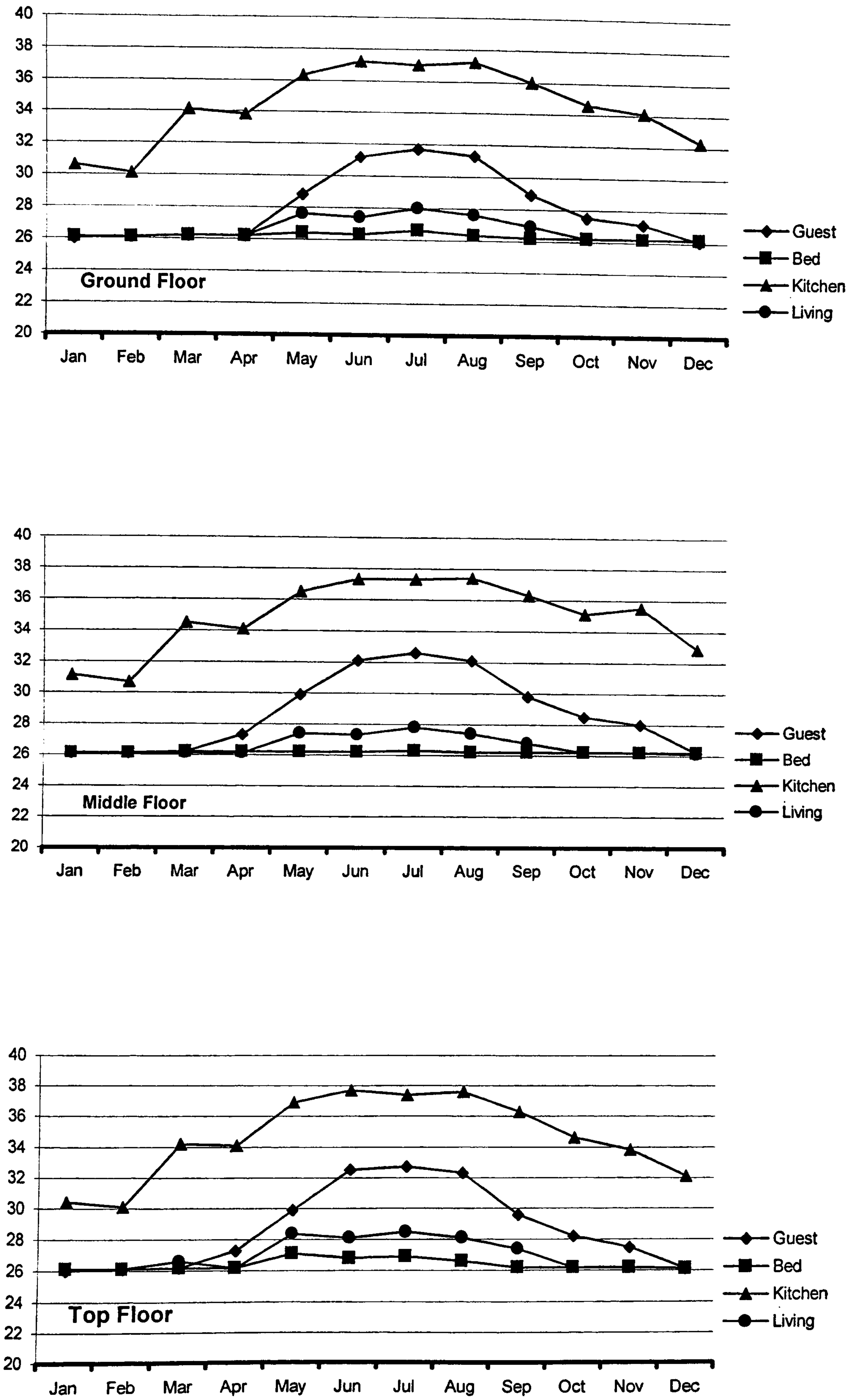


Figure 9. 1: Typical Predicted Indoor Monthly Average Temperature Profiles

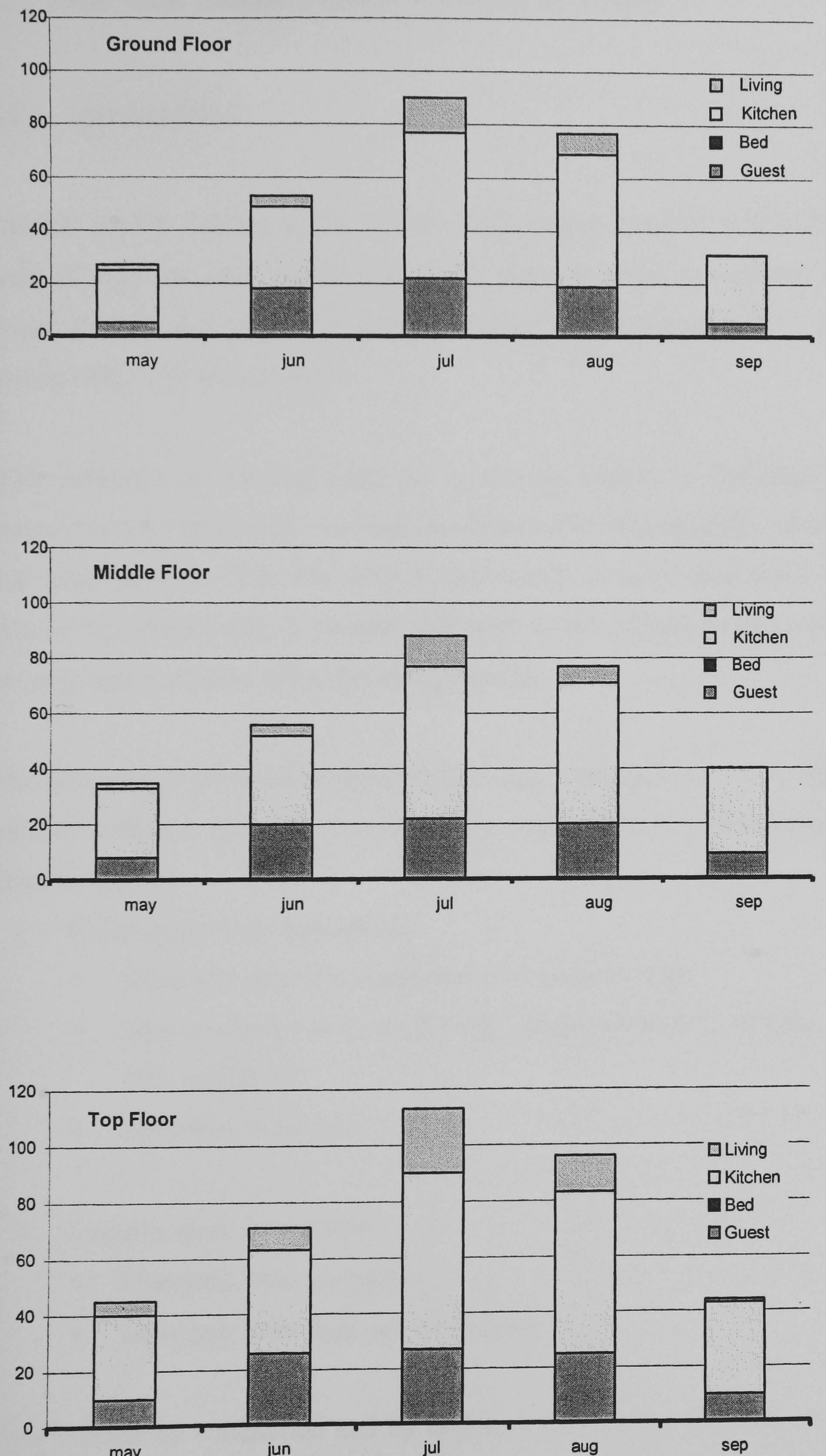


Figure 9. 2: Typical Number of Hours under Cooling in the A/C System

9.3 Heat Gain Loads through Building Envelope

9.3.1 Introduction

Thermal load is defined as the rate at which energy must be removed from (cooling load) or must be added to (heating load) space in order to maintain a constant air temperature in this space. A space is defined as a subsection of a building which corresponds to an actual room.

With reference to cooling load, as a relevant aspect in building and economic environment for this study, the loads are obtained by VisualDOE2.5 load program in a two steps process. The first step is calculation of space heat gains from different sources the second step is to pass this load to the system program to calculate the cooling load needed to offset the heat gain load.

The components involved in calculation of space heat gain can be divided into several parts according to the ways of energy flow and generation. These components can be listed as follows:

1. Building envelop dependents:
   - Solar heat gain from radiation through glass area
   - Heat conducted to space through opaque surfaces in contact with outside air
   - Infiltration heat gain

2. Casual source dependents:
   - Heat gain from occupants
   - Heat gain from light and equipment

Heat transfer by conduction and by radiation through the building skin is calculated by VisualDOE2.5 using the response factor method and taking into account the delayed effect of thermal mass, sun angle, climatic factors, building orientation and any architectural features. Infiltration load is computed on the base of the difference between the inside and outside conditions and an assumed infiltration rate. Internal energy sources are computed according to operational scheduling pre-assigned for each source as a function of occupancy pattern.

The simulation process is begun for the proposed model after securing all data for modelling needs and cross checking the operation for input error.

9.3.2 The Thermal Effect of Building Construction and Vertical Location

Annual thermal loads of the conventional types of construction adopted for this model were calculated for each configuration type by VisualDOE2.5 and the results are described in the following text. Figure 9.3 illustrates the annual total heat gain loads for each type of construction according to program outputs. Each construction has been treated here for comparison reason as one unit despite the three apartments it contains. Constructions No. 1 and 4 have the lowest load among the four types. The difference is very small between Con. No. 1 and Con No. 4 (77891 kWh for Con. No. 1 and 78822 kWh for Con. No. 4). Meanwhile, Con. No. 2 is gain more load by 2.8% (80167 kWh) and Con. No. 3 gain more load by 4.3% (81418kWh) with relation to Con. No.1 & 4.within the accuracy of prediction.

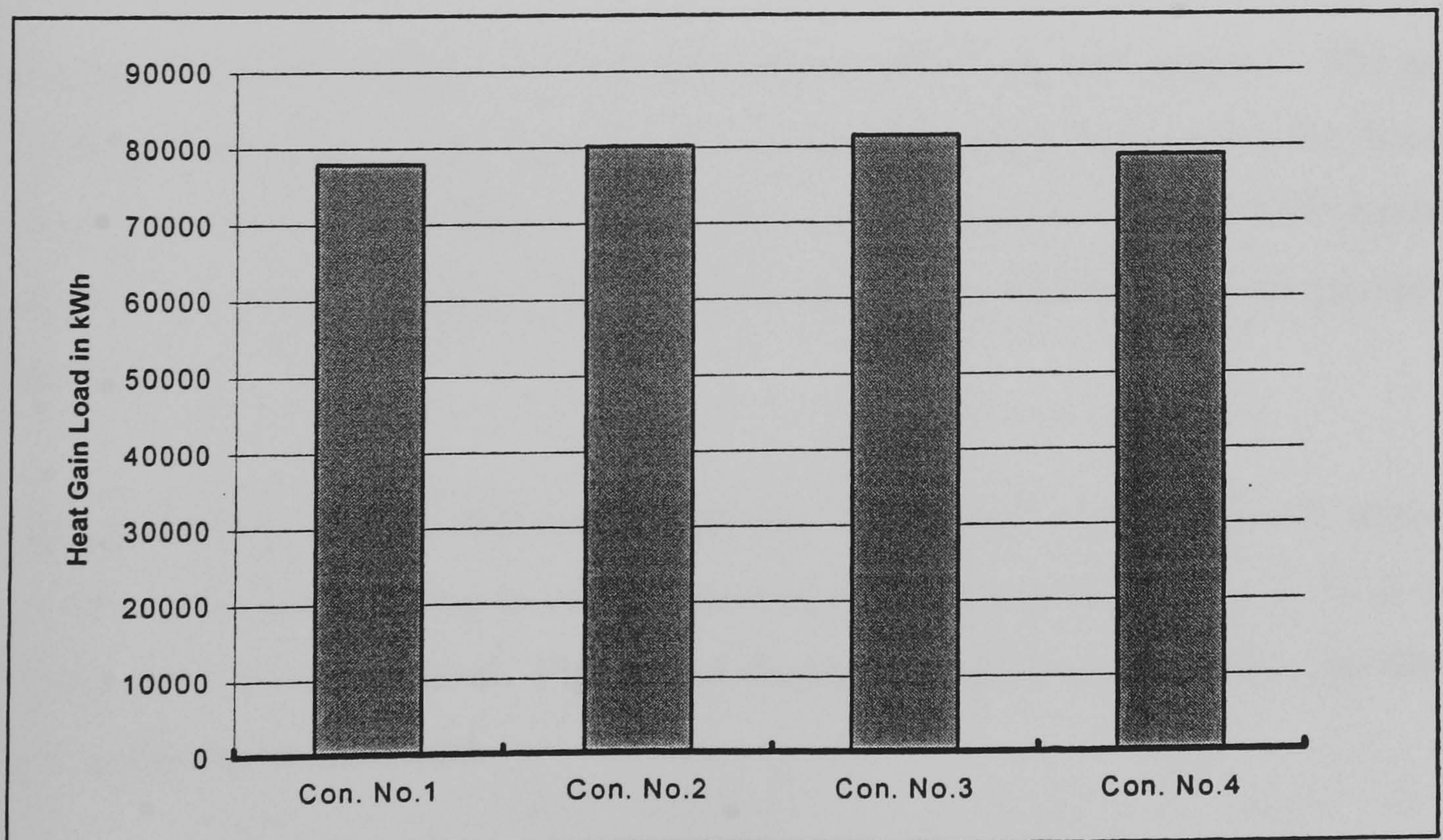


Figure 9. 3: Annual Total Heat Gain Load for All Types of Constructions

Annual loads indicated here are inclusive and comprise all heat gain from building components for all apartment levels. The overall performance of the construction types that can be noticed from this comparison reflects the virtue of Con. 1 and Con. 4 over the other types in terms of the total amount of heat gain admitted inside the respective units. The scenario in this stage of the simulation aims to look all impact of the improvement measures together as one scheme.

Annual total heat gain pattern for individual apartment in different levels is listed in Table 9.1. Maximum load occurred in the top floor apartment of Con. 3 with a value of 28363 kWh; meanwhile the minimum heat gain occurred in middle floor apartment of Con. 1 with a total value of 24158 kWh. Monthly average heat gain load for the apartment range between (2013 kWh - 2364 kWh).

Floor Level	Construction No.1		Construction No.2		Construction No.3		Construction No.4	
	kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2
Ground	26437	189	27256	195	27705	198	26770	191
Middle	24158	173	24930	178	25350	181	24470	175
Top	27296	195	27981	200	28363	203	27582	197

Table 9. 1: Annual Heat Gain Load Pattern in Relation to Apartment Levels

Vertical location seems to have a pronounced effect on load pattern. The general findings show that the top floor has the maximum energy flow among the floors and this observation can be drawn for all types of construction. Middle floor apartments receive the minimum energy for all cases, with slight differences from ground floor apartments.

The percentage of the differences between the highest and the lowest amount of energy received according to vertical location is 4.6% at ground level, 4.7% at middle level, and 3.8% at top level. Figures 9.4 display the data from Table 9.1, and illustrate the difference in heat load.

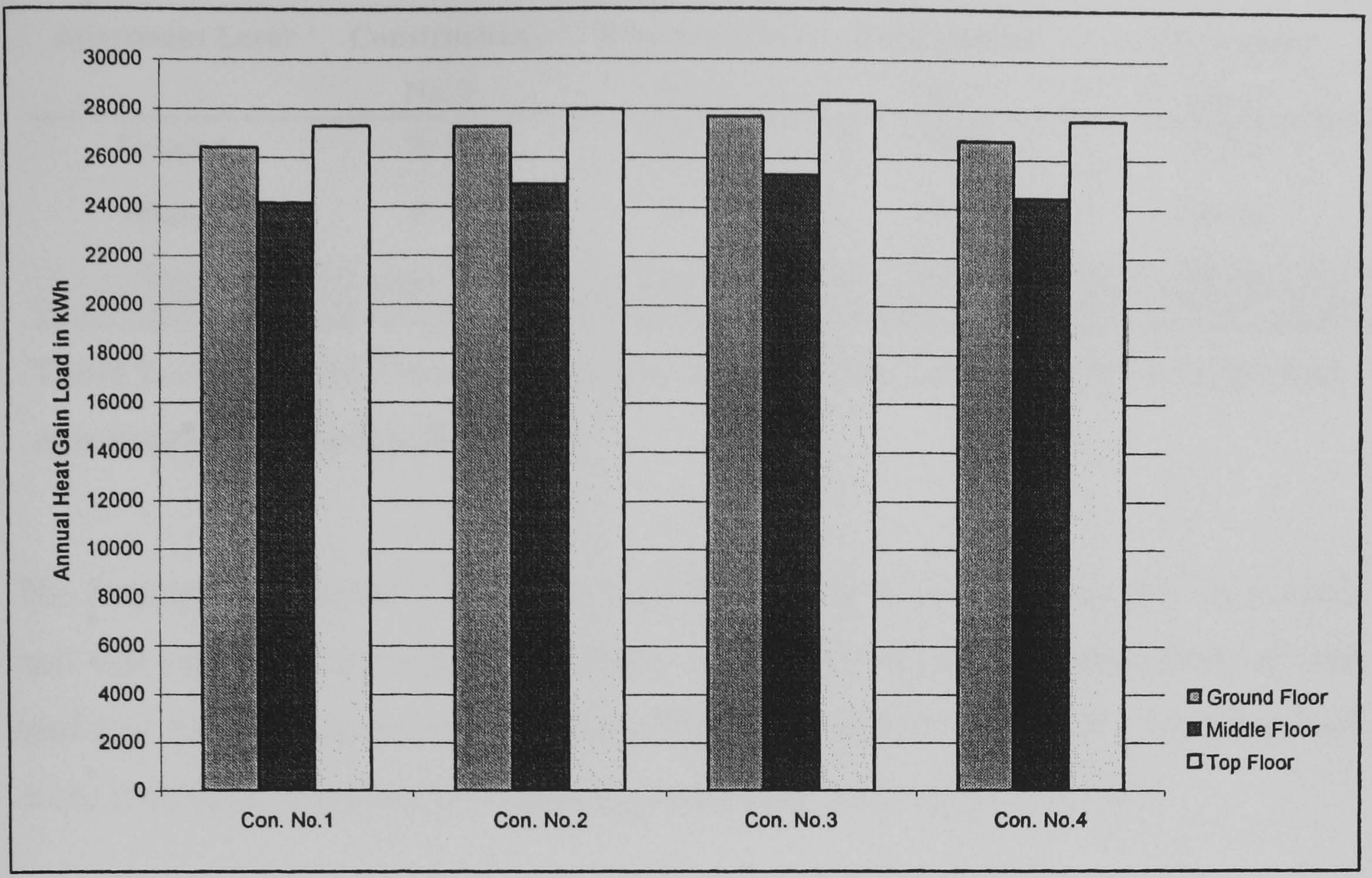


Figure 9. 4: Annual Heat Gain Load for all Types of Constructions

The effect of vertical location on load pattern within each type of construction is listed in Table 9.2. Load variations relating to vertical location can be understood in the light of the exposed surface area in direct contact with the outdoor environment and the reflected effect of surrounding surfaces.

Top floors have the maximum due to the roof factor that represent an additional source of energy. Meanwhile, middle floors are totally protected from above and below, and hence receive heat only from wall surfaces. This is why they display the lowest amount of heat load, and therefore they are considered to be the favourable locations for apartments in multi storey buildings in terms of energy demand.

Ground floor levels collect some additional heat more than the middle floors through the presence of the ground factor and the surrounding reflective objects.

Apartment Level	Construction No. 1	Construction No. 2	Construction No. 3	Construction No. 4
Ground	93 %	96 %	98 %	94 %
Middle	85 %	88 %	89 %	86 %
Top	96 %	99 %	100%	97 %

Table 9. 2: Effect of Vertical Location on Heat Gain Load Related to Top Floor Apartment in Construction no.3.

The forgoing discussion is based on the performance of each construction as a whole unit that represents a typical multi storey apartment building. A breakdown of total load gain has been extracted from VisualDOE2.5 reports in order to have a closer look at the individual roles that each building component plays in this context.

In Figure 9.5 the total load is split up into the major components that can be recognized as heat gain sources. The components are: wall load, roof load (if applicable), windows load, casual loads and infiltration loads.

Casual heat gain loads represents approximately one third of total heat gain 30% - 33% in all cases. This percentage is considerable with regard to thermal load generated and circulated internally. However, it is controllable and it can be dealt with by rationalizing customary behaviour towards energy use by occupants and also by employing a good management operation for casual sources.

Heat admitted by wall fabrics comes next with a spectrum of 24% - 30%. Heat load delivered through windows by direct and diffused solar radiation comes in third place with a percentage of 22% - 24%. The rest of the loads share the remaining percentage that may distributed as follows: heat gain through infiltration is 6% - 7%, window conduction heat gain is 6% -7%, and in the last place comes heat gain from roofs with 4% - 5%. It should be noted here that heat gain from roofs listed above has a low percentage because of its relatively small area in comparison to other surfaces involved in the evaluation. Table 9.3 summarizes the effects of each building component on heat gain load.

Sources	Construction No. 1	Construction No. 2	Construction No. 3	Construction No. 4
Total Heat Gain	100 %	100 %	100%	100 %
Wall Gain	24	28.4	30.3	25.5
Infiltration Gain	6.6	6.4	6.3	6.5
Win. Con. Gain	6.9	6.4	6.3	6.7
Win. solar Gain	24.5	22.8	22	23.9
Casual Gain	32.8	31	30.3	32.3
Roof Gain	5.2	4.9	4.8	5.1

Table 9. 3: Summary of the Percentages of Heat Gain Load for Building Components

Casual heat gains comprise the scheduled operation for the lightning system and the electric equipment system according to the customary occupancy pattern. These schedules can be modified to be in harmony with energy conservation efforts. Public awareness of this percentage is perhaps underestimated. Yet the possibility of minimizing heat gain coming from these sources is very manageable; it has a great impact on reducing the energy needed to offset these loads.

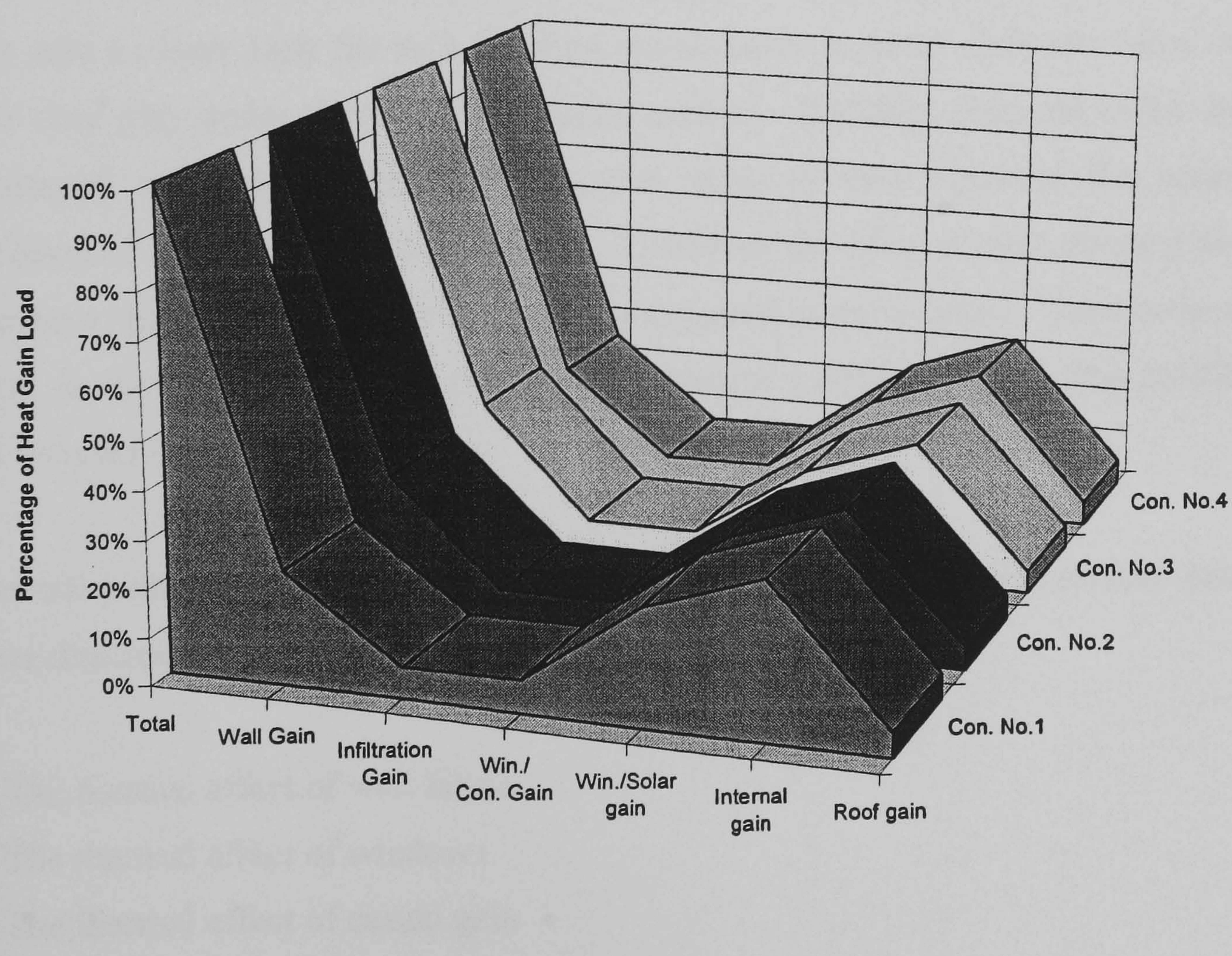


Figure 9. 5: Percentage of Heat Gained by Building Components

In general, the predicted roles that different building components play as heat gain sources can be classified to two major categories according to their level of contribution to heat gain process. These categories are:

- High heat gains access components, i.e. envelop fabrics, window openings, and casual sources.
- Low heat gain accesses components, i.e. infiltration.

Energy consumption is a dependent factor that can be valued in connection with the amount of heat gain through building elements. High level of heat gain leads to high-energy consumption and the verse held true. Building fabric takes a substantial share of heat gain loads and logically it should be considered as a spinal core in any thermal improvement procedure.

In practice, the improvement can be manageable and more tangible results can be achieved if the investment goes to improve building fabrics. On the other hand, casual gain is very crucial but no positive result can be guaranteed out of this factor because this factor deals with people and behaviours. The following section of this chapter take a closer look for each building components in order elaborate more on the role they play under thermal performance context. Building elements under the first category take more consideration in this study as they represent the major contribution of the heat gain in the building. Therefore, the effect of each element has been given a special attention and has been investigated in more detail. Nevertheless, elements in the second category, though it represents a little impact in this model, should not ever be underestimated.

The thermal performance of building elements with regards to their effect on heat gain loads are discussed in the following order:

- The thermal effect of wall fabric
- The thermal effect of windows
- The thermal effect of casual gain

9.3.3 The Thermal Effect of Wall Fabrics

The effect of building construction materials and systems is reflected greatly in wall thermal performance. As the four types of construction have been under investigation, the thermal roles that wall fabric plays have been established for each individual type.

Total wall surface area for the simulated model is 155 square meters evenly distributed over the four geographical directions.

The load pattern in relation to the U-value of each construction is shown in Figure 9.6. Construction No. 1 displays the best performance and the lowest heat gain. The annual total heat gain from this construction is 18697 kWh and this represents a percentage of 24% less than the maximum heat gained by construction No. 3 (24630 kWh). Construction No. 4 with a heat gain of 20072 kWh and a percentage of 18.5% comes second. Construction No. 2 is third in order with a total heat gain of 22736 kWh and a percentage of only 7.7 % less than the maximum. Case order has been altered in the chart to show an ascending order of heat gain against the ascending order of u-value for the constructions.

The overall thermal evaluation for these four construction systems gives the highest rating to construction No. 1 built by hollow clay blocks, which has the lowest U-value (1.887 $W/m^{2o}C$) and is very popular in the local area. Almost 85% of building construction in the Makkah area uses this material for its relatively lightweight, good manufacturing quality, ease of construction and handling, and reasonable unit price. It is also produced with variable sizes and shapes suitable for any wall design.

Construction No. 4 built from traditional fired clay brick, has a very similar performance as in construction No. 1. This type of construction material was prevalent in the local market before the introduction of other types of material. Though the use of this material as building envelope has diminished for large-scale projects nowadays, still a large segment of potential house owners prefer to use it.

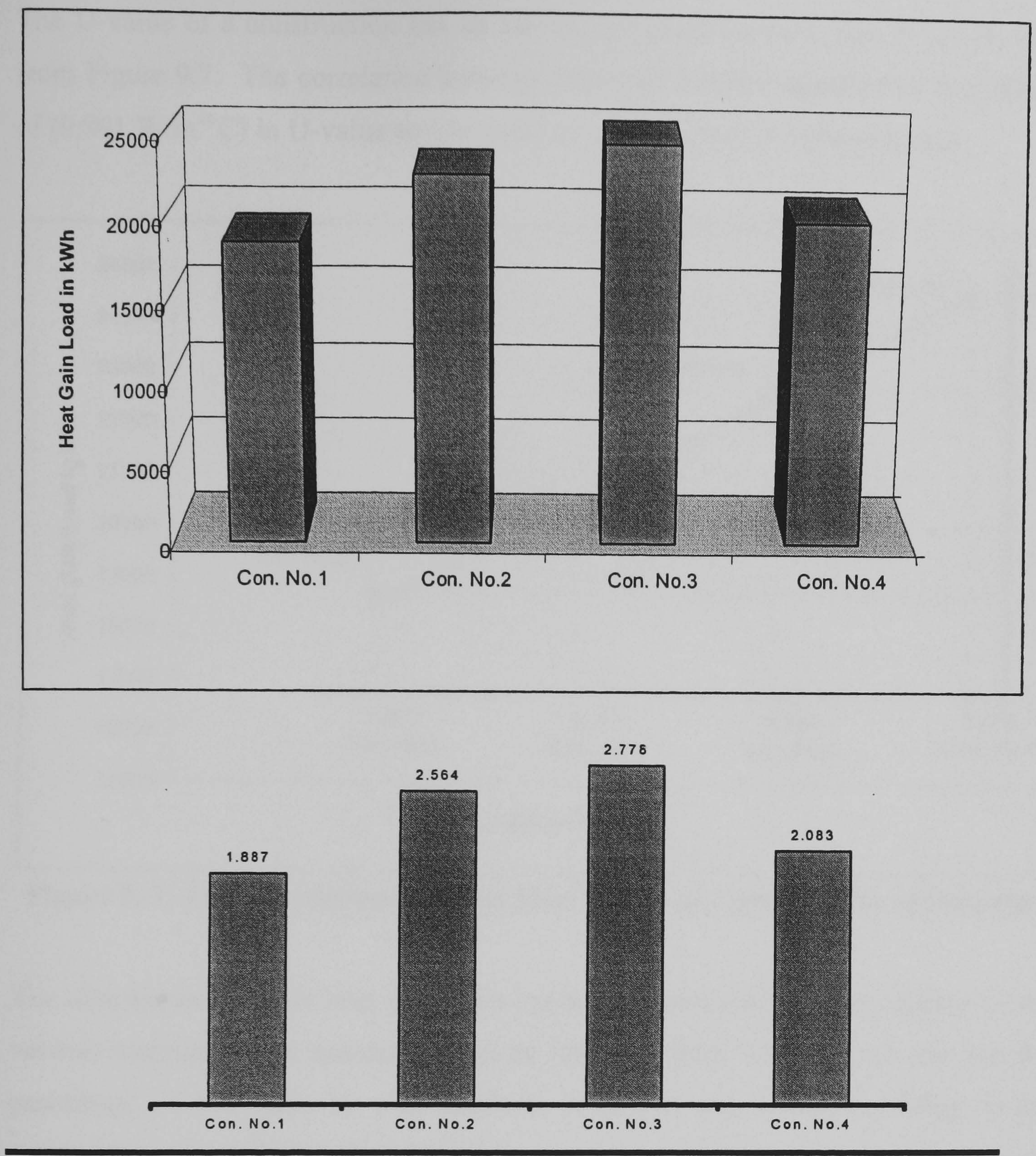


Figure 9. 6: Annual Heat Gain Load Admitted by Wall Fabric with relation to Constructions' U-value

Most of the existing buildings in our survey fall within this range of thermal coefficient (U-value). Therefore, they have less heat gain than if they were constructed with other materials in the comparison. Construction No. 3 is a dense and highly conductive construction (U-value 2.778 W/m^2 °C) built with solid concrete blocks. This kind of building materials is not popular in the construction market and very low percentage of building are built using this block The effect of these materials is exhibited by high heat gain rate for this type of construction.

The U-value of a construction has an ascending impact on heat gain as can be seen from Figure 9.7. The correlation between these two factors suggests that an increase of (0.891 W/m^{2o}C) in U-value would result in an increase of 32% in heat gain.

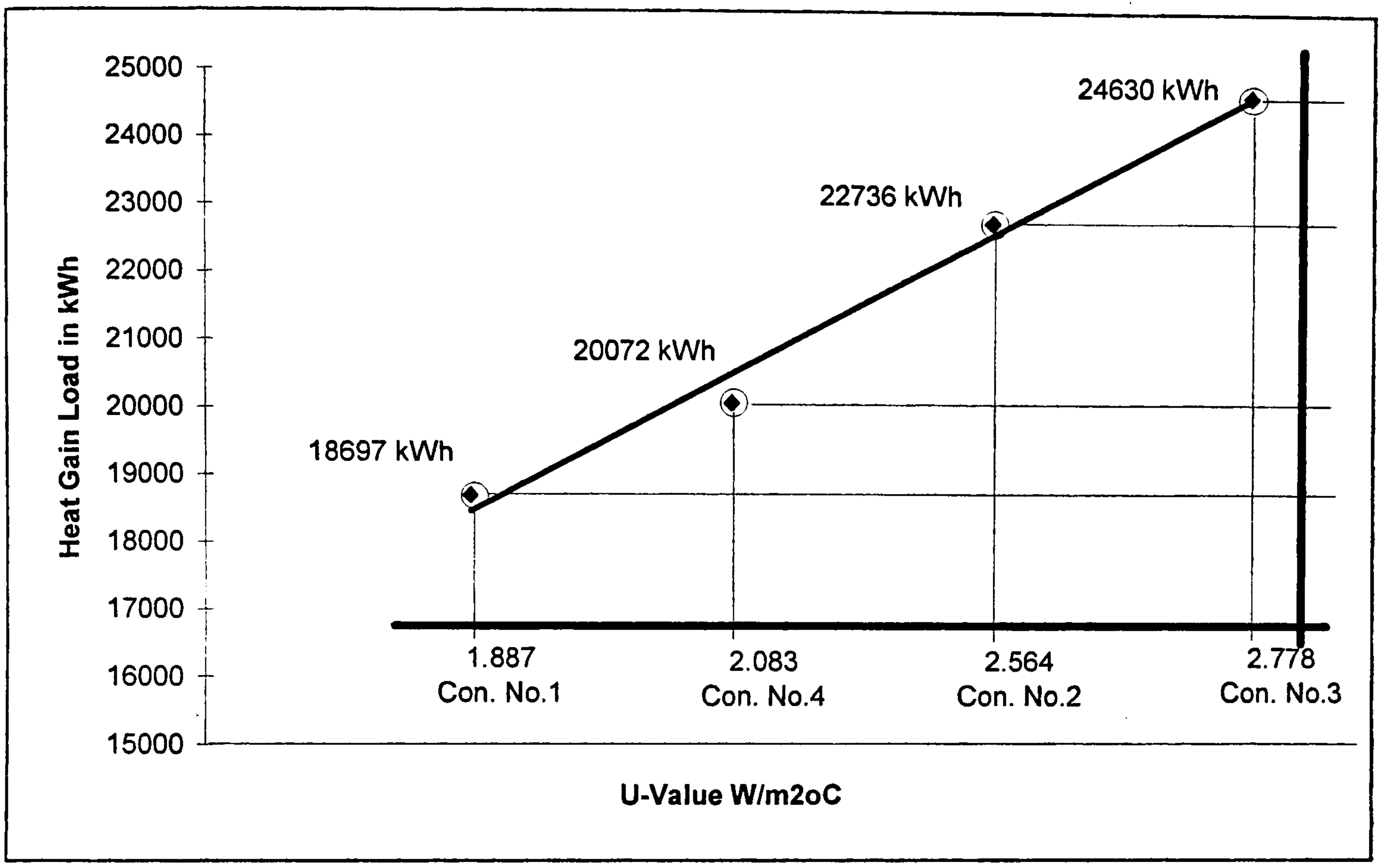


Figure 9. 7: The Correlation between Heat Gain Load and U-value of Material

The distribution of wall heat gain load inside the individual case in relation to the vertical location of the apartments can be seen in Figure 9.8. We can see that the percentage of heat gain by wall fabric to total heat gain varies according to the construction type and apartment location.

The load gain by ground floor apartments represents 30% - 36% of the total load; middle floor apartments have a percentage ranges from 23% - 29%.

In top floor apartments the percentage of load gain by wall is less (19% - 25%). Top floors have the lowest thermal gain, followed by middle floor, and ground floors have the maximum.

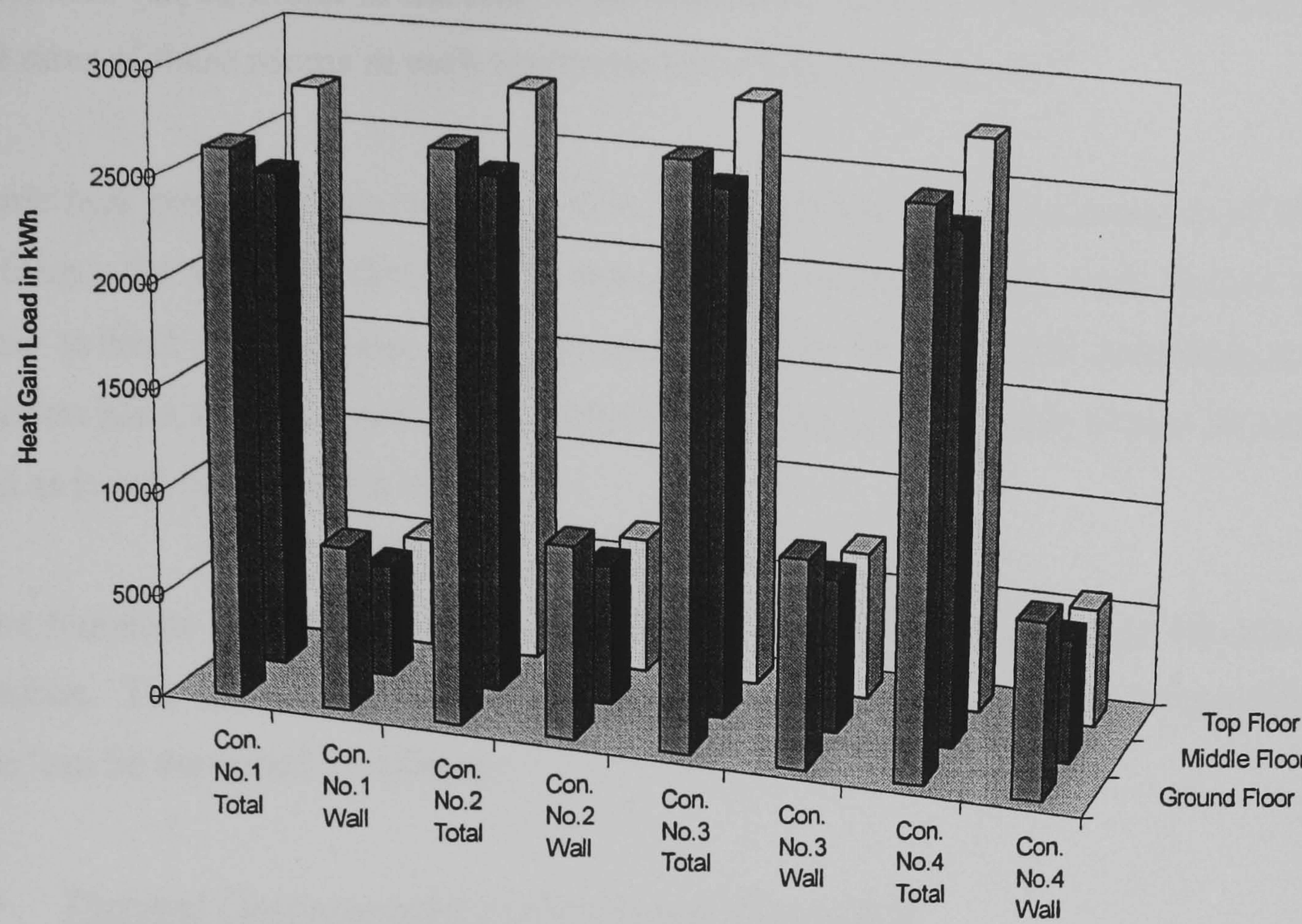


Figure 9. 8: Heat Gain Distribution Chart in relation to the Vertical Location of the Apartments

9.3.3.1 Inter Zone Heat Gain Loads and Orientation Influence (Selected Case – Construction No. 1)

In order to see the different wall performance inside each function zone, further detail on heat gain loads has been extracted. The selected case to be detailed is construction No. 1 and the detailed information of the other cases are given in Appendix IV.

Construction No. 1 has been chosen here due to its predominance over other construction types and it will be taken as a detailed sample among the other constructions whenever the detailed analysis is needed. It represents a typical internal arrangement for small Saudi family. The major functions under observation inside the apartment model are: guest room, bedroom, kitchen, and living room. In practice, the difference can be found in the size of the individual apartment depend on the number and sizes of these rooms in each apartment according to family size.

Fabric heat gain is influenced by the area of wall surfaces and the orientation of these surfaces. So what are discussed in this part are differences that these factors may cause to heat gain process. Occupancy scheduling for each zone according to its function has a slight impact in this analysis, but it has a considerable impact on casual load as it will be discussed later.

Zone functions will be used to indicate the orientation and wall areas for the zone in question. The fabric performance of the case according to the previous consideration, then, can be described as follows:

- ***Thermal Characteristics at the Ground Floor Level***

At ground level fabric heat gain increases to its maximum in the bed zone. The bed zone is a corner location zone with 30 square meter of wall surface and a southeast orientation. In the summer period, July heat gain reaches 403 kWh, which represents the maximum for this zone. The minimum is represented by the month of January with a negative sign, – 47 kWh, which indicates a reverse action (heat loss) due to winter condition.

Next to the bed zone comes the kitchen zone, located at the southwest corner with a wall surface of 25 square meters. The maximum heat gain for this orientation is 335 kWh and the minimum is –35 kWh. Then come the northeast oriented zone (guest zone) and the northwest oriented zone (living zone), and with a maximum heat gain of 326 kWh and minimum gains of –54 kWh and – 55 kWh respectively.

Annual heat gain admitted by walls in the southeast orientation is 24% higher than in the northeast oriented zone, 22.8% higher than in the northwest orientation, and 15% higher than the southwest.

- ***Thermal Characteristics at the Middle Floor Level***

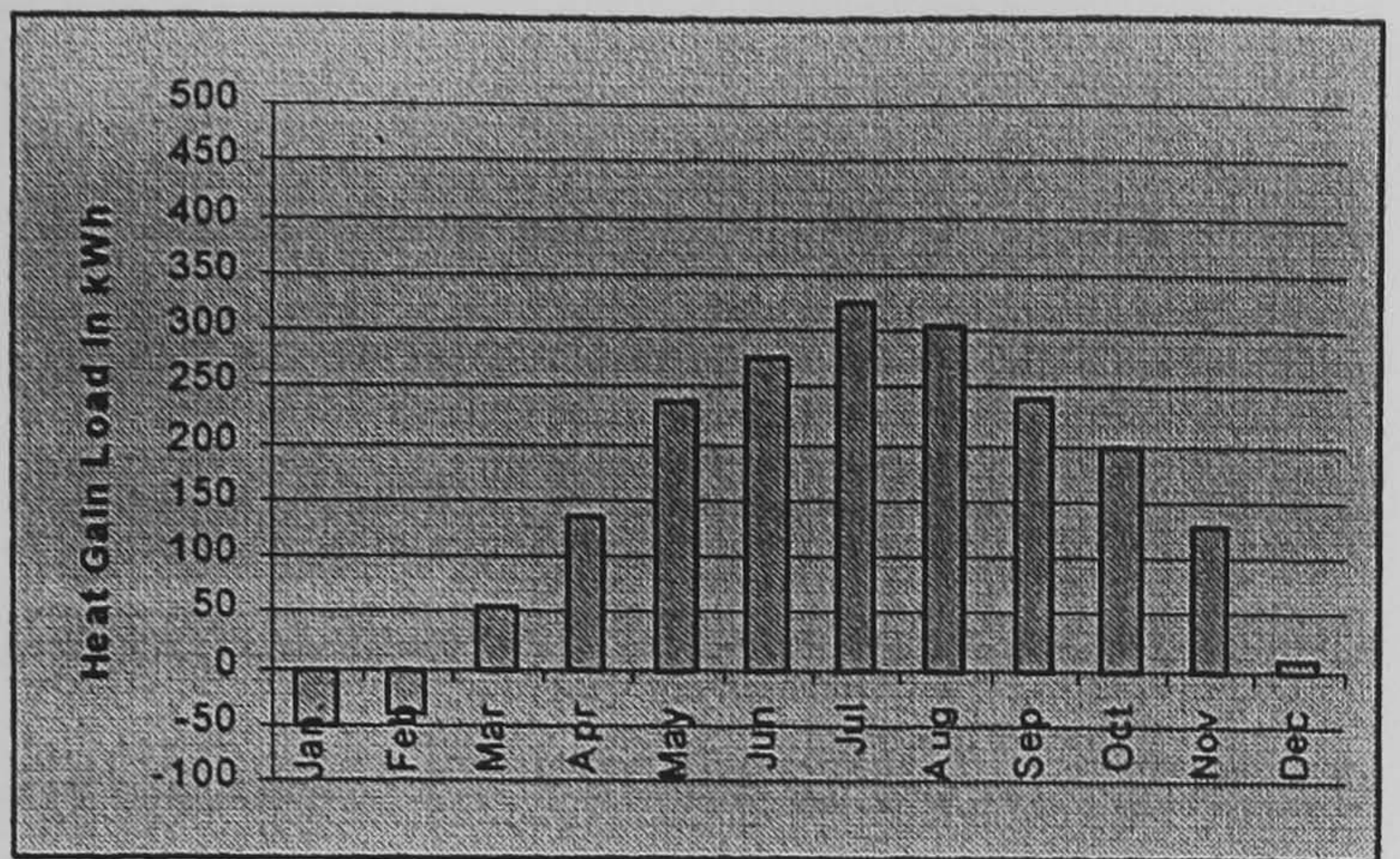
The middle floor heat gain is relatively lower than the ground floor. Maximum gains values are 294 kWh, 251 kWh, 197kWh, and 197 kWh for southeast, southwest, northeast, and northwest zones in respective order. Again, total loads follow the previous order in terms of orientation but the difference in percentage between the maximum (southeast zone) and the minimum (northeast, northwest zones) is higher at this level (34% - 36%).

- ***Thermal Characteristics at the Top Floor Level***

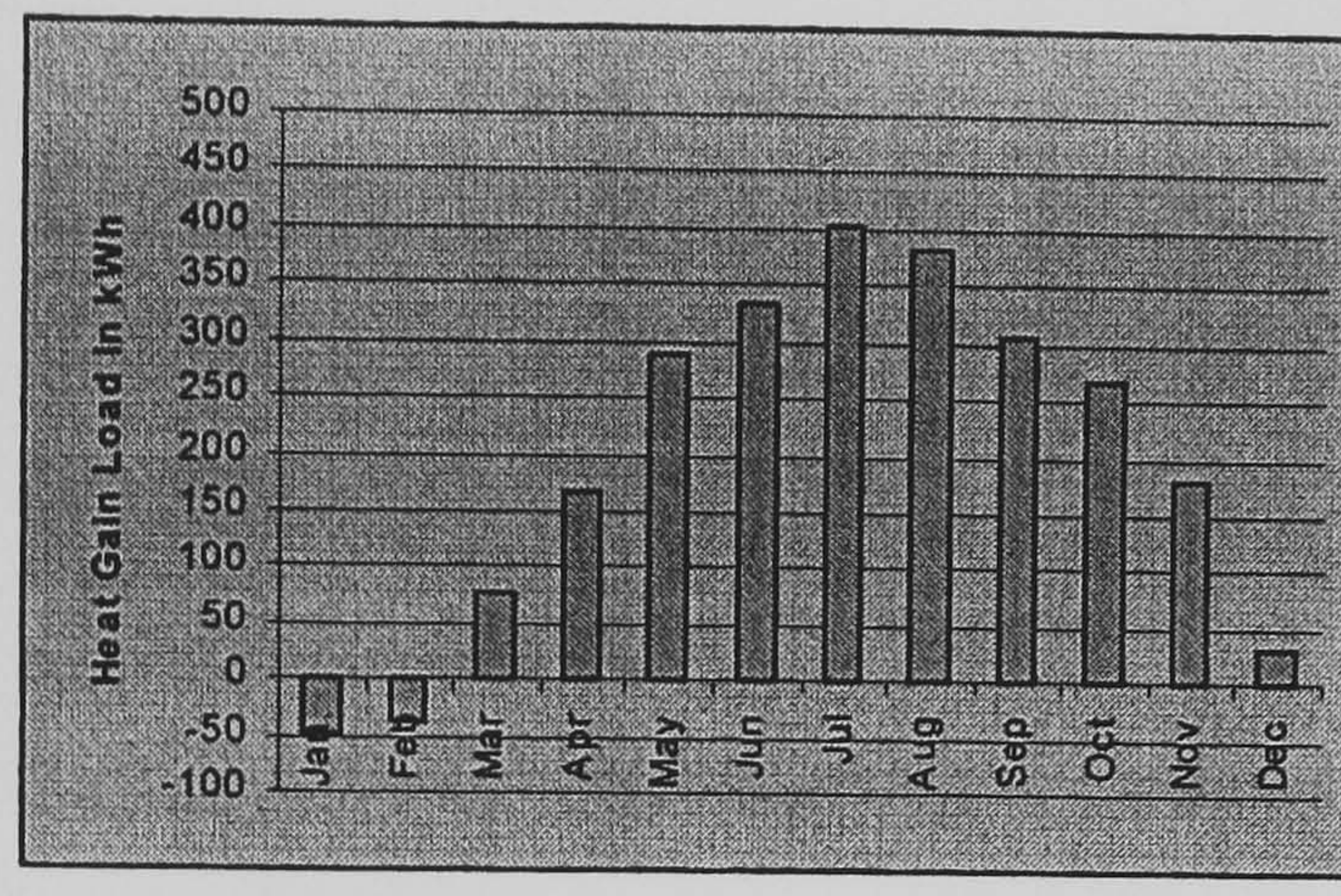
Maximum heat gain at this level is 285 kWh, the lowest among the levels. The percentage margin between the maximum and minimum is increased to 37% - 39%. However, the same order in heat gain load is maintained with the reference to orientations.

Overall observation concludes that the amount of heat gain through wall fabric degrades with altitude; the higher the level is, the lower fabric heat gain is received. Southeast and southwest orientations transmit a highest amount of heat than northeast and northwest. The percentage of differences between these orientations and vertical height has a positive relationship.

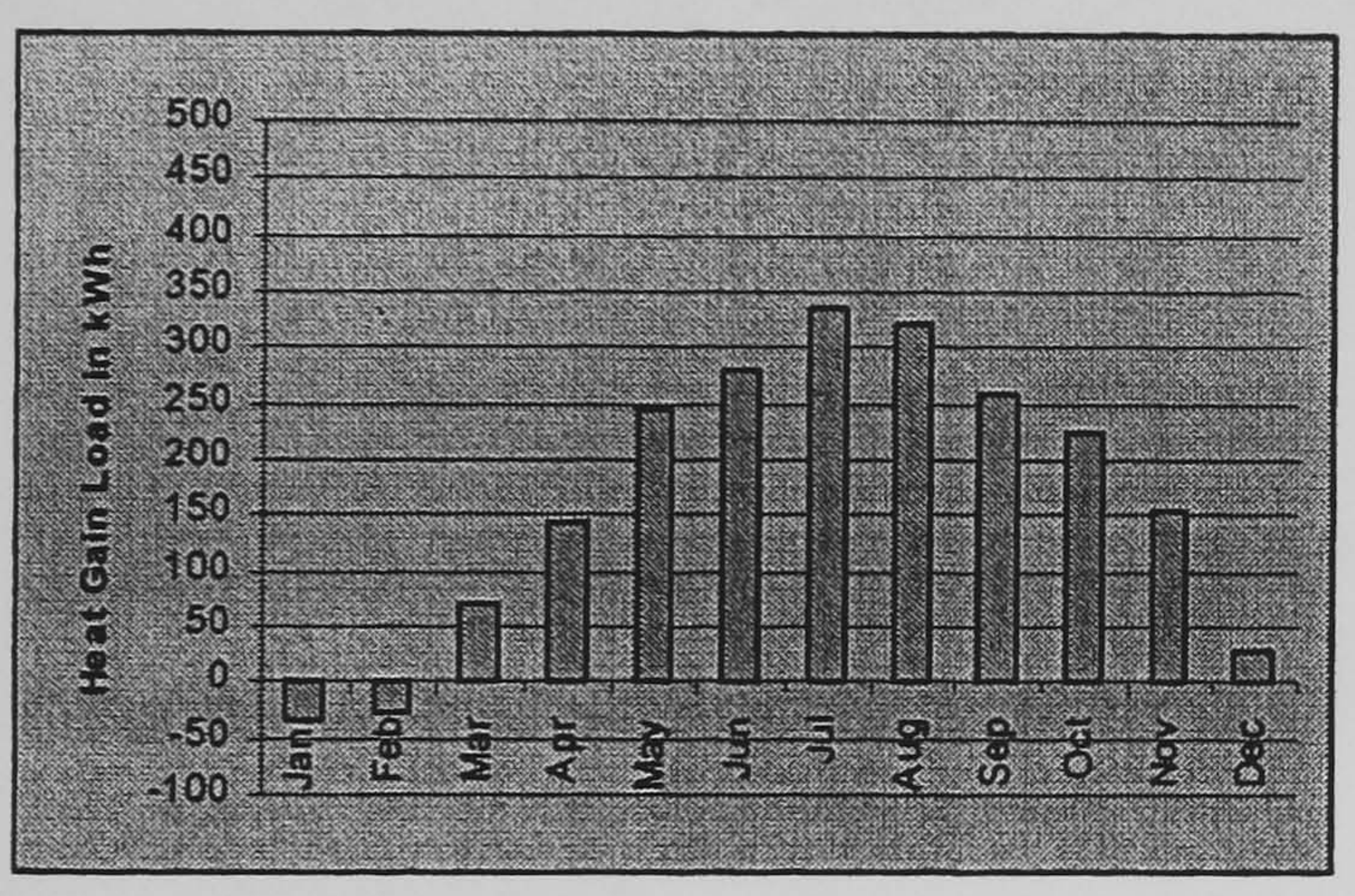
An increase in percentage of the differences between maximum gain and minimum gain has been noticed at higher levels. In other words, the top floors receive less heat in all directions than the lower floors and the differences in heat gain for unfavourably orientated zones (southeast, southwest) and favourably orientated zones (northeast, northwest) increase when going up. The relationships inside case number one are fully depicted in Figures 9.9 – 9.11.



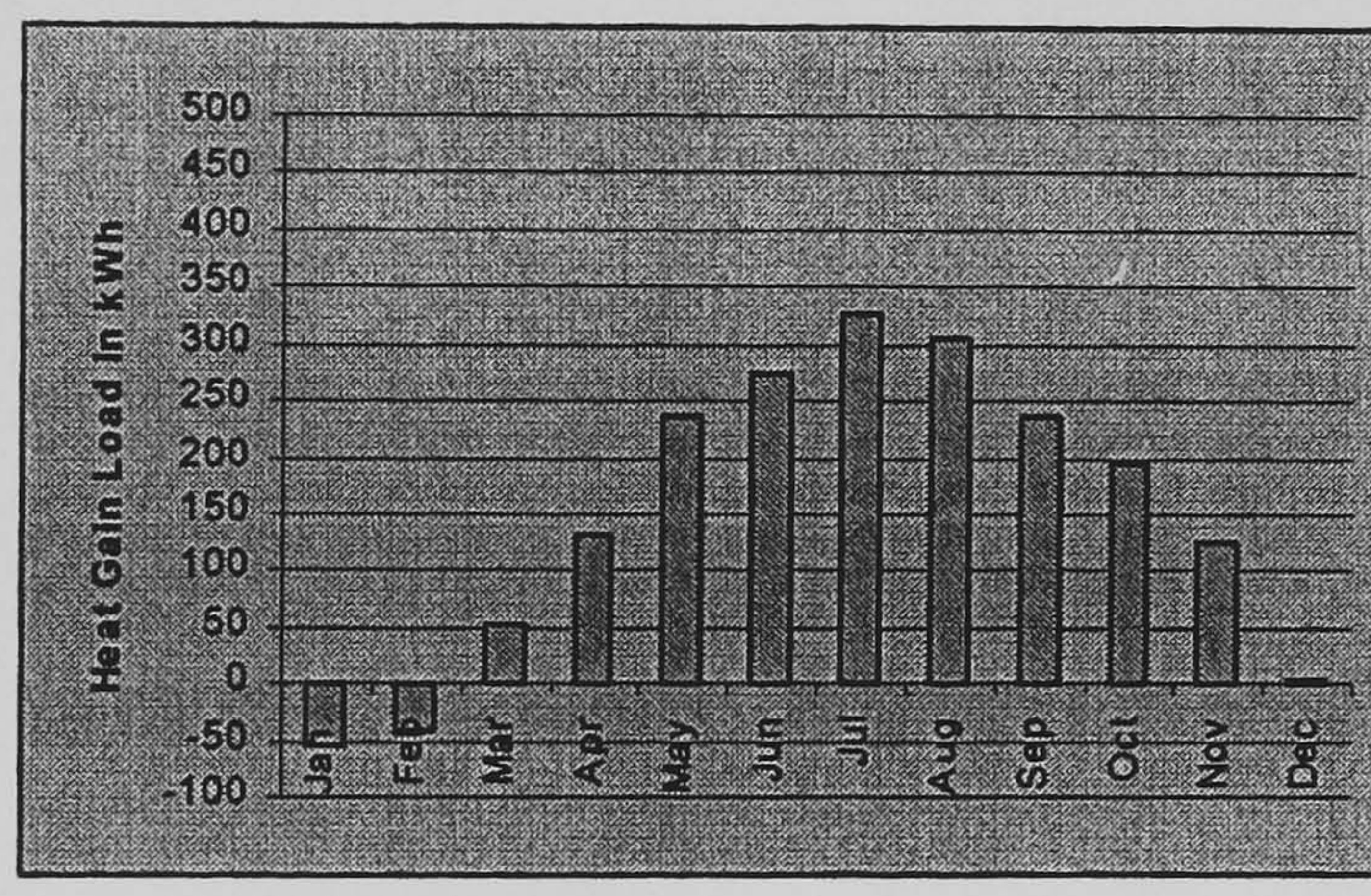
Guest Zone



Bed Zone



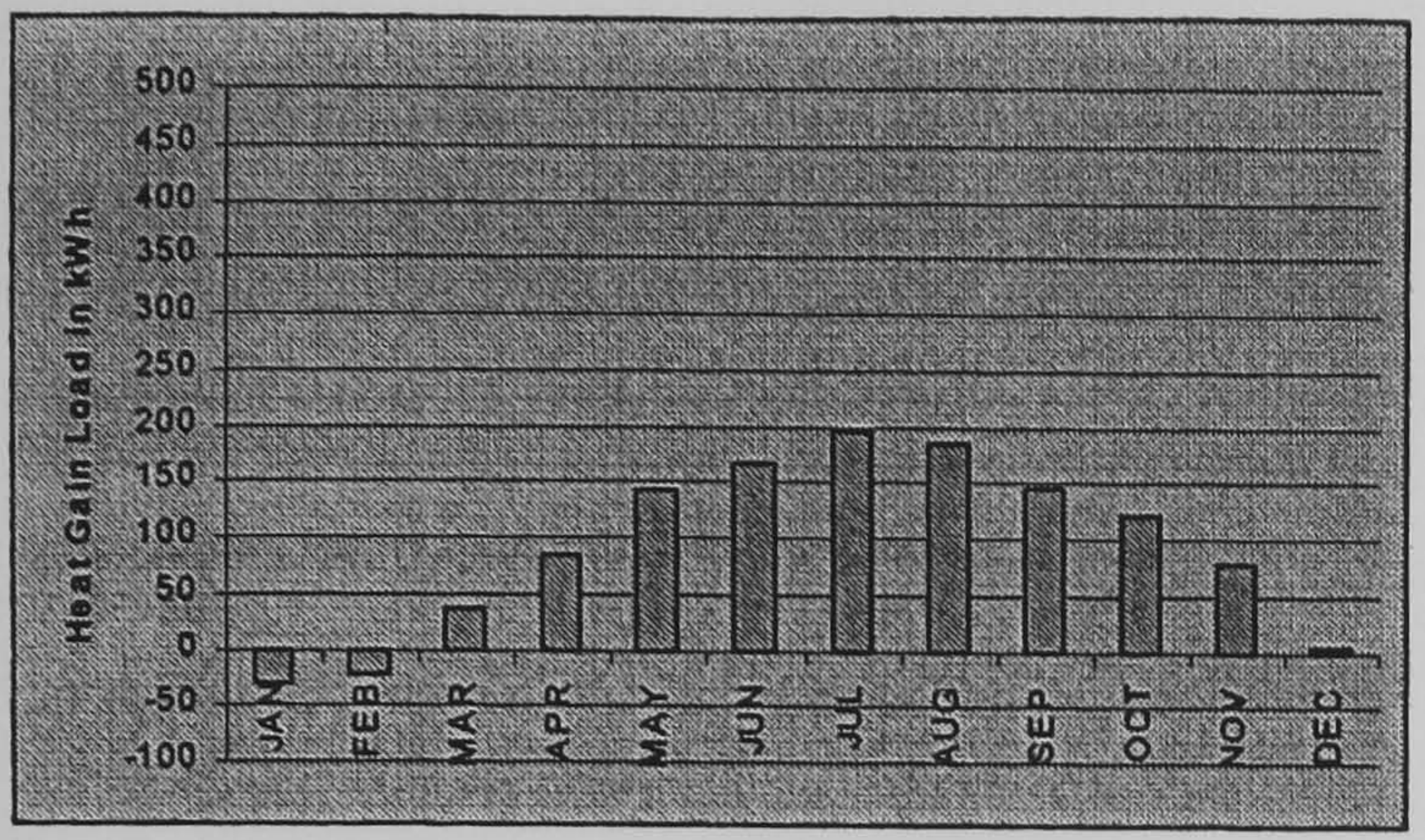
Kitchen Zone



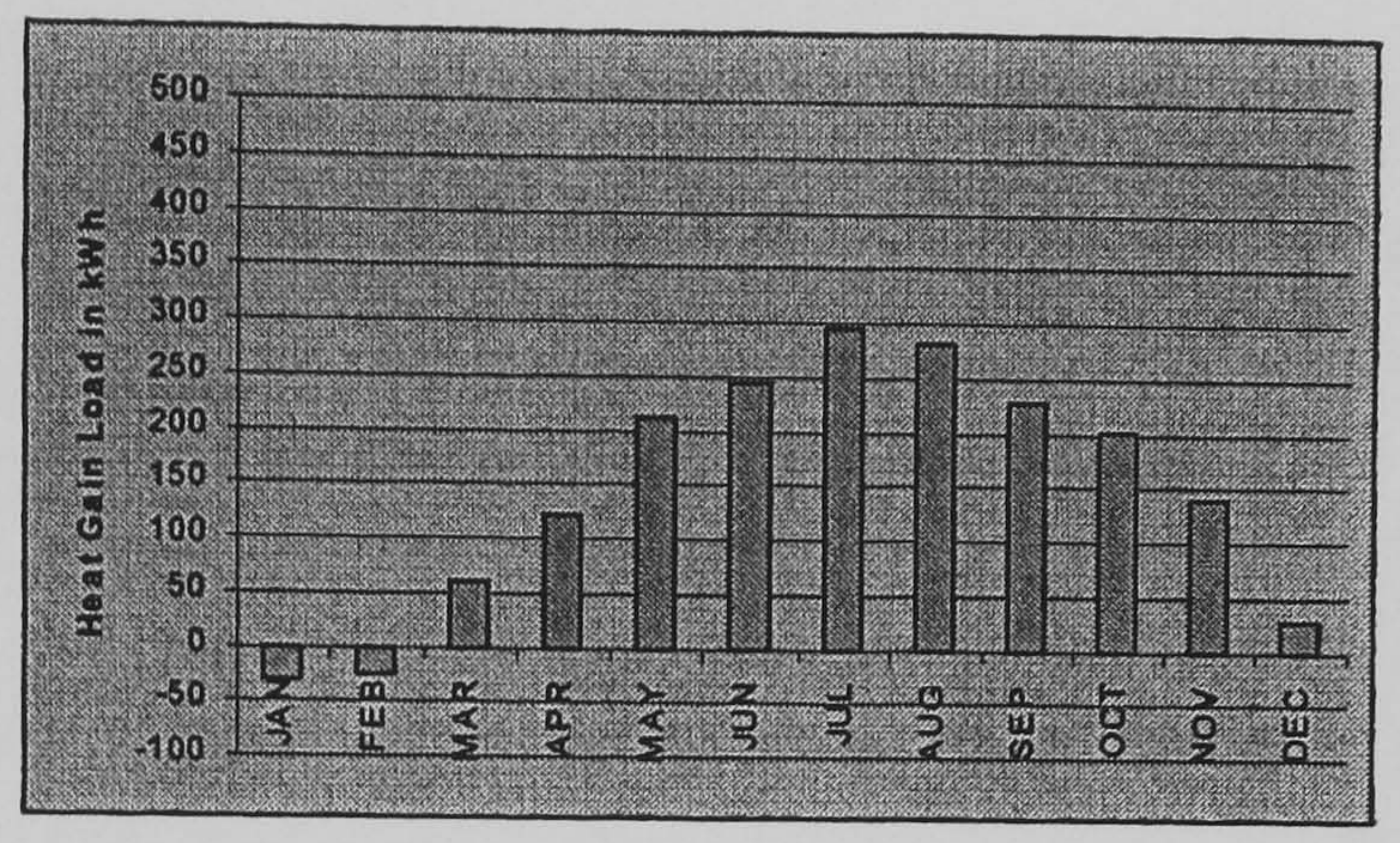
Living Zone

Total Heat Gain Load

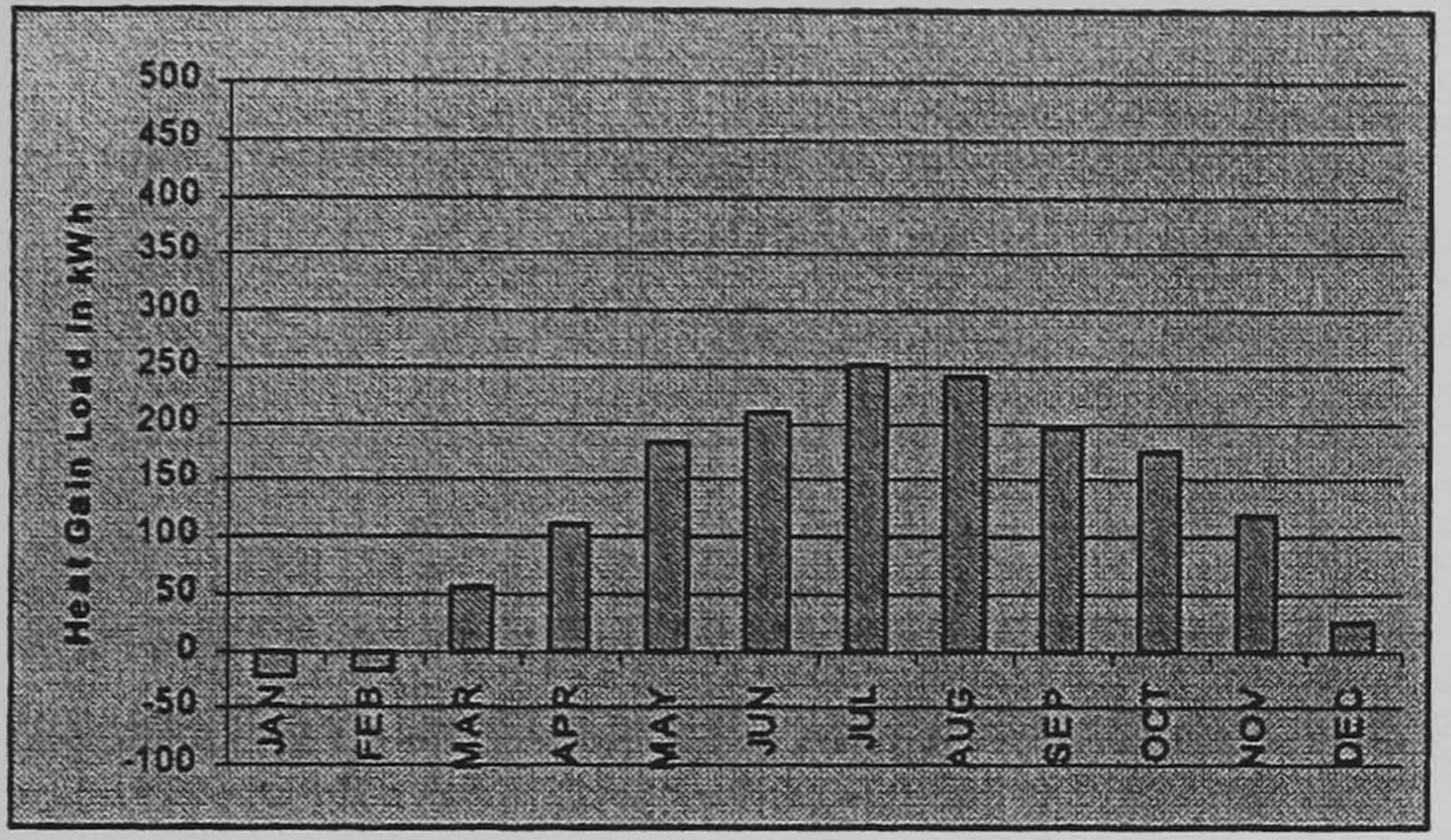
Figure 9. 9: Typical Ground Floor Inter-Apartment Heat Gain Load Profile Admitted by Walls



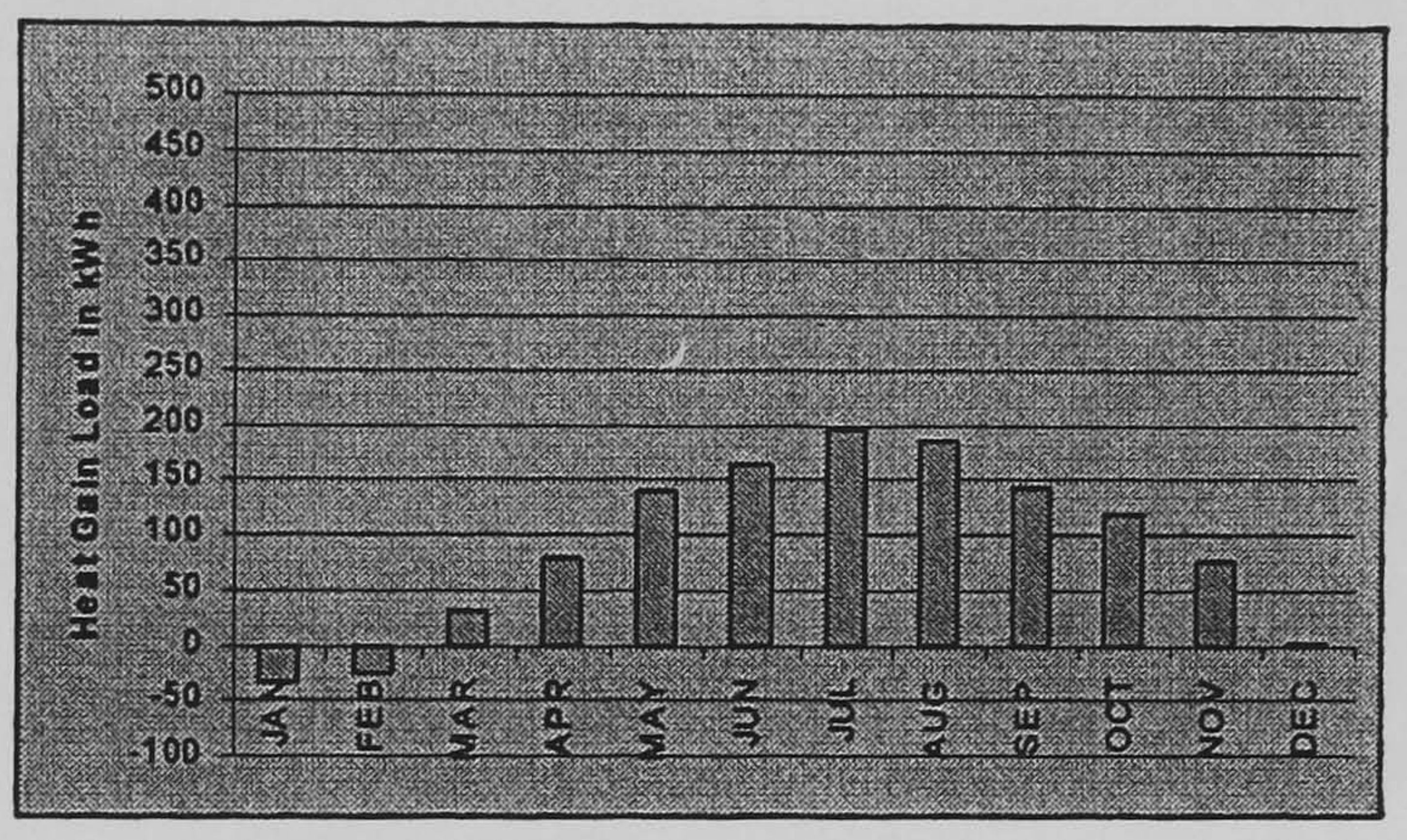
Guest Zone



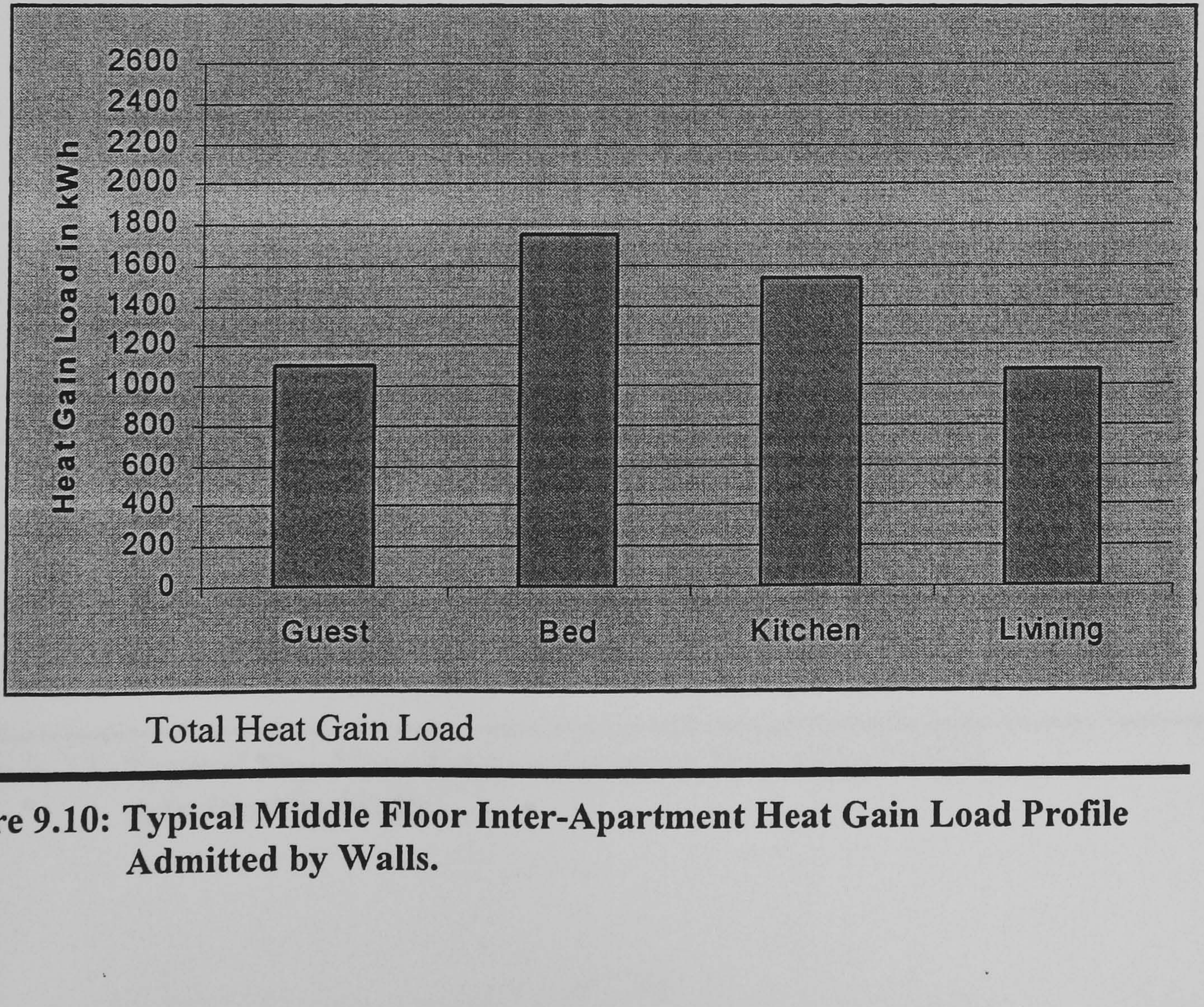
Bed Zone



Kitchen Zone

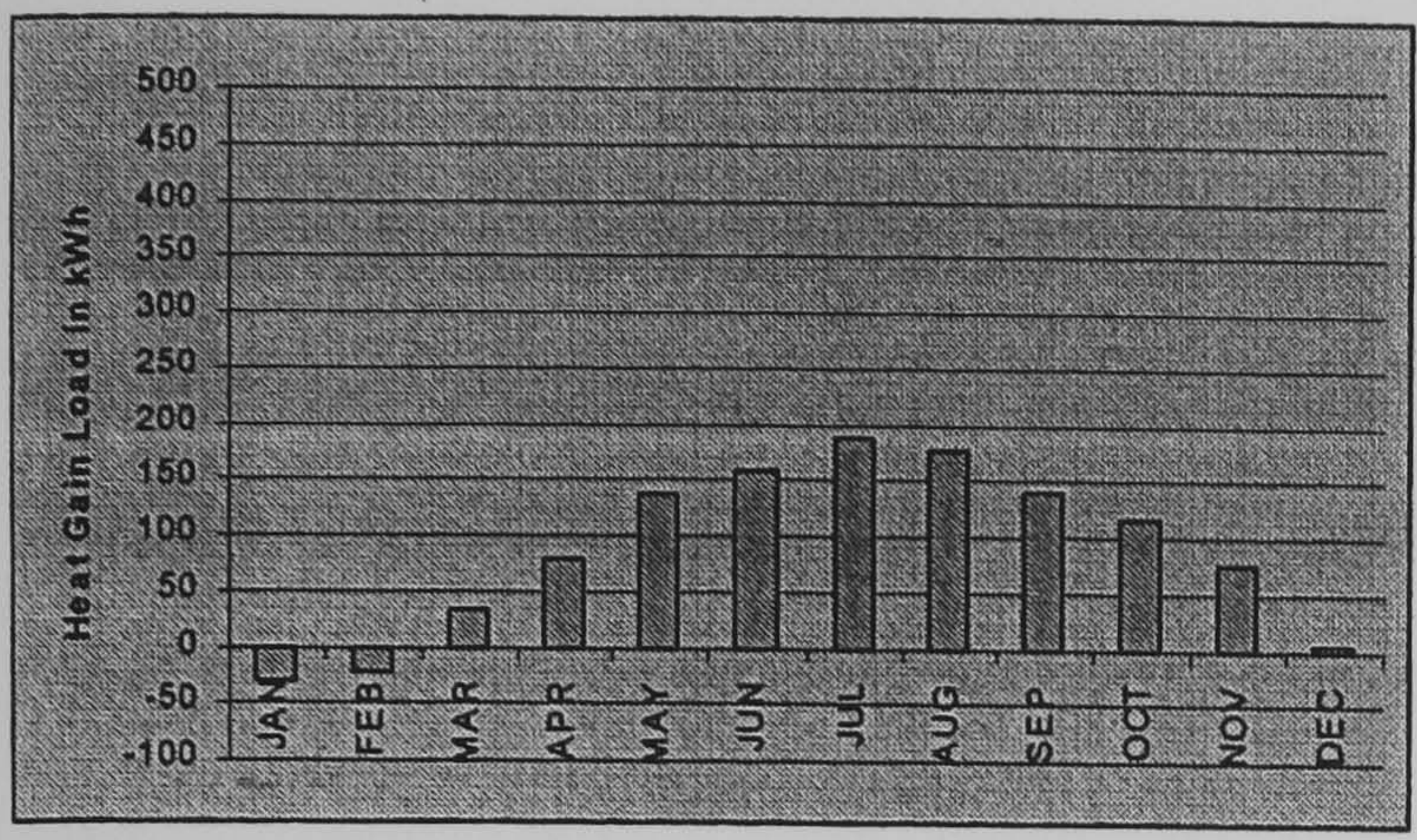


Living Zone

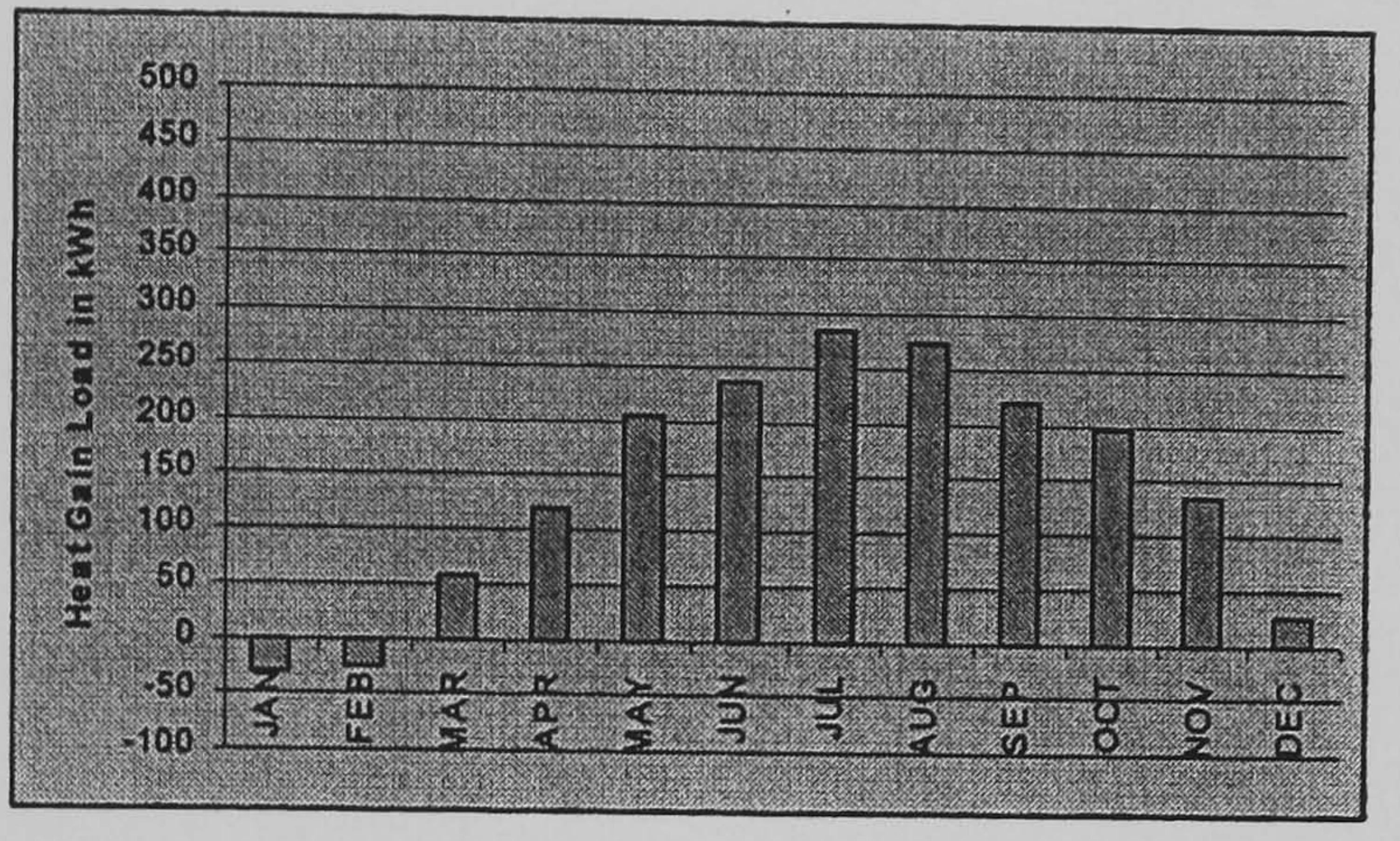


Total Heat Gain Load

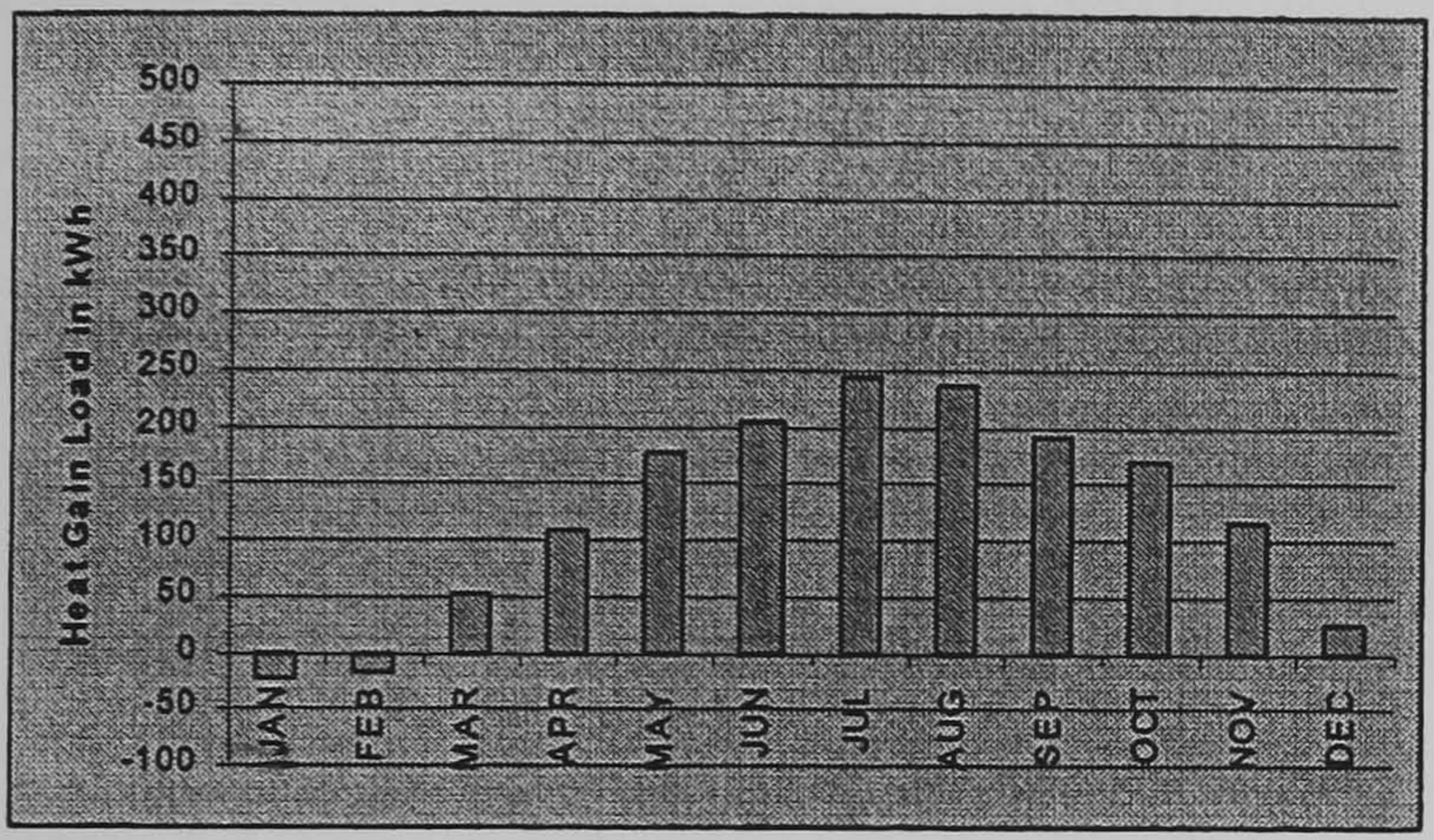
Figure 9.10: Typical Middle Floor Inter-Apartment Heat Gain Load Profile Admitted by Walls.



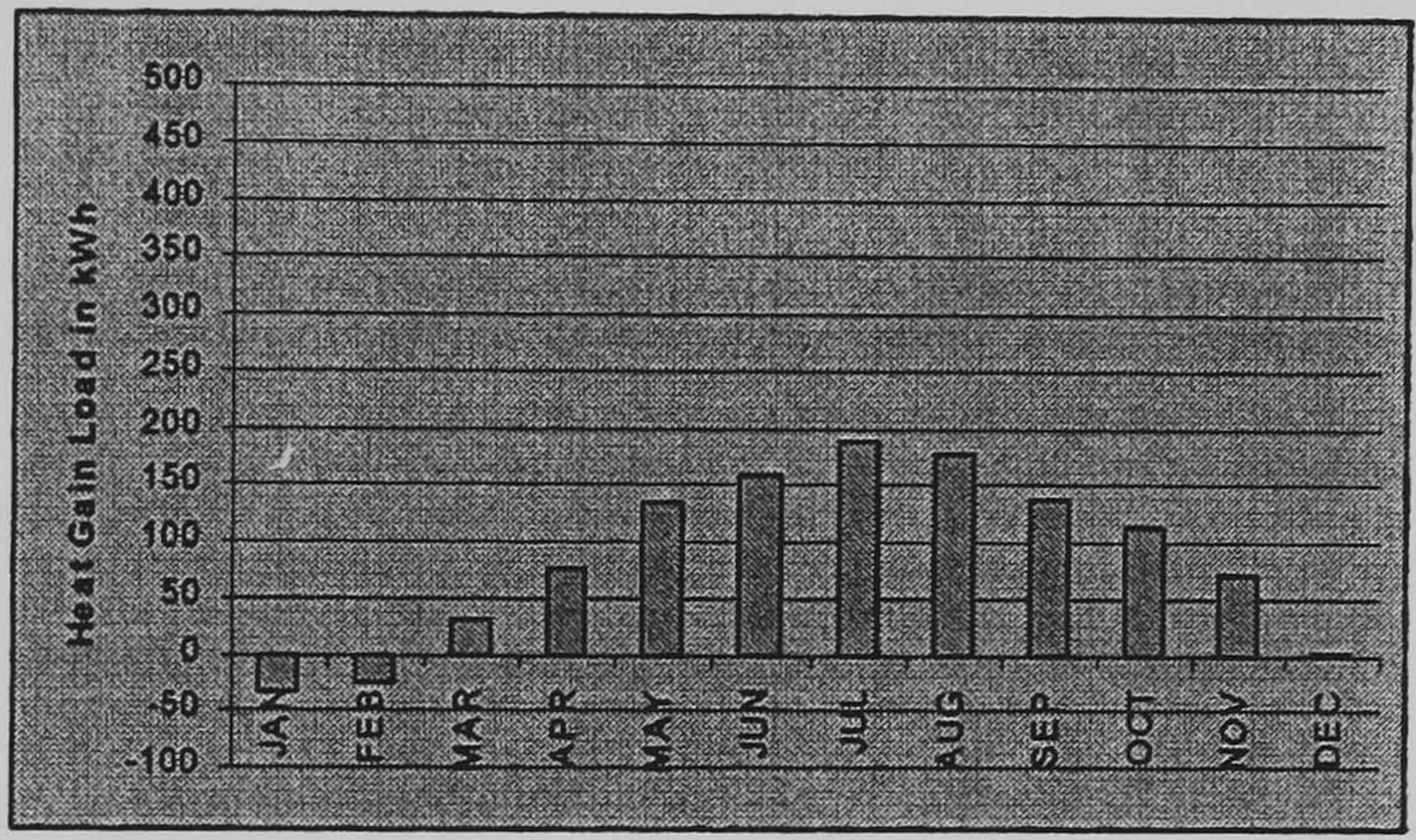
Guest Zone



Bed Zone



Kitchen Zone



Living Zone

Total Heat Gain Load

Figure 9. 11: Typical Top Floor Inter-Apartment Heat Gain Profile Admitted by Walls.

9.3.4 The Thermal Effect of Windows

The contribution made by windows takes two major forms, by conduction through window openings and frames and by solar radiation penetration through the glass. The former contribution is bounded by the opening area, U-value, and the differences between outside air temperature and indoor air temperature; thus heat gain through this medium is relatively low. The latter form of contribution is more associated with types of glass and shading devices around these openings.

Heat gain through windows by conduction represents generally less than 10% of total heat gain. This percentage seems to be low compared to other heat gain sources but at the same time it should not be ignored.

The tendency for higher percentage is inevitable if there is an increase in window/wall surface ratio. The effect of these openings on heat gain is illustrated in Figure 9.12. Lowest gain is presented by construction No. 3 and construction No. 2. Construction No. 1 and construction No. 4 present the highest.

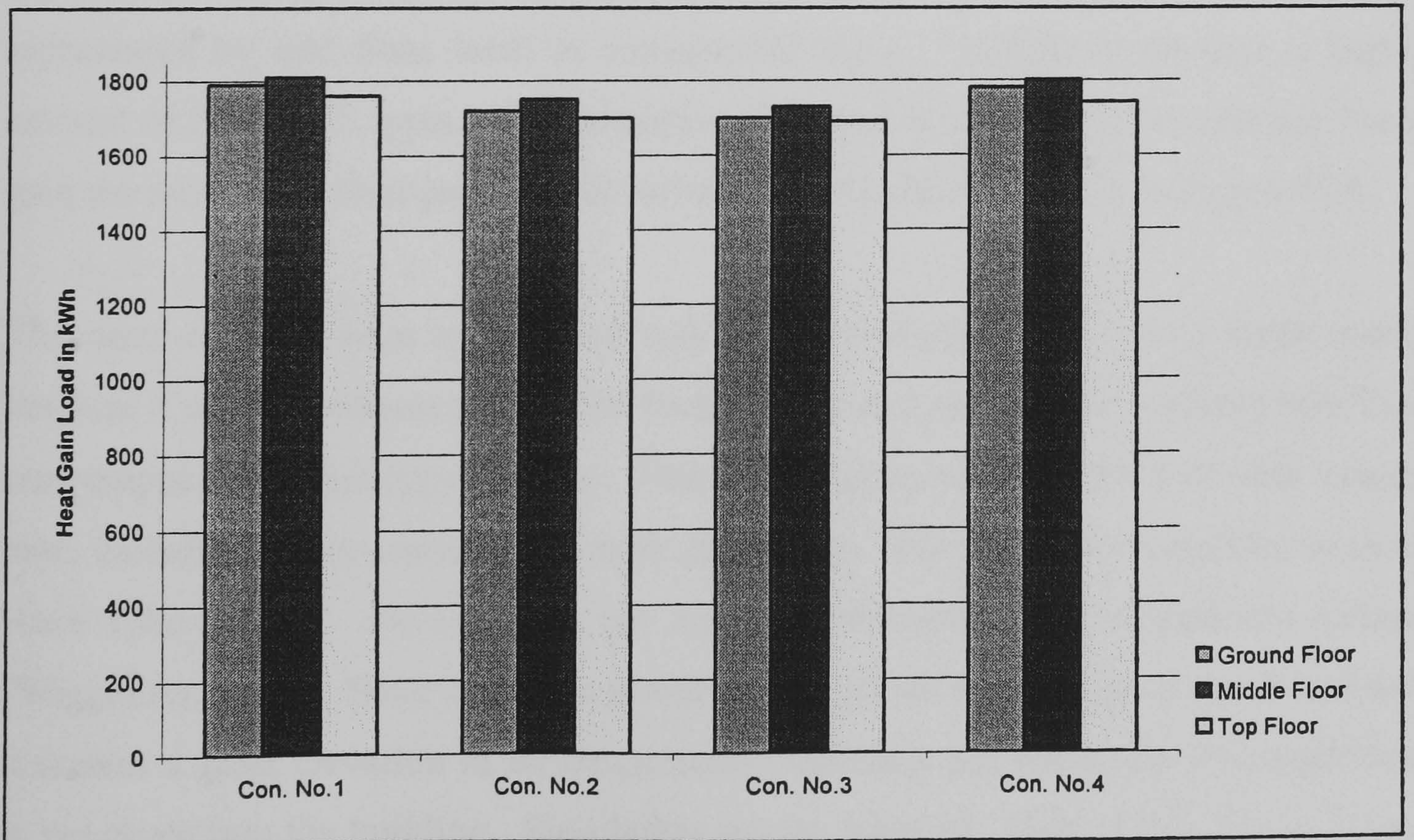


Figure 9. 12: Heat Gain Load through Windows by Conduction

Middle floors in all constructions gain a relatively higher amount of heat. This is followed by top floors then ground floors. The amount of heat gain ranges from 1640 kWh – 1818 kWh, equal to 9% difference between the minimum and the maximum values. Window/wall surface ratio is 1/6; average annual heat gain is 85 kWh per square meter of window openings.

Solar radiation has a significant effect on the heat gain process. Direct and diffused solar radiation is transmitted directly through the glass surfaces and turns to heat. This process takes into account the heat storage factor when solar radiation heats up the surrounding objects and the stored heat resulting from this process is released later to space in form of radiant temperature.

This form of heat gain represents a 24% of the annual total (Figure 9.5), which is the third largest heat gain source affecting the building. The distribution pattern of this source among the four cases is not uniform one. Case No. 1 and case No. 4 have the highest pattern. Case No. 2 and case No. 3 are relatively low. This may reflect the heat storage property for these constructions and its ability to absorb and store more heat inside their structure. Heat gain values range from 5862 kWh as a minimum represented by top floor level in construction No. 3 to 7860 kWh as a maximum represented by mid floor level in construction No. 1. Middle floors gain a higher amount of heat in all types of construction, followed by ground floors, and top floors gain the minimum. Heat gain load by solar radiation effect is shown in Figure 9.13.

The simulation has been investigated only one type of glass (6 mm clear single sheet) because it is the common type in the local market and most of the existing buildings are equipped with this type of glass. This type of glass transmits 84% of solar radiant heat, including the re-emitted heat after absorption. It is a perfect transmitter to short wave solar energy. However, at the longer wavelengths, it is completely opaque (Wigginton, 1996). Solar radiation intensity is immense at this spot of the World and it creates a great elevation in air temperature externally and internally if it is allowed to penetrate into the building. Simulation results, however, suggest that this is a poor type of window material that rapidly transmits heat to internal space (either by conduction or through solar radiation).

The control over this factor can be either to improve the glazing type quality or protect the glazing surfaces from getting into direct contact with radiation. The former scheme is very costly and can be useful to certain extent, but it definitely will not cut off the contact with the radiation, hence the glazing surfaces will still be exposed. The latter scheme is more effective approach that prevents the radiation from getting to the glazing surface with the aid of shading devices. These two techniques are rarely thought of within the local construction practice due to the lack of knowledge and experience about the crucial impact of this factor on heat gain loads.

The study has intentionally focused on getting the impact of this source as an overall picture and not to go into detail with other related subject as the effect of different type of glass, orientation, and different period of the year. By knowing the total percentage of heat contribution through this building element (windows), a more careful attention would be established whenever dealing with this factor. Almost third of the heat gain load in building is due to the performance of this element and any enhancement in this performance can bring this percentage down no matter how far and this would surely reflect on the consumption.

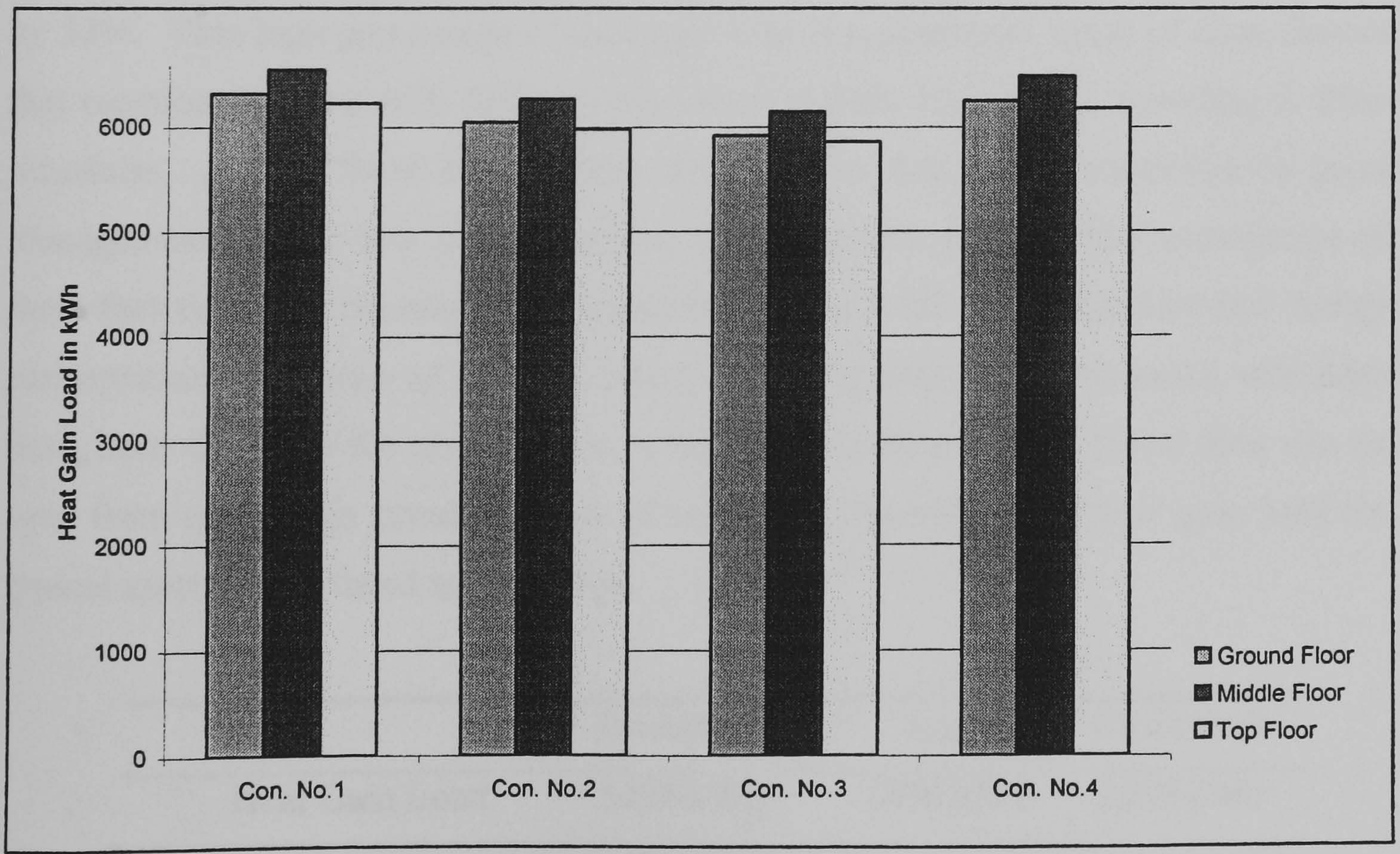


Figure 9. 13: Heat Gain Load through Windows by Solar Radiation

9.3.5 The Thermal Effect of Casual Gain

The third important source of heat gain within the building is the casual source. This source combined many internal heat sources like occupants, light, and equipment. Although this combination form the characteristic of this factor, but the issue of the casual gain is an integrated one. Different elements in this context react and influence each other to produce the overall resultant. The key factor for this issue is the occupant and their life style behaviour.

Unlike the two elements that mentioned earlier, this element is far beyond any prediction and control due to its unsystematic and unknown behaviour. The simulation for this element takes a practical assumption which based on a preset schedules that suit the common social and cultural life. These schedules consider zone function and the most appropriate occupancy pattern for this function in terms of light and equipment demanded by this zone.

The four base cases have been simulated with the same schedules and simulation run has revealed that this casual source has a significant contribution to the heat gain load by 32%. This high percentage of heat gain load is a combined result of three factors that mentioned above with different contribution from each factor according to their schedules. Among these three factors there are two that can be controlled by good management. These two are light source and equipment source. The contribution of these factors can be decreased or increased with the level of life standard and energy conservation awareness of the first factor (the occupants). As occupancy schedules have been the same for all the cases, a detail description for the casual gain can be seen from one of the simulated case (Case no.1). Annual casual heat gain load for typical apartment is listed in Table 9.4.

	Occupants	Light	Equipment
Heat Gain Load	5430 kWh	1320 kWh	2339 kWh

Table 9. 4: Annual Casual Heat Gain Load

Heat dispatched by occupant takes the major part of the casual gain with a 59% (Figure 9. 14). The load resulted from this source count for the number of occupant occupying different zones with different occupancy schedule and participates in light activity work. There is no role to control this amount of heat gain except by reducing the number of occupant and the occupancy hours for any designated zone.

For large families, this portion of heat gain may increase dramatically specially if it is associated with different kind of activities that elevate the metabolism rate and dispatch more energy and moisture to indoor environment. This issue is totally dependent on the family nature and their way of utilizing the spaces inside their apartment. Furthermore, it has it is reflection on the other two accompanied sources, the more occupants' presence in space the more utilization of the space service, e.g. light and equipment.

The second element in this issue is the equipment's heat that generated during the operation and participates by 26% to the total casual gain loads (Figure 9.14). Equipment in apartment consists of small appliances that any household usually posses, i.e. refrigerators, washing machine, TVs, VCRs, audio, and other appliances. Again, this source is also has a great tendency to increase its contribution from heat as the operating schedule increases. It is very significant in the area where the need for the equipment is high, i.e. the kitchen zone, and this zone has the major contribution to this source. The control over this source can be achieved by controlling the operation time for the different domestic appliances and by providing an adequate ventilation system that may get red of most of this energy to out side the indoor environment. Unfortunately, mechanical ventilation system has never been existed not only in the existing apartment but also in the building to be constructed.

Light comes next after the equipment factor in delivering heat into the space. Light sources account for a 15% of the heat gain based on the preset lighting schedule and intensity. Heat omission by light could be more or could be less depends on the type of the light fixtures, positions, and the ventilation around these fixtures. Usually, ventilation does not exist as a part of lighting design in local practice and light sources directly discharge their energy into the space. The control over this source of heat can be very manageable with an easy one-step action (turn light on and off). But the misuse comes from the using of different light intensity that suits different occupants.

In practice, the illumination standard inside the living zones is usually more than the need of the space. People used to adopt high illumination level in their spaces and usually do not feel comfortable with low light intensity. Another heat intensity of this source comes with the use of multi light bulb fixture, e.g. chandelier, that usually can commonly be found in the living rooms and the guest rooms. This practice increases the intensity of heat by many times according to the number of light bulbs.

High efficiency and low energy light source have not been considered in this part of the simulation, as it does not exemplify the existing situation. The predicted heat gain load by lighting system has been simulated according to the current practice in the exiting apartment.

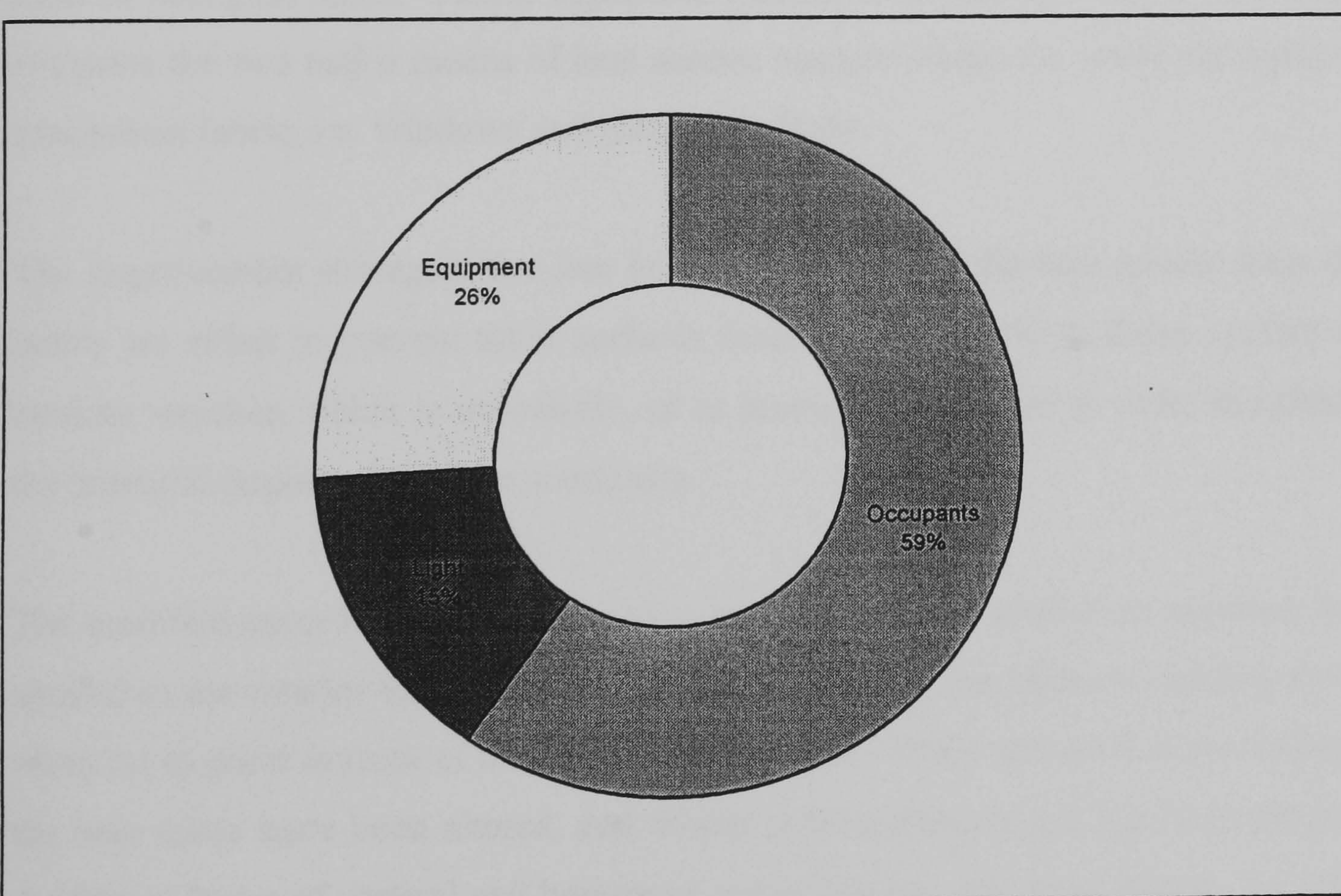


Figure 9. 14: Casual Heat Gain Contribution Percentage

9.4 Simulation Results of the Modified Cases

9.4.1 Introduction

The previous chapter has looked at the thermal characteristics of the base cases and identifies the role of building components as well as the role of internal loads in energy consumption.

The simulation of the base cases is meant to create circumstances similar to those which exist in actual apartments, i.e. similar occupancy schedules, similar room activities, and similar occupant numbers.

The strategies of modifications to these base cases, which form the main concern of this research, are limited to one broad type: the rise of building fabric efficiency in front of heat gain loads. Fabric dependent factors, as explained early in this chapter, comprise the two major means of heat access: opaque fabric, i.e. walls and roofs, and transparent fabric, i.e. windows and glazing surfaces.

The improvement strategies that can be used to minimise the heat access from these points are either to prevent these surfaces from being exposed to direct contact with outdoor weather, which is unrealistic, or to protect the surfaces in order to minimise the potential impact of outdoor conditions.

The modified cases have been prepared to test the effect of insulation materials when applied to the exterior building envelope, and also to test the effect of shading devices when set in place in front of the transparent surfaces. Walls and roofs construction for the base cases have been altered, and 50mm polyurethane board has been proposed. A 500mm frame of vertical and horizontal projection has also been introduced around the window openings (see Chapter 8). All other settings have remained the same. Simulation results for these new configurations have demonstrated that the proposed modification will potentially have the effects described under the following title.

9.4.2 The Impact of the Modifications on Building Thermal Performance

In order to see the overall image of the changes that occurred, each of the four cases has again been treated as one unit despite the three levels it contains. This arrangement has been considered for the purposes of comparison. Annual heat gain loads for the modified cases, the base cases, and the percentage of the reduction are shown in the Table 9.5.

Heat Gain Loads (kWh)	Construction No.1	Construction No.2	Construction No.3	Construction No.4
Base Case	77891	80167	81418	78820
Modified Case	57673	58314	58631	58285
Difference %	26%	27.3%	28%	26.1%

Table 9. 5: Annual Heat Gain Load for the Modified Cases

The four modified cases retain the same order as that in the base cases, i.e. Construction No.1, No.4, No.3, and No.2, in terms of the amount of heat gain conceived by each type. Construction No.1 has the lowest value of 57673 kWh while the rest constructions have a value of 58314 kWh, 58631 kWh, and 58285 kWh in respective order. The difference between Construction No.1 (the lowest U-value and the lowest heat gain load) and Construction No.3 (the highest U-value and heat gain load) is small (958 kWh). This difference represents only 1.7% more loads in Construction No.3 then in Construction No.1 and, still, gives the advantage to Construction No.1 over the other constructional types. (Figure 9.15)

However, regardless this tiny differences in heat gain load between the modified cases, the main point to infer from this simulation is that all the modified constructions perform almost the same due to the enhancement of the U-value of the construction fabrics. This enhancement has brought the U-values of the fabrics much closer, hence improve their thermal performance equally. The simulation also indicates clearly that the modifications have succeeded in reducing the heat gain load dramatically with comparison to the situation in the base cases.

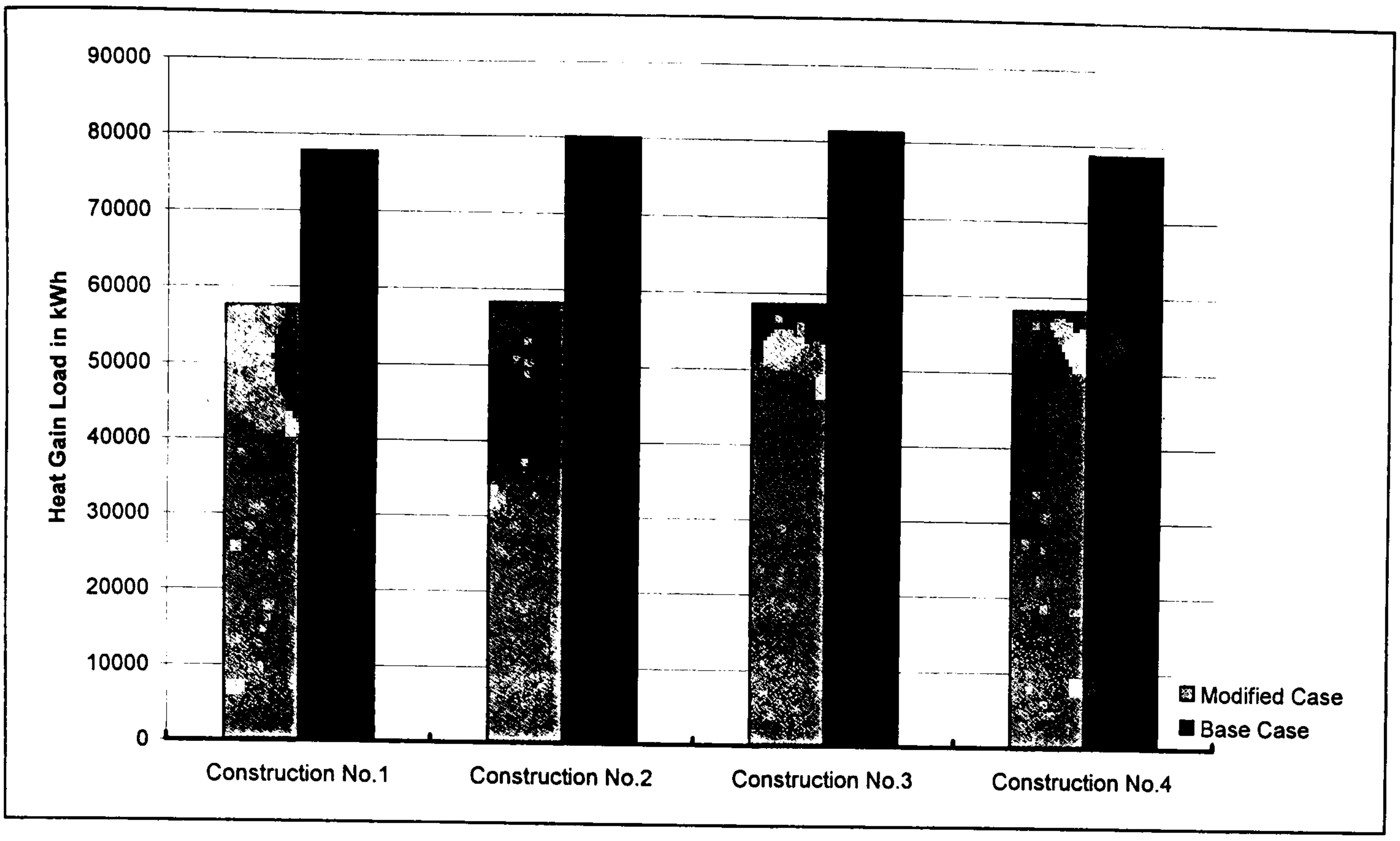


Figure 9. 15: Heat Gain Load for the Modified Cases in Comparison to the Case Cases

The comparison between annual heat gain loads of the base cases and the modified cases shows that a considerable reduction has been achieved in all cases.

The improvement in thermal performance of Construction No.1 is 26% and the reductions gained in the other constructional types are 27.3%, 28%, and 26.1% respectively. These reductions are a result of the combined effect of insulation materials and shading devices (the individual impact of each strategy will be elaborated upon later in this chapter). The effect of applying these strategies on apartment vertical location is examined in Table 9.6. The comparison is made here against the base cases in order to observe the potential differences in heat gain loads with relation to the vertical locations that result from applying such strategies.

	Con. No.1			Con. No.2			Con. No.3			Con. No.4		
	Base	Mod.	%	Base	Mod.	%	Base	Mod.	%	Base	Mod.	%
Grd	26437	20214	23.5	27256	20441	25	27705	20551	25.8	26770	20777	22.4
Mid	24158	18020	25.4	24930	18232	26.9	25350	18338	27.7	24470	18035	26.3
Top	27296	19439	28.9	27981	19641	29.8	28363	19742	30.4	27582	19473	29.4

Table 9. 6: The Effect of the Modification on Heat Gain Load

The differences in reduction of heat gain loads between the base cases and the modified cases vary between 22% and 25.8% at ground floor level, 25% and 27.7% at the middle floor level, and 28% and 30% at the top floor level.

The middle floors, still, have the advantage of being the floors to receive less heat gain load than the other floors. But, unlike the situation in the base cases where the top floors have the maximum, the ground floors in the modified cases have the maximum and the top floors come next.

The percentage of the reduction in heat gain load increases moving upwards from the ground level, with a difference of 8% between the lowest reduction (Construction No.4) and the highest reduction achieved (Construction No.3). (Figure 9.16)

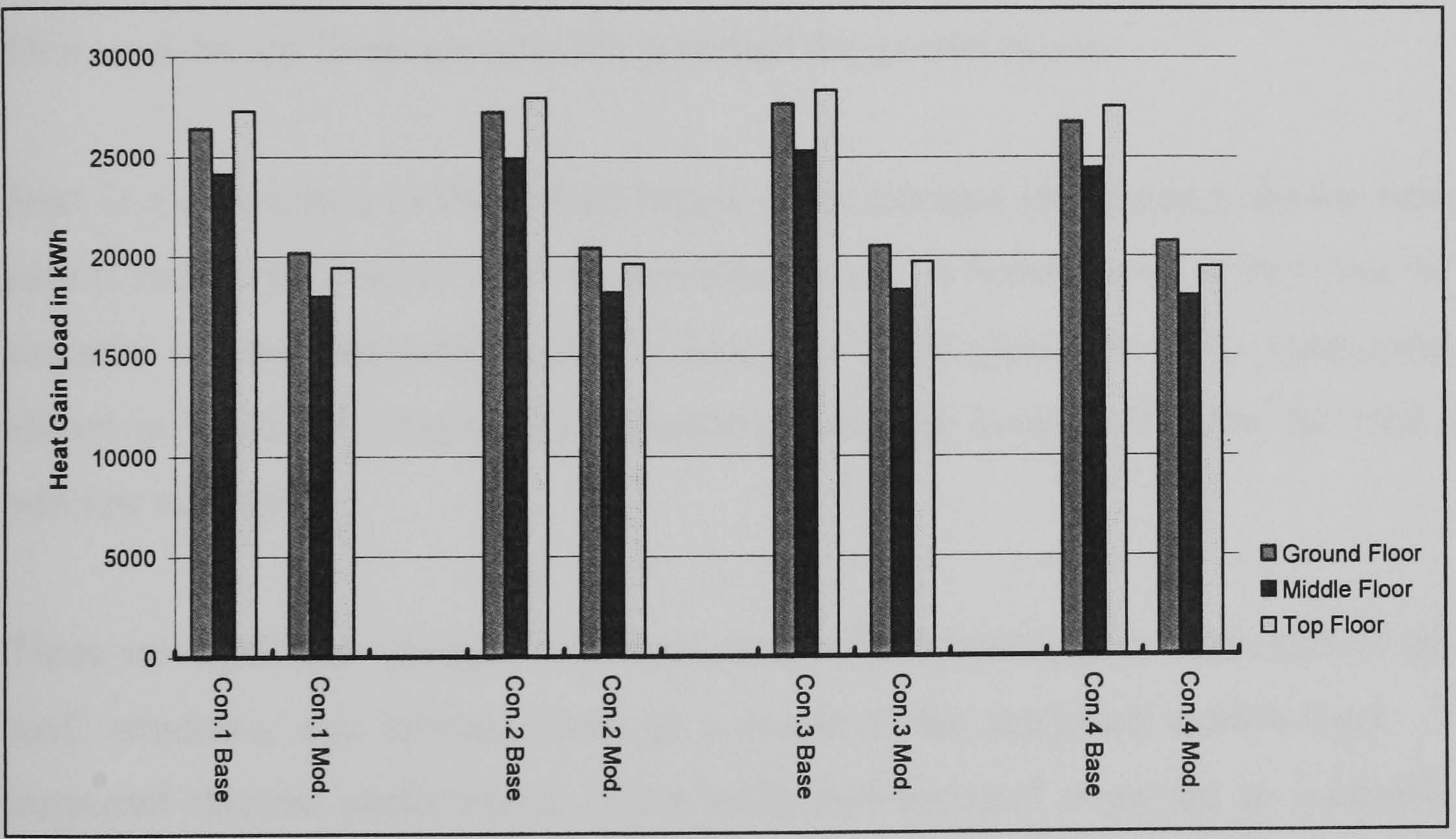


Figure 9. 16: Heat Gain Load Reduction Profiles

In other words, the efficiency of insulation and shading devices is more visible on upper floors than the lower ones. The maximum benefit from these strategies can be observed at top floor where the reduction in heat gain goes up to 30.4%. This might be attributed to the combined reduction gained from walls and roof together. As far as construction materials are concerned, the high U-value construction (Construction No.2 and 3) achieves with the modification more reduction in heat gain load than the relatively low U-value construction (Construction No.1 and 4).

Table 9.7 illustrates the percentage of thermal improvement in the modified cases with relation to different apartment levels. The improvement in performance is referenced to the ground floor where the heat gain load is maximum (100%).

	Con. No.1	Con. No.2	Con. No.3	Con. No.4
Ground Floor	100 %	100 %	100 %	100 %
Middle Floor	89 %	89 %	89 %	87 %
Top Floor	96 %	96 %	96 %	94 %

Table 9. 7: Percentage of Thermal Improvement with relation to Ground Floor

The effect of modification is almost uniform with regard to apartment levels. Ground levels have the highest values, middle levels are lower with 11% less than the ground floor, and the top floors are only 4% less than the ground floors.

Next is a description of the overall image of the thermal performance for the sample case (Construction No.1) from the modified case. A break down of this case to its essential components with regard to heat gain loads gained by each component is shown in Table 9.8. Figure 9.17 illustrates heat gain loads in kWh/m^2 for wall and window surfaces.

There are significant changes have been noticed in the thermal performance of walls, roof, windows, and internal loads as a result of the proposed modification. The improved thermal performance of the walls and the roof is gained as a benefit of applying thermal insulation. Windows also have a positive reduction for the amount of heat gain load coming through solar radiation and this improvement may be attributed to the use of shading devices.

Casual gain has slightly been increased due to the application of insulation materials that put more control on the flow of heat in both directions (inward and outward). This sign could be a disadvantage of insulation as it helps to accumulate the internal heat inside the indoor environment for longer period of time.

	Ground Floor			Middle Floor			Top Floor		
	Base	Modified	%	Base	Modified	%	Base	Modified	%
Total kWh	26437	20214	23.5	24158	18020	25.4	27296	19439	28.8
Wall	7958	3582	55	5462	1279	76.6	5277	1260	76.1
Infiltration	1832	1834	-	1647	1649	-	1640	1648	-
Win./ Conduction	1785	1699	4.8	1819	1726	5.1	1759	1700	3.4
Win./ Solar	6320	4003	36.7	6553	4143	36.7	6230	4055	34.9
Casual	8537	9091	-6.5	8679	9221	-6.2	8362	9077	-8.6
Roof	x	x	x	x	x	x	4028	1677	58.4

Table 9. 8: Detailed Description of Thermal Performance for Construction No.1 (base case and modified case)

It can be seen that the modified case achieves a 23.5% reduction in total heat gain load in comparison with the base case on ground level, 25.4% on the middle level, and 28.8% on the top level. The modification seems to be more beneficial at the upper level, as the reduction percentage is the highest at this floor. Nevertheless, the middle floor has benefited more. The reduction percentage at the top floor combined the reduction gained from all common components as in other floors but the roof in this case plays a part in the calculation as well. At ground floor, wall performance has improved by 55%, and heat gain through windows by conduction and by solar radiation has been reduced by 4.8% and 36.7% respectively.

Heat gain load at the middle floor has been reduced by the following amounts: 76.6% reduction achieved from the improve performance of the walls, 5.1% and 36.7% reduction achieved from cut down conduction and solar radiation coming from the windows.

Top floor performance is more like that of the middle floor. The reduction gained by the wall is 67.1%, and the reductions gained by the windows are 3.4% and 34.9%. The roof has achieved a 58.4% cut down in heat gain load.

It is obvious that there is a great potential to reduce heat gain loads by applying these two straightforward strategies on any building. One observation needs to be mentioned here, and that is that these strategies, applying insulation materials in particular, may have a negative impact on the heat gain load generated internally by casual sources.

In all levels, there is a slight increase (6%-8%) in casual heat gain load in the modified case in comparison to the base case. The reason for this shortcoming might be attributed to the thermal detention that insulation materials effect on the indoor air temperature (Figure 9.17). Insulation prevents heat from escaping and allows it to accumulate for longer periods of time; hence it increases the thermal load generated by internal resources. This load together with loads resulting from the building fabric dependent factors is crucial for the system load, hence for the end-use energy consumption rate.

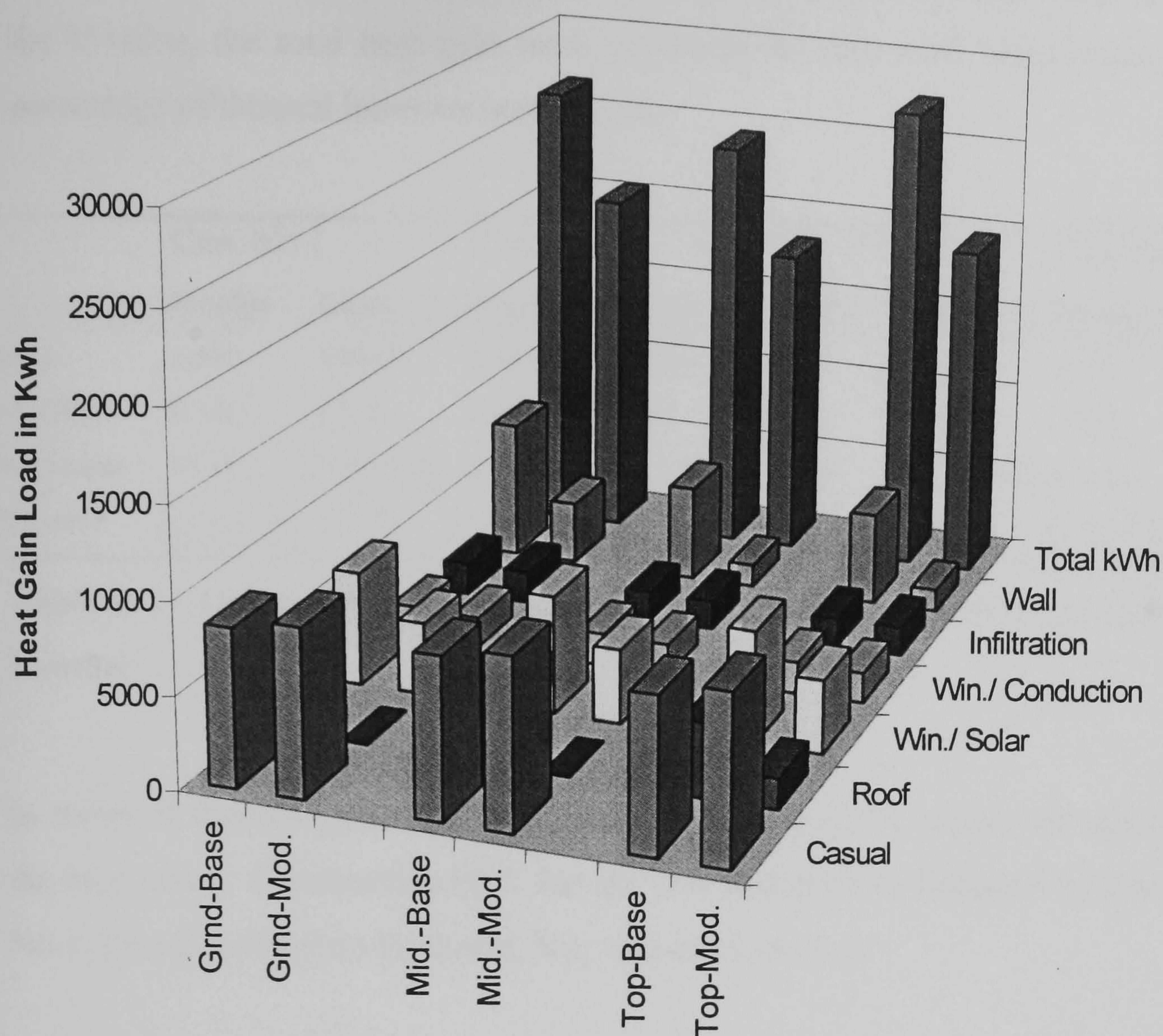


Figure 9. 17: Detailed Heat Gain Load Chart for Construction No.1

9.4.3 Thermal Performance of the Modified Walls

Installing 50mm of insulation to the outer skin in all construction types reduced dramatically the over all U-value for these constructions and achieved substantial reduction in heat admitted to internal spaces through these constructions.

The insulation layer has reduced the U-values of all constructions by a large margin from the base U-values (80%-82%), and therefore the returns are immense. Almost two thirds of total walls heat gain loads have been cut off by the use of the insulation materials. Construction No.1 has reduced the heat gain loads by 67.2% and Constructions No.2, 3, and 4 have gained a reduction of 68.9, 69.3, and 69% respectively.

Table 9.9 shows a comparison between the base and the modified cases in terms of the U-value, the total heat gain loads produced by each wall construction, and the percentage of thermal improvement gained.

	Con. No.1		Con. No.2		Con. No.3		Con. No.4	
	U-value	Loads	U-value	Loads	U-value	Loads	U-value	Loads
Base	1.887	18697	2.654	22736	2.778	24630	2.083	20072
Modified	0.356	6124	0.495	7078	0.546	7558	0.372	6223
% U-value	81.1%		81.3%		80.3%		82.1%	
% Loads		67.2%		68.9%		69.3		69%

Table 9. 9: Thermal Improvement in Wall Performance in Relation to Materials U-value

In terms of thermal performance the modified cases still maintain the same order as the base cases. Construction No.1 has the best performance followed by Construction No.4, then Construction No.2 and, last, Construction No.3.

The thermal performance of roofs has been improved by 57%-58% from the base cases as a result of reducing the U-value of the roof construction by 61%. Roof construction in the modified cases is unified for all types and this represents the conventional roofing system in local area. Because of this, the difference in heat gain loads is relatively slight in the construction types in the base case (maximum 151 kWh), but almost diminished (maximum 10 kWh) in the modified cases. Table 9.10 shows these differences with relation to the U-value and heat gain loads.

	Con. No.1		Con. No.2		Con. No.3		Con. No.4	
	U-value	Loads	U-value	Loads	U-value	Loads	U-value	Loads
Base Case	1.613	4028	1.613	3921	1.613	3877	1.613	3998
Modified	0.625	1677	0.625	1667	0.625	1661	0.625	1676
% U-value	61.3%		61.3%		61.3%		61.3%	
% Loads		58.4%		57.5%		57.2		58.1

Table 9. 10: Thermal Improvement in Roof Performance in Relation to Materials U-value

A summary of heat gain loads admitted by building envelope components, i.e. walls and roofs, in relation to vertical locations for the base cases and the modified cases is depicted in Tables 9.11 & 9.12 and charted in Figure 9.18. The amount of loads in comparison to total heat gain loads produced by each apartment level demonstrates the effectiveness of insulation as a heat transmission barrier. Ground floor heat gain loads represent 17%-19% of the total loads whereas this percentage is 30%-36% in the base case. On the middle floor, the percentage of fabric loads is 7%-10% of the total, whereas this percentage is 22%-29% in the base case. The top floor fabric loads contain two components, walls and roofs. The percentage of loads from walls is 6%-8% against 19%-25% in the relevant floor in the base case.

Base Case	Ground Floor (kWh)		Middle Floor (kWh)		Top Floor (kWh)		
	Total	Walls	Total	Walls	Total	Walls	Roof
Con. No.1	26437	7958	24158	5462	27296	5277	4028
Con. No.2	27256	9348	24930	6801	27981	6587	3921
Con. No.3	27705	10002	25350	7429	28363	7199	3877
Con. No.4	26770	8436	24470	5917	27582	5719	3998

Table 9.11: Heat Gain Load (kWh) in relation to Vertical Locations (base cases)

Modified Case	Ground Floor (kWh)		Middle Floor (kWh)		Top Floor (kWh)		
	Total	Walls	Total	Walls	Total	Walls	Roof
Con. No.1	20214	3582	18020	1279	19439	1260	1677
Con. No.2	20441	3910	18232	1595	19641	1573	1667
Con. No.3	20551	4071	18338	1750	19742	1737	1661
Con. No.4	20777	3618	18035	1312	19473	1295	1676

Table 9.12: Heat Gain Load in relation to Vertical Location (modified cases)

Roof loads in the modified case represent a flat value of 8% of the total in all cases, whereas this value is 13%-15% in the base case. The roof is one of the building elements that the most exposed to direct radiation and other climate factors hence, it takes a major part in the building thermal performance. Only the upper level of the building is usually affected the most by roof construction quality. Insulation improves roof performance by almost twice and reduces the amount of heat gain by almost 50%.

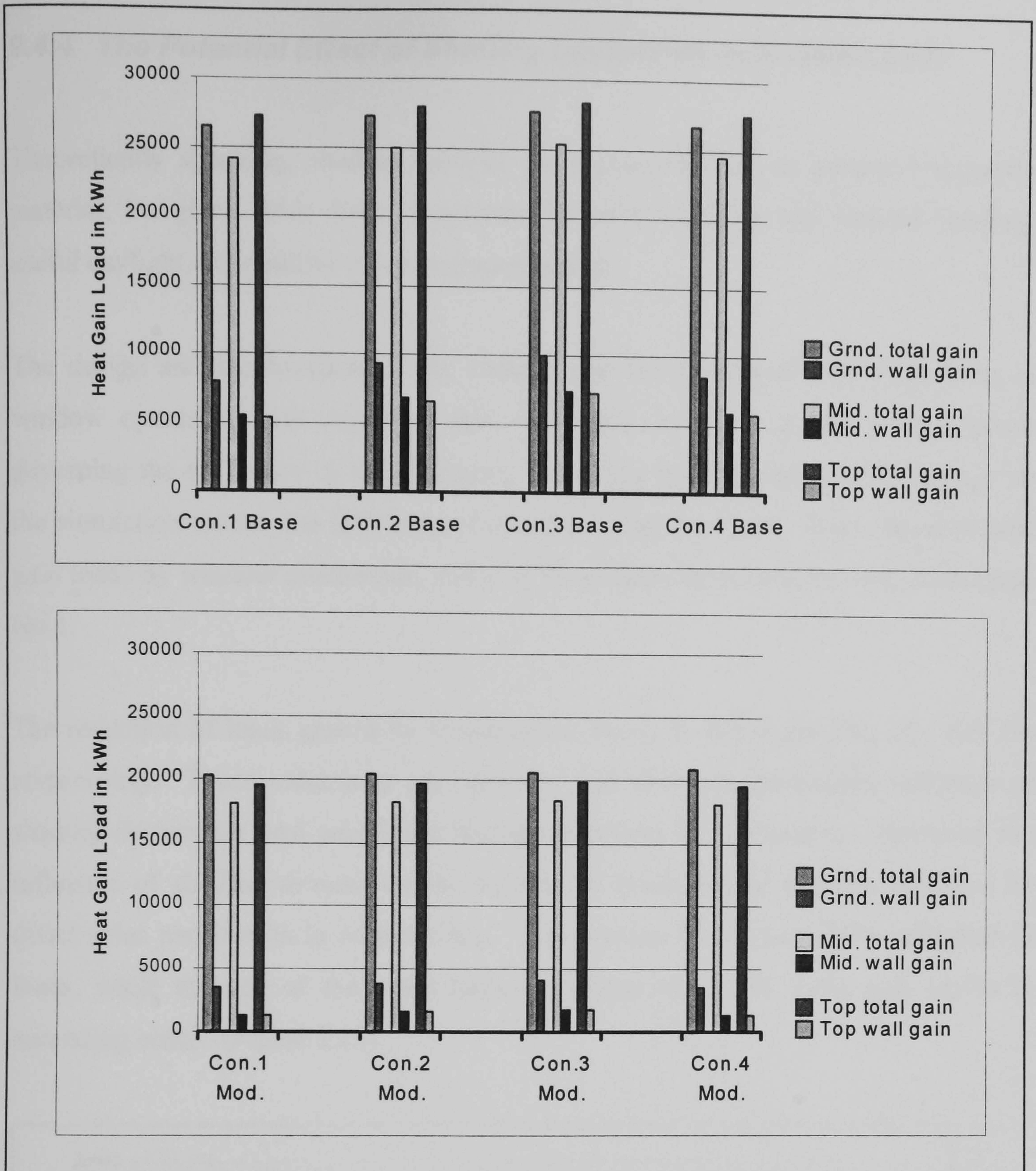


Figure 9.18: Wall Heat Gain in relation to Total Heat Gain (the base cases and the modified cases)

Although different ranges of heat gain loads have been observed between apartment levels in the base cases and the modified cases, the same order in terms of heat gain loads has been retained. The ground floor tends to gain the higher amount if heat through its wall fabric, while the middle floor receives less, and the lowest amount of heat gain loads is found on the top floor. Considerable reduction has been gained in each floor through the application of thermal insulation materials. Wall thermal performance improved by more than 16%, in relation to total loads, at the ground level, 19% at the middle level, and 17% at the top level. The thermal performance of roofs has also improved by 7% in relation to the total loads.

9.4.4 The Potential Effect of Shading Devices on Heat Gain Loads

Theoretically speaking, shading devices are a practical way to protect transparent material, i.e. glass, from direct penetration of solar radiation and without blocking useful daylight and outdoor visual communication.

The design and the location of the vertical and the horizontal louvers in front of window openings, with regard to sun movement angles, is a very crucial factor governing the efficiency of these devices. Tracking the influence of this strategy on the simulation model, the following observations may be made. With regard to heat gain loads by window conduction, 4.4% of these loads have been cut in Construction No.1.

The reduction of loads gained by Construction No.2, 3, and 4, are 2%, 1%, and 3% respectively. These reductions are very tiny and illustrate the limited influence of shading devices on heat gain loads through windows by conduction. However, the influence of shading devices on the amount of loads gained through windows by direct solar penetration is considerable. Construction No.1 has a 36% reduction in loads, while the rest of the cases have reductions of 33.9%, 33%, and 32.4% in ascending order. (Figure 2.19)

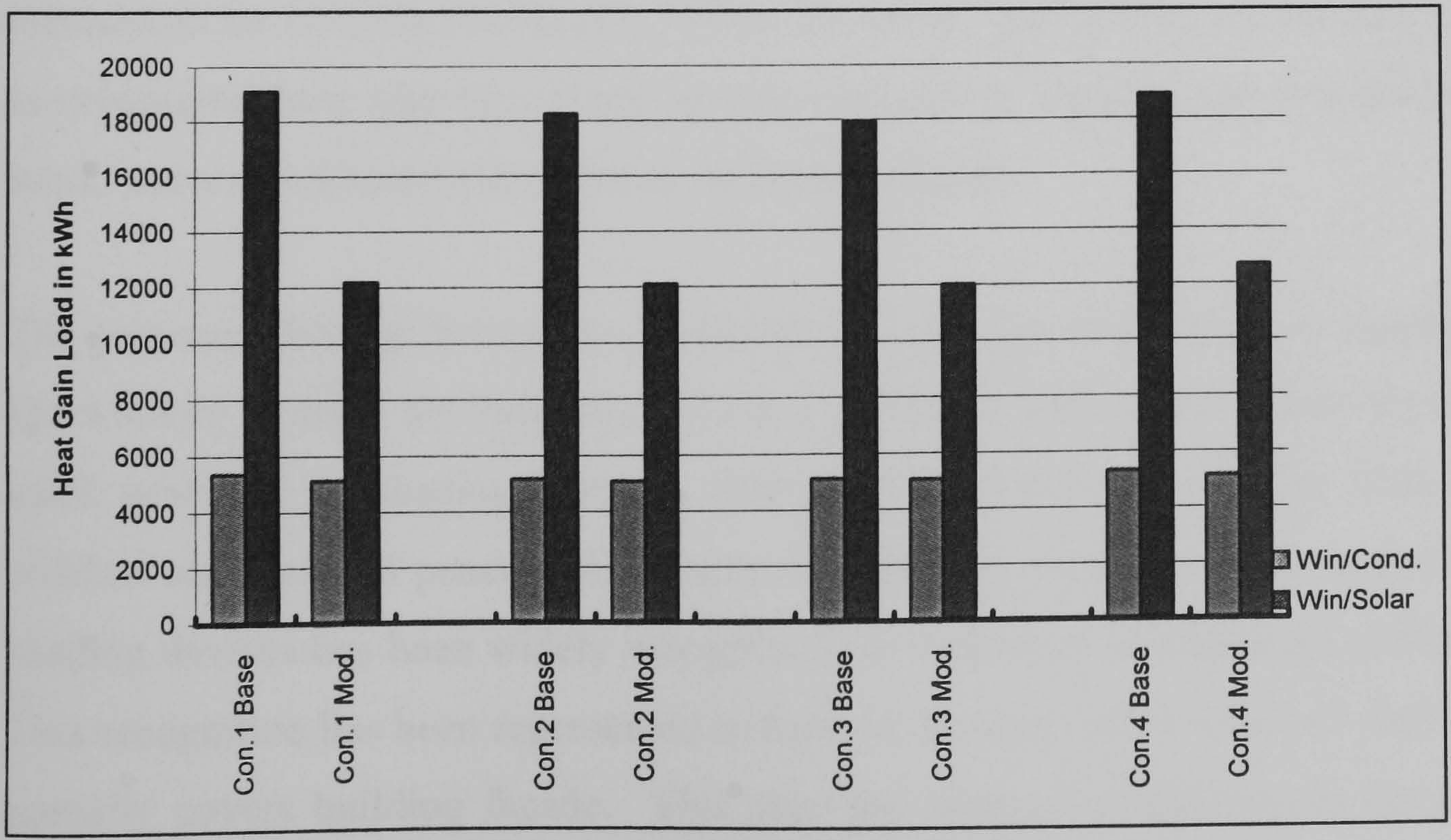


Figure 9. 19: The Potential Effect of Shading Device on Heat Gain Load

Heat transmission via conduction depends mainly on glazing type and glazing properties. Heat flow easily through glass as a transparent surface with high heat transmission coefficient. The rate of the heat flow is almost the same even through several layers of contacted glass. Therefore, the difference in heat gain load between the base cases and the modified cases (cases occupied with shading device) through window by means of conduction is negligible. Thermal benefits via glazing surfaces can be improved by introducing air space among multiple glazing layers. Air space between the layers interrupts the path of heat flow by conduction and significantly reduced the rate of heat gain.

Different types of glasses can enhance the performance of the glazing surfaces as well. Among these types are glass with high thermal performance, e.g. heat-absorbing glass and reflective glass. These types have a great advantage over the traditional single glass sheet, especially if they fitted as double or treble layers. In most developing countries, the application of these types of lass system is common in building construction industry. In contrary, single glass sheet is still the most popular type in local construction despite the availability of the other advanced systems. The shortage in using these systems can be attributed to their high prices and to unavailability of adequate information about these systems.

Thermal performance of the advance glazing system is more efficient in reducing heat conduction by 10-12% (Al-Naimi, 1989). However, it is not the aim of this research to investigate these glazing systems as they only can be found in very limited building stock that not included in the current case study subject.

The proposed shading device has a substantial impact on solar radiation impinging on the window to enter the building. Glazing surface is held under a constant shading mask provided by shading device. This mask prevents the radiation from hitting window surfaces and penetrates instantly to indoor environment. The importance of shading devices has been widely recognized and employed in traditional architecture. This recognition has been represented in form of wooden lattice windows that fully or partially covers building façade. This case has changed completely in the existing building where no consideration has been given to this factor.

Technical and economical merits of applying shading device are visible and encouraging and make such energy conservation measure, as a retrofit solution, practically acceptable. The device can made as a pre-fabricated attachment to the original walls and can be made of lightweight, strong and flexible materials. Moreover, it can be designed to give an optimum utilization for useful sunlight in colder period of the year.

9.5 Summary of Remarks

Exploring the complex interaction and overlapping process of different building components that resulted in shaping its thermal identity is a difficult task to perform. The field survey has revealed some of the information needed but definitely this information is not sufficiently informative alone and has to be integrated with more in-depth analysis in order to see the whole picture. Simulation has been considered as one of the important research tools for getting more elaborate information about physical and behaviour attributes of building components as well as of the building occupants.

The nature of the research topic dealing with existing buildings means that only practical solutions can be supplied. Unlike the situation in the new projects that may demand and accept wide range of assumptions and solutions, the situation with the existing buildings is restricted to what could be practical, applicable, and acceptable within the actual context of problem. Therefore, the simulation assumptions in this part of the research were straightforward and take into the consideration the limitation of the solutions offered in reality. With this reason in mind, the simulation process put into the tests only the common construction materials together with practical design parameters that accept simple solution approaches. Trying to investigate multiple construction configurations that could never be applied in reality has been completely avoided and attention has been focused on what has been gathered form the fieldwork survey. Apartments have been dealt with in comprehensive way as integrated units and their performances as a whole reflect their identity and characteristics.

Simulation results, in general, came out in compatibility with the measurement survey and with information provided by social survey. The four construction materials found commonly in the existing situation, hollow clay block (Con. No.1), hollow cement block (Con. No.2), solid cement brick (Con. No.3), and red fire clay brick (Con. No.4), perform slightly different from each other. The difference is not essential to make a distinguish change in the indoor thermal environment and does not influence energy consumption rate greatly. This finding revealed that the performance of the basic construction materials is associated with the air conditioning system in such away that, under the same operational schedule, the difference in thermal performance for these materials is diminished. This difference could be substantial if no mechanical cooling has been involved where in this condition the basic properties of these materials prevailed. However, the little difference among the constructions types is in favour of low density and the low U-value construction.

Indoor temperature profile is governed with the thermostat setting of the air conditioning units and the frequency of operation. The lower temperature profile normally can be found in zones with high A/C operational schedule, i.e. the bed zone and the living zone. While in a zone where the A/Cs operational hours are limited, the temperature profile goes to its maximum after the A/C has been turned off, i.e. the kitchen zone and the guest zone. The comfort zone is maintained within the thermostat setting of 22°C to 26°C and as long as the air conditioning system is on. The important factor to be considered in the actual condition is that these kinds of settings are very rare utilised and improperly used.

Occupants usually turn their thermostat to the lowest point, which means the A/Cs units are kept in continuous operation for longer periods before they can cope with this level of temperature. The thermal properties of building construction are so poor that the indoor temperature starts to elevate quickly once the A/Cs have been turned off.

In terms of vertical location, the middle floor is very well protected and hence it has a lower heat transmission, this is followed by the ground floor, while the upper floor can be expected to have a tendency to receive more heat from both sides, the walls, and the roofs.

The simulation findings have tried to limit the influential building components and to quantify their thermal contribution as a part of the identification process to the most problematic heat access. It has been inferred that the major heat accesses that heavily contribute in heat gain process are: casual gain with a contribution of 33%; wall fabric that can contribute up to 30%, and windows with 25% from the total heat gain loads. The rest of the percentages are distributed between window conduction and infiltration with small ratios. Figure 9.20 summarizes the impact of the modifications on thermal performance of all construction types and a detailed improvement for Construction no.1 is shown in Figure 9.21.

The most applicable strategies which are thought to be of more benefit to the thermal performance of these building components have been investigated thoroughly. These strategies are limited to three major techniques, which are: upgrading building envelope by insulation materials, reducing solar impact on windows by shading devices, and the third technique is concerned with controlling internal casual loads by occupant behaviour. These techniques have a promising potentiality both in reducing the amount of heat gains and in reducing the system-cooling load and hence energy consumption.

In spite of these high return percentages, the implementation for these techniques has not been visible yet in the actual context for many social, economical, and administrative obstacles. Above all is the absence of real motives whither it is self-motivation or outside compelling motives. What has been also concluded is that improvement in building fabric can contribute to saving energy. Nevertheless, this contribution might be meaningless if it associated with irrational energy behaviour. The driving force for energy conservation is the quality of energy use, the more the use is the more the consumption there is and the more damage to the conservation concept occurs.

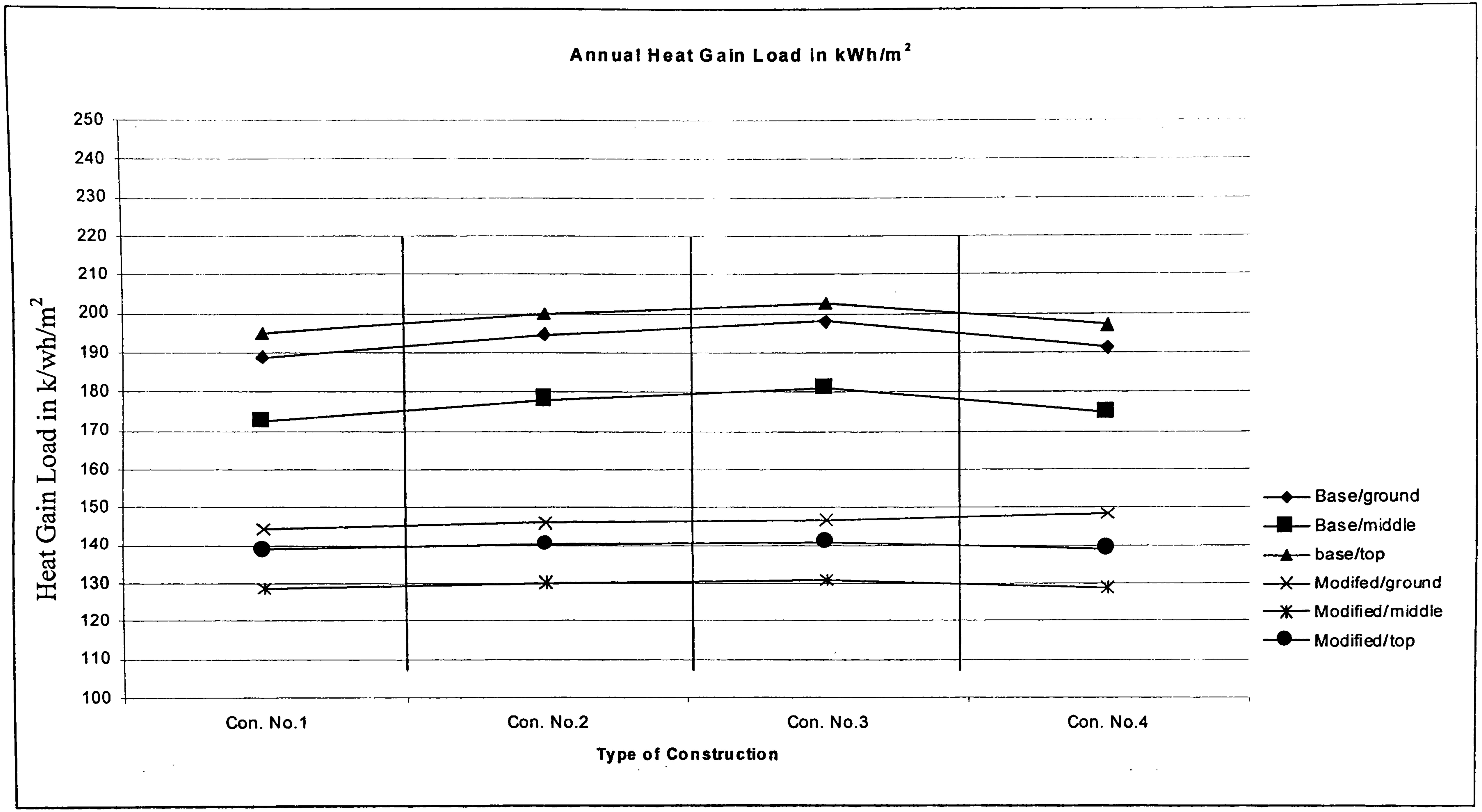
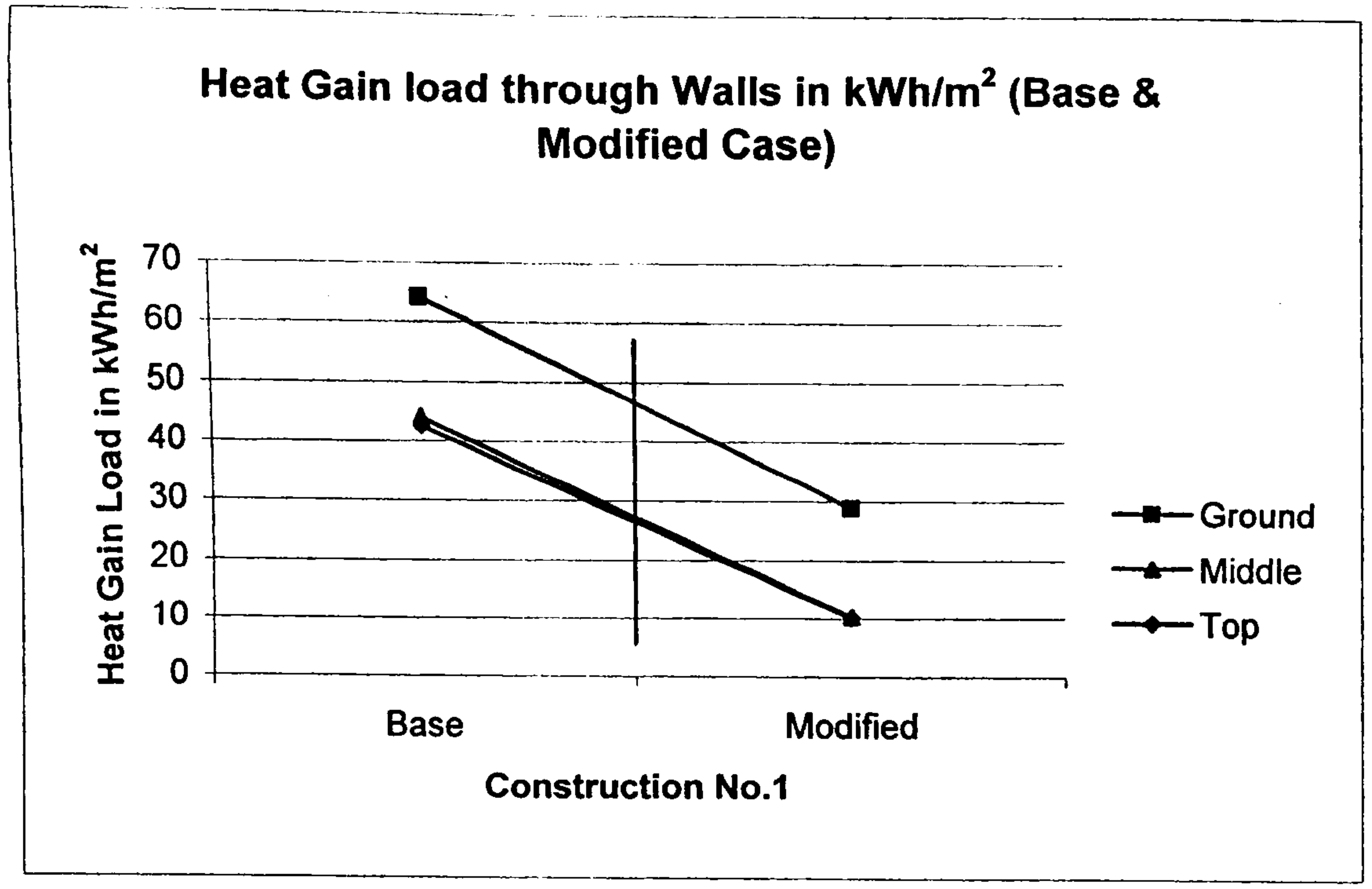
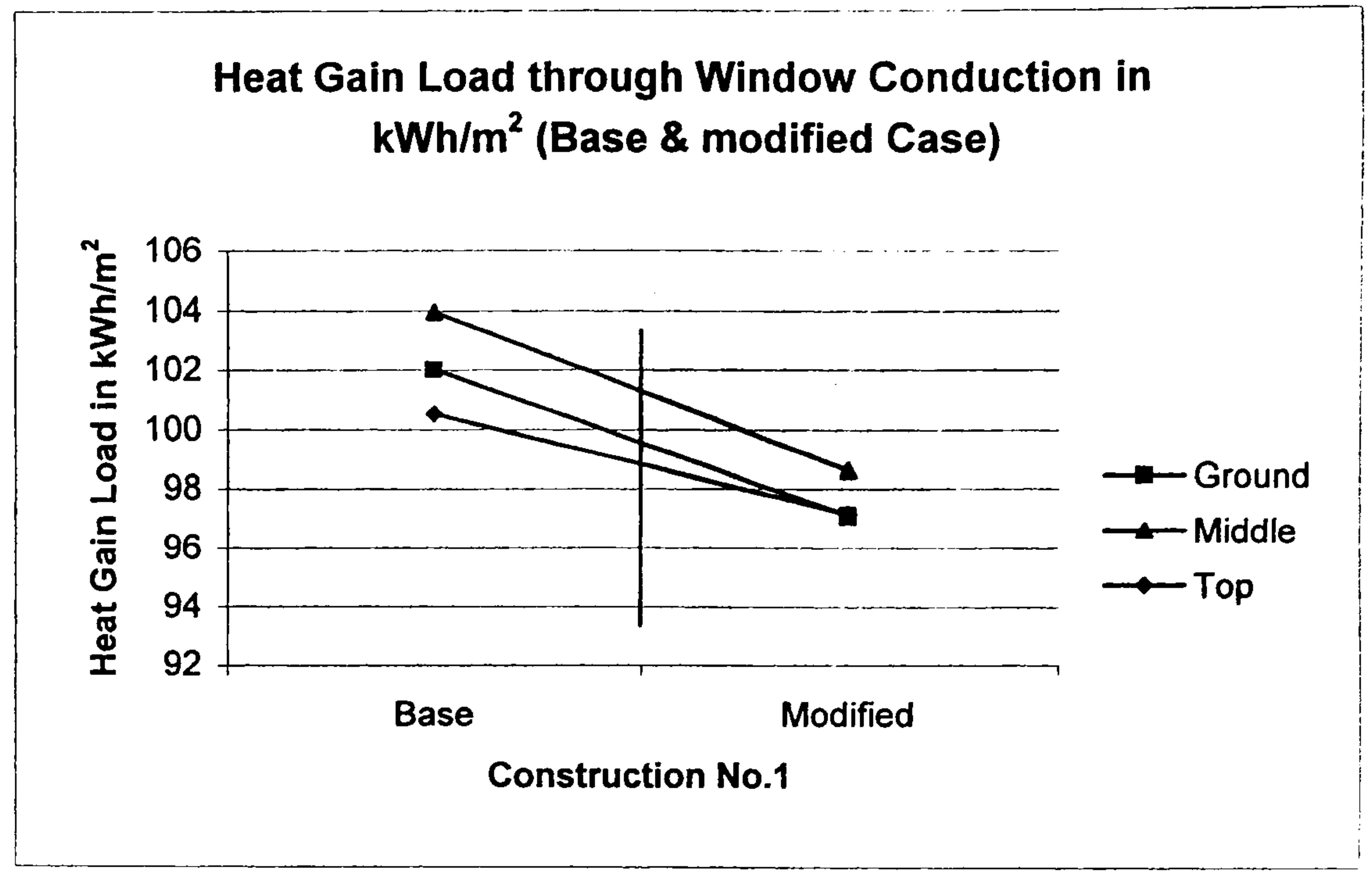


Figure: 9.20:
Annual Heat Gain Load in kWh/m2 for the Base Cases and the Modified Cases in all Apartments Levels





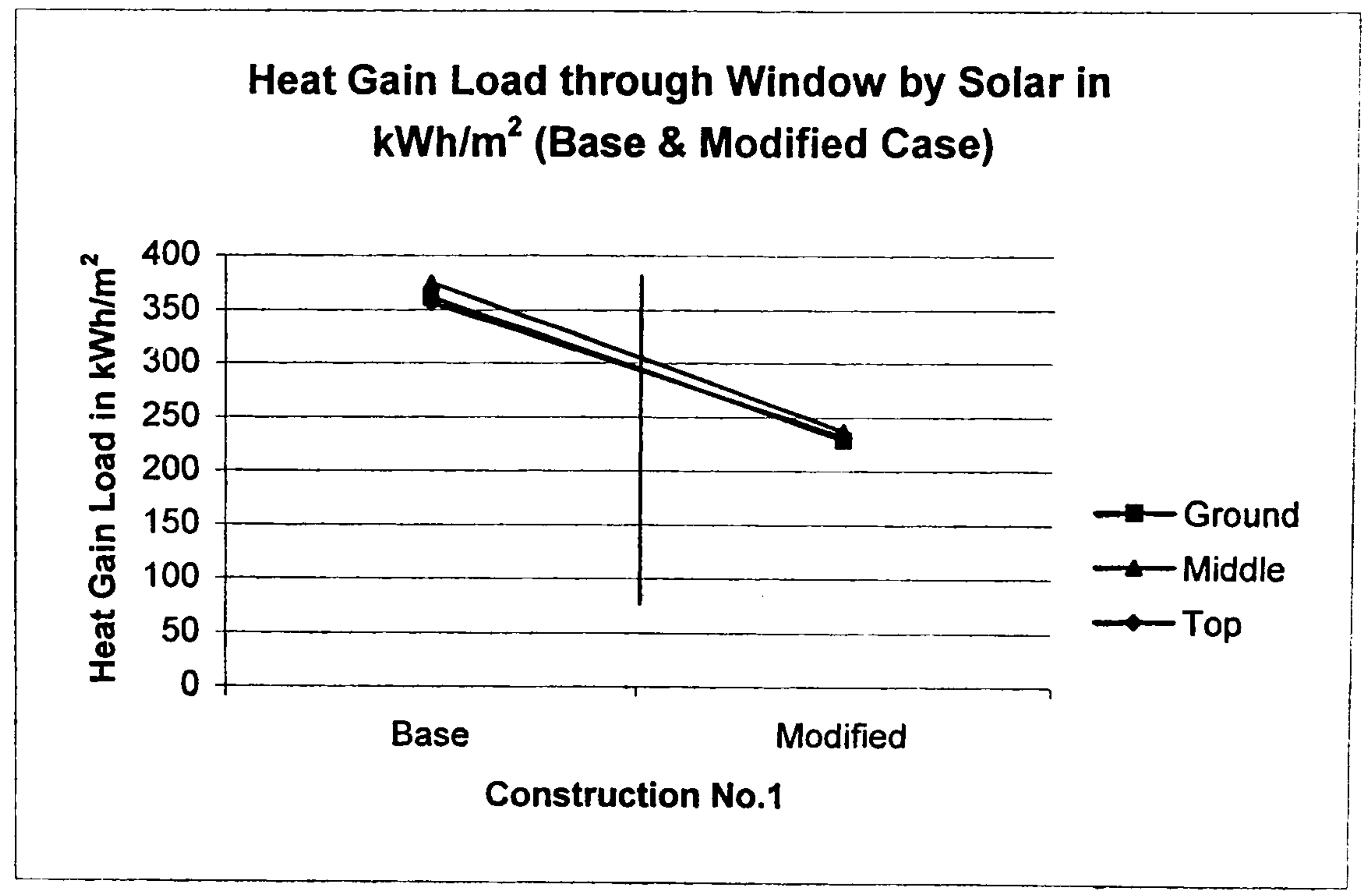


Figure 9.21:
Graphs shows the difference heat gain loads between the base case and the modified case (Construction no.1) through walls, windows by conduction, and windows by solar radiation

Chapter 10

Energy Saving Measures

Chapter 10

ENERGY SAVING MEASURES

The Practicality and the Effectiveness of Application

10.1 Introduction

'Energy saving measures' is a term use to refer to any techniques that could reduce energy consumption by any amount without sacrificing the health and comfort of the public. They vary in concept, application, and potential results. However, the key factors in applying certain types of these measurements relate to the ultimate goals of conservation plans, the different types of function of the buildings, and the building condition (design stage, under construction, or existing).

This study is focused on the existing building situation. Therefore, any saving measures investigated in this context should be practical, applicable, and versatile. The task of managing improvements in the thermal situation of existing buildings is very difficult for many reasons, primarily the reality of the location as a living object that contains people and their daily activities. Cultural values impose many restrictions in front of any active research dealing with indoor living environment. This is a very strong barrier which considerably reduce the amount of information and hinder the attempts to explore the energy behaviour within the families. Moreover, privacy for local families is a holy word that never allowed to be invading by any means not even to the sake of improvement. This is why there is not much knowledge around about what is going on inside the families with regards to many different issues in general and energy issue in particular.

However, the two conservation measures under consideration in this study, insulation and shading device, have taken into account the obstacles that mentioned above. For these two measures, they are both externally applicable and the opportunity to make use of them in existing building situation. No disturbance and no invasion to family's' privacy can be caused as all work can be done externally.

The efficiency of energy saving measures can be considered under their physical, economical, and social effectiveness. Successful approaches frequently combine these three factors in their final results. In realistic terms it is economy that has always been the driving force behind energy conservation from the national scale to the small scale of individual family. At family level the potential benefits that may result from the application of any conservation plans can be discussed under two major themes: firstly the occupants' thermal comfort inside the building, and secondly the direct economic saving as a result of decreasing energy consumption.

The analysis in Chapter 9, the improvements gained in the thermal performance of building components when applying specific energy saving measures, i.e. insulation material and shading devices, has shown very positive results. These results, have significant reduction on heat gain load, may make their contribution to the first concern (human comfort). However, there are no indications that this contribution can create, alone, a comfortable indoor temperature nor that a comfortable indoor temperature can be achieved without air conditioning. Therefore, the second theme - direct economical saving - is vital in the evaluation process of the energy conservation strategies related to the thermal comfort of the occupants of a building.

Domestic energy consumption is comprehensive and combined direct electricity consumption resulted from the operation of electrical appliances and lightning system and the indirect consumption resulted from the operation of the A/Cs. The former source is independent of the surrounding factors such as climate and human activities, hence it can be calculated for each appliance with relation to its operation schedule. Cooling load that directed the latter source is dependent on multi-variable sources inside the dwelling unit (include the electrical appliances).

The prediction of this load is very difficult to determine as it combines the effects of many sources such as climate factors, building fabrics, occupants, and appliances. Therefore, the simulation results in this chapter concerned only with the prediction of energy consumption resulted from the cooling loads required to offset all heat gains sources.

A discussion of how the proposed strategies might affect system loads, energy consumption, and economic benefits for all the parties involved in this context (building occupants, building owners, and the government) now follows.

10.2 Potential Effect of the Proposed Modification on System Load

The mechanical cooling systems simulated in this study are single window type units, as described in Chapter 8, and they simulate the systems in use in actual situations. These units perform individually as they assigned to serve only one functional zone.

Energy consumption by these air conditioning units (A/Cs) in one apartment is a product of the sum of each A/C's operational schedule under same preset thermostat setting and the same environmental condition. The cooling (system) load for each apartment has been generated after the implementation of the insulation materials and the shading device strategies to the base case.

The potential for saving is promising for both strategies as demonstrate considerable reduction in the cooling load from the original construction of the base case. The effect of these strategies can be studied individually as follows:

10.2.1 The Effect of Thermal Insulation on Cooling Load

Building envelope resist heat transfer phenomena by the thermal properties of its construction materials, i.e. quality of resistance, capacitance, and absorption. Modern constructional materials depends more on the thermal resistance property in producing the desired exclusion of the outer climatic factors meanwhile the capacitance property of the materials is more concerned in the traditional buildings.

Heat capacity of any building material is the ability of this material to store heat in its mass before transmission to either side can be occurred. The ratio between the heat absorbed and that stored in the materials depends on mainly on the heat capacity of the envelope, i.e. on the product of its weight (density and thickness) and specific heat. Thus, under periodic variations in outdoor conditions and with given conditions of temperature differences and thermal resistance, heat flow into a building decreases as the heat capacity of its structure increases. Heat capacity moderates the rates of heat flow in and out of the building interior, and hence the indoor temperature fluctuations. In addition, it causes a delay in the timing of the heating and cooling periods of the temperature and heat flow cycle (time lag effect). Heat capacity is almost entirely regulated by the weight of the structure. Any increase in heat capacity achieved by higher density is accompanied by an increase in thermal conductivity, thus reducing the thermal resistance (the case of most of the existing constructions). When the wall thickness is increased to raise the heat capacity, the over all thermal resistance increases also almost proportionally which leads to the traditional architecture used in hot arid climate.

The use of insulation materials along with the mass property may significantly affect the thermal performance and enhance the over all resistance. Insulation materials compliment the heat transfer cycle that produced by the effect of mass property. It further dampens the amplitude of the peak heat flow and act together with dampens and shifts the time of the peak that produced by the mass. The placement of heavyweight, i.e. conventional structure, with lighter materials of higher thermal resistance, i.e. insulation materials, with no change in thickness only reduces the heat capacity and is therefore only moderately effective in improving the thermal condition.

Modern constructions are more responsive to climatic changes. They heat up and cool down rapidly which make them poor barrier to the daily heat transmission cycle. This is the case in most of existing apartment buildings where outdoor climatic factors take no time to reach the indoor environment and effect space cooling demands. With these types of constructions heating and cooling requirements are proportional to the weather factors. Thermal insulation material is a material used to retard the flow of heat and regulate the harsh transfer of heat more smoothly. The benefits of applying thermal insulation materials to building construction is based theoretically on three fundamentals, which can be related to the thermal properties of these materials. These fundamentals are:

1. The material's potential to reduce the energy consumption required for cooling/heating demands inside the building.
2. Its potential to improve the indoor thermal quality.
3. Its potential to protect other building materials from excessive heat or cold.

The physical effectiveness of thermal insulation on the heat gain load of different constructions has been discussed and acknowledged earlier in Chapter 8, and their simulation results show the substantial influence that such material has on heat gain load. The reduction of energy consumption is usually the primary objective behind the use of thermal insulation and the economic saving hoped for has always been the ultimate motive. Insulation use will normally reduce the amount of heat gain load and hence reduce the size and operation period of the mechanical/electrical systems. The construction materials market in the Kingdom of Saudi Arabia is rich in all types of insulation whether domestically manufactured or imported. However, this availability has not meant an increase in the use of these materials in building construction except in recent years when they have become essential for obtaining building permits.

Most of the building stock built before 1990 exhibits capacitive insulation resulting from the massive properties of the basic construction materials rather than resistive insulation provided by light insulation materials. This capacitive insulation is usually a by-product of the selection of building materials that mainly serve as structural materials. In traditional architecture the massive load-bearing walls in conjunction with the property of the basic building materials, e.g. mud and stone, create a thermal barrier that can hardly be breached, and this is an excellent example of capacitive insulation in traditional construction. However, capacitive insulation associated with more modern building materials and designs do not come up to this level and indeed acts inadequately in the face of its heat flow. The resistive insulation produced by insulation materials usually is very light and does not serve any structural function. It added to a basic form of construction and helps greatly in enhancing the U-value for this construction without adding too much load and thickness.

The performance of the building envelope combining these materials on the system load has been simulated in order to recognise the potential saving behind them. The comparison of the annual total system load between the base cases and the modified cases is shown in Table 10.1 and charted in Figure 10.1. Cases have been treated in this comparison as an individual unit despite the internal multitude of apartments that every case contains.

	Con. No.1	Con. No.2	Con. No.3	Con. No.4
Base Case	52342 kWh	51621 kWh	51463 kWh	52236 kWh
Modified Case	41996 kWh	41778 kWh	41713 kWh	42318 kWh
Reduction %	19.8 %	19.1 %	18.9 %	19 %

Table 10.1: Potential Effect of Insulation Materials on System Load

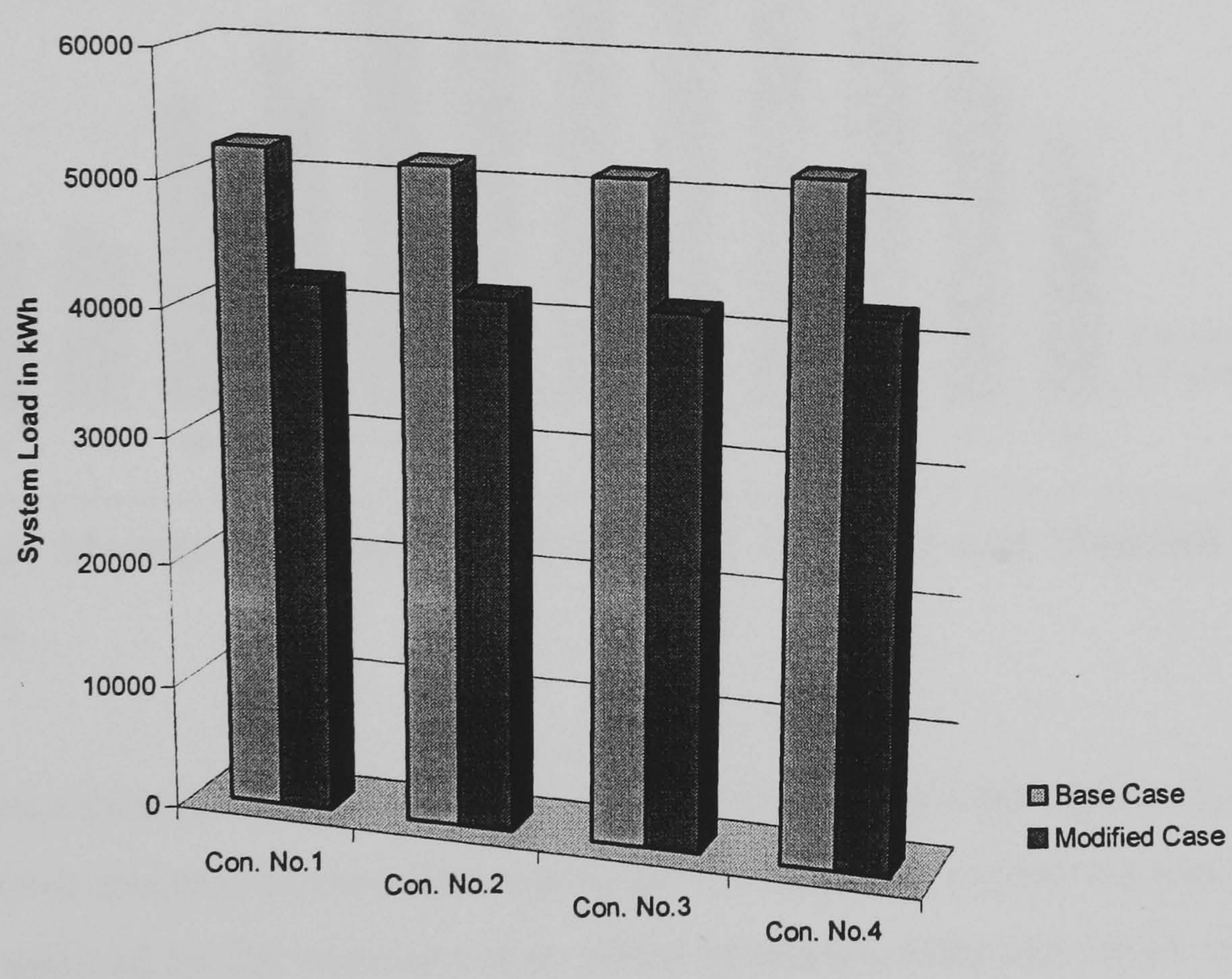


Figure 10.1: Potential Effect of Insulation Materials on System Load

The order of construction types, in terms of the amount of energy consumed by each construction in the modified cases for cooling purpose, is the same order as seen in the base cases. The high-density construction (Construction No.3) has the lowest consumption of 41713 kWh, followed by construction No.2 (41778 kWh), then construction No.1 (41996 kWh) and, last, construction No.4 (42318 kWh). The difference between the maximum cooling load (42318 kWh) exhibited by Construction No.4 and the minimum (41713 kWh) shown by Construction No.3 is only 605 kWh. This relatively small difference demonstrates the merit of applying insulation materials to the high-density construction (Construction No.3) above the other constructions. Monthly consumption profile, for base case and modified case, for typical apartment (Con. No.1) is shown in Figure 10.2.

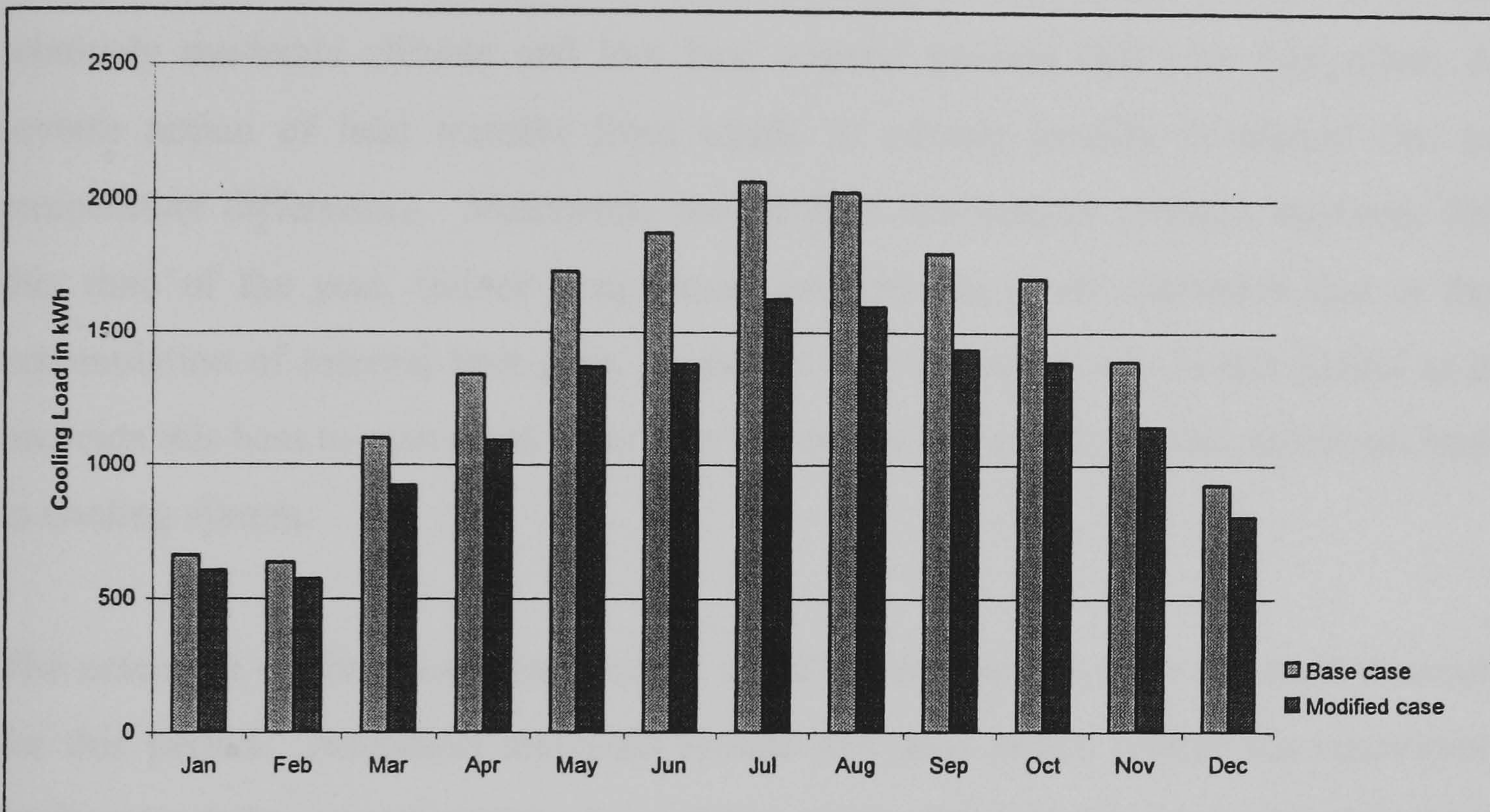


Figure 10.2: Monthly Consumption Profile for the Base and Modified Cases (Con. No.1).

As can be seen from the above figure that the reduction in the consumption in the hot period (summer months) is more than during the cooler period (winter months). This might be explained by the reserve action of the insulation materials which trapping internal heat and prevented the outward losses of this heat.

The strategy of applying insulation material to an existing façades enhanced the thermal performance of these façades mostly all over the year. However, the behaviour for this measure is relatively different with seasonal changes, i.e. summer and winter.

In summer where the outside temperature is high and the solar radiation at its maximum level, external insulation seems to be more effective in reducing the amount of heat transfer through the external wall hence reducing the cooling load. The reduction in energy consumption for cooling which resulted from applying insulation is clearly shown during summer months as insulation moderates the amount of external climatic impact on the internal environment (Figure 10.2).

In winter, slight difference in energy consumption between the base case and modify one can be noticed. Energy required for cooling in this period is less due to the relatively moderate climate and low heat transfer process that may take place. A reverse action of heat transfer from inside to outside usually developed due to temperature differences. Meanwhile the outdoor temperature remains moderate for this time of the year, indoor temperature continue its usual escalation due to the accumulation of internal heat gain. Insulation may act negatively in this period as it prevents this heat to pass on to other side the matter that still represent additional load to cooling system.

The extensive cooling loads in summer usually take place to meet the peak demand for this period. Insulation materials reduce this peak hence reduce the equivalent cooling loads by a good margin. In contrary, winter has no peak demand imposed by climatic condition during this time therefore cooling load for this period is low and usually required to offset heat accumulation from the internal gain. Insulation has a limited contribution, as can be seen from the small differences between the cooling load in the base case and the modified case in this period (Figure 10.2). An increase in the level of ventilation would be necessary to over come this disadvantage of insulation in this period.

However, with regards to Makkah climate, the relatively cold period is short and the advantageous resulted from applying insulation, therefore, is predominant for most of the year.

It should be noted here that the above comparison is for the over all performance of the different constructions and consider, once again, each construction type as a complete apartment building (apartment building contain three apartments, one apartment for each floor level). Cooling load profile for these constructions are almost similar, as illustrated above, and this similarity can be seen among the base cases as well as among the modified cases. Annual average of energy consumption for cooling demand among the base cases is 51915.5 kWh (sum of cooling load for all base cases / 4). Therefore, the monthly average energy consumption for cooling demand is **1442 kWh** (annual average / 3 apartments per case / 12months) for the apartment in the base cases. This average is taken as Predicted Monthly Consumption Reference Value **(PMCRV)** for the base case.

In the modified case, the use of insulation has a potentiality to reduce energy consumption load by 19%, hence, energy consumption rate for the modified cases will be 1168 kWh. The monthly saving in terms of energy units is 274 kWh (19% of the predicted reference point of the base case).

The monthly saving in terms of energy units is 274 kWh (19%). This means that using 19% less energy in the indoor environment and can still be in the comfort zone as it is pre-set in the occupancy schedules. On the other hand, occupants can expand their indoor comfort over longer A/C operational hours with the same rate of consumption. The effect of insulation materials on cooling load for all cases with regard to all vertical levels is shown in Table 10.2 with reference to the cooling load occurring in the base cases.

	Ground Floor Cooling Load in kWh			Middle Floor Cooling Load in kWh			Top Floor Cooling Load in kWh		
	Base	Mod.	%	Base	Mod.	%	Base	Mod.	%
Con. No.1	17278	14053	18.7	17225	13816	19.8	17839	14127	20.1
Con. No.2	17078	14010	18	16943	13712	19	17600	14056	20.1
Con. No.3	17035	14000	17.8	16888	13684	19	17540	14029	20
Con. No.4	17254	14175	17.8	17184	13901	19.1	17798	14242	20

Table 10.2: Detailed Description of the Effect of Insulation Materials on Cooling Load in Different Cases.

In each individual apartment unit, insulation has achieved an annual reduction valued at 17% - 20% of the total cooling load in each apartment. The percentage of reduction is almost the same for all types of construction. The top floor benefits relatively more (by 2%) than other floors, followed by the middle floor, and the ground floor comes last.

The difference in terms of the amount of cooling load required by each construction is almost eliminated and the cooling load rate is levelled for all types. Adding insulation layers to the basic constructions enhances the U-values for these constructions and almost levels the basic differences in their thermal properties. This means, in other words, that insulation materials can improve thermal performance with regard to cooling loads in a common manner regardless of the basic types of construction involved, provided the occupancy and operational schedule settings remain the same.

10.2.2 The Effect of Shading Devices on Cooling Load

There is no doubt that windows represent a direct major heat path that substantially elevate the inside heat and hence increase the cooling load on the system if it is to level this heat. The most effective way to reduce this heat path appears simply to put these openings under continuous shade. In order to investigate this strategy, the effect of shading devices in reducing the cooling load has been simulated and assessed separately. The reduction gained by applying this strategy is depicted in Table 10.3 and charted in Figure 10.2. The annual cooling load for the base cases is compared with the modified cases (cases with shading devices) in this table and the difference of reduction in this load is calculated.

	Con. No.1	**Con. No.2**	**Con. No.3**	**Con. No.4**
Base Case	52342 kWh	51621 kWh	51463 kWh	52236 kWh
Modified Case	35282 kWh	36515 kWh	34369 kWh	36190 kWh
Reduction %	32.6 %	29.3 %	33.2 %	30.7 %

Table 10.3: The Potential Effect of Shading Devices on Cooling Load

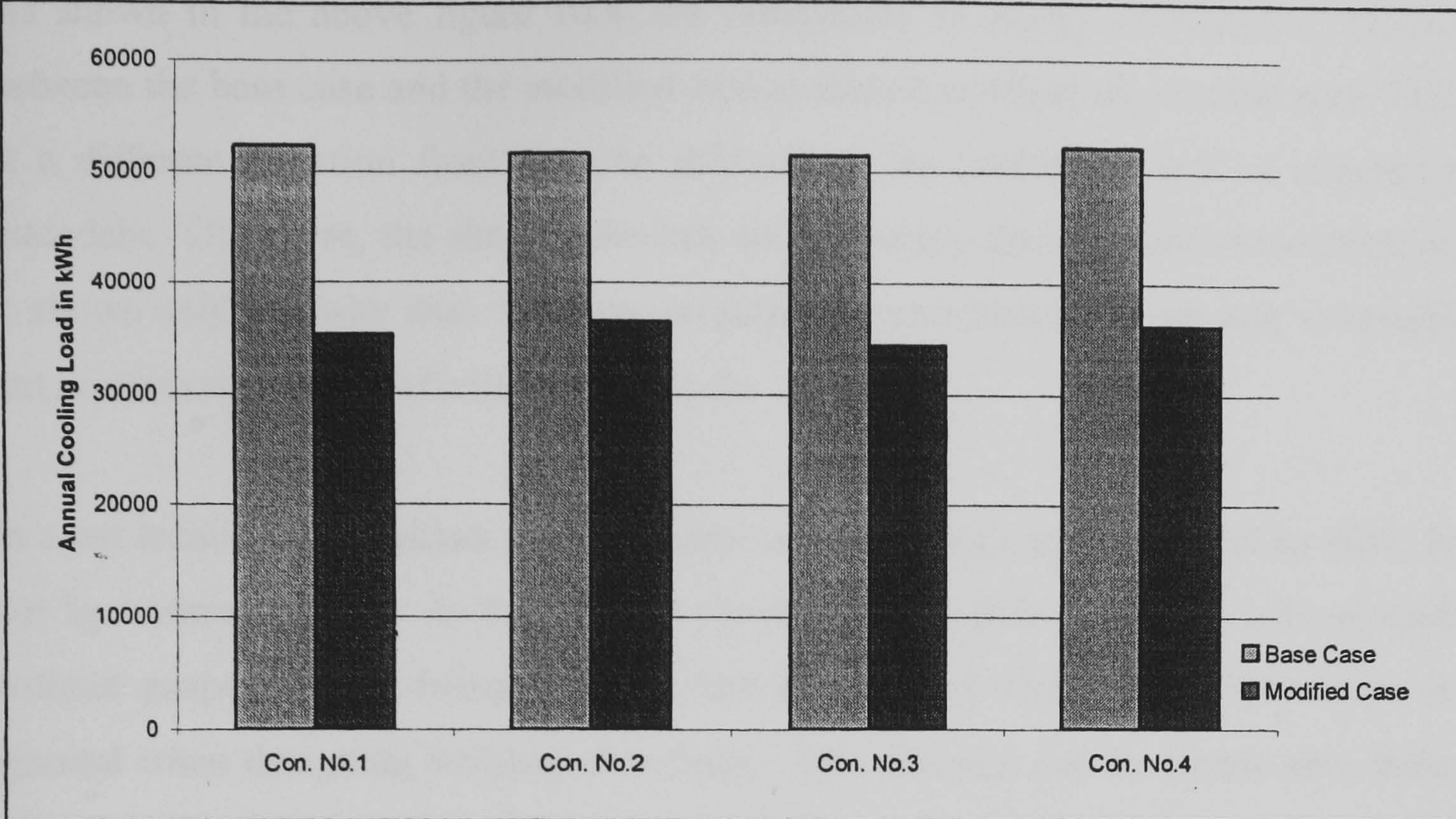


Figure 10.3: The Potential Effect of Shading Devices on Cooling Load

The protection over the apartment's openings can reduce the system load by 29% - 33% from the actual situation seen in the base cases. The monthly average energy consumption for cooling demand with the application of this energy saving measure is 989 kWh (average consumption for the four modified cases / 3 apartment per each case / 122 months) against 1442 kWh in the base case (31% reduction in average). Monthly consumption profile for typical apartment is shown in Figure 10.4.

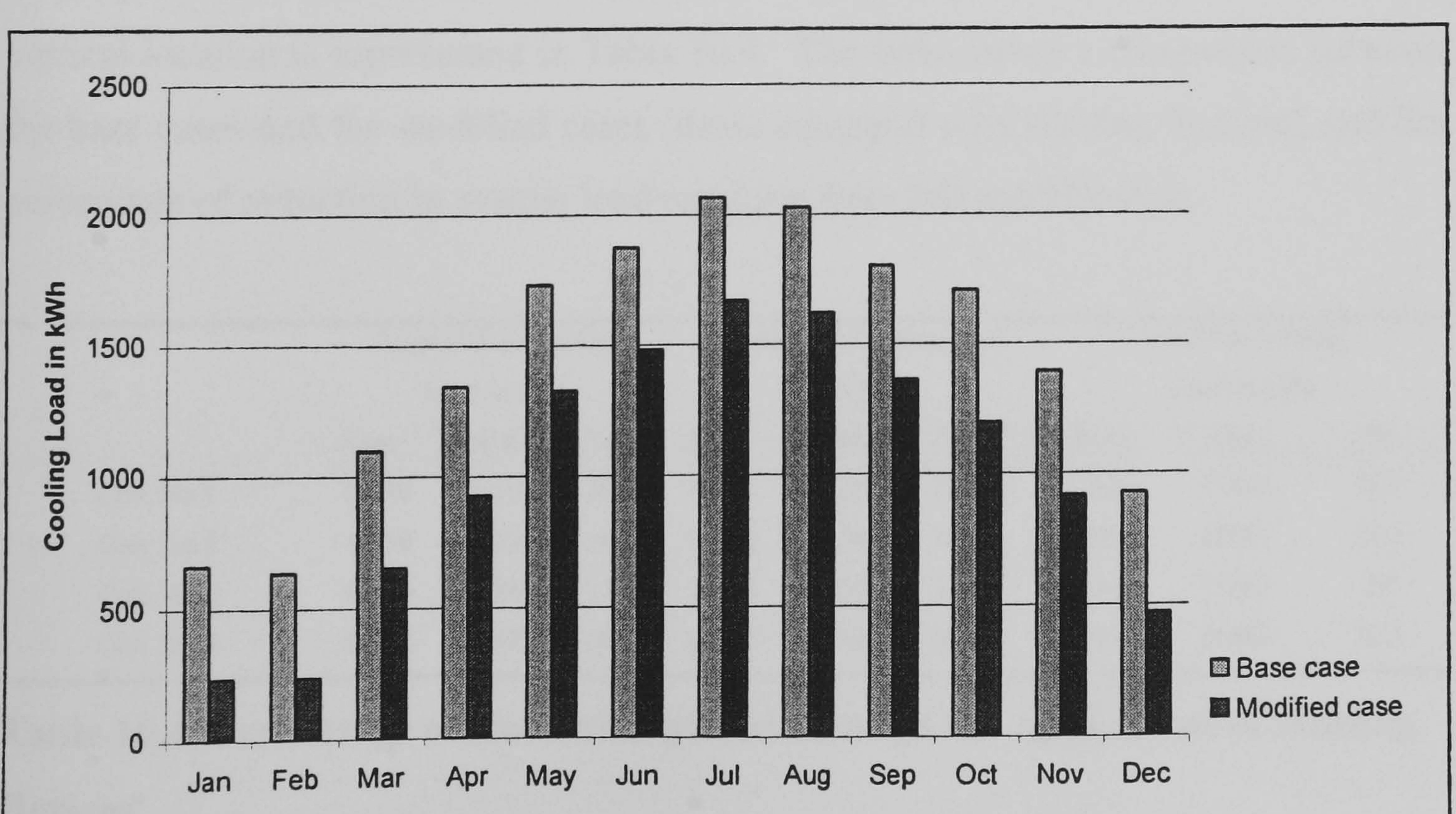


Figure 10.4: Monthly Consumption Profile for Construction no.1

As shown in the above figure 10.4, the differences in energy consumption pattern between the base case and the modified case is almost constant all over the year. This is a different situation from the one inferred by the potential effect of insulation materials. Of course, the shading devices act differently from insulation materials as it allows only one way heat transmission path (transmit heat from out side to inside) but no reverse action is allowed to this cycle.

In a hot locality like Makkah solar radiation is very strong and intense and its effect is not be underestimated. In the existing situation, many buildings have been erected without proper respect being given to this source, and often indeed this factor is ignored when designing building elevations. This problem can be clearly seen from plain building facades where windows represent exposed large openings inviting most of the solar to penetrate indoors.

Window curtains or internal shading, though they are very popular, cannot totally block the sun's radiation and once the radiation penetrates into the indoor space it is absorbed by surrounding objects (including curtain fabric) in the form of heat and reflected into indoor space as a radiant temperature.

A detailed assessment for each apartment of different construction and different vertical location is represented in Table 10.4. The table shows a comparison between the base cases and the modified cases (those equipped with shading devices), and the percentage of reduction in system load resulting from this modification.

	Ground Floor Cooling Load in kWh			Middle Floor Cooling Load in kWh			Top Floor Cooling Load in kWh		
	Base	Mod.	%	Base	Mod.	%	Base	Mod.	%
Con. No.1	17278	12104	29.9	17225	11353	30	17839	11825	33.7
Con. No.2	17078	12194	28.6	16943	12240	27.8	17600	12081	31.4
Con. No.3	17035	11435	32.9	16888	11541	31.7	17540	11393	35
Con. No.4	17254	11922	30.9	17184	12401	27.8	17798	11867	33.3

Table 10.4: Percentage of Reduction gained through the Application of Shading Devices

The average reduction in cooling load that the application of the shading device has achieved is 31%. The maximum reduction has been achieved by the top apartment floor in Construction No.3 (35%) and the minimum reduction has been achieved by the middle apartment floor in Constructions 2 and 4 (27.8%).

The effect of zone orientation with regard to the cooling load offset by shading devices follows this pattern: maximum reduction occurs in the north-west zone with 34%, followed by the north-east zone (30%), then the south-east zone with 28%, and last comes the south-west zone with cooling reduction of 26%.

These percentages are very effective and encouraging as energy saving measures especially when bearing in mind that the application of this strategy to the existing situation could be easy, non-destructive, and disturbance-free.

10.2.3 The Effect of the Casual Loads on Cooling Load

Applying energy saving measures as mentioned above is only a part of the solution, and indeed cannot form even a part of it if somehow they cannot be implemented in the existing situation. Another important aspect of the overall picture that should be closely assessed is the occupants' behaviour. Energy saving measures cannot be put into practice without appropriate response from occupants, and their behaviour in this respect can be controlled by elevating their awareness of the problem of excessive energy consumption.

Casual loads are greatly influenced by occupants' attitudes towards the usage of energy resources. These loads usually represent more than 30% of the heat gain loads that is transferred to system loads beside the energy that is consumed directly by domestic appliances as electricity.

In order to shed light on the importance of casual loads, which can steer conservation strategies towards more effectiveness, a new set of simulations has been undertaken for the same model, but without employing any schedule for casual loads, i.e. no lighting, no occupancy, and no equipment is involved.

In practice, this situation does not exist because it is unreal. However, this scenario has been proposed to show how crucial this factor might be for energy consumption. Table 10.5 shows total system loads for the base cases as well as the cases after the new configuration (no casual gains have been considered).

	Con. No.1	Con. No.2	Con. No.3	Con. No.4
Base Case	52342 kWh	51621 kWh	51463 kWh	52236 kWh
Base Case (no casual loads)	35029 kWh	35418 kWh	35535 kWh	35172 kWh
Reduction %	33%	31.4%	31%	32.7%

Table 10. 5: The Effect of Casual Gains on System Load for the Base Case Apartments.

The comparison has been made here with the base cases only in order to see the effect of the casual gain on cooling load without any other modifications. The reduction in cooling load is remarkable in these cases and it will be massive if it is combined with other energy saving strategies. 33% saving represent the extreme situation where casual gains set to zero but saving can be achieved, practically, in variable percentages within this ultimate limit if a proper energy utilisation and management has been adopted. However, this matter is completely dependent on occupant's behaviour and their way of living and their economy standard as well.

10.3 Economical Considerations

With these three influencing factors in mind, the potential to save energy as a reduction in cooling load and as direct electrical consumption is inevitable if they have been considered, whether individually or together, in the conservation scheme. However, there is still a great deal of uncertainty behind the implementation tools and the embodiment policies of these measures, especially in relation to the existing apartment building stock, still a very considerable number of structures. Also playing a part in the situation are the comparatively small group of building owners and the comparatively large group of tenants. It is a matter of uncertainty which of these two groups, if at all, will take the initiative in the implementation of measure in connection with the thermal rehabilitation of the existing buildings.

Building owners will not be motivated by this idea unless they know how it will be paid back to them and tenants usually have neither the financial means nor the actual interest and time to think about this subject. Authority has also abandoned legislation and policies in relation to the building code, which thus has no effective capacity to enforce any plans with regard to the existing building situation.

Most research studies tackle the subject of thermal performance in buildings from a technical point of view and demonstrate their results with regard to the potential benefits of energy saving strategies in the same way. Although this approach is right for the professional people it cannot relate directly to people with ordinary levels of knowledge and simple interests. Results need to be expressed in language that relates more to daily life in order to be more vivid and convincing. The advantages of the energy saving strategies mentioned above have to be converted to more tangible rewards, for any one of the parties who have been mentioned, which can be seen in the light of their cost effectiveness.

Among many techniques for economic analysis, the two common methods to determine the cost effectiveness of alternative design solutions are life-cycle cost/benefit analysis and simple payback analysis.

The life-cycle cost/benefit analysis provides an economic assessment of competing design alternatives over the economic life of each alternative. It is neither a decision-making process nor a set of economic guidelines. Rather, it is an analytical technique that can be used in the context of a decision-making process to generate economic guidelines. This method employs a set of economical functions in calculation and usually considers a long time-frame for the analysis, which makes forecasting uncertain in relation to the daily changing economy.

Furthermore, the life-cycle in the existing apartment building stock is difficult to determine due to its physical condition, construction quality, and maintenance. Therefore, considering life-cycle analysis here is impractical for a variety of reasons.

Payback analysis is used to determine the number of years in which the initial extra expenditures for different alternatives are paid back. Simple payback can be calculated as following:

Simple Payback Period = Initial Cost of Energy Saving Measure / Annual Savings

In order to demonstrate the economical effectiveness of the proposed strategies by using payback analysis, an annual saving profile has to be established for each construction in contrast with the common energy consumption profile in typical existing apartment buildings (assessed by the survey analysis). Also, some information about building construction prices, which include materials and labour, will be needed to address this analysis properly. Among the three strategies proposed for this study the first two concern materials and labour (insulation and shading devices) and the third concerns mainly indoor energy management and mechanical/electrical systems, i.e. type and size of A/Cs, lighting systems, and electrical appliances.

The process of modifying the existing situation is mainly concerned with the three parties involved: building occupants, building owners and the government bodies. These parties participate in building upgrading issue with different interest but they all share in the economical interest.

The role that each of these parties play in the context of the building modification is governed by the saving returns and the feasibility of applying the proposed saving measures on the practical ground without difficulties. Building occupants are mainly influenced in this issue, as any modification made in their buildings will be directly reflected on their short/long daily life and economical standard. Meanwhile, building owners have less impact on the issue, as they are not directly exposed to any stresses resulted from energy consumption. However, they still have a substantial role to play in improving the existing building situation if they considered as an active part within an integral national scheme. Occupants and owners are two connected partners who share in one physical element, i.e. the building, hence they see the upgrading issue from the same point of view. The third party (the government) has a completely different role in this context. The government party receives the economical consequences of the extravagant use of energy and has a good reason to act positively towards conservation plans. The potential saving, that might be resulted from applying energy saving measures to existing building, for these parties will be discussed next.

10.4 Saving Feasibility for Building Occupants and Building Owners

As mentioned above, these two parties involve together in determining to how far the implementation of the upgrading process can go, weather they should consider this modification or not, and who will take the major part in this subject. The tie that governed the relationship between these two parties is completely of an economical interest nature. Under the market laws, owners have places to let and tenants need these places to accommodate their daily life. The agreement between these two parties usually complies more to the owner in terms and conditions rather than tenant desires.

Tenants may have much to negotiate about the rental cost but they only have very little to say about the physical condition of the buildings. Therefore, whatever the thermal quality of the building was, tenants have nothing to do to improve the situation, even if they want to, except with the owners permission. Meanwhile, building owners can improve their buildings thermally and structurally if they persuade to do this and if they have a technical and financial support available. One scenario of making the action of improvement feasible for building owners is to get higher rentals from their tenants. But for the middle income group, there is a rental limit that they can not afford to go beyond (maximum 20000 SR/annum), therefore, any amount more than this limit will not be highly acceptable.

However, all parties need to know first some information about how building thermally perform in this context and what is the potentiality of saving that might be gained on short and long term. This part falls in the duty of the architects and the professionals, as they have to provide this information and make it available to the other parties for the ease of making the right decisions.

Saving return for building occupants and building owners with regards to the three basic strategies: applying insulation materials, applying shading devices, and controlling the consumption by management, is discussed next in more detail.

10.4.1 Potential Saving by Insulation Materials

The MCRV (2047 kWh) that concluded earlier in Chapter 7 for the existing apartment is valued by 2047 kWh /month.

This consumption rate falls into the first and lower electricity bracket charged at a rate of 0.05 SR/kWh of energy consumed. The monthly electrical bill, therefore, will be an amount of 102 SR. In this scenario where average energy consumption is considered, the amount of money paid for electricity is very reasonable for the consumers and may not represent any economic stress.

The government generously subsidises this service for the public, as the actual cost for the kWh without this subsidization goes as high as 0.17 SR and the average monthly bill will goes to 348 SR (3.4 times the subsidised bill). These figures shows the imperative need for energy conservation from the government point of view but they do not show the same need form the public point of view.

Table 10.6 sets out a comparison between the MCRV in existing apartments against the PMCRV concluded from the simulation for the four basic types of building materials under investigation. The MCRV (2047 kWh/month) includes energy consumed for cooling purposes as well as energy consumed as direct electrical current by other apartment systems. Many studies have concluded that about 70% (Al-

Rabghi, *etal*, 1999) of this consumed energy is devoted to air conditioning systems. Therefore, the reference rate for energy consumption by system will be 1433 kWh (70% of the MCRV (2047 kWh/month)).

	MCRV Survey	PMCRV Base Case 1	PMCRV Base Case 2	PMCRV Base Case 3	PMCRV Base Case 4
Monthly Energy Consumption	1433 kWh	1453 kWh	1434 kWh	1429 kWh	1451 kWh
Monthly Electricity Cost	72 SR	73 SR	72 SR	71 SR	73 SR

Table 10. 6: Average Monthly Energy Consumption (actual and predicted for base cases)

Referring to the above table (10.6), there is a very close agreement between the Monthly Consumption reference Value (MCRV) that has been established from the survey investigation (Chapter 7 & 8) and the Predicted Monthly Consumption Reference Value (PMCRV) inferred by simulation. The percentage of discrepancy between the two values is 0.7 %, which is very small difference. This agreement indicates the level of the accuracy for this simulation and also enhances all the simulation assumptions with regard to operation schedules and the proposed pattern of occupancy.

This level of accuracy is not uncommon in energy simulation programs but it is difficult to get such matched results. In this simulation, the close agreement might be attributed to the way of handling the model as one integrated unit rather than separated it in to detailed components. Also, adopting the use of averages, in the simulation results analysis and in the survey results analysis, reduces the discrepancies to its minimum. It also indicates that with this predicted amount of system load the indoor comfort zone is mostly achieved for different apartment zones by the pre-set thermostat setting and the A/C operational schedules. However, it also implies, on the other hand, that the indoor comfort has not been achieved if a large sized apartment relies on present thermostat and operational settings.

Installing insulation materials reduce the system load by 19%. The monthly average of electricity bill for the base cases is 72.25 SR and the annual average is 867 SR (£144.5). The application of insulation materials, therefore, would make this annual electricity charge go down to 702 SR (867 * 0.19) with total annual saving of 165 SR.

To calculate the payback period if insulation has been fitted, the initial cost of insulation materials has to be known. Insulation materials, as mentioned earlier, are various in their organic structure, form, size, performance, and cost.

The market is flooded by these materials of different manufacturing quality. True and concise information about the product is often unavailable and the price of these products is usually subjected to marketing laws. Usually imported insulation material has a higher price than that domestically produced.

Quality, installation workmanship, maintenance, packing, and technical advice service are other factors involved in cost determination for such products. But the common acceptable price for the type used in simulation analysis (polystyrene board) is around 30 SR/m^2.

This price has been quoted from personal interview with local building contractors and it is inclusive of the material cost and installation. This cost is lower than would be expected in the U.K. and Europe and this indicates, the tax free market, low wage rates and as polyurethane is a by-product of oil refining process, the material is inexpensive.

For the wall area of the simulation model (151 m^2) the initial cost for this simulation material will then be an amount of 4530 SR. Therefore, the payback period for this material will be over 27 years (4530 SR / 165 SR). This is a discouragingly long period from the occupants' point of view whose average living period in one apartment is between 5-8 years as it inferred from the survey analysis in chapter 6.

Annual potential saving in energy due to the installation of insulation materials is illustrated in Figure 10.5.

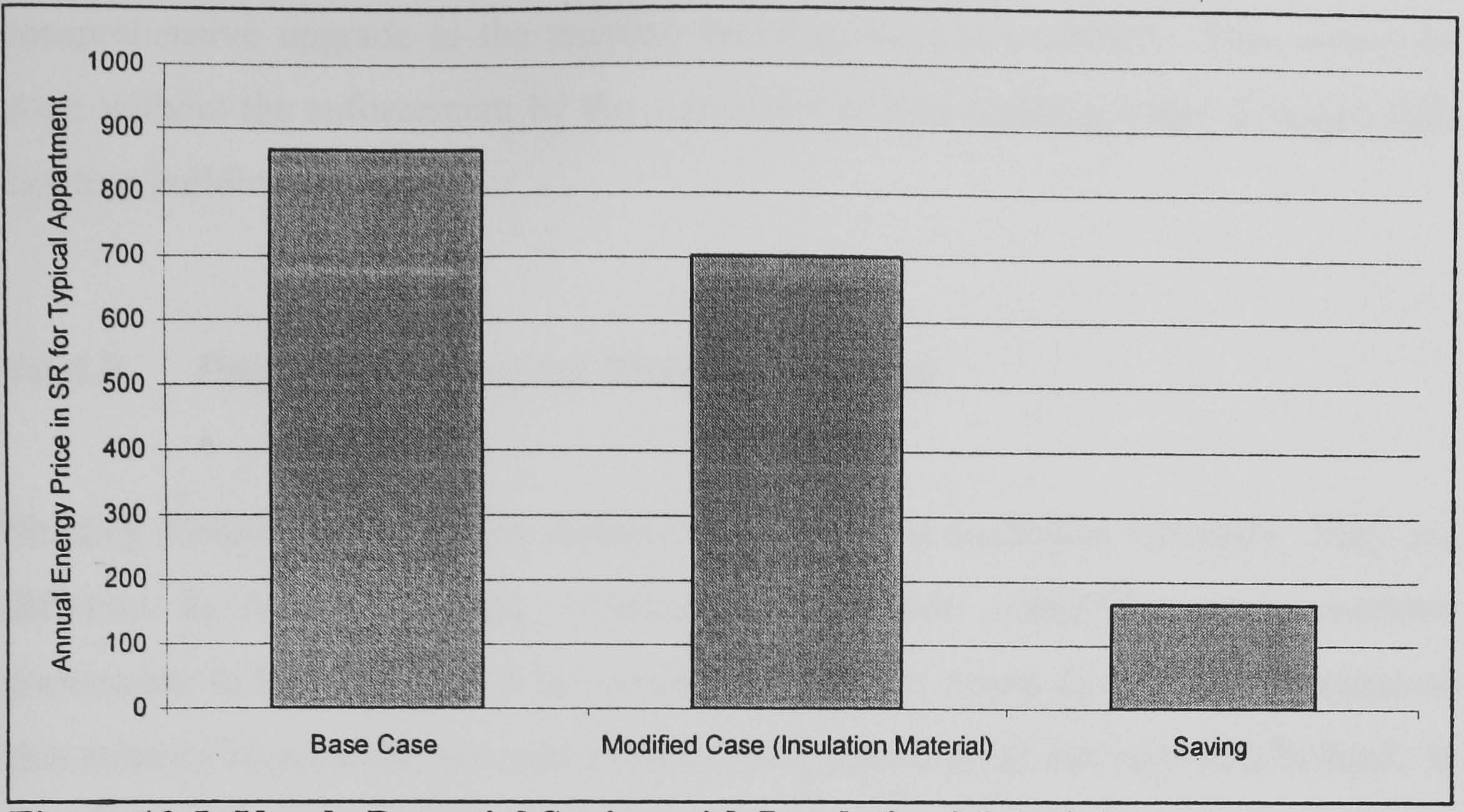


Figure 10.5: Yearly Potential Saving with Insulation Materials

This discussion has weakened the possibility of promoting the application of this strategy at least from the occupants' (the tenants') side for many reasons. Perhaps the most important reasons are:

1. The historically low energy cost policy that the government has adopted, as illustrated above, puts no economic strain on occupants' shoulders. With a very low monthly payment for electricity service, large energy consumption can be enjoyed and waste seems unimportant.
2. The long payback period, especially if we take into our consideration the tenancy nature of the occupants. and their tendency to change places from time to time (average living period is 5-8 years (see Chapter 6)).
3. The assumed building life-cycle may not permit such a long payback period to be achieved.

It is clear that the building users (the tenants in this research) have very little choice regarding this strategy. However, they can be self-motivated in relation to the energy conservation concept but through some other channels, e.g. rationalisation of their energy behaviour. The remaining bodies in the picture (the government authority and building owners) are more concerned with the effectiveness of this strategy on the long run. The potential saving on national economy will be massive if a comprehensive upgrade to the existing building stock is executed. This cannot be done without the enforcement by the authorities of new building codes designed with existing buildings in mind.

10.4.2 Potential Saving by Shading Devices

Shading devices form a totally different concept from insulation materials. They are different in concept, design, installation, and their availability as a common commodity in local market. It is extremely difficult to assess the cost effectiveness of this strategy because the physical sides of the application are not very well defined. It depends totally on the designer and the solution that he comes up with according to the nature of the building openings and orientations. In practice, it is very rare that building facades are modified. The role that this strategy plays in reducing the cooling load is very encouraging as the cut in energy consumption reaches up to 30%. Exterior shading devices take many forms such as:

1. Architectural projections both vertical and horizontal, or both, louvers projecting in front of a window and provide a shade for the glazing area. These projections are an essential part of the building elevation considered since early design stages and could be very effective in blocking direct and diffused solar radiation.
2. Sun screens, e.g. the "Mashrabia", found in traditional buildings considered, once again, as a part of the building envelope.
3. Exterior shutters which take a flexible form and have the merit of being portable and simple in action. They can be hinged on the top or to the side of windows and manually control the angle of the openings as desired.
4. Exterior roller blinds act as a blind on a roller at the head of the window and can be adjusted to present a completely opaque or semi-opaque sun barrier.

The simulation has been made with a proposed architectural projection frame around each window opening in very simple form. Such a configuration will be difficult to apply in existing situation unless it designed and made from light materials that can be fixed externally without causing destruction to the outer wall skin. The comparison of the effectiveness of this strategy on energy consumption with the reference rate is listed in Table 10.7.

	MCRV Survey	Predicted Alt. Case 1	Predicted Alt. Case 2	Predicted Alt. Case 3	Predicted Alt. Case 4
Monthly Energy Consumption	1433 kWh	980 kWh	1014 kWh	954 kWh	1005 kWh
Monthly Electricity Cost	72 SR	49 SR	51 SR	48 SR	50 SR

Table 10.7: The Effect of Shading Devices on Average Monthly Electricity Cost. (actual and predicted for the alternative improved cases).

Remarkable monthly saving in relation to the reference rate has been achieved. The average monthly electricity cost with the application of this strategy is 49.5 SR and the annual average energy consumption is 594 SR. The annual saving in energy price is 273 SR (annual average for the base case (867 SR) – annual average for the modified case (594 SR)). (Figure 10.6)

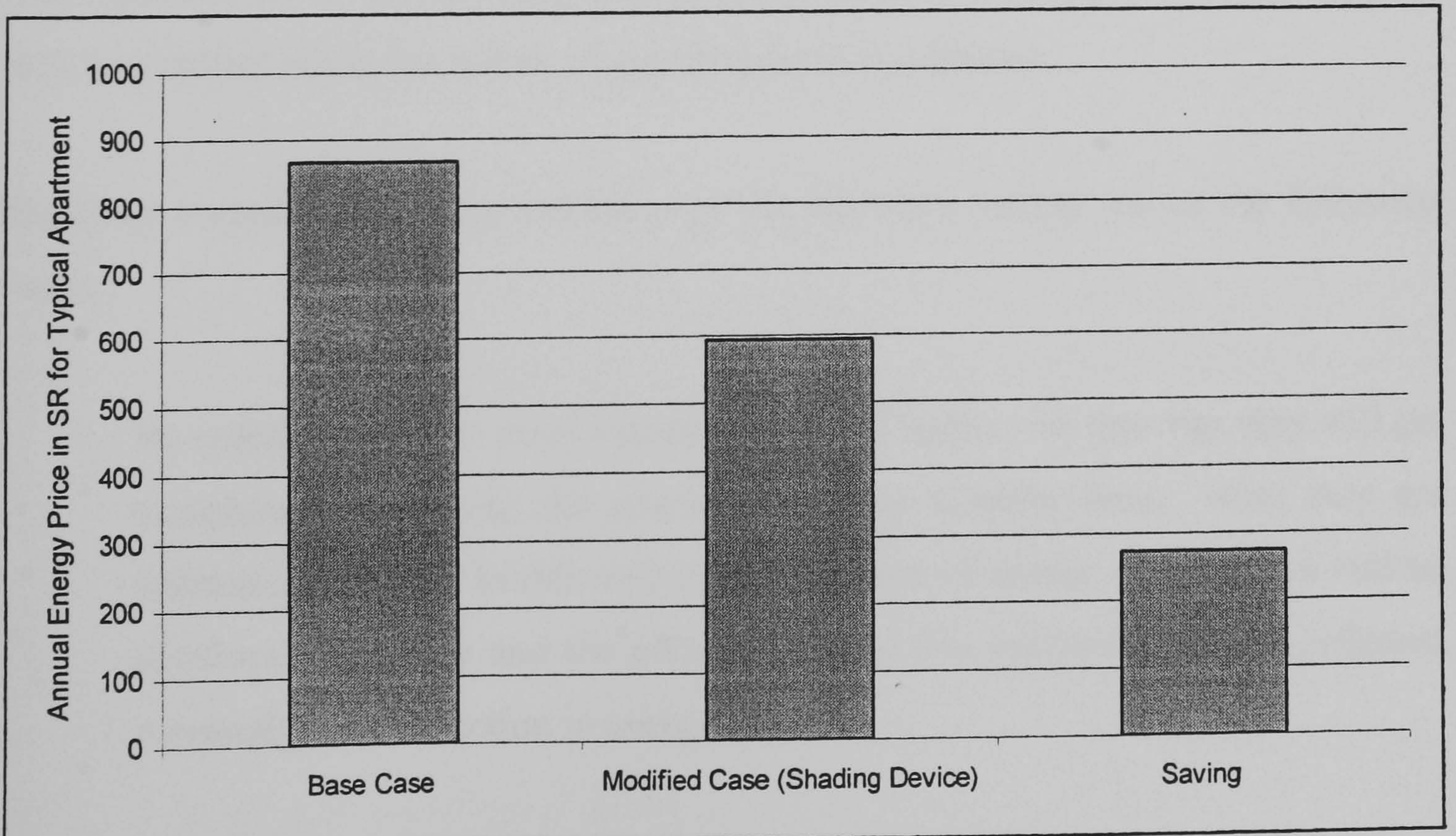


Figure 10.6: Yearly Potential Saving by Shading Device

Assuming the cost for a proposed portable shading device system made of PVC louvers is 50 SR/length meter. The initial cost of implementing this strategy in an existing apartment is 1750 SR. Therefore, this strategy will pay back its initial cost within six and half years (1750 SR./273 SR). This is a relatively reasonable initial cost for an effective strategy and a relatively short payback period, suitable to invest in. The question that raises itself again is about who will take this action.

10.4.3 Potential Saving by Energy Management

Energy management relates to the energy behaviour of the occupants, which is closely connected to casual heat gain sources and energy consumption. This term covers many aspects that need careful management in order to get the best savings. Two factors to consider are lighting systems and domestic electrical appliances, both of which consume electricity. As a matter of fact, any attempt to conserve energy without seriously considering the use made of these by occupants will be questionable. Indeed occupants' behaviour is crucial in this context; only the occupants can employ lighting systems and domestic appliances in effective ways. The contribution of the government authority, building owners, and even designers will be minimal when the matter of actual usage is considered.

Building occupants can take control over the domestic energy use in the following ways:

1. By concentrating on requirements instead of habits. In this way they will get accustomed to using the energy what they actually need, what they are habitually used to. In this way high awareness of energy conservation will be developed naturally and the effectiveness of this behaviour will be reflected eventually as a reduction in energy cost.

2. By shifting peak loads to off-peak period by avoiding the peak hours where the maximum load occurs (usually from 1:00PM –5:00PM).

3. By using energy-saving lighting over traditional lighting systems. There are great saving opportunities, which may be achieved by substituting traditional high wattage light bulbs with long-life low energy consumption lights.

An excellent example of the cost effectiveness of this approach can be seen in the following: a 60W traditional tungsten lamp working for eight hours daily would consume 480Wh per day, 14.4 kWh monthly, and 172.8 kWh yearly. It will cost the occupants 8.64 SR to pay for the consumption of this single lamp. The alternative is an energy-saving lamp that gives the same lumen as the traditional lamp (600 lumen) but only operates with 11W and has a ten times longer operating life than the traditional bulb (1000 hrs in a traditional lamp against 10000 hrs in an energy-saving lamp). The annual consumption rate for this lamp is 31.68 kWh and the electricity cost is 1.6 SR (81.5% less than the traditional light bulb). The annual saving as energy cost therefore is 7.04 SR. The initial cost of the energy-saving lamp is usually 20 SR, and hence the payback period for this cost will be 2.8 years.

One of the characteristics of occupants' behaviour inferred from the field survey is that they are heavily dependent on artificial light. Following the use of low energy lights as indicated above would help greatly in reducing their consumption even though they still overuse this source.

High efficiency electrical appliances and mechanical systems can account for a very high percentage of a home's total energy use. Occupants can significantly lower the consumption by carefully choosing their equipment. The more efficient the product, the less energy it needs to do the same job.

Energy labels has been recently introduced into markets and are displayed by law on all the new domestic appliances. These labels contain rating scales for the efficiency of the products which state how much energy is consumed by the appliances.

The promotion of this approach among occupants can result in a positive contribution in solving a major part of the problem. In fact, this is the only role through which occupants can participate in the solution. Apart from controlling their behaviour other factors are beyond the reach of individual occupants and they cannot realistically take any action.

There are many obstacles that can hinder the application of energy saving strategies in the real world. The can be classified as:

- Physical obstacles
- Economic obstacles
- Administrative obstacles.

The physical obstacles that stand in the way of the application of certain strategies are represented by the social costume nature that might be disturbed the upgrading process. Usually, the installation of insulation material is a destructive process, where the building envelope has to be cleared to provide a space for the insulation layer. This is not convenient and may cause a lot of disturbance to the occupants, and therefore it forms a physical obstacle preventing the procedure to be accomplished.

The economic obstacle can be understood in terms of the initial cost of the saving measure that has to be considered when handling this solution. This cost could be high and cannot be borne by the occupants.

Administrative obstacles can be demonstrated by the absence of common ground between the government and the occupants on one side and the building owners on the other side, which can inhibit the launch of constructive co-operation that depends on persuasion rather than enforcement. Also the absence of the qualified energy advisors and the lack of knowledge about this issue within the local architecture practice.

10.5 Saving Feasibility for the Government

The payback period for the initial cost of applying energy saving measures is not encouraging for occupants and owners, hence the feasibility of investing any money would be degraded by the long payback period. The picture might be reversed when taking the government into consideration. The crucial point for the government with regards to the existing situation of energy problem is the amount of subsidy for electricity that the government supported in their development plans. Energy in general and domestic energy in particular has been heavily subsidised since the early stage of introducing this service (electricity) in the late Fifties. Subsidization plans act in favour of people prosperity but, in the long term, it will be exhaustion for the national economy and a rapid depletion for energy resources.

The selling price for the government is 0.17 SR, and the consumer price is 0.05 SR. The government pays 0.12 SR for each kWh consumed.

Considering the PMCRV per apartment holder is 1442 kWh, as concluded early in this chapter, then the government would pay monthly 173.4 SR (1442 kWh * 0.12 SR) per apartment. Typical apartment would cost the government 2081 SR (173.4 SR * 12 months) on annual bases. This amount of money is a large waste especially if people keep misuse the consumption. Moreover, this policy will not enhance the government attitude to conserve energy and to rationalize the consumption as people use the subsidy to consume more energy than they actually need.

From this prospective, the government has a real need to think about this subject in more practical ways. The potential for high returns for the government is overwhelming if they manage to substitute electricity subsidy by active plan to financially support the upgrade the existing buildings sector. The economical feasibility of this solution is acceptable based on the calculation of the payback periods that mentioned earlier in this chapter. The initial cost for installing insulation materials in a typical apartment unit is 4530 SR, yet the government is paying a subsidy of 2081 SR per annum per apartment. If this money goes to building owners or building occupants as a cash to support the upgrading process for their buildings, the payback period for this money will be dramatically reduced from 27 years to 2.2 years (4530 SR / 2081 SR). In terms of government expenditure this payback period would be a little over two years. Making this energy conservation measure very cost effective.

The same applies for the shading device strategy which the initial cost for this strategy is 1740 per apartment unit. The payback period will be 0.8 year (6.5 years from the occupants and owners prospective). (Figure 10.7)

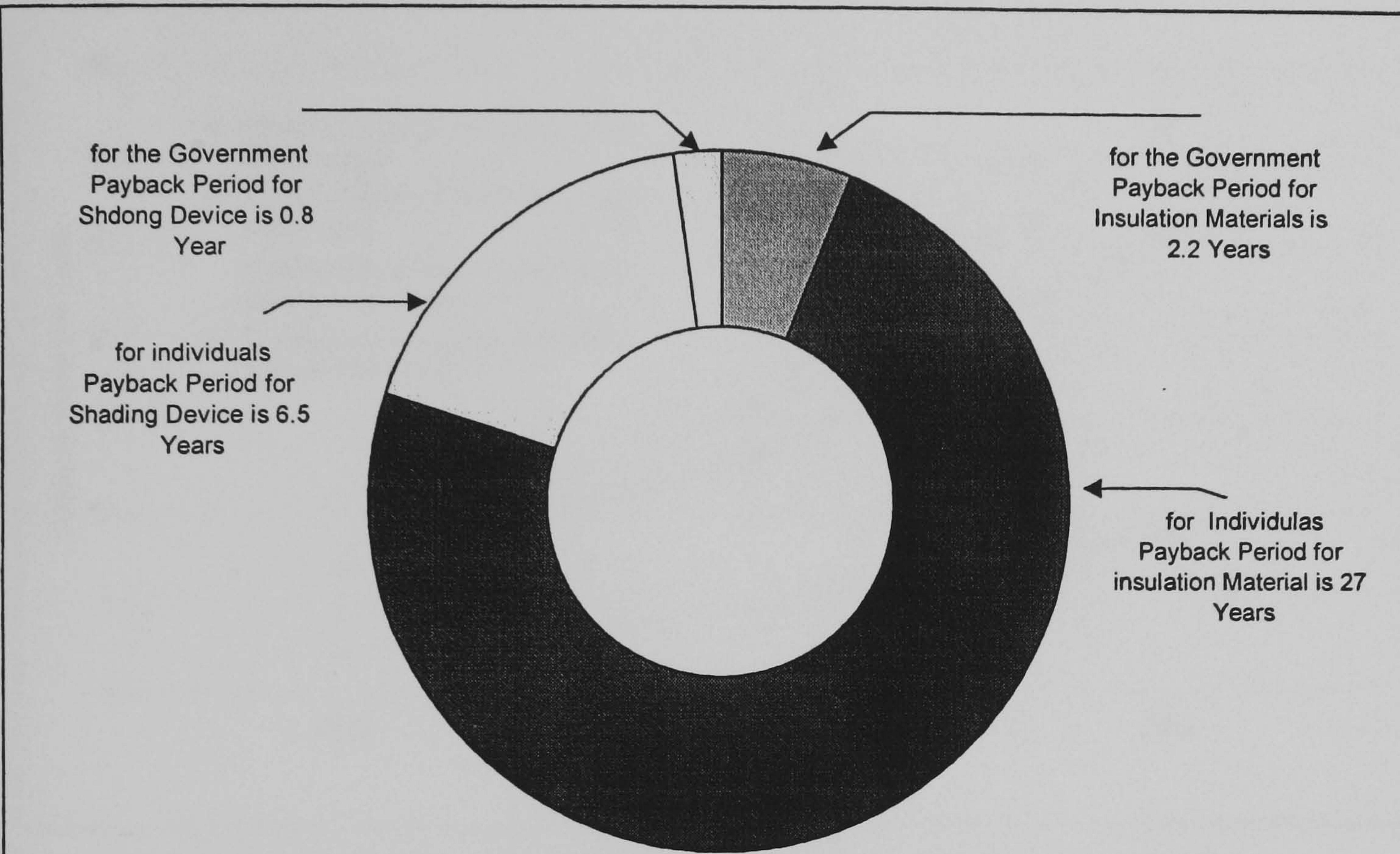


Figure 10.7: Payback Period for Different Energy Saving Measures.

Tremendous saving can be achieved for the government following this strategy. However, different scenarios can be applied with less percentage of lifted subsidies in case of phasing this strategy over many years. Table 10.8 lists these scenarios with a 50% and 25% of lifted subsidy and the consequence results of this action on the payback period. (Figure 10.8).

Percentage of Lifted Subsidy	Insulation Payback Period	Shading Device Payback Period
100% (0.12 SR)	2.2 Years	0.8 Years
50% (0.06 SR)	4.4 Yeas	1.6 Years
25% (0.03 SR)	8.8 Years	3.4 Years

Table 10.8: Payback Period for Energy saving Measures with Different Percentage of Lifted Subsidy

The economic feasibility of the saving, when apply energy saving strategies, on the government is very obvious. It seems that the government is the most harmed parties but the most benefited party when applying energy saving strategies.

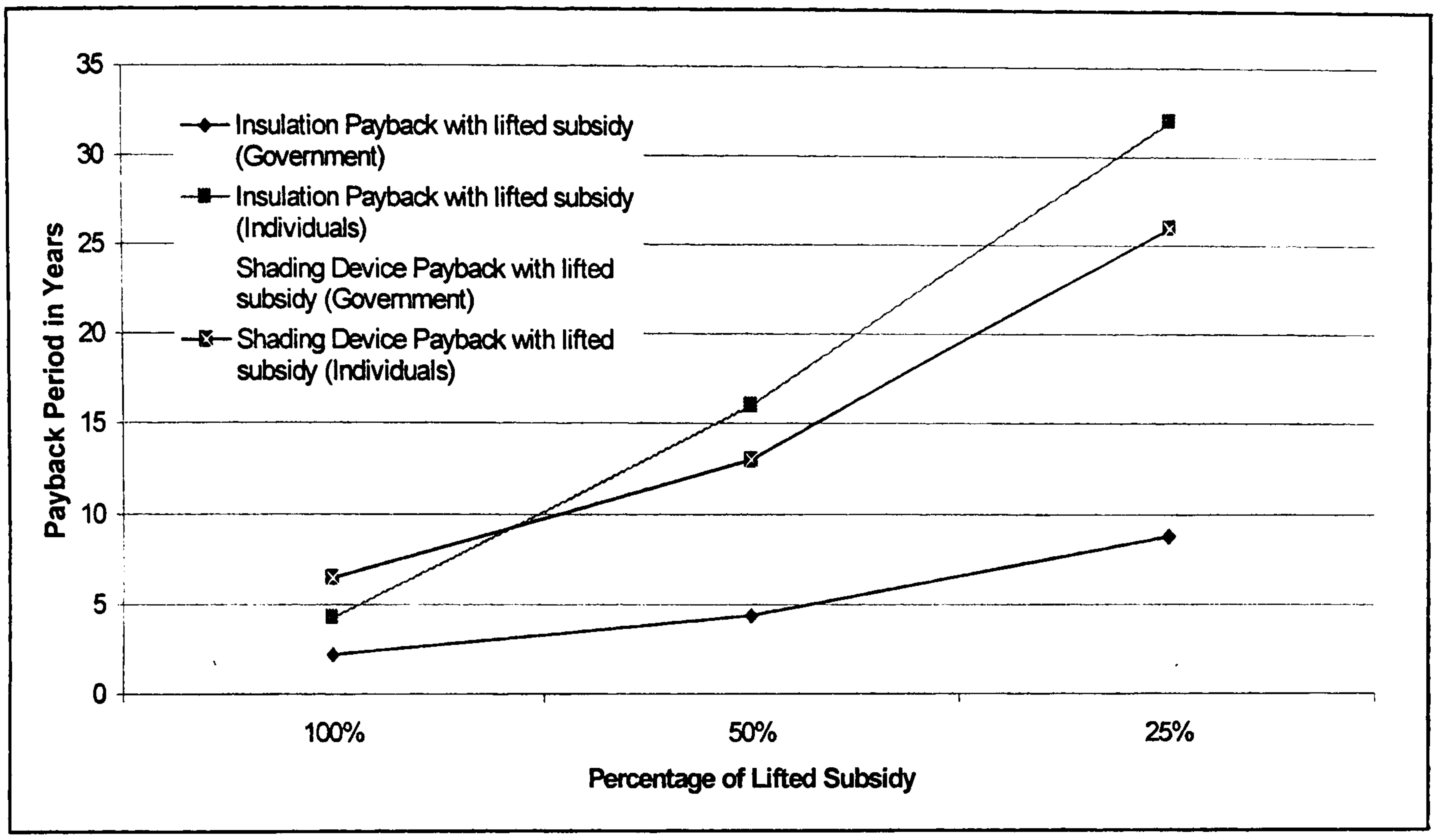


Figure 10.8: Payback Period with Different Lifted Subsidy Assumption

Chapter 11

Summary and Recommendations

Chapter 11

SUMMARY AND RECOMMENDATIONS

11.1 Summary

Energy conservation has been a matter of never-ending attention even in the world's largest oil reserve country, the Kingdom of Saudi Arabia. The concept reflects an approach to design to limit dependence on energy in administrating social services affecting daily life, by establishing a code of practice in order to attain energy conservation target. In the building industry, there is still a long way to go before earning any fruitful returns due to continuing construction developments that constrained by only limited and unorganised controls. The residential building stock accounts for a very large part of the building market and logically consumes a huge amount of energy to maintain habitual conditions. The majority of the residential buildings are apartment buildings, which, are an important and energy-problematic type of residential stock.

Existing apartment buildings stock suffers from inadequate design and construction quality and this is reflected in the poor thermal performance and excessive energy consumption. The National economy allocates large share of its yearly capital to subsidising the cost of energy, which makes energy so cheap that people tend to over-use it and lack of a need to develop a conservation culture. This expenditure could be avoided and directed to support more national projects if the problems associated with it were clearly exposed.

This research has been carried out with this problem in mind. Its objective is to study the existing apartment building stock in Makkah, a city of unique socio-cultural, climatic, and geographical setting. The study aims to identify the thermal characteristics of this type of building and recognise the pattern of the occupants' energy behaviour. It also aims to point out the potential for saving in energy through the application of practical measures to improve the existing building stock.

The attainment of these targets has to go through two major analysis stages: the fieldwork survey that comprises two parts, social survey and fields measurements; and a computer simulation for a prototype apartment unit subjected to the same conditions as in real cases. Through the fieldwork survey the researcher has been able to study the research subject in depth and establish the characteristics that identify this building stock. Through the simulation, the researcher has been able to investigate the thermal performance of the most common and popular building materials, identify their contribution, and test some practical energy saving measures to upgrade performance.

The problem of the existing apartment buildings has been looked at from two major points of view: the thermal performance problem and the energy consumption problem. The former is mainly concerned with the occupants of buildings as direct users in continuous interaction with the spaces and for whom improvement of the thermal living quality in their buildings is needed. The latter part partially concerns the occupants, but it also is a focus of concern for the government authorities, as they are the bodies who bear the economical consequences of the extravagant use of energy by the occupants. The role of the professions, i.e. architects, energy analysts, and designers, may be seen as related to both occupants and the authorities.

The prevailing harsh climate of Makkah city is the reason for the uncomfortable thermal conditions inside the apartment units most of the year. Indoor comfort is obtained naturally, only for very short period of the year. No passive cooling strategy is capable alone of creating indoor comfort outside this period. Passive strategies, e.g. reducing infiltration, using light colour, using night ventilation etc., can be useful as supportive design strategies and they may be applied to prevent the indoor situation from getting worse and lighten the load on mechanical devices. It is inferred from the analysis that the indoor temperature falls outside the comfort zone most of the year and mechanical cooling is essential for creating comfortable indoor thermal environment for the modern apartment building.

Fieldwork survey was carried out in summer 1998 from July till September in apartment buildings in Makkah, Saudi Arabia. The social survey sample consisted of 542 apartments in different city locations. The main data gathering tools were self-administration questionnaires containing questions about different social, economical, and energy issues deeply connected to the daily lives of the occupants of the apartments. A full discussion of the occupants' responses together with the measurement survey of the eight selected typical apartments have been provided in Chapter 6 & 7. A summary of these findings is as follows:

11.1.1 Physical Characteristics of the Apartment Buildings

- Apartment buildings in Makkah represent more than 75% of the residential buildings. They usually exist as low-rise building with three to five floors in low-density areas and eleven to seventeen floors in high-density areas (usually in the central area around the holy mosque where the pilgrims like to be accommodated).

- Apartment sizes vary according to the land area. Land lots usually sized by 900m^2 and it is the owner's decision to built on it with two or three and sometimes four apartments on one floor area. This decision has a great effect on apartment size. Common apartment sizes can be classified into three major categories: small (up to three rooms), medium (apartment with four or five rooms), and large (apartment with more than five rooms).

- It is rare to find apartments with four facades; more common are apartments with three facades, and commoner still are apartments with two facades; one-facade examples are limited to small land plots.

- Most of the stock of existing apartments buildings may be considered to be newly built (within the last ten years) and they are very similar in constructional system (a system of reinforced concrete frames and plastered walls build with hollow clay blocks).

- Insulation materials are not common and most of the existing buildings are not fitted with such material. The major reasons behind this are the absence of a compelling code, low energy prices, and a lack of adequate information about these materials.

11.1.2 Occupants' Characteristics

The relevant characteristics of the occupants are family size, economic status, daily activities, and energy behaviour with regard to their habitual use of the mechanical, lightning, and electrical equipment. A summary of the findings inferred from the analysis is as follows:

- Family size by apartment is usually from 3 persons to 7 persons, though families of larger size (more than 7 people) are not uncommon and they usually occupy a bigger size of apartment (normally their own).

- The great majority of apartment occupants is in the middle income group. This group shares much the same living standard with no clear distinction between one family and another in this respect.

- The poor thermal performance of apartments has been deduced from the feedback from respondents, as they have recognised the need for air conditioning most of the year. The operation pattern of the A/Cs is that they are limited to the space in common occupancy and can be in use for as long as eighteen hours daily (usually in the living rooms).

- Occupants show a wide range of the number of electrical appliances in their possession. Electrical ovens and microwaves are not in common use, but almost all apartments are well equipped with A/C units.

- Total dependency on mechanical cooling for producing comfortable indoor environment decreases the comfort level among the occupants. Moreover the thermostat setting is often set to a unnecessarily low temperature so that an overcooling is often experienced and more exhaustion of energy is being practised.

- Occupants show a great dependence on artificial light and very limited utilisation of natural light, which is governed by the window use policy within the family. It is inferred that making use of windows has been kept to the minimum for many reasons, primary amongst these being family privacy.

- The monthly electricity consumption pattern usually exceeds 2000 kWh. Vast numbers of the apartment holders pay above 100 SR and, due to cheap energy prices, still define this amount as moderate and do not feel any economic stress. Furthermore, they are satisfied with what they get as thermal comfort and what they pay for this. However, there is still a considerable proportion who think they are paying high bills, though this can be related to their high consumption rate.

- The Monthly Consumption Reference Value inferred by the Questionnaire survey (MCRVQ) is 2113 kWh. This reference value has been extracted from the actual readings for one-year consumption for the survey sample. The MCRVQ falls in the lower category of electricity consumption brackets and represent approximately a 3% of normal occupant's monthly income.

- The energy conservation awareness of the occupants is acceptable, though they do not have a concrete idea of the meaning of the concept. They act instinctively in not squandering resources as they motivated by religious directives, but this behaviour will be more fruitful if it combined with some concrete energy conservation awareness.

The social survey has provided the foundation to understand the behaviour of the building users, which is a product of social, economic, and religious factors eventually reflected as energy demand and energy consumption.

11.1.3 Thermal Characteristics of the Apartment Buildings

A closer look at the thermal performance aspects of these units has been enabled through the measurement survey carried out in eight typical apartments. The thermal characteristics of typical apartment buildings in Makkah is manifested as follows:-

- The indoor temperature profile has been monitored inside these units; when air conditioning units are on it reaches a high of 25°C and goes down as low as 17°C. The temperature profile without cooling varies from 29°C up to a very hot 42°C (usually in the kitchen). This high temperature profile reflects the existing quality of building construction and its poor thermal performance, the upper limit of the indoor comfort zone (26°C) being beyond its natural cooling capacity. Therefore, these apartments have a high tendency to consume more energy for cooling purposes if a tolerable indoor thermal condition is targeted.

- Monthly electrical consumption recorded for these cases show a great disparity between individual cases. The maximum consumption recorded among the cases exceeds the 4500 kWh level while the minimum consumption recorded is as low as 500 kWh. This variation in consumption relates partially to physical factors such as apartment size, family size, and cooling system size and efficiency, but also to economic status and the capability of different families to pay more for electricity. However, it is also greatly influenced by the behavioural patterns of family members, i.e. longer A/C working hours as seen in Case no 7 & 8.

- The Monthly Consumption Reference Value inferred by the Measurement survey (MCRVM) is 1980 kWh. A good agreement between the MCRVM (1980 kWh) and the MCRVQ (2113 kWh) has been found.

- Actual Monthly Consumption Reference Value (MCRV) has been established by averaging the MCRVQ and the MCRVM. The MCRV is 2047 kWh which represent a practical value for energy consumption pattern inside the apartment building in Makkah – Saudi Arabia.

- Almost all of the apartments in the cases surveyed are built from basic construction materials except one where insulation material has been included. However, this apartment performs no better in term of indoor temperature in than other cases, the temperature profile without mechanical cooling in this apartment is as high as in any other apartment (as seen in case no 4).

- One problem of this building stock is the high infiltration rate. Air-tightness inside these apartments has not been given enough attention. An improvement in this area would have a great potential to lighten the cooling load on the system as effective air-tightness would block a considerable, and quick, access of heat carried inside by hot air.

- Relative humidity (RH) is low in the spaces not subject to air conditioning and is associated with the dryness of the weather, while in the air conditioned spaces the situation is comfortable except for the kitchen, where a high percentage of RH related to various housework activities may be noted.

- Two patterns of occupancy in these apartments have been recognised. The first pattern is the organised use of spaces according to zone function, and this pattern was taken as a base for scheduling the occupants' activities in the simulation stage. The second pattern is more casual and is built on the daily movement from one apartment zone to another following the lower temperature offered by any one particular zone at certain daily times. The latter pattern depends mainly on using the zones as multifunction areas and might be interpreted as occurring coincidentally. Therefore, this finding should not be generalised; rather it should be understood in relation to the cultural and habitual background of the apartment users.

The information produced by the analysis of the survey has been utilised to predict the thermal influence of building components and to investigate their implications for energy consumption. This information is difficult to obtain without the aid of computer calculations. An internationally recognised simulation program (DOE-2) has been adopted for the simulation of typical apartment models. The investigation also set out to observe the advantages and the disadvantages of energy saving measures with regard to certain types of building materials. The simulation has revealed some interesting results that diagnose the causes of poor thermal performance and show up the potential for further improvement in performance and in reducing consumption loads. The summary of these findings can be exhibit as follows:

- The Predicted Monthly Consumption Reference Value found by simulation (PMCRV) for cooling purposes is 1442 kWh.

- Great correspondence between the actual MCRV for cooling loads (1433 kWh which represent 70% of the actual measured consumption) and the predicted PMCRV (1442 kWh) has been achieved with simulation process. This value gives a difference of 0.6 % and indicates a high accuracy of the simulation and enhances the modelling assumptions.

- It has been found that the common basic building materials under investigation behave differently towards heat transmission. The high density and high U-value constructions tend to have relatively higher heat gain loads than the low U-value constructions. However, these differences are not substantial. Higher percentages of high heat gain load occur through casual gains, window solar penetration, and building fabrics in that order. Some practical energy saving strategies have been tested and found to be of a good potential in improving the situation and minimising heat gain loads through channels indicated.

Among various strategies for energy conservation in buildings, the research has adopted two major energy saving measures for investigation. These measures are application of external insulation materials and provision of shading device to the exposed window surfaces. Using insulation materials is a common practice nowadays dictated by building regulations in the newly built constructions.

Insulation industry in the Kingdom of Saudi Arabia is well established, as most of the insulation materials produced in the local market are oil-based products. This is guarantee the availability of a wide range of these products with low competitive prices. However, still the vast majority of the existing buildings are not equipped with this strategy and the potential for retrofitting with this measure is high. Insulation moderates heat transfer flow through building fabric and helps keeping in the cold of the conditioned air for longer period and hence reduces cooling load on systems which leads to a reduction in energy consumption.

The first proposed retrofit solution considered in this research in order to upgrade thermal performance in the existing buildings is to add an external layer of insulation. The simulation results have demonstrated that a reduction up to 19% in system cooling load can be achieved by installing 50mm polyurethane to external wall.

The second proposed retrofit solution is shading the building envelope. The concept of putting the entire building envelope under shade is an effective retrofit technique that isolates the inner building skin from direct contact with the climatic factors. However, it is a difficult technique to adapt in practice for economic, structural, and aesthetical points of view. Partial shading of the most critical heat path in building envelope, i.e. windows openings, has been considered for investigation.

The simulation results have demonstrated that a reduction of up to 30% in system cooling load can be feasible by proper shading of window openings. Shading devices should provide a complete shade for the openings throughout the day to cut off the direct penetration of solar energy through the glazing surfaces. By eliminating the impact of this crucial factor, the simulation results have shown a significant reduction in heat gain load.

The technical aspects associated with the application of these two measures are manageable in practice and fall within the limited capability of the local professions and local market. Moreover, these measures are socially applicable as they can be carried out without involving any privacy issues for building users, which make them favourable strategies for application in practice.

- The proposed alternative design strategies demonstrate promising results with regard to the amount of energy saving that could be achieved through the reduction on system load. Economic considerations for alternative design solutions, based on the initial cost of the energy saving measures to be applied and the payback period for these measures, has been studied. Some payback periods represent obstacles to the implementation of any one system because of the unreasonably long time involved, especially for tenants. Casual gain has been found to be the most controllable aspect and the most applicable in that it suits the tenant nature of apartment building occupants. It requires neither great initial cost nor any construction procedure in order to be implemented. It rather needs a good attitude towards the energy conservation principal.

To conclude, the problems of the existing situation in building apartments as explored by the research analysis can be seen from three different angles:

1. The first angle concerns the problem facing the building users (occupants). Here the primary concern has been the indoor thermal quality, mainly degraded by the thermal performance of the buildings and the possibility for occupants to live in a comfortable environment.

As things stand at present, this problem appears to have been solved by the extensive use of mechanical cooling, and the occupants are fairly satisfied with this situation for the time being. Their satisfaction, though it may be temporary, has been attained through the low energy cost policy which compensates the disadvantage of the high energy consumption needed by the occupants to balance the poor thermal performance for their buildings.

Although the potential for saving energy through the application of energy saving strategies is overwhelming, the economic motives are not there to compel those occupants towards changes or at least to raise their concern about the situation. If and only if, the government makes a decision to lift the subsidy will the whole picture be redrawn.

Such a scenario will certainly impose a considerable economic stress on the occupants and will introduce a new tension between thermal comfort and economic comfort. In the short term either one of these notions will prevail over the other, but both of them are essential for the long-term comfort of the occupants.

Proposed strategies such as the application of insulation materials and the installation of shading devices are neither practical nor applicable from the particular angle of the occupants. Being tenants or temporary occupants will not encourage the modification of an apartment, even if it is badly needed, although the existence of effective enforcement tools would make a major difference to this aspect of the situation.

A further key to dealing with this obstacle lies with the owners of buildings; they can invest in their buildings as apart of an integrated national scheme to upgrade the existing buildings for the sake of the national economy. This is, of course, a difficult goal to achieve but not an impossible one. It can be done by adopting a comprehensive plan where the government plays the major part in providing the facilities and even the money, in order to make the implementation of such strategies more workable from the owners' side.

2. The problem from the government's point of view has primarily an economic dimension. The housing stock represents a continuous exhaustion of the national energy and economy resources. This is of great importance because of the policy that the government has adopted to make this vital service available and accessible to every body without any economical difficulties, as in many other fields. This approach costs the government a fortune, as it has to subsidise this service in very generous way.

The subsidisation harmonises with public needs and indeed it works very well in their favour. However, the other side of the coin is that this provision of subsidies is liable to abuse in a very irresponsible manner. This observation has been made possible from monitoring the unnecessary electrical consumption for residential buildings in general and for this type building in particular, and it has been a very noticeable phenomenon in recent years. This is very well known to the authorities and for this reason electrical price brackets have been developed to limit the excessive use of energy. Nevertheless, the bracket prices are still within easy reach of the public and the problem still exist from the government point of view.

What the government can do is to invest in the upgrading of the existing situation in such a way that any small reduction in energy consumption which comes as a result of this upgrading could count considerably in the long run. Not only will this prove economical for the public but it will also help reduce the need for subsidy on electricity, hence enhancing national economy.

3. The third angle on this problem is that of the building professional. The main concern of these professionals is with new projects and developments. However, they do have a potential contribution to make in relation to the energy concerns of existing buildings, which is something that they have shown some reluctance to undertake because, in general terms, it is not a financially profitable area.

Architects, energy analysts, and all the relevant professionals in the building industry are concerned with the technical aspects of the problem, but one of the obstacles to the implementation of energy saving measures is the lack of information provided by building professionals.

Almost all other parties in this circle need to be fully aware of the nature of the problem, its technicality, its dimensions, and its effective solution. So in this sense the professionals need to provide society with more factual data so that any decision to be taken would be founded on very solid ground.

More involvement and interaction with the users of this building type is needed, through investigation by empirical and fieldwork studies, in order to understand more about the existing situation.

11.2 Study Recommendations

Dealing with the defects of existing buildings is a complex situation that involved many other factors rather than the building, which imposed further difficulties for retrofit. The research has recognised the rules of each element participating in this problem with regards to thermal performance and energy behaviour and proposed two broad lines for the solution. The first concerns the physical up grade of the building envelope and the second concerns the human contribution to this problem.

In order to rehabilitate the existing apartment buildings, energy wise, the study has derived the following recommendations:

1. The necessity to develop a national campaign for energy conservation that incorporates a retrofit scheme to existing building sector as a major tool.
2. Increase thermal efficiency of the building envelope by the use of external insulation, i.e. adding 50mm of polyurethane as a second layer.
3. Protect all the exposed openings from direct solar contact by continuous shade on these openings.
4. Formulate a practical design approach to implement, technically, these strategies on a large scale that match the scale of the existing building sector.
5. Establishing information office to provide consultation and technical support to satisfy any enquiries form the individuals with regards to these issues.
6. Support further researches on insulation materials and its behaviour in local constructions.

In the second view, the recommendations of this study are based on one crucial fact, which is the difficult nature of dealing with existing buildings. This point requires to be more fully and realistically appreciated in order to produce suggestions that are most practical and applicable.

All the recommendations for this point of view concentrate on three main questions:

- What can be done?
- How can be done?
- Who will be doing it?

There are several major remedies, stated in order according to their practical applicability. The first remedy is to educate the society concerned, providing all necessary information needed to elevate and to enrich people's consciousness about the importance of energy resources and how to conserve these resources. This can be done through a comprehensive campaign in the public media and can be carried out by the government institutions and private sector areas most closely associated with the public services.

The second major remedy is to encourage the use of energy efficient lighting and equipment systems by adjusting the specification of the products to meet a higher level of quality control, and also by imposing further restrictions on imported and relevant local productions. Again this can be done through the government institutions represented by the Ministry of Commerce, The Saudi Commercial Chamber, and the Saudi Arabian Standards Organization (SASO).

Thirdly, it is recommended to establish a government fund to provide a long-term loan (like the currently existing Real State Fund) to building owners and to provide free technical advice and consultation as well as to enforce full supervision of improvements for the parties who will benefit.

Fourthly, there should be established an independent energy department that takes the responsibility for the co-ordination between the different government institutions with regard to energy issues. Also, promoting the researches of applied sciences in this field should be given priority.

11.3 Further Research Directions

There is several research directions can be inferred from this study. These directions would complement some issues in this research that surrounded with uncertainties in some aspects of the practical evaluation. One of these directions concerned with further field study for an existing project with regards to upgrading construction and insulation quality. This direction may investigate not only the thermal performance of the upgrading procedure and results, but also investigate the actual cost of this upgrading with connection to long-term energy consumption prices.

Another research direction could be an investigation into the construction techniques and how to introduce and implement new strategies that could make the upgrading practically feasible and acceptable within the conservative social context such as the society of Makkah. More detailed investigations about some critical factors that effecting building environment such as infiltration and air movement are needed. This direction leads to better understanding for these factors that form important criteria in indoor comfort.

Another research direction may investigate the current electricity cost bracket structure to make it an effective tool as energy conservation measure. This tool is disabled in its current form and does not give the incentive for the public to rationalize their energy usage neither by compulsion nor by persuasion. Further study for restructuring this tool is needed to realize the potential economic benefits from the upgrading remedies, i.e. the use of the insulation materials and shading devices. The importance of this research direction will not only be reflected on building users, but also help the government to reduce the subsidy on electricity. Finally, this study has tackled a difficult task that deals with energy conservation in existing situation of a large sector of the residential building type (apartment buildings in Makkah) and the findings and the recommendation must be considered as a suggestive and guide lines rather than conclusive. However, another continuation for this research is to consider it as a part of similar investigations in apartment building stocks in different cities in the Kingdom of Saudi Arabia. This series will be useful to develop a national code of practice for energy conservation in the existing apartment buildings.

Bibliography

Bibliography

Abdulbagi, M., 1984. 'Makkah Al-Mukarammah – Expansion and Local Structure', Paper presented in the Saudi Cities Symposium (August 1984), Department of Geography, King Saud University, Al-Riyadh, pp.14-21. (Arabic)

Abdulbagi, M., 1991. 'Makkah Al-Mukarammah – The Continuous Urban Planning', Paper presented in the Al-Azhar Engineering Second International Conference (December 1991), Al-Azhar University, Cairo pp. 50-63. (Arabic)

Ahamad, B. Y., 1992. 'The Climate of Makkah', Social Science Research Series, No.15, Scientific Research Institute, Umm Al-Qura University, Makkah.

Al-Abdaly, S., 1975. Housing in Saudi Arabia, Unpublished Master Theses, Liverpool, University of Liverpool.

Al-Afghani, A. S., 1987. A study of the Hajj to the Holy City and a Design of the Pilgrims' Accommodation Center in Makkah, Saudi Arabia, Master Theses, Texas, Texas Tech University.

Al-Afghani, A. S., 1991. The Saudi Houses in the Past, Present, and Future: A Study of Changes, Ph.D. Theses, Glasgow, University of Glasgow.

Al-Bis, A. & Al-Harbi, T., 1993. 'Architecture in Makkah Al-Mukarammah and Al-Madinah Al-Munawarah between Old and New', Paper presented in the Al-Azhar Engineering Third International Conference (December 1993), Al-Azhar University, Cairo, pp.72-98. (Arabic)

Al-Bis, A. & Seraj, M., 1991. 'The Influence of the Post Modern Architecture Trends on Architectural Development in Kingdom of Saudi Arabia', Paper Presented in the Al-Azhar Engineering Second International Conference (December 1991), Cairo, pp.1-32. (Arabic)

Al-Ghamdi, A., Al-Saryani, Mirza, & Kutbi, Z., 1985. Makkah Al-Mukarammah - The Holy Capital, Al-Safa Press, Makkah, Saudi Arabia.

Al-Hammad, A. 1992. Load and Energy Requirements in Residential Buildings in Saudi Arabia: a Comparative Study. International Journal of Energy Research, No.16, pp. 533-543.

Al-Hussayen, M., 1980. Building Problem in Saudi Arabia: The Need for Building Research, and the Development of Building Research Approaches, Ph.D. Theses, Michigan, University of Michigan.

Al-Mujahid, A. & Zaidan, M., 1995. Comparison Study for the Thermal Performance of Insulation in Buildings, Al-Muhandis, Vol.9, No.3.

Al-Naimi, I., 1989. The Potential for Energy Conservation in Residential Buildings in Dammam Region, Saudi Arabia, Ph.D. Theses, The University of Newcastle.

Al-Rabghi, O., Al-Beiruty, H., & Fathalah, A., 1999. "Estimation and Measurement of Electric Energy Consumption due to Air Conditioning Cooling Load", Energy Conservation and Management, Vol. 40, p.p. 527-542.

Al-Sibai, A., 1965. History of Makkah, Vol.1, Dar Koriesh, Makkah.

Amor, R., Hosking, J., Donn, M., 1993. Integrated Design Tool for Total Building Evaluation, Building and Environment, Vol. 28, No.4, pp.475-482.

Amre, M., Stamper, E., 1995. Historical Development of Building Energy Calculation, ASHRAE Transaction 101, pp. 841-848.

ASHRAE, 1985. American Society of Heating, Refrigeration, and Air -Conditioning Engineering, Handbook of Fundamentals, Atlanta, GA.

ASHRAE, 1989. Fundamental Handbook, American /society of Heating, Refrigerating and Air Conditioning Engineers Inc, Atlanta. U.S.A.

Augenbroe, G., 1992. "COMBINE: A Joint European Project Towards Integrated Building Design Systems", Building System Automation-Integration'92, Dallas, Texas, U.S.A.

Auliciems, A., 1997. "Comfort Clothing and Health", Applied Climatology Principles and Practice, Russell *et al* eds., Rotledge, London.

Baldwin, R. et al., 1990. "An Environmental Assessment for New Office Design", BREAM 1/90, Watford, BRE.

Birdsall, B. et al., 1990. Overview of the DOE-2 Building Energy Analysis Program, Simulation Research Group, Lawrence Berkeley Laboratory, University of California.

Bitan, A., 1984. 'Climatic Data Analysis and its use in Representation for Planners', Energy and Buildings, Vol.1.

Bojie, M., et al., 2002. Thermal Insulation of cooled Spaces in High Rise Residential Buildings in Hong Kong, Journal of Energy Conservation and Management, Vol.43, pp 165-183.

BRE, 1991. BRE Digest 358 CFCs and Buildings, Watfrod, BRE.

Burckhardt, J., 1968. Travel in Arabia, Frank Cass & Company Limited, London, p.p. 103-106.

Busch, R., 1996. Modeling Building Energy Systems, *In.* B. Hunn, ed. Fundamentals of Building Energy Dynamic, The MIT Press, Cambridge, Massachusetts.

CIBSE, 1986. CIBS Guide, Weather and Solar Data; Sol-Air Temperature and Long-Wave Loss, The Chartered Institution of Building Services, London.

Clarke, J. A. & McLean D., 1988. "ESP-A Building And Plant Energy Simulation System", Energy Simulation Research Unit, University of Starthclyde.

Clarke, J. A., 1985. Energy Simulation in Building Design, Adam Hilger, Bristol.

Cook, J., ed.1989. Passive Cooling, the MIT Press, Cambridge, Massachusetts.

Department of Geography, 1980. Makkah Al- Mukkaramah, City Study, Department of Geography, Umm Al-Qura University, Makkah, K.S.A.

Danby, M., 1984. "The Internal Environmental Aspects of the Traditional Arab House and their Relevance to Modern Housing", Proceedings of Colloquium on the Arab House, Ed., Hyland, A., and Alshahi, A., University of Newcastle upon Tyne, Newcastle upon Tyne.

De Vaus, D. A., 1996. Surveys in Social Research, UCL Press, London.

Devis, T. R., 1963. 'Acclimatization to Cold Man', Temperature, its Measurement and Control in Science and Industry, Hardy, J. D. ed., Part 3, Rienhold Pub. Corp., New York (Review).

Dillman, D. A. 1978. Mail and Telephone Surveys, The Total Design Method, New York, Wiley.

Diprose, P. R., & Robertson, G., 2001. "Towards a Fourth Skin? Sustainability and Double Envelope Buildings", http://www.diprose.co.nz/WREC/WREC.htm.

Drydale, J., W., 1951. 'Climate and Design of Buildings: Physiological', Study No.2, Technical Study 35, Commonwealth Experimental Building Station, Sydney (Review).

ELEY, 1997. VisualDOE2.5 Manuals, ELEY Association, San Francisco, CA, U.S.A.

Evans, B., 1989. Trouble in the Air-Ozone/Greenhouse Effects', Architect's Journal, April, pp. 75-80.

Fadan, Y., 1980. 'Traditional Houses of Makkah: the Influence of Socio-Cultural Themes upon Arab-Muslim Dwelling', Paper Presented in the Islamic Architecture and Urbanism Symposium (January 1980), King Faisal University, Dammam.

Fadan, Y., 1983. The Development of Contemporary Housing in Saudi Arabia (1950-1983): A Study in Cross Cultural Influence under Conditions of Rapid Change, Ph.D. Theses, MIT.

Fanger, P. O., 1970 & 1973. Thermal Comfort, Analysis and Application in Environmental Engineering, McGraw-Hill Book Co., New York.

Gagge, A. P., Burton, A. C., Bazett, H. C., 1941. A Practical System of Units for the Description of the Heat Exchange of Man with his Environment, Science, Vol. 94.

Geiber, R.A., 1975. The Climate Near the Ground, Harvard University Press.

Gibbons, H. 1982. Energy the Conservation Revolution: Plenum Press, London.

Giles, E., 1889. Australia Twice Traversed, Low, Marston, and Rivington, London.

Givoni, B., 1981. Man, Climate, and Architecture, Second Edition, Applied Science Publishers ltd., London.

Givoni, B., 1994. Passive and Low Energy Cooling of Buildings, Van Nostrand Reinhold, New York.

Givoni, B., and Hoffman, E., 1968. Guide to Building Design in Different Climatic Zone, Building Research Station, Haifa.

Gough, M. C. B., 1986. Component based building energy system simulation, International Journal of Ambient Energy, No.7, pp.137-143.

Hariri, M., 1981. "Traditional Architecture in the Kingdom of Saudi Arabia", Vol.2, Saudi Research and development Corp., Jeddah.

Hariri, M., 1986. Housing in Central Makkah, The Influence of Hajj, Ph.D. Thesis, University of Newcastle upon Tyne, U.K.

Hay, H., 1971. The California Solar Architecture House, Hay's New Roof for Hot Dry Regions, Ekistics, No. 183.

Hedley, D. 1986. World Energy the Facts and Future: Euro-monitor Publication Limited.

Henderson, G. and Shorrock, L. D., 1990. BRE Information Paper 2/90, Green house, Gas Emissions and Buildings in the U.K., Watford, BRE.

Holite, D. E., 1993. All Building System Must Be Fully Integrated, ASHRAE Journals, Official Product and Show Guide, January, pp. S232.

Hong, T., 1999. Building Simulation www.geocities.com/capecanveral/5190/bsfaq/html. 06/15/99, 16:36.

Hoppe, P., 1988. 'Comfort Requirements in Indoor Climate', Energy and Buildings, No.11, (p.p. 249-257).

HRC, 1991. 'Examples from the Traditional Buildings in Makkah', Technical Report, Haj Research Center, Umm Al-Qura University, Makkah.

Humphreys, M. A., 1975. "Field Studies of Thermal Comfort Compared and Applied", Proceedings of the Symposium on Physiological Requirements of the Microclimate, Prague, Czechoslovakia.

Humphreys, M. A., 1977. 'Field Studies of Thermal Comfort Compared and Applied', Energy, Heating, and Thermal Comfort, BRE Building Research Series, Vol. 4, p.p. 237-265.

IEA, 1994. "Empirical Validation Of Thermal Building Simulation Programs Using Test Room Data", Vol. 1, Final report.

IEA, 1995. Calculation of Energy and Environmental Performance of Buildings; Appropriate use of Programs, Energy Conservation in Buildings and Community system Program, Vol.1.

IEA, 1997. Statistical World Total Final Consumption by Energy, www.iea.org/stats/file/selstats, 10/25/97.

IHVE, 1970. Guide Book A, the Institution of Heating and Ventilation Engineers, London.

Irving, S. J., 1986. APACHE-an Integrated Approach to Thermal and HAVC System Analysis, International Journal Ambient Energy, No.7, pp. 129-136.

Jencks, C. & Chaitkin, W.,1988. Architecture Today, Harry N. Abrams Inc., New York.

Jenning, B. H., & Givoni, B., 1959. Environmental Reactions, ASHVE Journal, Jan. Edition, p.p. 3-10.

Jensen, S., 1995. Validation of Building Energy Simulation Programs: a Methodology, Energy and Buildings, Vol. 22, No.2, pp.133-144.

Johanson, S., 1993. Greener Buildings. Environmental Impact of Properties, the McMillan Press Ltd., London.

KACST, 1983. Solar Energy Atlas, Kingdom of Saudi Arabia, the King Abdulaziz City for Science and Technology, UPM Press.

KACST, 1986. Wind Atlas, Kingdom of Saudi Arabia, The King Abdulaziz City for Science and Technology, UPM Press.

KACST, 1996. The Present and the Future for Energy Resources. KSA: King Abdulaziz City for Science and Technology.

Kamon, E., 1978. Physiological and Behavioral Responses to the Stress of Desert Climate, Urban Planning for Arid Zones, Ed. Golany, G.

Kano, A, 1971. A Study of the Need for Housing and Development of housing system for Saudi Arabia and the Arabian Gulf, Ph.D. Theses, Houston, Texas, University of Texas.

Kilical, A.,1990 'Vernacular Approach Climatic Variables in Saudi Arabia', King Saud University Journal, Vol.2, Architecture and Planning, Riyadh, pp.99-118,

King, G., 1998. The Traditional Architecture of Saudi Arabia, London, I. B. Tauris and Co (Review).

Koenigsberger, O. H., et al., 1974. Manual of Tropic Housing and building, Longman, London, 1974.

Konya, A., 1980. Design Primer for Hot Climate, Architecture Press, London.

Lawrie, L. K., 1992. Day-to-day use of Energy Analysis Software, Energy Engineering, No 89, pp. 41-51.

LBL, 1981. DOE-2 manuals, Lawrence Berkeley Laboratory, U.S.A.

LE PECO, 1992. "Overview of the Hourly Analysis Programs, Available from Carrier S.A.", Climatisation and Development Group, Paris.

Leach, S. J., 1985. "Energy Saving through Management", Proceeding of the CLIMA 2000 World Congress on HAVC, Copenhagen, Vol.1, pp. 91-103.

LOC, 1997. Saudi Arabia, A Country Study, The Library of Congress **www.http://Icweb2.loc.gov/frd/cs/satoc.html#sa0015**, 10/25/97 pp.1-5.

Lomas, k. J., 1992. "Thermal Modeling of Building Envelopes, The State-Of-The-Art", Proceeding Of Symposium On Energy Efficient Buildings, Kowloon, Hong Kong.

Lowis, D., Michal, C., & Pietz, P., 1979. Design of Residential Building Utilizing Natural Thermal Storage, Division of Buildings and Community System, U.S. Department of Energy, June.

Makki, G. A., 1978. Mecca, The Pilgrimage City, A Study for Pilgrimage Accommodation, CROOM HELM, London.

Makki, G. A., 1981. Characteristics of Pilgrim Accommodations in Mecca and Recommendation for Improvements, Ph.D. Theses, Michigan, Michigan State University.

March, C., 1988. Exploring Data: An Introduction to Data Analysis for Social Science, Cambridge, Polity.

Macquarie University, 2001.
http://atmos.es.mq.edu.au/~rdedear/ashrae rp884 climates.html

Markus T. A., Morris E.N., 1980. Building Climate and Energy, Pitman, London.

Markus, T. A., et al., 1984. The Influence of Climate on Housing, a Simple Technique for the Assessment of Dynamic Energy Behavior, Energy and Building, No.7, pp. 243-259.

Mazaria, E., 1979. The Passive Solar Energy Book, Rodale Press, Emmaus, PA, U.S.A.

MDAMEPA, 1996. Surface Annual Climatological Report, Makkah, Ministry of Defense and Aviation, Meteorology, & Environmental Protection Administration, (Climate Data)

METZ, H. C. 1992. Saudi Arabia, a Country Study. USA: Federal Research Division Library of Congress, U.S.A.

MFNE, 1997. Statistical Year Book, Riyadh, Ministry of Finance and National Economy.

MIE, 1995. Electricity Growth and Development in the Kingdom of Saudi Arabia. Annual Report, Ministry of Industry and Electricity, KSA:

MIE, 1996. Electricity Growth and Development in the Kingdom of Saudi Arabia. Annual Report, Ministry of Industry and Electricity, KSA:

Milbank, N. & Harrington-Lynn, J., 1978. "Thermal Response and the Admittance Procdure", Energy Heating and Thermal Comfort, BRE Building research Series, Vol.4.

Mirza, M., 1985. 'The Impact of Natural Factors on Urban Growth for Makkah Al-Mukarammah', Islamic Cities and Capitals Journal, No.4, pp. 24-40. (Arabic)

Mitalas, G. P., 1972. 'Transfer Function Method for Calculating, Cooling Load, Heat Extraction Rate, and Space Temperature'' ASHRAE Journal, No. 14, pp. 54-56.

MMRA, 1985. Deputy Ministry for Town Planning, Makkah Region, Comprehensive Development Plans, Ministry of Municipal and Rural Affairs Dar Al-Handasah Consultant, Vol.1, Report No.4, pp.106-115.

MMRA, 1989, Makkah, Annual Report, Riyadh, Ministry of Municipal and Rural Affairs.

MMRA, 1989, Rules and Procedures of Obtaining Building Permits, Riyadh, Ministry of Municipal and Rural Affairs.

Mofti, F., 1989. 'Transformation in the Built Environment in Saudi Arabia', Urban Futures, Vol.2, No.4.

MOI, 1992. The Kingdom of Saudi Arabia, Riyadh, Ministry of Information.

MOP, 1975. Second Five-Year Development Plan, Riyadh, Ministry of Planning (Review).

MOP, 1985. Fourth Five-Year Development Plan, Riyadh, Ministry of Planning (Review).

MOP, 1990. Fifth Five-Year Development Plan, Riyadh, Ministry of Planning (Review).

MOP, 1995. Sixth Five-Year Development Plan, Riyadh, Ministry of Planning.

Nevins, R.G. & Mcnall Jr, P. E., 1972. 'ASHRAE Thermal Comfort Standard as Performance Criteria for Buildings', Thermal Comfort and Moderate Heat Stress, Proceeding of the CIB Commission, W45, Human Requirements Symposium, London, No.1, pp.2-11.

Newsham, G. R., 1990. Investigating the Role of Thermal Comfort in the Assessment of Building Energy Performance using a Spatial Thermal Model, Ph.D. Theses, Cambridge.

O'Callaghan, P. W., 1978. Building for Energy Conservation, Pergamon Press, Oxford.

Oesterle, Lieb, Lutz, & Heusler, 1999. Double-Skin Facades, Integrated Planning, Prestel, London.

Ogard, O., Novakovic, & Brustad G., 1988. "HVAC-DYNAMIC – A Training Simulator for Dynamic Analysis of HVAC Plants", Selected Papers IFAC Symposium on Computer Aided Design of Control System, Beijing, PRC, pp.461-466.

Olgyay &Olgyay, 1957. Solar Control and Shading Devices, Princeton University Press, Princeton, New Jersey.

Olgyay, V., 1973. Design with Climate; Biological Approach to Architecture Regionalism, Princeton University Press.

Patton, M. Q., 1990. Qualitative Evaluation and Research Methods. Newbury Park, California, SAGE Publication.

Ragin, C. C., 1994. Constructing Social Research. Thousand Oaks, California, Pine Forge.

Rerkoz, S., Saeed, & Al-Hussayen, M., 1989. An Analytical Study of the Building Production systems Recently Introduced in Saudi Arabia, General Directorate of Research Grants Programs, King Abdulaziz City for Science & Technology, Riyadh (Review).

Roaf, S. & Hancock, M., eds., 1992. Energy Efficient Building, a Design Guide, Blackwell Scientific Publications, London.

Robert, K., 1994. Case Study Research Design and Methods, SAGE Publication Ltd., London (Review).

Rogers, B. T., 1972. "Passive Heat Recovery as an Energy Conservation Measure", Building System Design, Part One.

Rousseau, P. G.,& Mathiews, E. H., 1993. Need and Trend in Integrated Building and HVAC thermal Design Tools, Building and Environment, Vol. 28, No.4, pp. 439-452.

Saini, B. S., 1980. Building in Hot Dry Climate, J. Willey & Sons, New York.

SASO, 1985. Reduce the Electrical Load using Thermal Insulation. Al-Mohandis, Vol.2, No.1, pp. 42-49.

SASO, 1989. Field Study about Reducing Electricity Waste by using Insulation Materials, Al-Muhandis, Vol.2, No1.

Sinden, F. H., 1978. A Two-Thirds Reduction in the Space Heat Requirement of a Twin River Townhouse, Energy and Buildings, Vol.1, pp. 243-253

Soweel, E. F., Hittle, D.C., 1995. Evaluation of Building Energy Simulation Methodology, ASRAE Transaction, 101, pp., 850-855 (Review).

Steadman, P., 1975. Energy Environment and Building, Cambridge University Press, Cambridge.

Strahler, A. N., 1969. Physical Geography, John Wiley & Sons Inc, New York.

Suliman, B. F., 1992. 'Bio-Climatic Analysis and the Evaluation of Building Environment in the City of Makkah', Paper represent at the Fourth Symposium of Geography in Kingdom of Saudi Arabia, Umm Al-Qura University, Makkah.

Szokolay, S. V., 1981. International Conference for Passive Solar Energy. Proceedings, California, U.S.A.

Talib, K., 1983. Shelter in Saudi Arabia, London, Academy Edition (Review).

Tewfik, K. M., 1993. Evaluating the Effect of Design and Construction Deficiencies on the Economic Performance of Wall Thermal Insulation System, Ph.D. theses, University of Michigan.

Tuddenham, D., 1983. Computers in Air Conditioning Load Estimation, *In* Air Conditioning System Design for buildings, A. G. Sherrat, Ed., McGraw Hill, London.

Utzinger, M., 1981. Solar Age, Solar Age Magazine, Harrisville, New Hampshire.

VIT, 1999. Simulation Models as a Decision Support Tool, Technical Paper, www.vit.fi/tte/pub/he4/sim42/engl/building-model.htm.

Walter, T., 1988. Architectural Application of Thermal Insulation, Al-Mohandis, Vol.2,

Warosn, D. & Labs, K., 1992. Climatic Building Design, Energy-Efficient Building Principles and Practice, McGraw-Hill Inc., New York.

Warren, B. R., 1982. Energy Saving in Buildings by Control of Ventilation as a Function of Indoor Carbon Dioxide Concentration, Building Service Engineering Research & Technology, Vol.3, No.1.

Watson, D., ed. 1979. Energy Conservation through Building Design, McGraw-Hill Inc., New York.

Watson, D., ed. 1993. Energy design Hand book, the AIA Press, Washington, D.C.

Webster Merriam, 1993. Webster's Third New International Dictionary, USA: Merriam-Webster Inc.

Wigginton, M., 1996. Glass in Architecture, Phaidon, London.

Wills, G., 1978. Inventing America, Doubleday, New York.

Wiltshire, T.A,. & Wright, A. J., 1987. "The Evaluation of the Simulation Models ESP, HTB2 and SERI-RES for the UK Passive Solar Program". A Report prepared for the Energy Technology Support Unit of the Department of Energy. Building Science. University of Newcastle, Newcastle upon Tyne.

Appendix I

Fieldwork Survey

Serial No. ☐ ☐ ☐ ☐

Please mark where appropriate.

1- Are you?

Owner ☐ 1
Tenant ☐ 2

2- Where is your apartment located?

Upper Floor ☐ 1
Middle Floor ☐ 2
Ground Floor ☐ 3

3- How many people live in this apartment?

__________ *Person*

5- How long have you lived here?

__________ *Years*

6- How many rooms does this apartment have?

__________ *Rooms*

7- How many facade does your apartment have?

One ☐ 1
Two ☐ 2
Three ☐ 3

8- Which way do they face?

East ☐ 1
South ☐ 2
West ☐ 3
North ☐ 4

9 - From the list below, what appliances do you have, and how many?

		No.
A/C	☐	______
Ceiling Fan	☐	______
Elec. Cooker	☐	______
Gas Cooker	☐	______
Micro Wave	☐	______

Prepared by :

Date: / / 1998

10- Approximatly, how many hours do you use them each day?

	No. of hours
A/C ☐	______
Ceiling Fan ☐	______
Elec. Cooker ☐	______
Gas Cooker ☐	______
Micro Wave ☐	______

11- Do you have the lights on during the day?

Not at all ☐ 1
Some time ☐ 2
Always ☐ 3

12- For how long you keep your light on each day?

Day and night ☐ 1
After sunset till midnight ☐ 2
afternoon till midnight ☐ 3
After sunset till sun rise ☐ 4

13- How many hours do you spend in your living room each day?

Between 0-6 Hours ☐ 1
Between 6-12 Hours ☐ 2
Between 12-18 Hours ☐ 3
Between 18-24 Hours ☐ 4

14- What time do you think you need to use your A/C?

All around the year ☐ 1
Only in summer ☐ 2
Some months only ☐ 3

15- What months? (only if you chose no.3 from the above question)

Months

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

16- When you use your A/C, how often during the day ?

1-6 Hrs ☐ 1
Between 6-12 Hrs ☐ 2
Between 12-18 Hrs ☐ 3
For 24 Hrs ☐ 4

17- Have you ever feel over cold when A/C is on?

Always ☐ 1
Most of the time ☐ 2
Rarely ☐ 3
Never ☐ 4

18- If you do feel over cold, what is your usual reaction?

Switch the A/C off ☐ 1
Use heavy cloth ☐ 2
Do nothing ☐ 3

19- Approximately, how many A/Cs usually work at the time?

No. of A/Cs ________

20- Without air conditioning, do you feel that you have the same temperature in all rooms.

Yes ☐ 1
No, only rooms with external facades ☐ 2
I don't know ☐ 3

21-Do you have curtains on your windows?

Yes ☐ 1
No ☐ 2

22-If yes, what is the major purpose for these curtains from your point of view?

Block-out sun radiation ☐ 1
Privacy ☐ 2
Decoration ☐ 3

23- How often in a day you open your windows?

Always ☐ 1
Few times ☐ 2
I don't open them at all ☐ 3

24- If you open your windows, for what reason do you open them?

- Only when outside weather is cool ☐ 1
- Open them for some light ☐ 2
- Only if electricity goes off ☐ 3
- Open it at night only for ventilation ☐ 4
- All the above ☐ 5

25- If you don't open your windows, for what reason you keep them close?

- Because it is very hot out side ☐ 1
- I keep it close for privacy ☐ 2
- Not to lose a/c's cool air ☐ 3
- Block-out the noise ☐ 4
- All the above ☐ 5

26- How much you pay for electricity each month in average?

- Less than 100 SR ☐ 1
- Between 100-200 SR ☐ 2
- Between 200-300 SR ☐ 3
- More than 300 SR ☐ 4

27- Thinking about your income, how would you say these bills are?

- High ☐ 1
- Not very high ☐ 2
- Low ☐ 3

28- Are you satisfy with your A/Cs cooling performance against what you used to pay for electricity?

- Satisfy ☐ 1
- Not satisfy ☐ 2

29- What appliances do you think that make your bills high?

- A/C ☐ 1
- Ceiling Fan ☐ 2
- Elec. Cooker ☐ 3
- Micro Wave ☐ 4

30- Have you used to live in comfortable indoor environment despite the expected high electricity bill?

Yes and I don't mind the high bills ☐ 1
No, I do control my A/Cs operation. ☐ 2
Not Sure ☐ 3

31- Do you think that you can have a comfortable indoor Temperature while maintaining low electricity bill?

Yes ☐ 1
Some times ☐ 2
No ☐ 3

32- If yes, would you please explain how can you do this?

____
____
____

33- How much do you think the following can help to reduce you electricity bills without sacrificing your indoor comfort?

	No effect	Little effect	Considerable Effect
Control A/C operational time	☐ 1	☐ 2	☐ 3
Open windows for natural ventilation at night	☐ 1	☐ 2	☐ 3
Limit your activities in one room	☐ 1	☐ 2	☐ 3
Shading your windows to prevent hot sun	☐ 1	☐ 2	☐ 3
Sealing your openings against infiltration	☐ 1	☐ 2	☐ 3

34- Have you ever tried to do any of these before?

Yes, all of them ☐ 1
Yes, most of them ☐ 2
No, I never think about it ☐ 3

35- Do you know about insulation materials?

Yes ☐ 1
No ☐ 2
I am not sure ☐ 3

36- Is this building insulated?

Yes ☐ 1
No ☐ 2
I don't know ☐ 3

37- If Yes, is it better than any uninsulated building you have lived in?

Yes ☐ 1
No ☐ 2
I don't feel any difference ☐ 3

38- Do you like to move to an insulated building?

Yes ☐ 1
No, insulation is not important to me ☐ 2
I am not sure ☐ 3

39- If you own this building, do you apply install thermal insulation?

Yes ☐ 1
No ☐ 2

40- If no, would you explain why not?

It is very costly ☐ 1
It cause disturbance ☐ 2
I am not sure ☐ 3

الرجاء التكرم بوضع اشارة داخل المربع المناسب

رقم العينة :

١- هل انت ؟
مالك ☐ ١
مستاجر ☐ ٢

٢- فضلا , اين تقع هذه الشقة بالنسبة للعمارة ؟
في الدور العلوي ☐ ١
في الادوار الوسطى ☐ ٢
في الدور الارضي ☐ ٣

٣- فضلا , كم شخصا يعيش هنا ؟
________ شخص

٤- كم سنة وانت تعيش هنا ؟
________ سنة

٥- كم عدد الغرف في هذه الشقة ؟
________ غرفة

٦- كم واجهة للشقة ؟

		شمال	شرق	جنوب	غرب
واجهة واحدة	☐ ١	☐	☐	☐	☐
واجهتين	☐ ٢	☐	☐	☐	☐
ثلاث واجهات	☐ ٣	☐	☐	☐	☐

٧- كم عدد الاجهزة التي لديك من القائمة التالية ؟
مكيف ________
مروحة سقف ________
فرن كهربائي ________
فرن غاز ________
مايكروويف ________

٨- تقريبا , ماهي عدد ساعات العمل اليومي لهذه الاجهزة ؟
مكيف ________ ساعة
مروحة سقف ________ ساعة
فرن كهربائي ________ ساعة
فرن غاز ________ ساعة
مايكروويف ________ ساعة

٩- هل تضيء الانوار الكهربائية في النهار ؟
لا اضيئها ابدا ☐ ١
اضيئها في بعض الاوقات ☐ ٢
اضيئها دائما ☐ ٣

١٠- تقريبا , ماهي فترة استخدامك للاضاءة الكهربائية في اليوم ؟
في الليل والنهار ☐ ١
من بعد المغرب حتى منتصف الليل ☐ ٢
من بعد الظهيرة حتى منتصف الليل ☐ ٣
من بعد المغرب حتى الفجر ☐ ٤

١١- ماهي فترة الاستعمال اليومي لغرفة المعيشة ؟

- من الصباح الي الظهر ☐ ١
- من الصباح الي المغرب ☐ ٢
- من بعد العصر حتى منتصف الليل ☐ ٣
- من الصباح حتى منتصف الليل ☐ ٤

١٢- في اعتقادك , ماهو الوقت من السنة التي تحتاج فيها لاجهزة التكييف ؟

- طوال العام ☐ ١
- في اشهر الصيف فقط ☐ ٢
- في اشهر محددة فقط ☐ ٣

١٣- اذا كان الجواب باشهر محددة , ماهي هذة الاشهر من فضلك ؟

محرم	صفر	ربيع ١	ربيع ٢	جماد ١	جماد ٢
رجب	شعبان	رمضان	شوال	ذوالقعدة	ذوالحجه

١٤- تقريبا , ماهي الفترة الاعتيادية لاستخدامك لاجهزة التكييف خلال اليوم ؟

- من ١ - ٦ ساعات يوميا ☐ ١
- من ٦- الي ١٢ ساعة يوميا ☐ ٢
- من ١٢ الي ١٨ ساعة يوميا ☐ ٣
- طوال الاربعة والعشرون ساعة ☐ ٤

١٥- هل حصل وان شعرت بالبرد اثناء عمل جهاز التبريد ؟

- دائما ☐ ١
- في معظم الاوقات ☐ ٢
- فقط في مرات قليلة ☐ ٣
- لا , لم اشعر بذلك ابدا ☐ ٤

١٦- اذا حصل وشعرت بالبرد اثناء عمل جهز التكييف , ماذا يمكن ان تعمل ؟

- اطفيء جهاز التكييف ☐ ١
- استعمل غطاء ثقيل ☐ ٢
- لا افعل شيء ☐ ٣

١٧- تقريبا , كم جهاز تكييف يعمل في نفس الوقت في اليوم ؟

______________ جهاز

١٨- بدون تكييف , هل تشعر ان جميع الغرف في منزلك لها نفس درجة الحرارة ؟

- نعم , جميعها متساوية ☐ ١
- لا , الغرف المطلة الي الخارج درجة حرارتها اعلى ☐ ٢
- لا ادري ☐ ٣

١٩- هل جميع نوافذك محمية بالستائر ؟

- نعم ☐ ١
- لا ☐ ٢

٢٠- ماهو السبب الرئيسي لاستخدامك للستائر ؟

- لمنع الضوء وحرارة الشمس ☐ ١
- للسترة والخصوصية ☐ ٢
- للزينة والديكور ☐ ٣

٢١- تقريبا , ما هو المعدل اليومي لفتح نوافذ منزلك ؟
- افتح النوافذ دائما ☐ ١
- مرات قليلة فقط ☐ ٢
- لا افتحها مطلقا ☐ ٣

٢٢- ماهو السبب الذي يجعلك تفتح نوافذك ؟
- عندما يكون الجو الخارجي لطيف ☐ ١
- للحصول علي اضاءة طبيعية ☐ ٢
- افتح النوافذ للتهوية الليلية ☐ ٣
- اضطر لفتحها عند انقطاع التيار الكهرباني ☐ ٤
- جميع الاسباب المذكورة ☐ ٥

٢٣- ماهو السبب الذي يمنعك من فتح نوافذ منزلك ؟
- حرارة الجو الخارجي ☐ ١
- خصوصية المنزل والسترة ☐ ٢
- لعدم تسرب هواء التكييف الي الخارج ☐ ٣
- الازعاج والضوضاء ☐ ٤
- جميع الاسباب المذكورة ☐ ٥

٢٤- تقريبا , ماهو المعدل الشهري لفاتورة الكهرباء ؟
- اقل من ١٠٠ ريال ☐ ١
- من ١٠٠ ال ٢٠٠ ريال ☐ ٢
- من ٢٠٠ ال ٣٠٠ ريال ☐ ٣
- اكثر من ٣٠٠ ريال ☐ ٤

٢٥- بالمقارنة لدخلك الشهري , كيف تصف هذة الفاتورة ؟
- عالية ☐ ١
- معتدلة ☐ ٢
- منخفضة ☐ ٣

٢٦- في مقابل ما تدفعة للكهرباء شهريا , هل درجة تكييف منزلك مرضية بالنسبة لك طوال الشهر ؟
- مرضية ولم اشعر بالحر مطلقا ☐ ١
- ليست مرضية , اضطر للاستغناء عن التكييف في بعض الاوقات ☐ ٢

٢٧- في اعتقادك , ايا من الاجهزة التالية تساهم في ارتفاع فاتورة الكهرباء لديك ؟
- مكيف ☐ ١
- مروحة سقف ☐ ٢
- فرن كهرباني ☐ ٣
- فرن غاز ☐ ٤
- مايكروويف ☐ ٥

٢٨- هل اعتدت الحصول علي افضل تكييف للداخل بغض النظر عن قيمة الفاتورة المتوقعة ؟
- نعم , اعتدت علي ذلك ☐ ١
- لا , اراقب استخدام التكييف باستمرار ☐ ٢
- لست متاكد ☐ ٣

٢٩- هل تعتقد ان في استطاعتك توفير جو مريح بفاتورة كهرباء اقل ؟
- نعم ☐ ١
- في بعض الاوقات ☐ ٢
- لا ☐ ٣

٣٠- اذا كان الجواب بنعم , كيف يمكن ذلك ؟

____
____
____

٣١- في وجهة نظرك , ماهو تاثير العوامل التالية في تقليص قيمة فاتورة الكهرباء من دون ان تؤثر علي درجة الحرارة المريحة بالداخل ؟

	لا يؤثر مطلقا	يؤثر	يؤثر كثيرا
أ- التحكم في فترات استخدام اجهز ة التكييف	☐ ١	☐ ٢	☐ ٣
ب- تبريد الداخل بو اسطة التهو ية الليلية من خلال فتح النوافذ	☐ ١	☐ ٢	☐ ٣
جـ- استخدام اقل عدد من الغرف لممارسة الانشطة اليومية	☐ ١	☐ ٢	☐ ٣
د- تقليل درجات الحرارة بواسطة حماية النوافذ من حرارة الشمس	☐ ١	☐ ٢	☐ ٣
هـ - احكام سد المنافذ لعدم تسرب الهواء من والي الفراغ الداخلي	☐ ١	☐ ٢	☐ ٣

٣٢- هل جربت ان تفعل هذه الحلول ؟
نعم , جربتها جميعها ☐ ١
نعم , بعض منها ☐ ٢
لا , لم افكر في ذلك مطلقا ☐ ٣

٣٣- هل لديك فكرة عن مواد العزل الحراري ؟
نعم ☐ ١
لا ☐ ٢
لست متاكدا ☐ ٣

٣٤- هل المنزل الذي تسكن فيه الان معزولا حراريا ؟
نعم ☐ ١
لا ☐ ٢
لست ادري ☐ ٣

٣٥- اذا كان معزولا حراريا , هل هو افضل من اي منزل غير معزول سبق وان سكنت فيه؟
نعم ☐ ١
لا ☐ ٢
لا اجد اختلافا ☐ ٣

٣٦- لو عرض عليك منزلا معزولا حراريا , هل يجعلك تفكر في الانتقال اليه ؟
نعم ☐ ١
لا , العزل الحراري ليس مهم بالنسبة لي ☐ ٢
لا , لست متاكد من انه سيكون افضل ☐ ٣

٣٧- لو كنت صاحب المنزل , هل تعمل علي تركيب العوازل الحرارية الان ؟
نعم ☐ ١
لا ☐ ٢

٣٨- اذا كان الجواب بالنفي , فلماذا من فضلك ؟
العملية مكلفة ماديا ☐ ١
العملية تحتاج الي هدم وتكسير وتسبب ازعاج للساكنين ☐ ٢
غير متاكد من فعالية العوازل الحرارية واحتاج الي معلومات اكثر ☐ ٣

المملكة العربية السعودية
وزارة الشئون البلدية والقروية
أمانة العاصمة المقدسة
الادارة العامة للتخطيط العمراني

مراحل النطاق العمراني المقترح

السكان

حدود حرم مكة
حرم حدود المشاعر
حدود النطاق العمراني
حد حماية التنمية

الطاقة الاستيعابية للنطاق العمراني الحالي والمناطق المقترح اضافتها

المنطقة	المساحة	الكثافة المقترحة	عدد السكان
الرمز	كم٢	شخص/هكتار	مليون نسمة
أولاً النطاق العمراني الحالي			
المرحلة الأولى	١٣٩٫١٠	متعددة	١٫٣٤٤
المرحلة الثانية (١)	٢٨٦٫١٧	٣٥ - ٦٧	١٫١٤١
جملة	٤٢٥٫٢٧		٢٫٤٨٥
ثانياً المناطق المقترح اضافتها			
حدود حرم مكة	١٧٤٫١	٣٥	٠٫٦٠٩
حد حماية التنمية	٢٩١٫٢	٣٥	١٫٠١٩
جملة	٤٦٥٫٣	٣٥	١٫٦٢٨
جملة (أولاً + ثانياً)	٨٩٠٫٥٧		٤٫١١٣

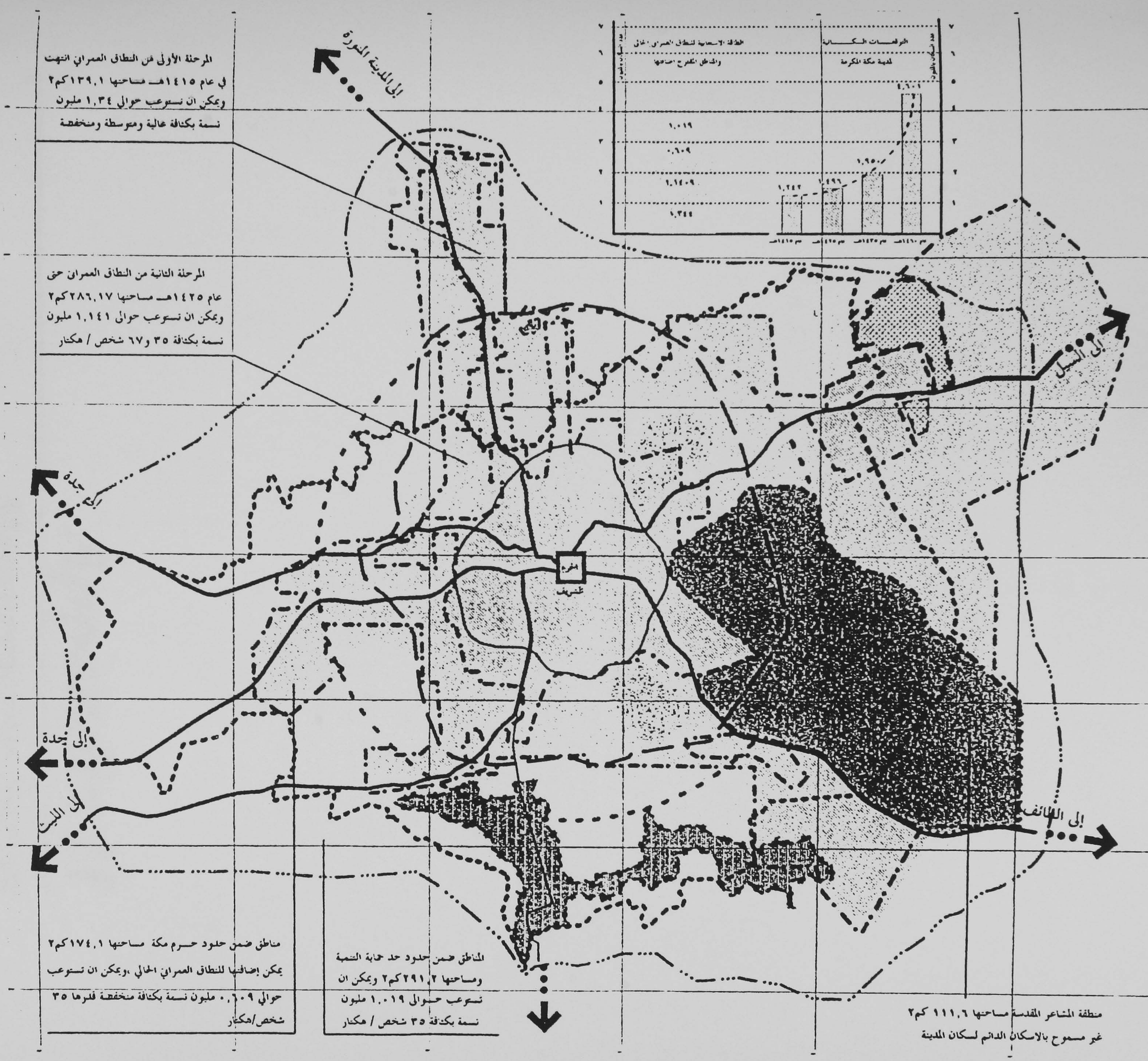
(١) ...

التوقعات السكانية لمدينة مكة المكرمة

عدد السكان عام ١٤٢٠هـ : ١٫٢٤٢ مليون نسمة
عدد السكان عام ١٤٢٥هـ : ١٫٤٩٦ مليون نسمة
عدد السكان عام ١٤٣٥هـ : ١٫٩٥٠ مليون نسمة
عدد السكان عام ١٤٦٠هـ : ٤٫٦٠١ مليون نسمة

مشروع
دراسات النطاق العمراني

الموضوع
السكان



Appendix II

Measurements Survey

DATA RECORD SHEET

Case no. : One

Apartment reference: Mr. A. H.

Date of record:

Start Logging : 19 July 1998

End Logging : 22 July 1998

Logging Details:

Probe No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1			1	3	No A/C Current measurement
2			2	4	due to wiring system
3			Corridor	5	
4				6	
5				2	* Co2 probe for this channel
6					
7					
8					
9			Corridor		* RH%
10					

Building Details :

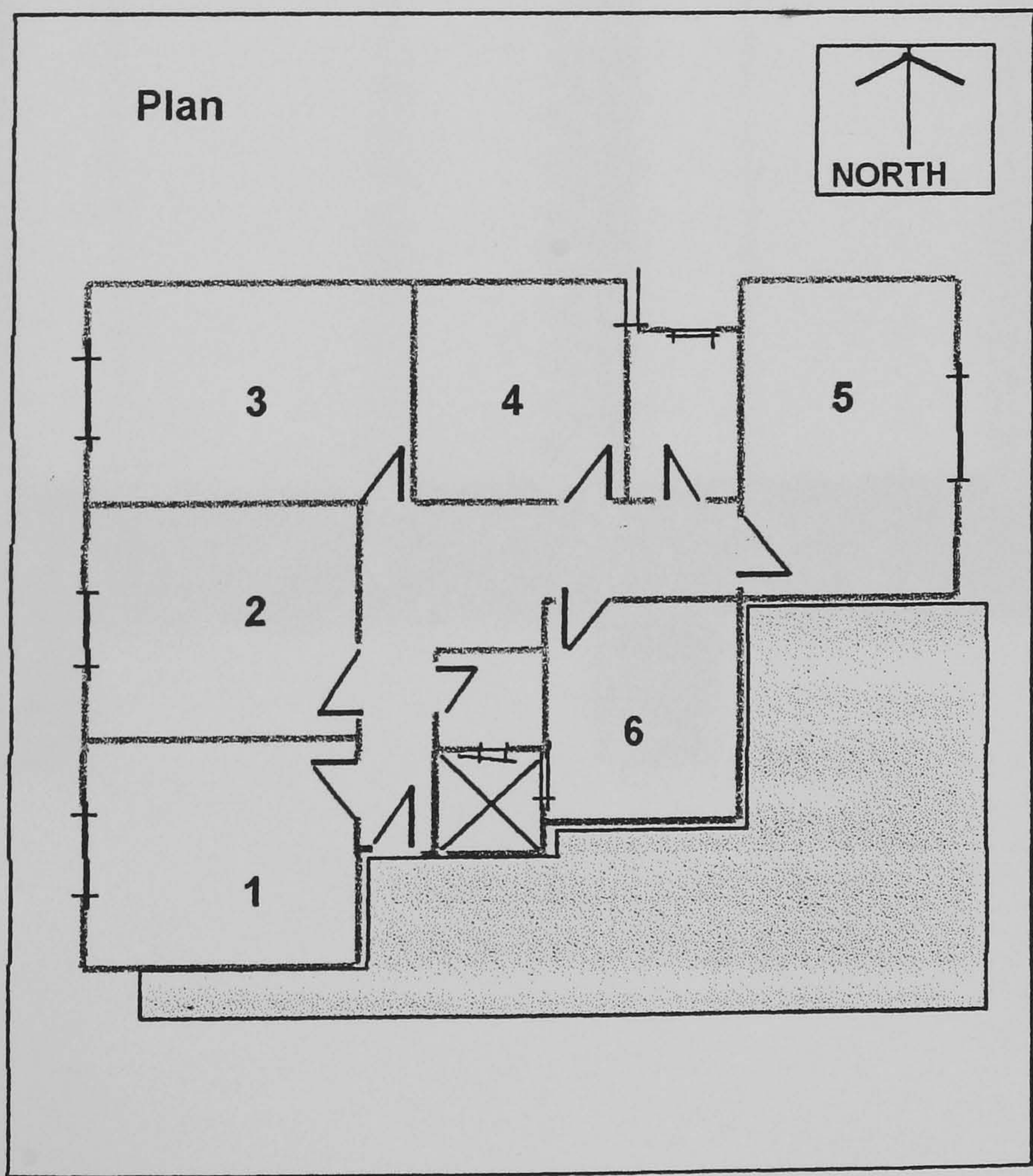
Location : Ground Floor Apartment

Construction :

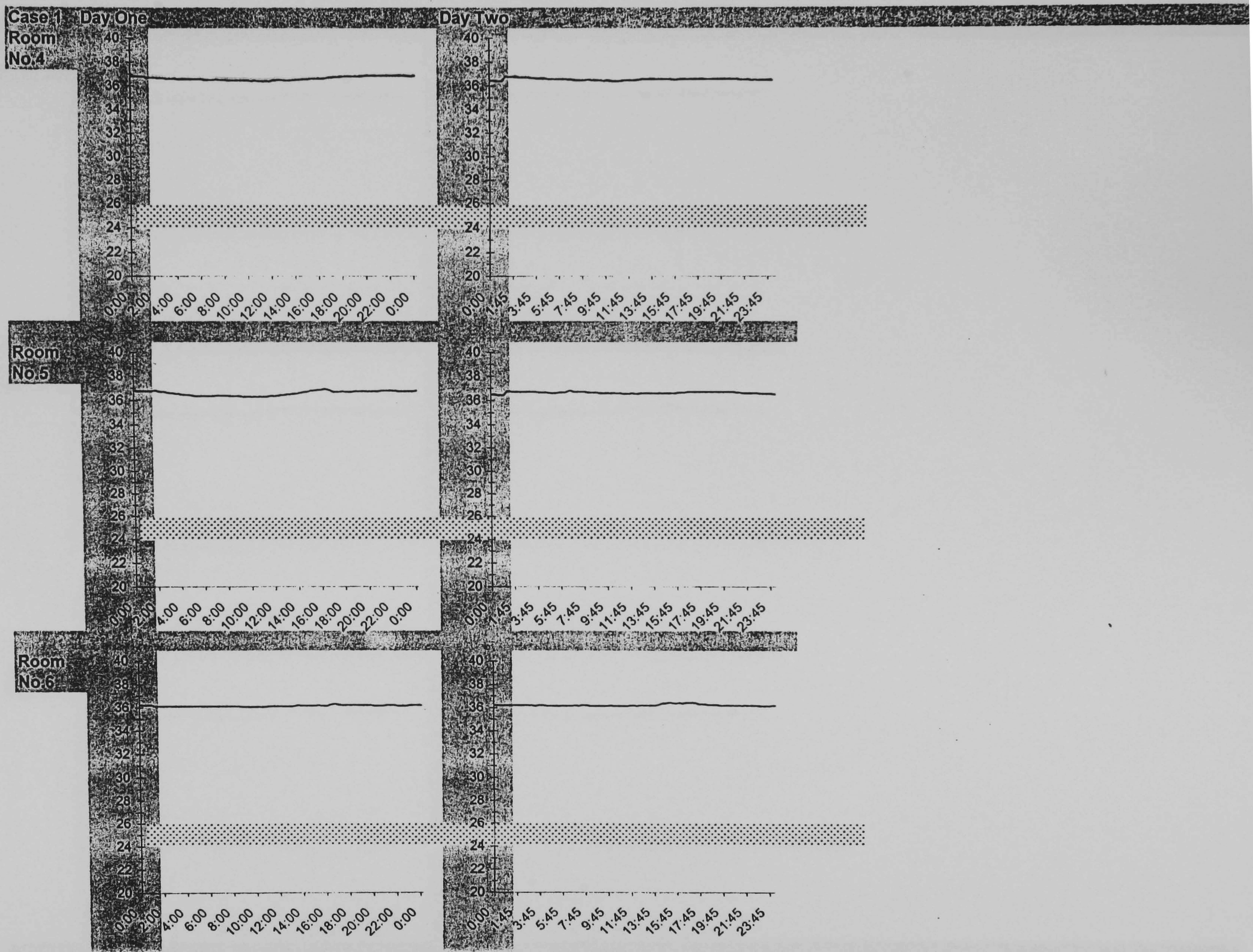
1- Reinforced concrete frame structure
2- Hollow ceramic block for the envelope covered with sand cement rendering
3- Single reflective glazing windows with aluminum frame

Notes :

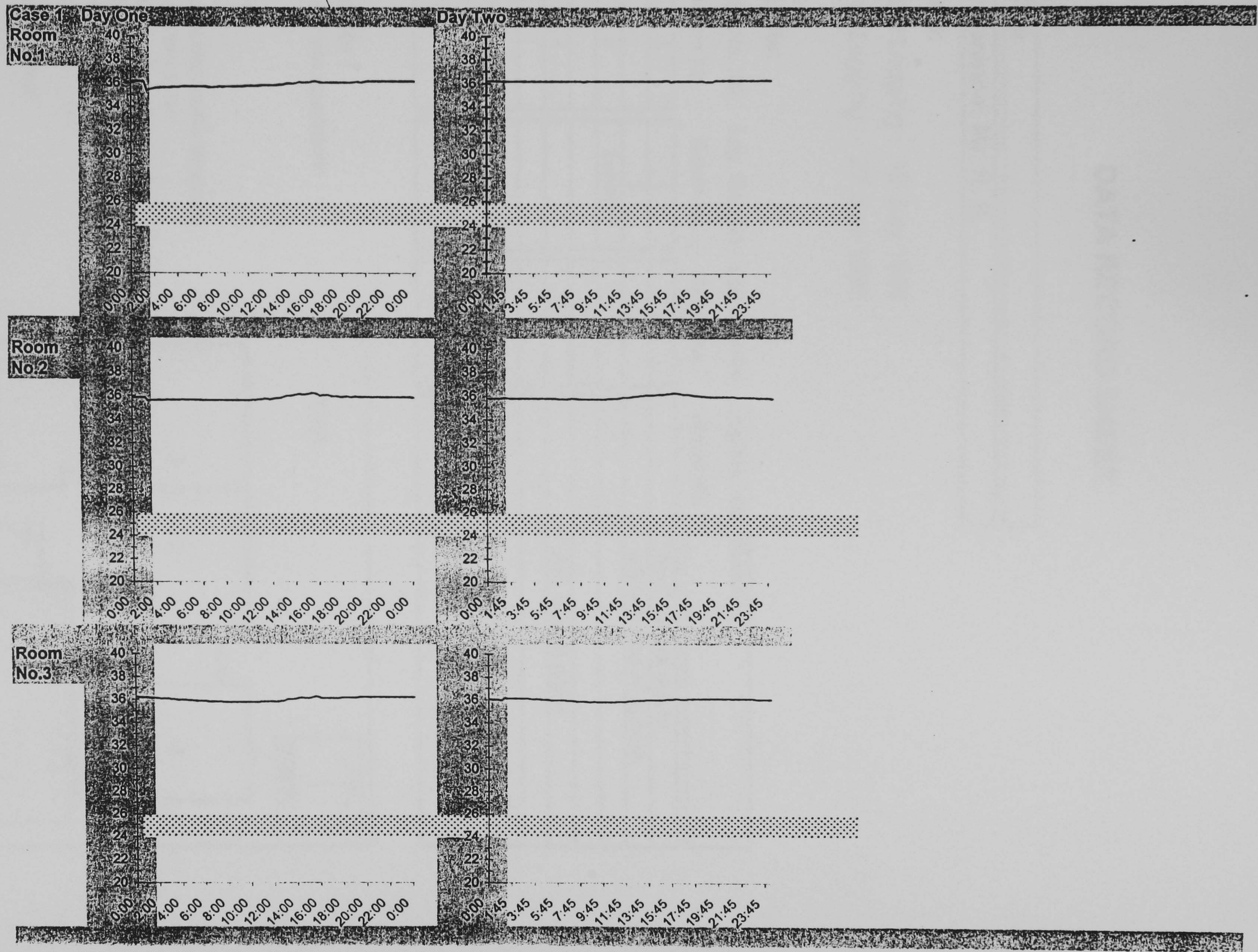
This apartment was not occupied when measurements took place.
No curtains or blinds on windows
No mechanical cooling used



c:/fieldwork/case1/8/14/00



Case 1
Day One
Day Two
Room No.4
Room No.5
Room No.6
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
1:45
3:45
5:45
7:45
9:45
11:45
13:45
15:45
17:45
19:45
21:45
23:45


Case 1: Day One
Day Two
Room No.1
Room No.2
Room No.3
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
1:45
3:45
5:45
7:45
9:45
11:45
13:45
15:45
17:45
19:45
21:45
23:45

DATA RECORD SHEET

Case no. : Two

Apartment reference: Mr. R. S.

Date of record:

Start Logging : 19 July 1998

End Logging : 27 July 1998

Logging Details:

Probe No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1	3	1			* No CO2 test due to
2		2			uncontrolled air spaces
3	4	corridor			
4					
5	4				* A/C current probe
6					
7					
8					
9	4	corridor			* RH %
10					

Building Details :

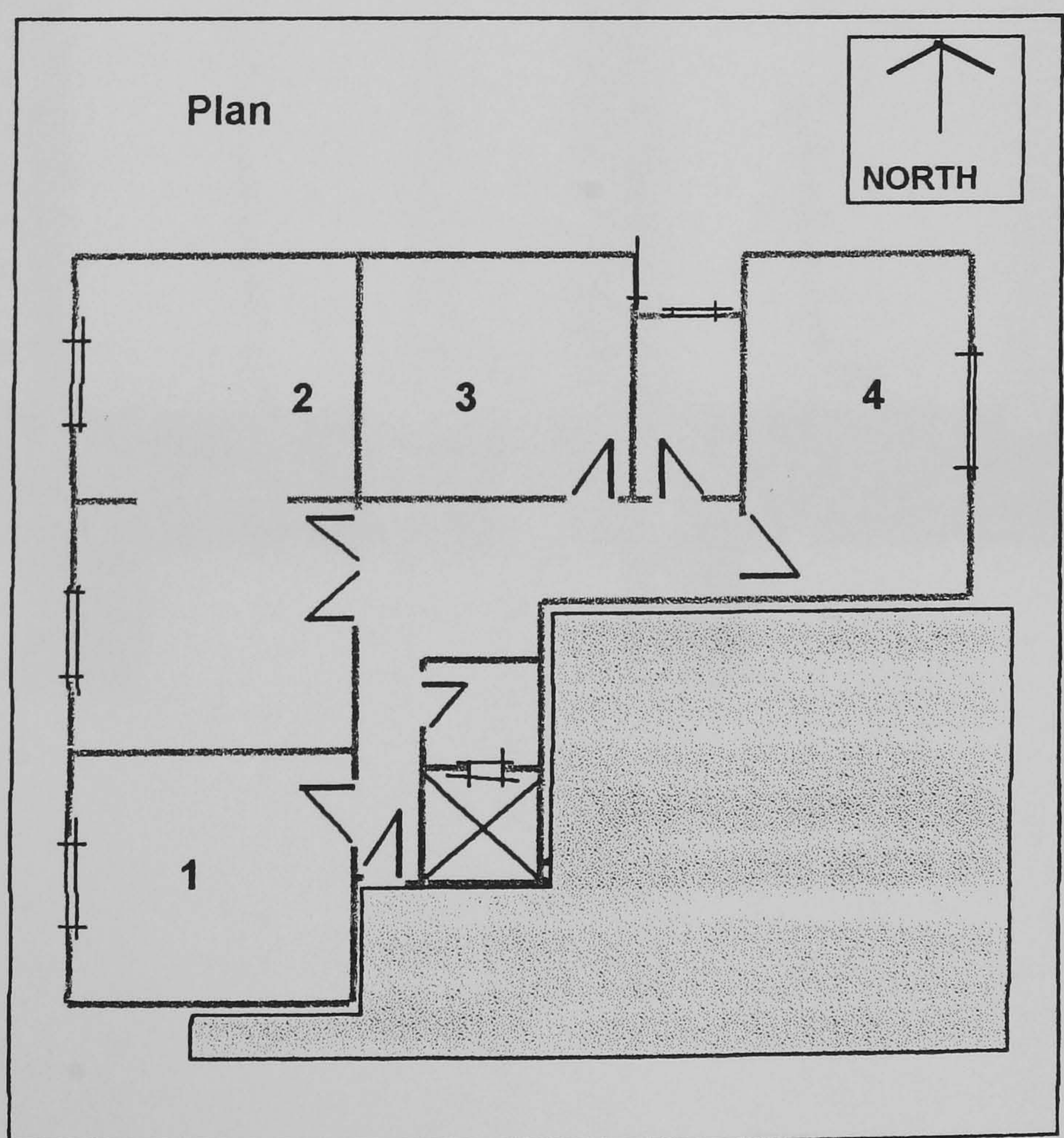
Location : Top Floor Apartment

Construction :

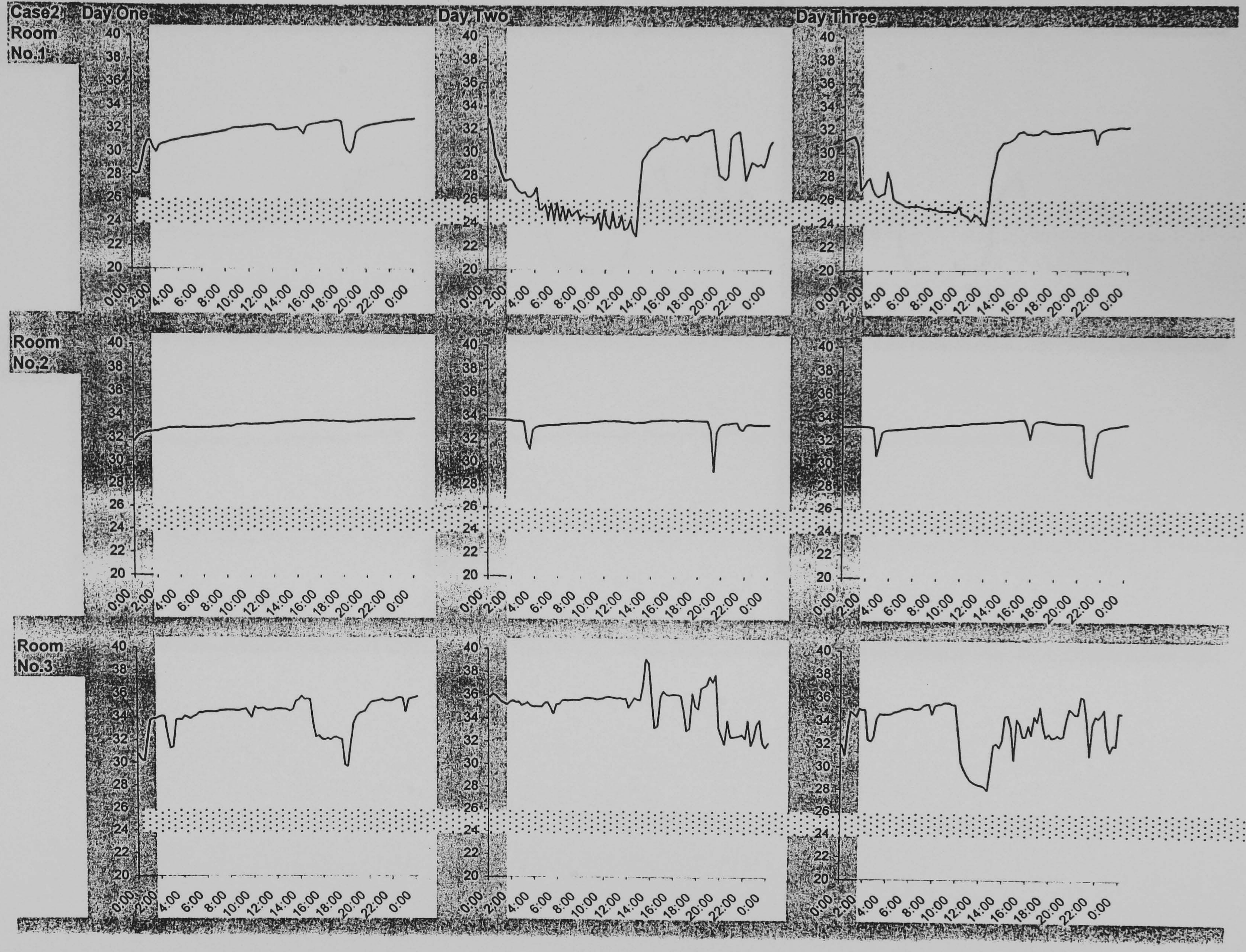
1- Reinforced concrete frame structure
2- Hollow ceramic block for the envelope covered with sand cement rendering
4- Single reflective glazing windows with aluminum frame
5- Exposed insulated roof

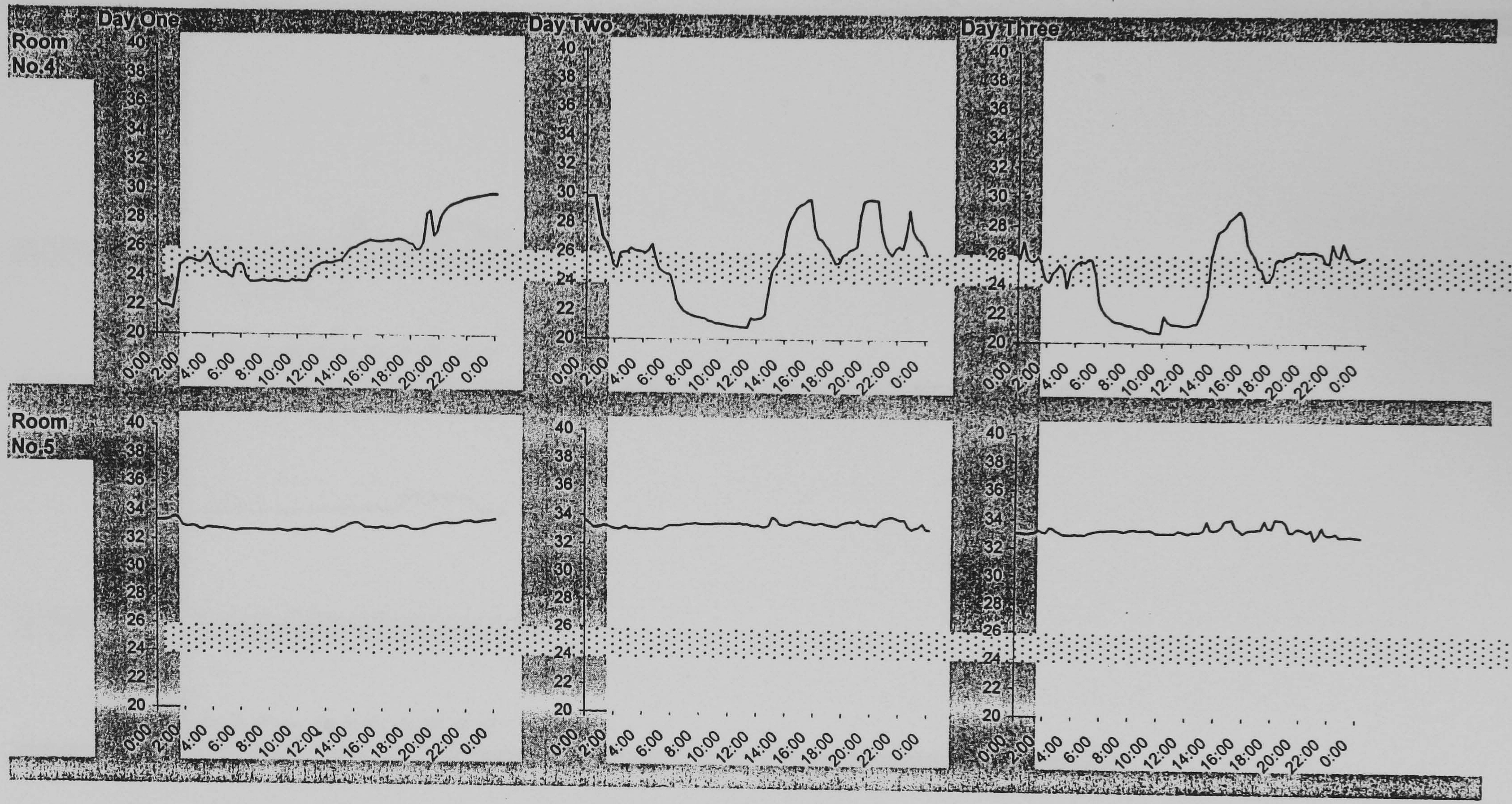
Notes :

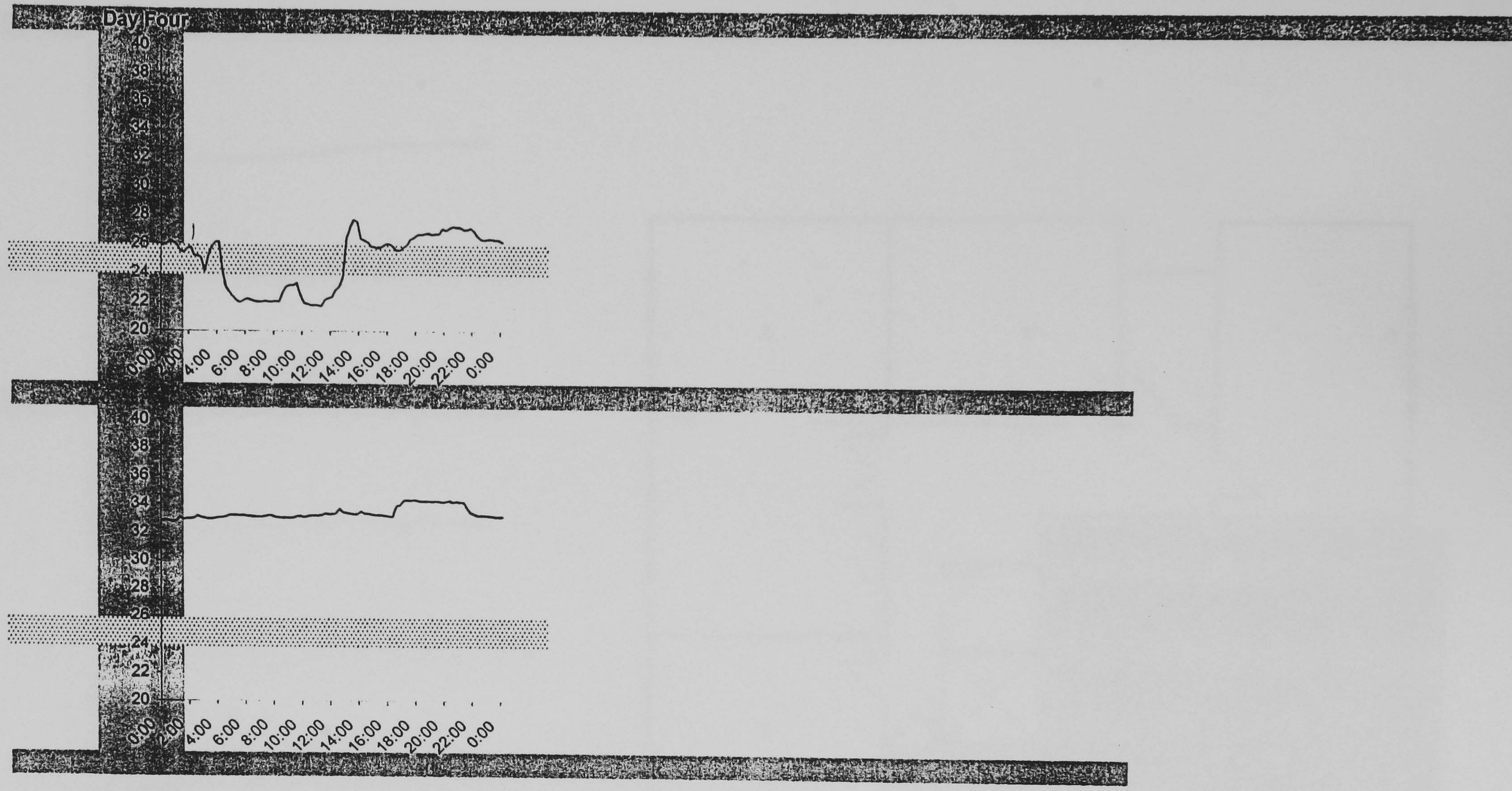
- Four Adults + Three childeren
- Living room has a daily occupancy of 20 hours
- All windows are with curtains
- All rooms are fitted with window type A/C units



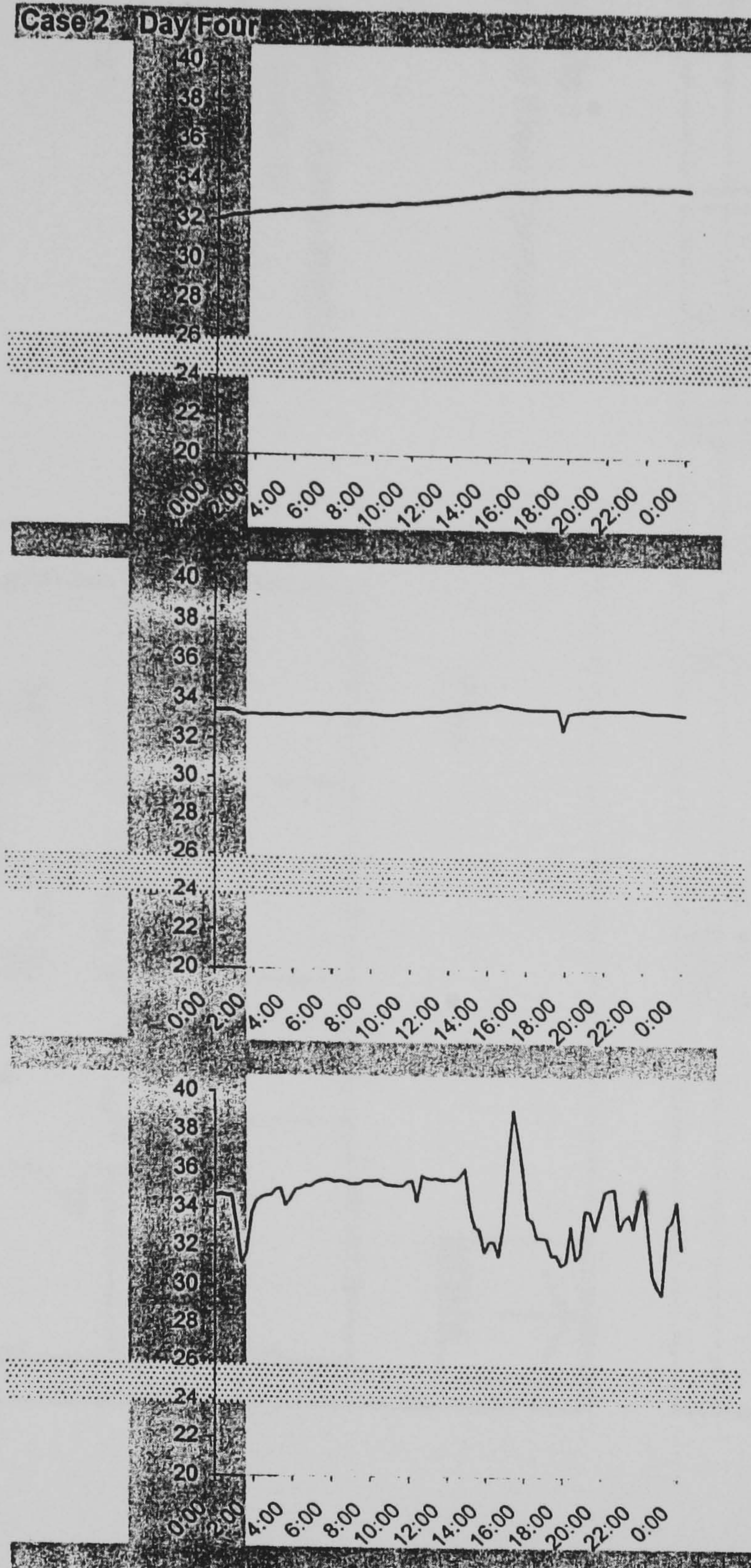
15


Case2
Room
No.1
Room
No.2
Room
No.3
Day One
Day Two
Day Three
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00

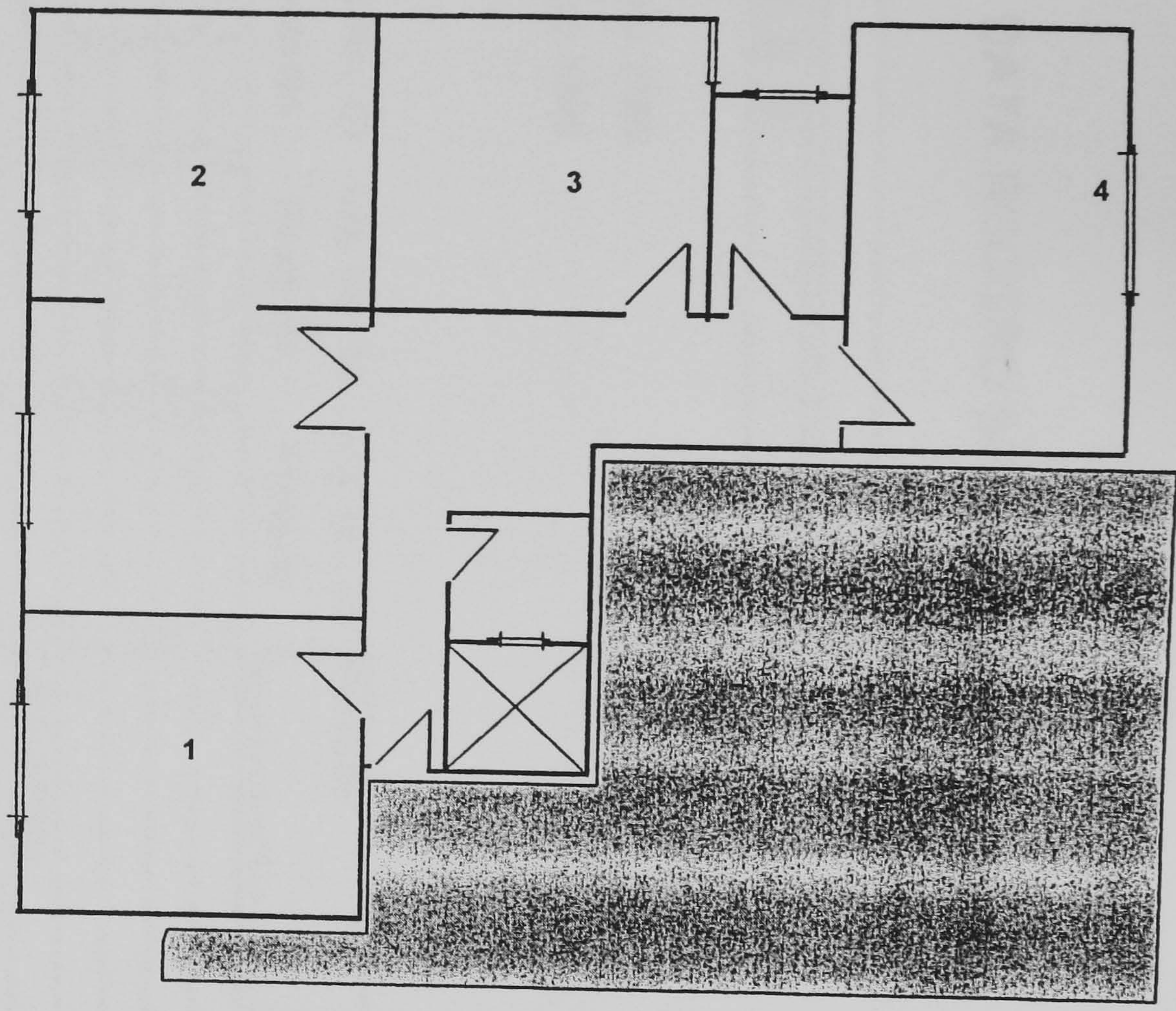

Room No.4
Room No.5
Day One
Day Two
Day Three
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00



Day Four
40
38
36
34
32
30
28
26
24
22
20
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00 0:00
40
38
36
34
32
30
28
26
24
22
20
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00 0:00



Case 2 Day Four
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00



2
3
4
1

DATA RECORD SHEET

Case no. : Three
Apartment Reference: Mr. S. M.

Date of record:

Start Logging : 2 Aug. 1998

End Logging : 8 Aug. 1998

Logging Details:

Ch. No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1		1			
2		3			
3		2			
4		4			
5		2			* A/C current
6					
7		4			* CO2 probe
8					
9		2			* RH %
10		4			* RH%

Building Details :

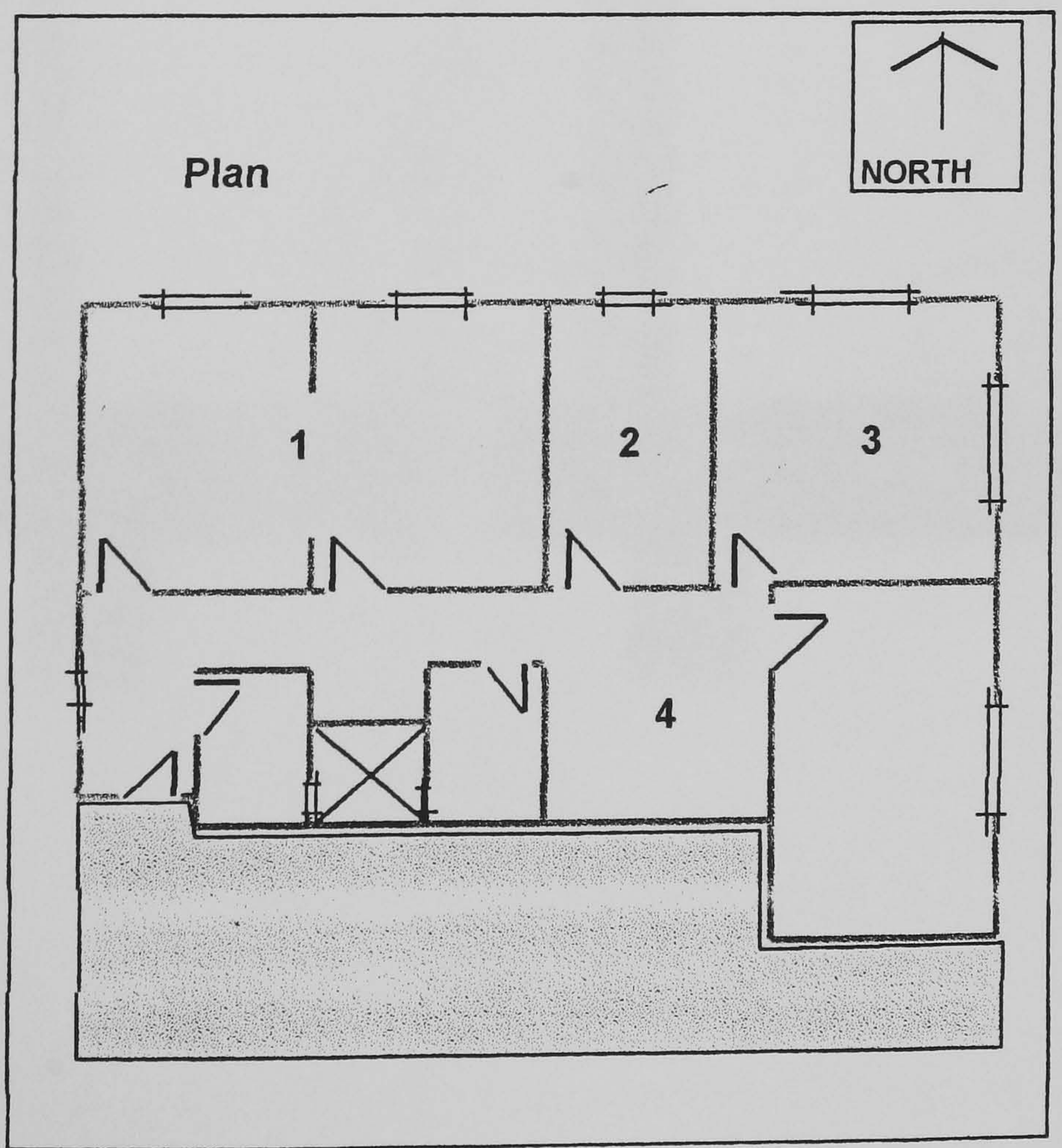
Location : Ground Floor Apartment

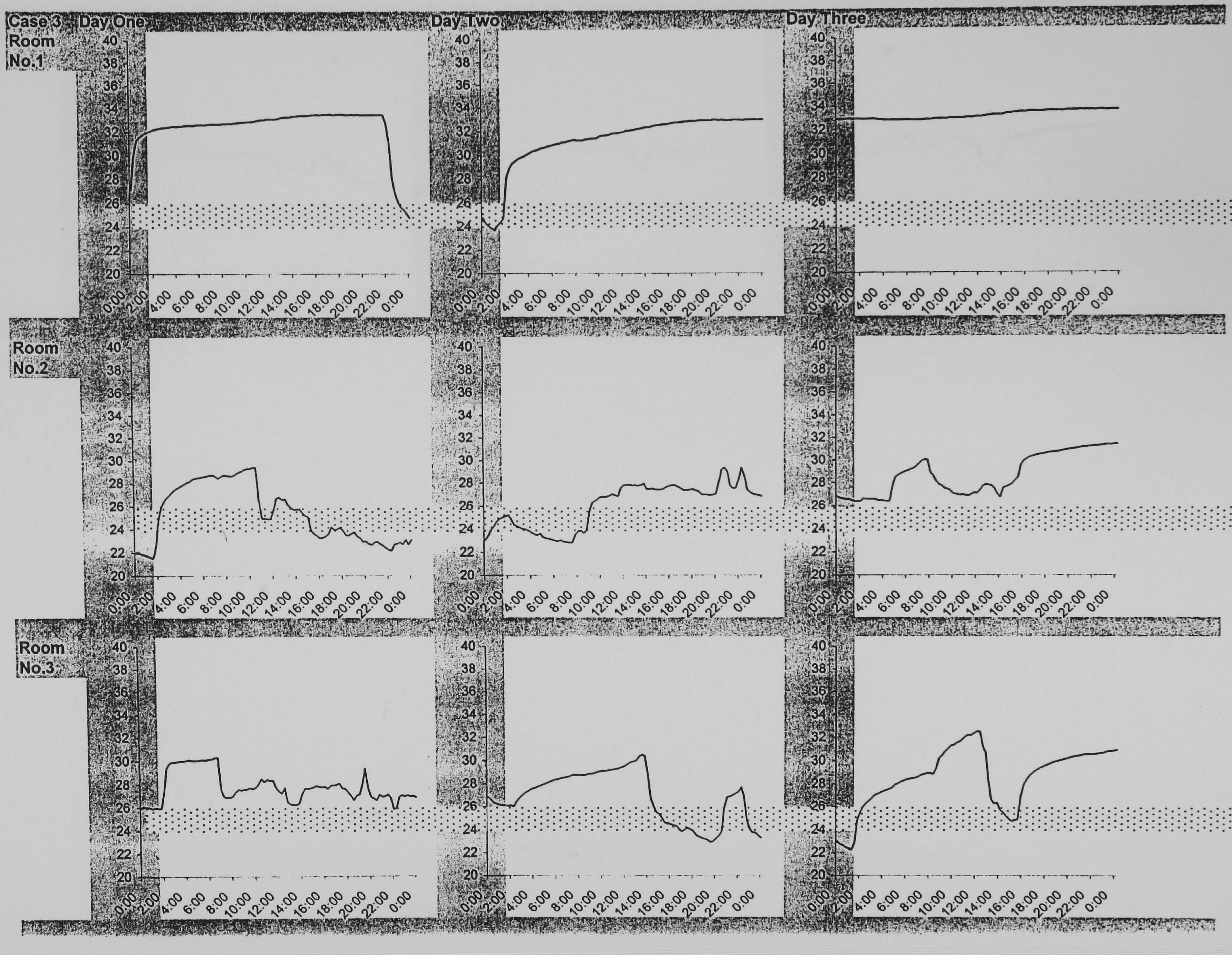
Construction :

1- Reinforced concrete frame structure
2- Hollow ceramic block for the envelope covered with sand cement rendering
3- Single glazing windows with aluminum frame

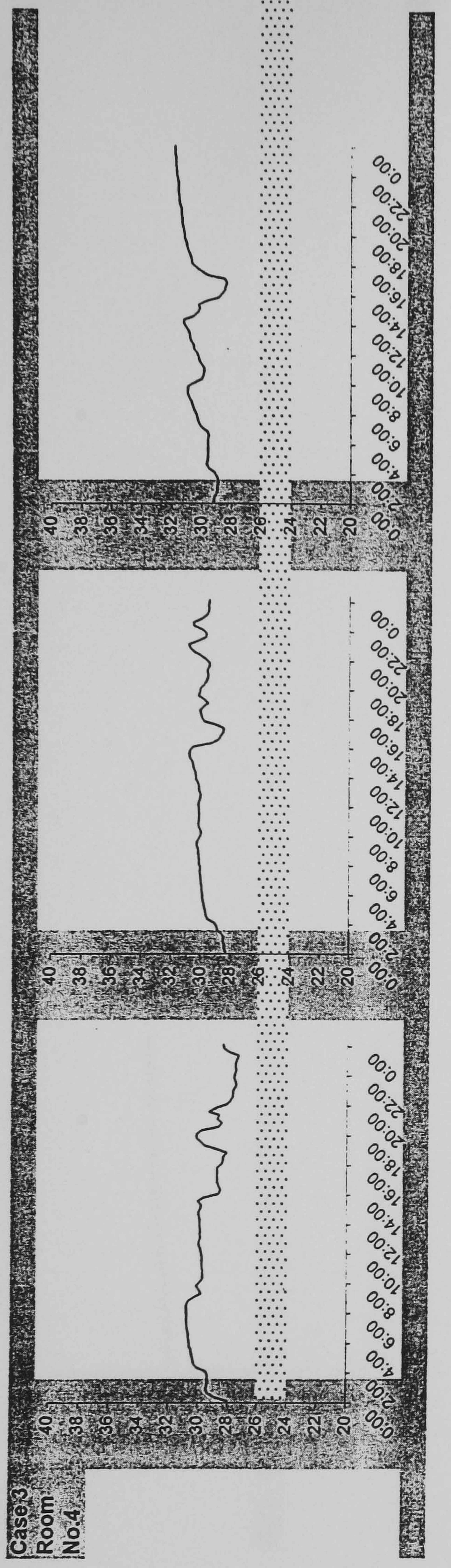
Notes :

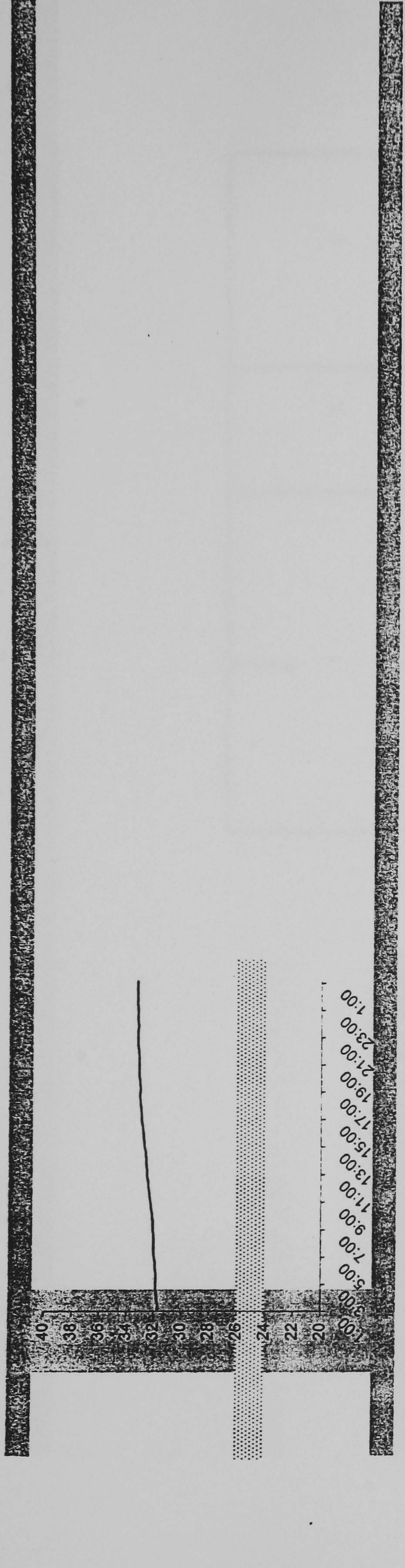
. Three adults + Three Children
. All windows are with curtains
. Window type A/C units are fitted in all rooms
. Living room has a daily occupancy of 16 hours
. No A/C in the Living space
. The living space is centrally located and has no outside surfaces



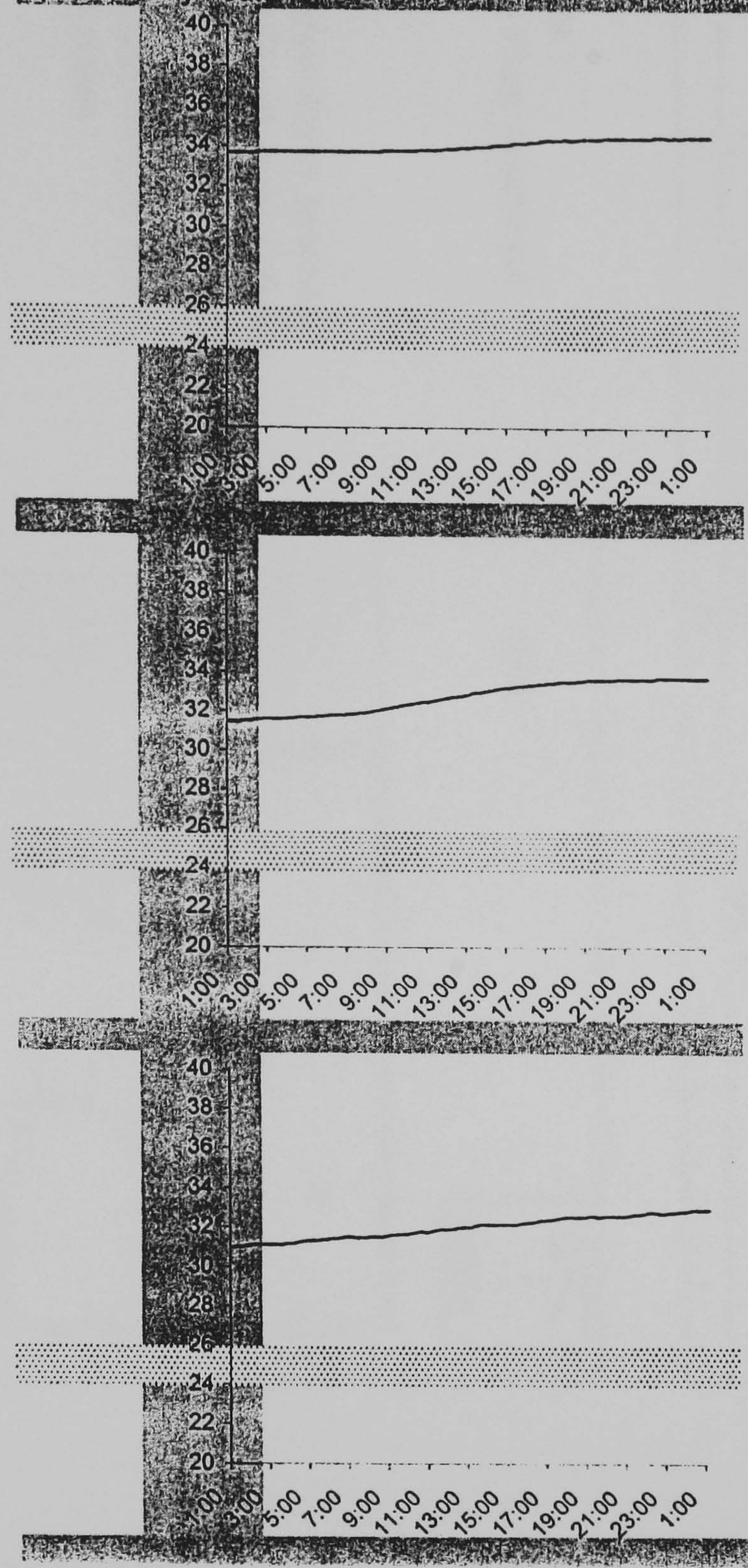


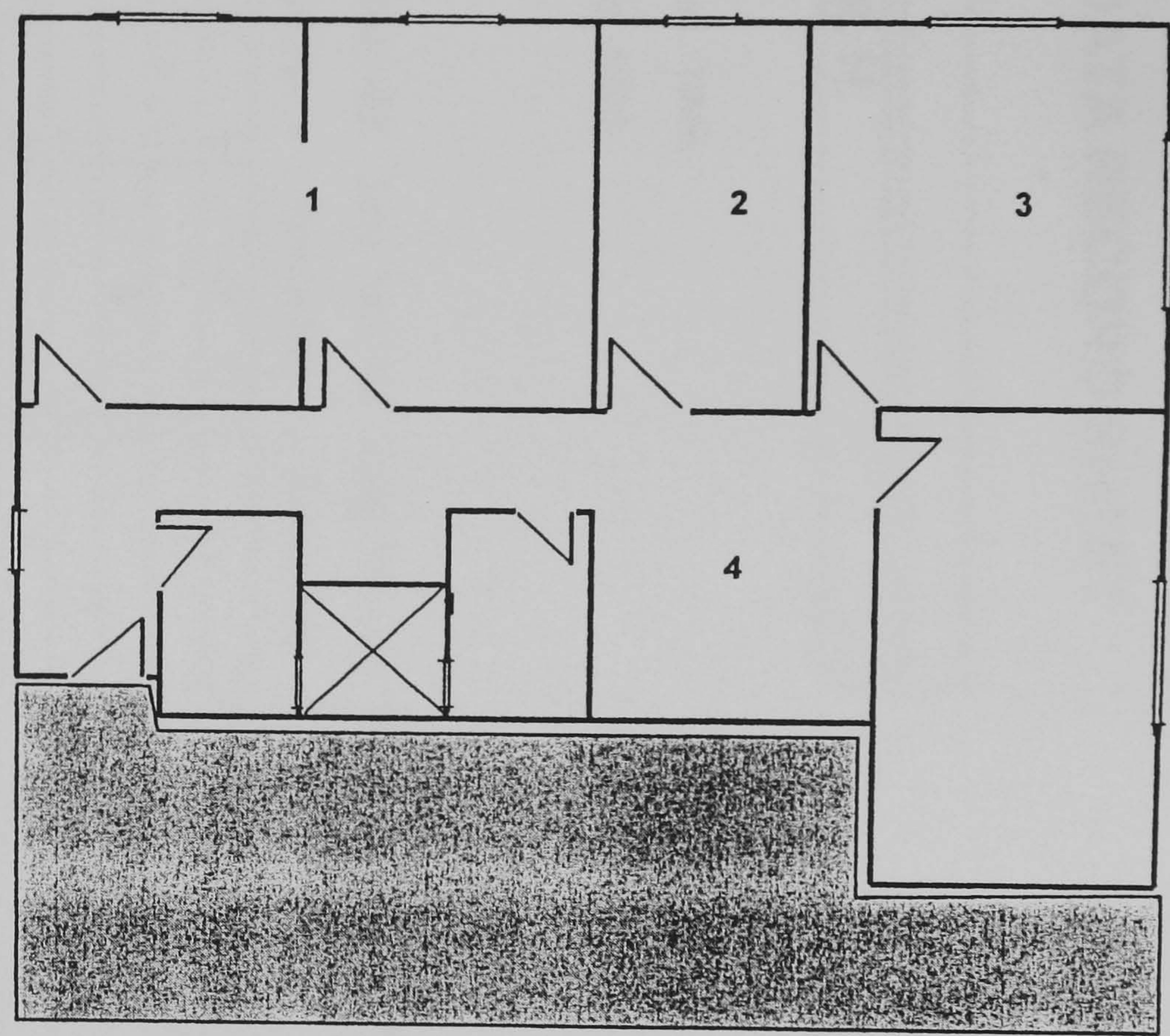
21


Case3 Room No.4
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00


40
38
36
34
32
30
28
26
24
22
20
1:00
3:00
5:00
7:00
9:00
11:00
13:00
15:00
17:00
19:00
21:00
23:00
1:00

Case 3 Day Four





DATA RECORD SHEET

Case no. : Four

Apartment reference: Mr. M. H.

Date of record:

Start Logging : 15 Aug. 1998

End Logging : 18 Aug. 1998

Logging Details:

Probe No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1		4	1		* No A/C Current measurement
2		5			due to wiring system
3		3	2		
4					
5		3			* CO2 probe
6					
7					
8					
9		3	2		* RH%
10					

Building Details :

Location : Middle Floor Apartment

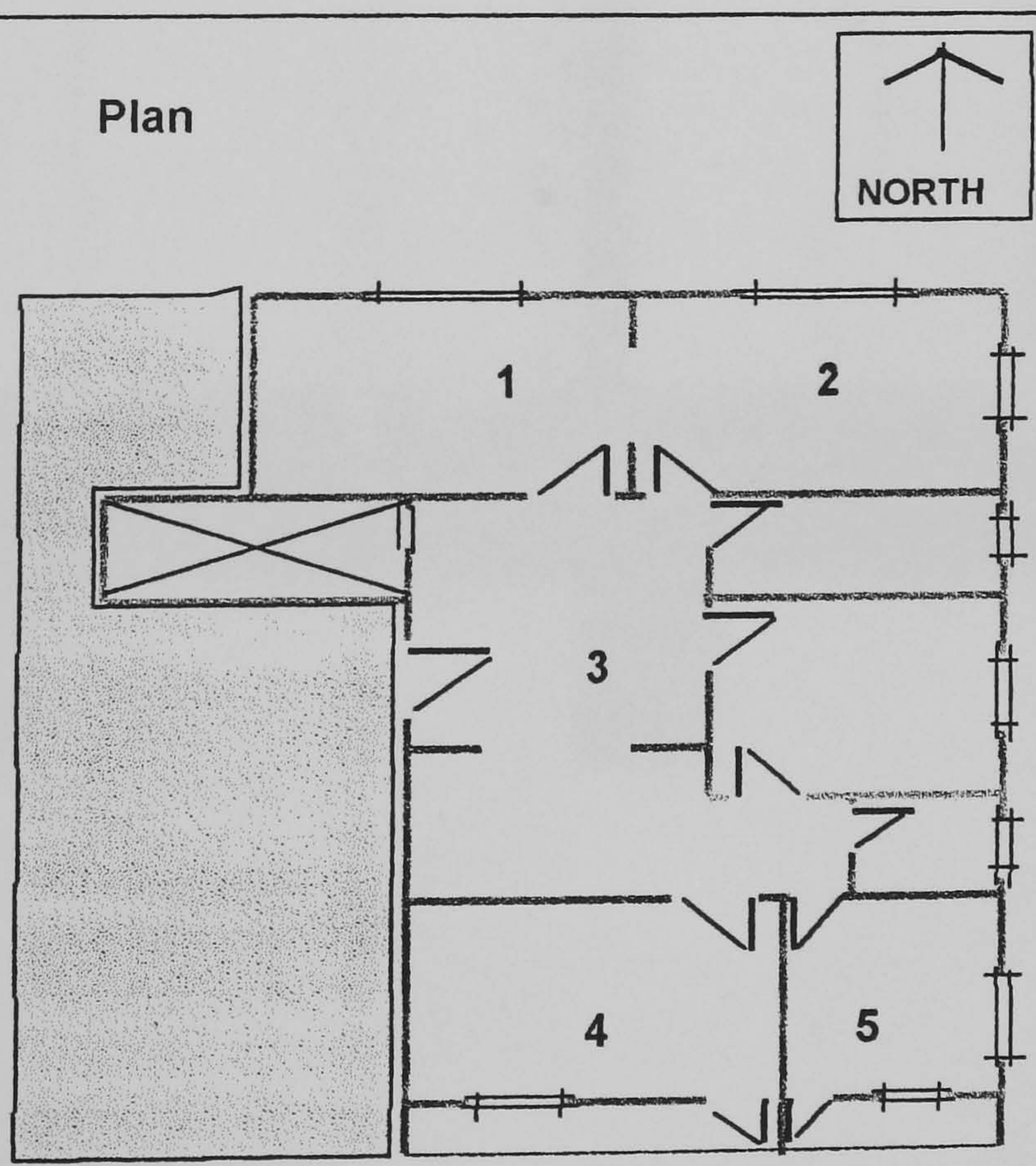
Construction :

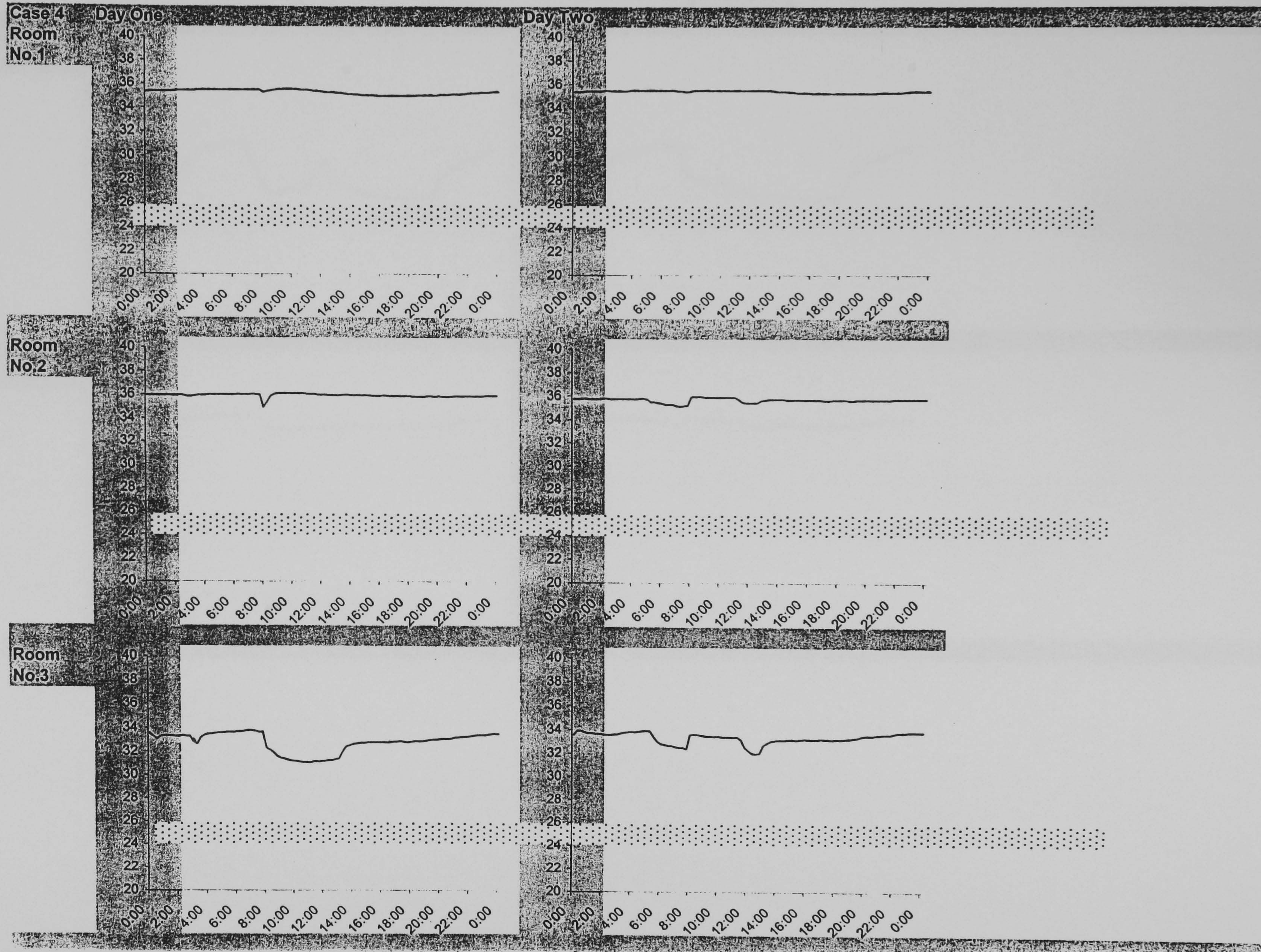
1- Reinforced concrete frame structure
2- External walls built with syprox blocks, Internal partitions built with hollow ceramic blocks covered with sand cement rendering
3- Wired single glasing windows with black aluminum frame

Notes :

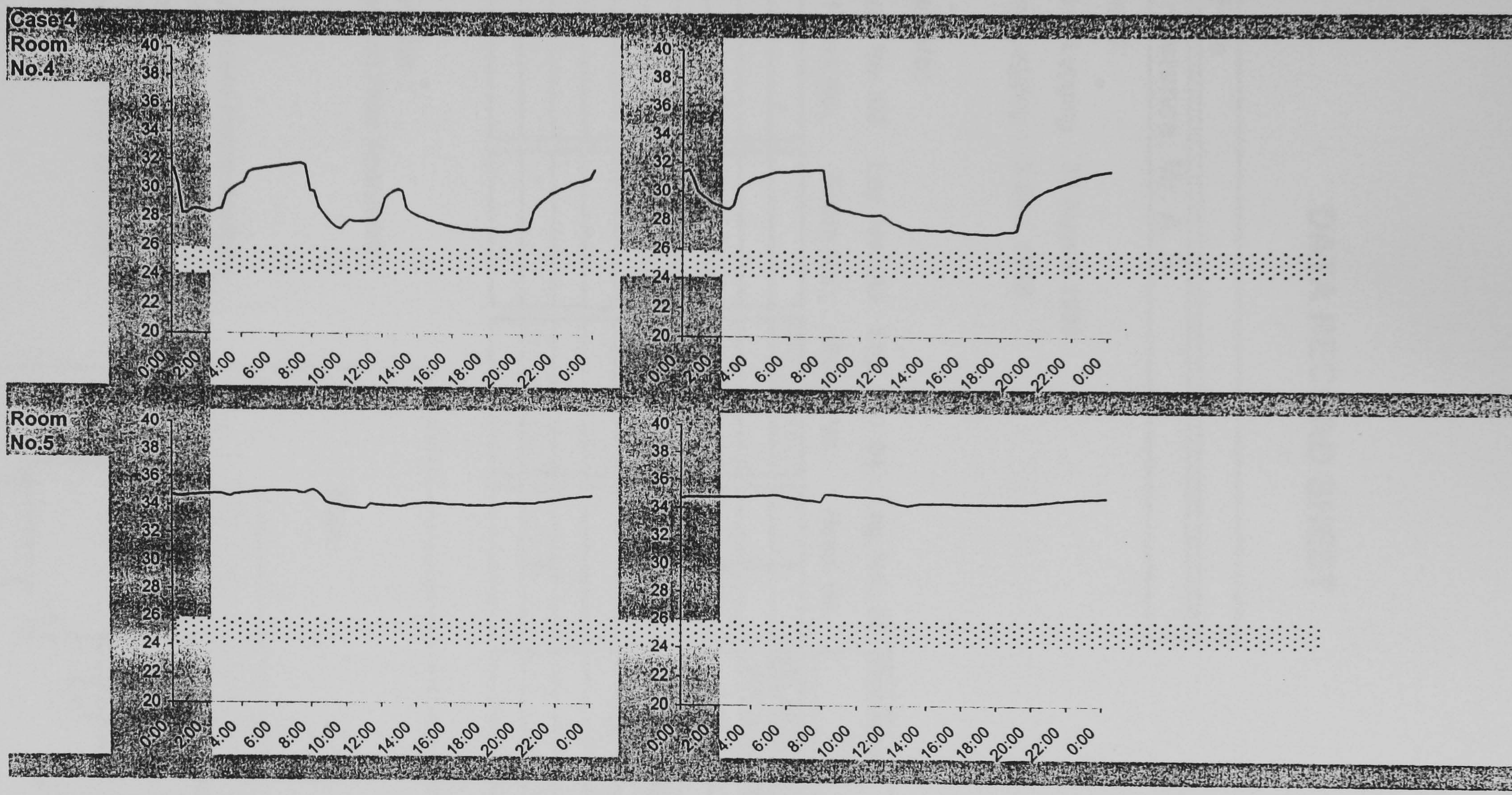
. Three adults + two child
. The apartment has three exposed directions
. All windows are covered with curtains
. All Rooms have a window type A/C units
. South wall windows are well shaded
. Living room occupancy is 8-10 Hours
.

Plan





Case 4
Room No.1
Room No.2
Room No.3
Day One
Day Two
40 38 36 34 32 30 28 26 24 22 20
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00 0:00



Case 4
Room
No.4
Room
No.5
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00

DATA RECORD SHEET

Case no. : Five

Apartment reference: Mr. A. S.

Date of record:

Start Logging : 26 Augest 1998

End Logging : 3 Sep. 1998

Logging Details:

Probe No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1			5	1	No A/C Current measurement
2			6	3	due to wiring system
3			4	2	
4					
5					* No Co2 Test due to uncontrolled
6					air spaces
7					
8					
9			4	2	
10					

Building Details :

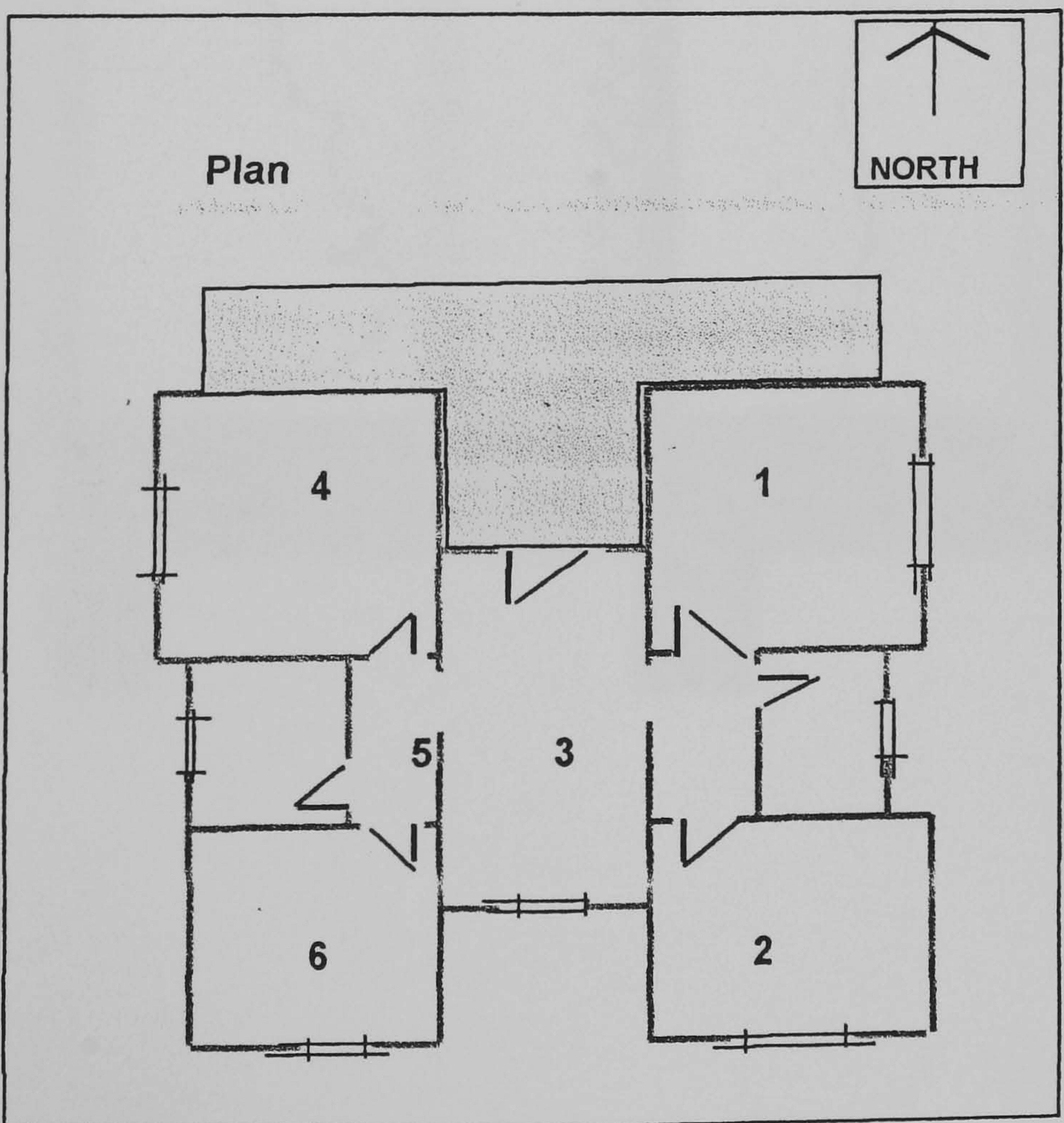
Location : Ground Floor Apartment

Construction :

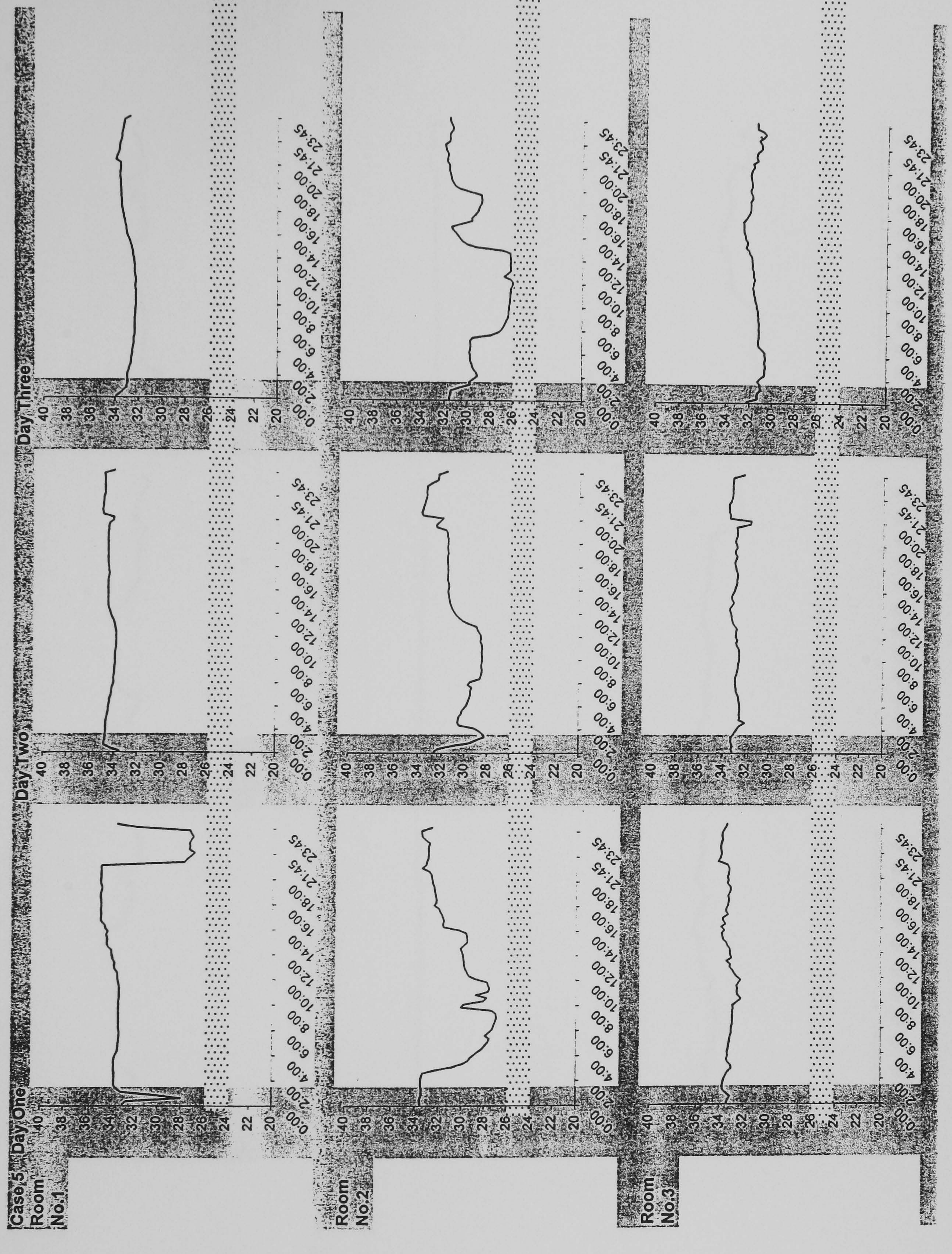
1- Reinforced concrete frame structure
2- Red burnt clay bricks, the envelope covered with sand cement rendering
3- Traditional windows with horizontal wooden stripes

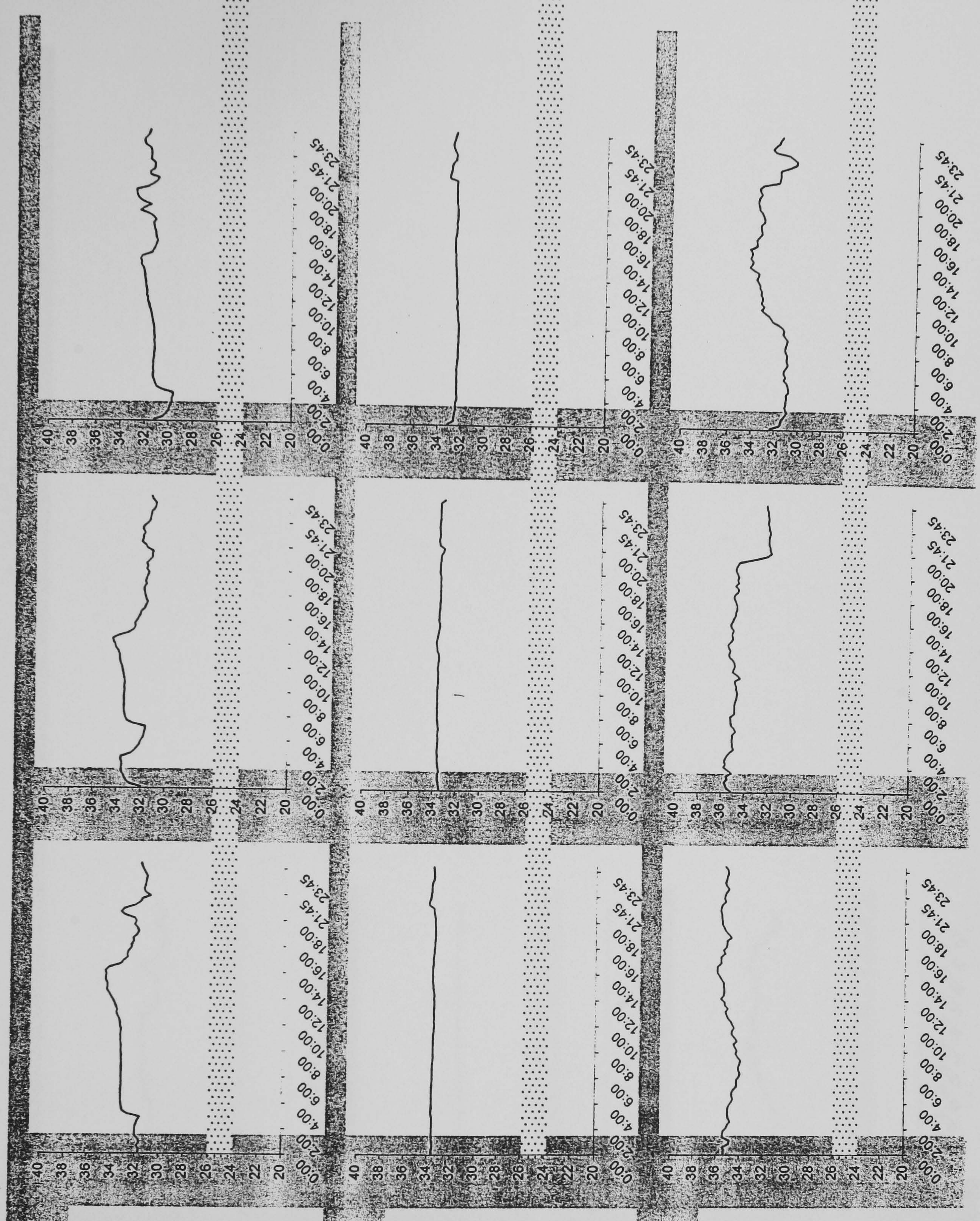
Notes :

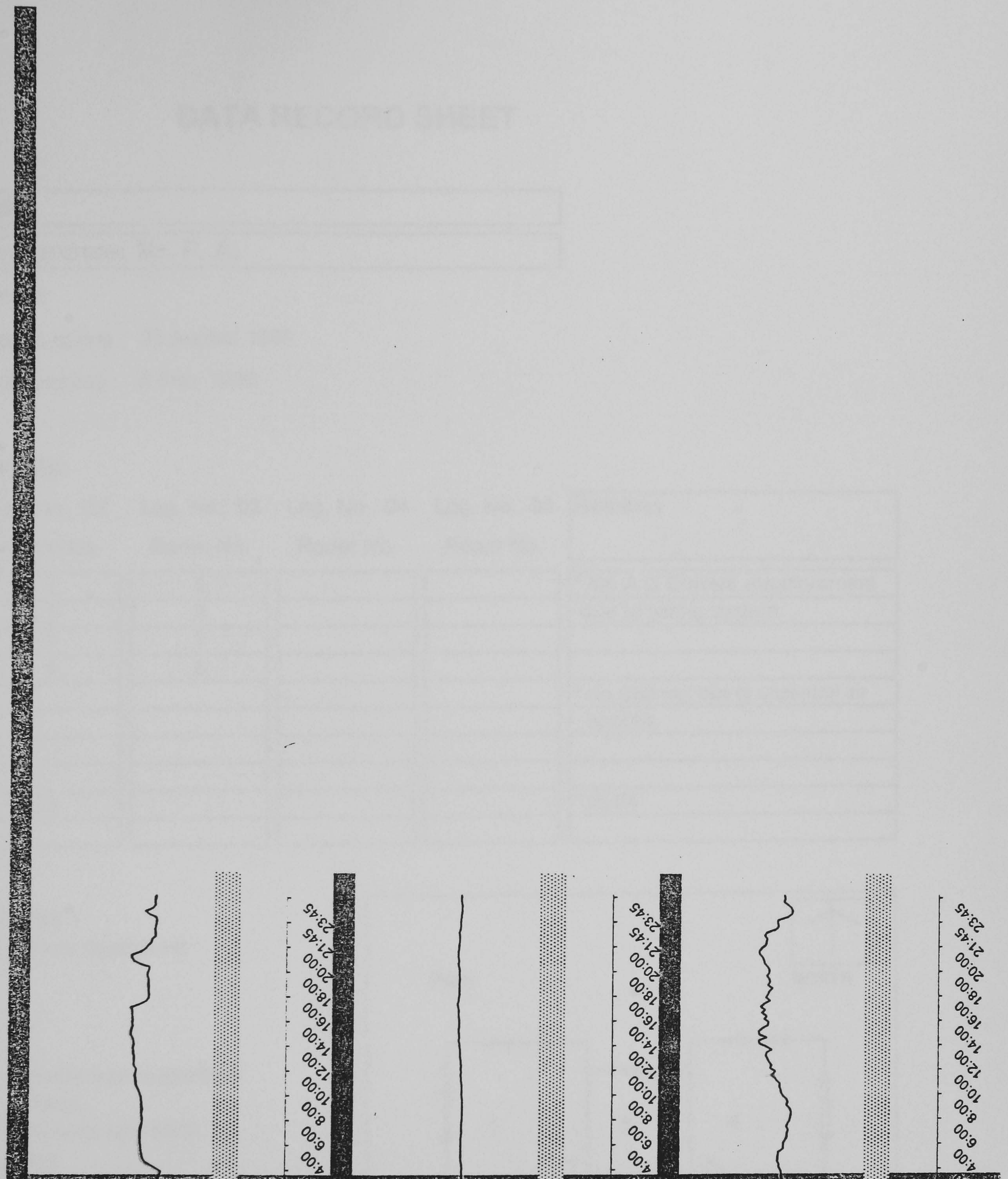
- Four adults + 2 children
- Three exposed elevations
- All windows have curtains
- All rooms have a window type A/C units
- Living room has an occupancy of 10-14 hours



28


Case 5
Room No.1
Room No.2
Room No.3
Day One
Day Two
Day Three
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
21:45
23:45


Room No.4
Room No.5
Room No.6



DATA RECORD SHEET

Case no. : Six
Apartment reference: Mr. F. A.

Date of record:

Start Logging : 26 Augest 1998

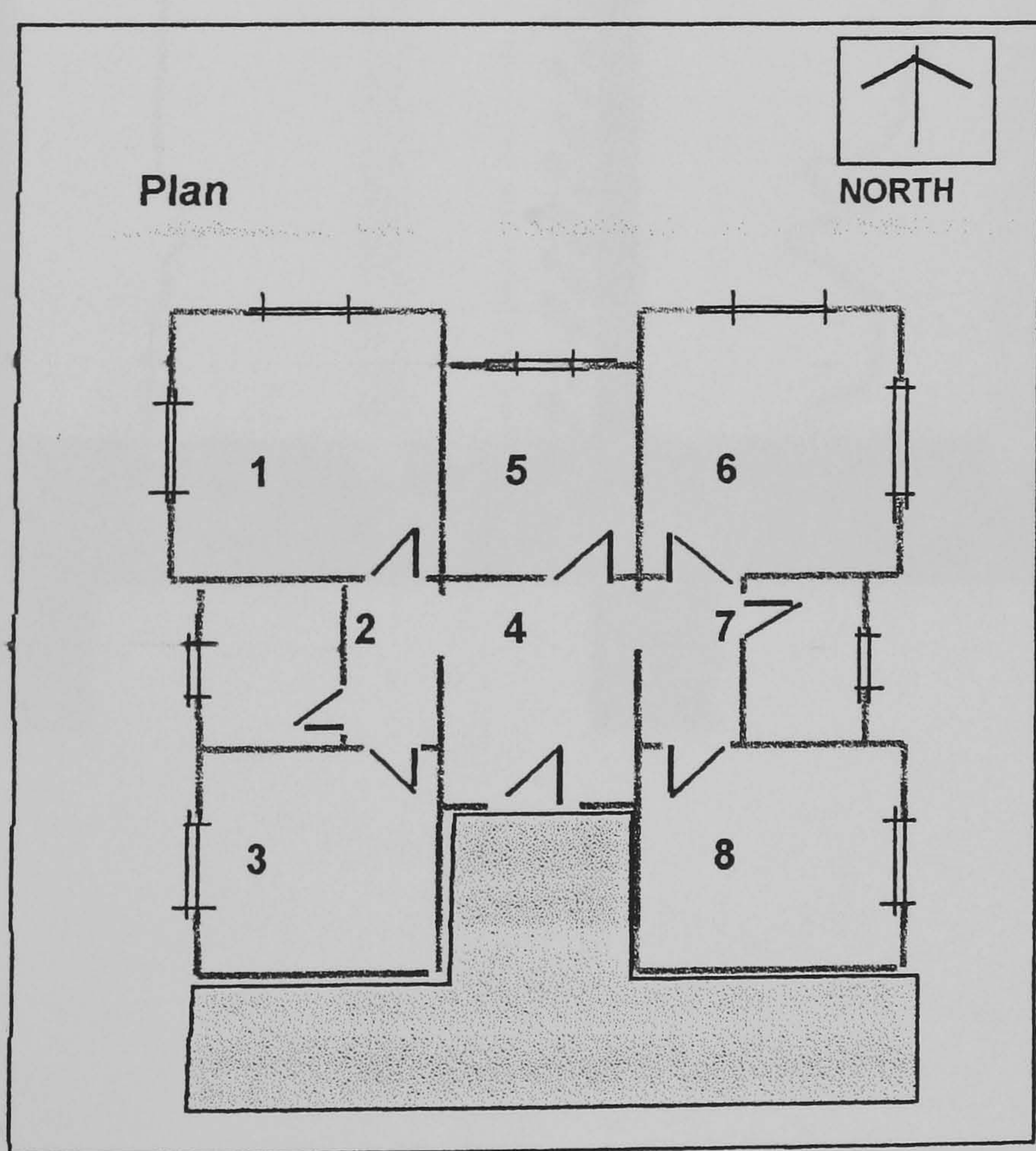
End Logging : 3 Sep. 1998

Logging Details:

Probe No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1	1	5			* No A/C Current measurement
2	2	6			due to wiring system
3	3	7			
4	4	8			
5					* No Co2 test due to uncontrol air
6					spaces
7					
8					
9	3				* RH%
10					

Building Details :

Location : Top Floor Apartment

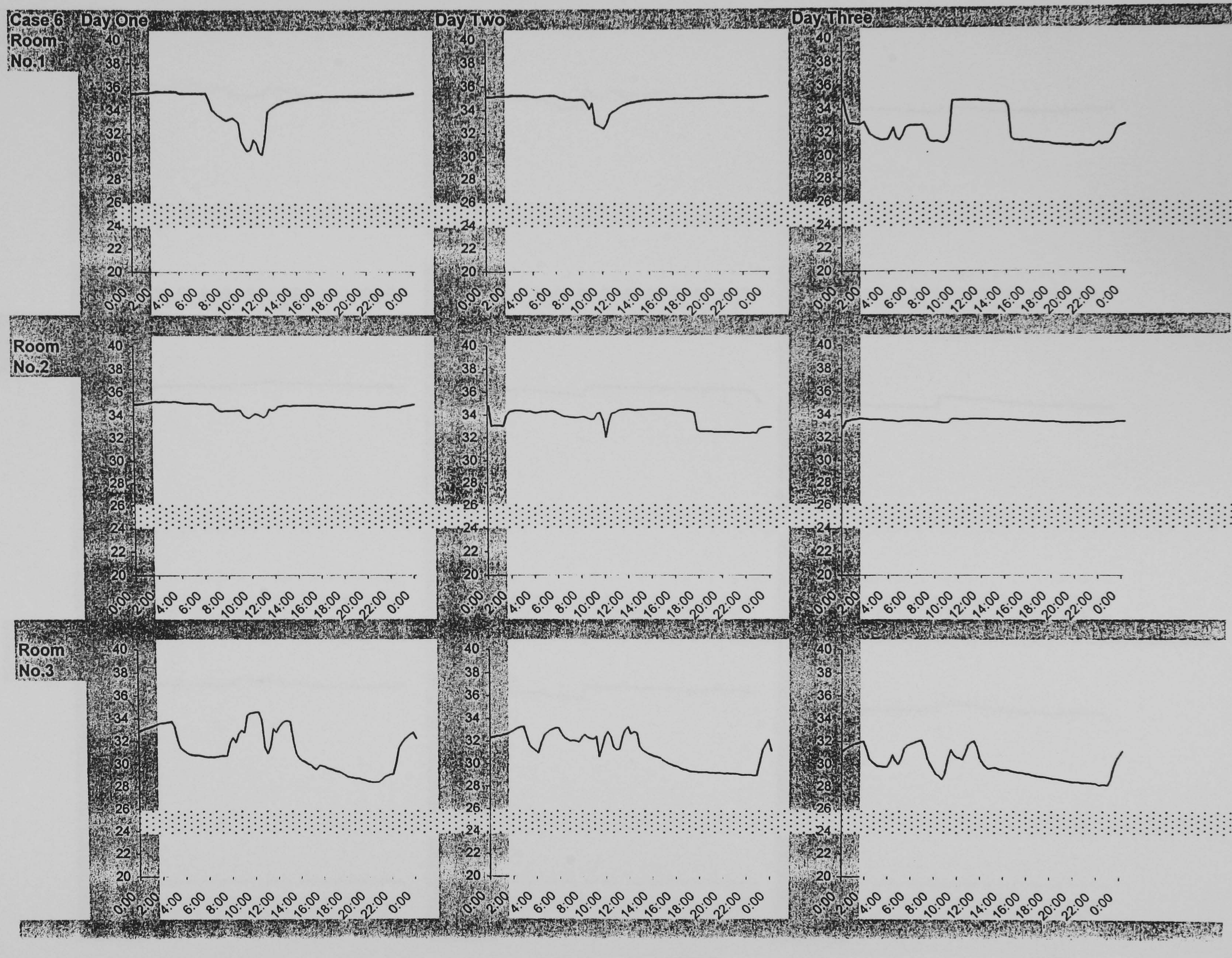


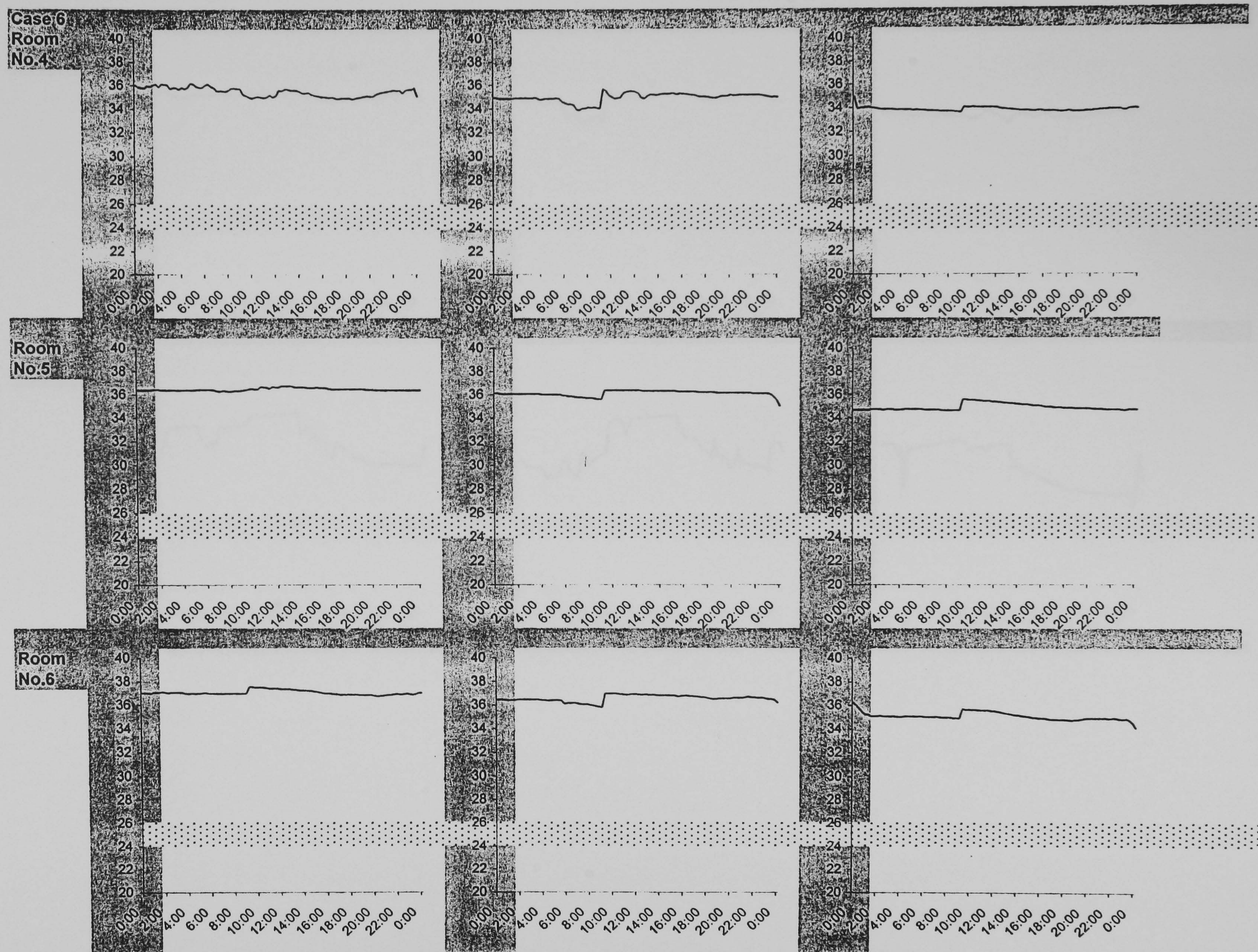
Construction :

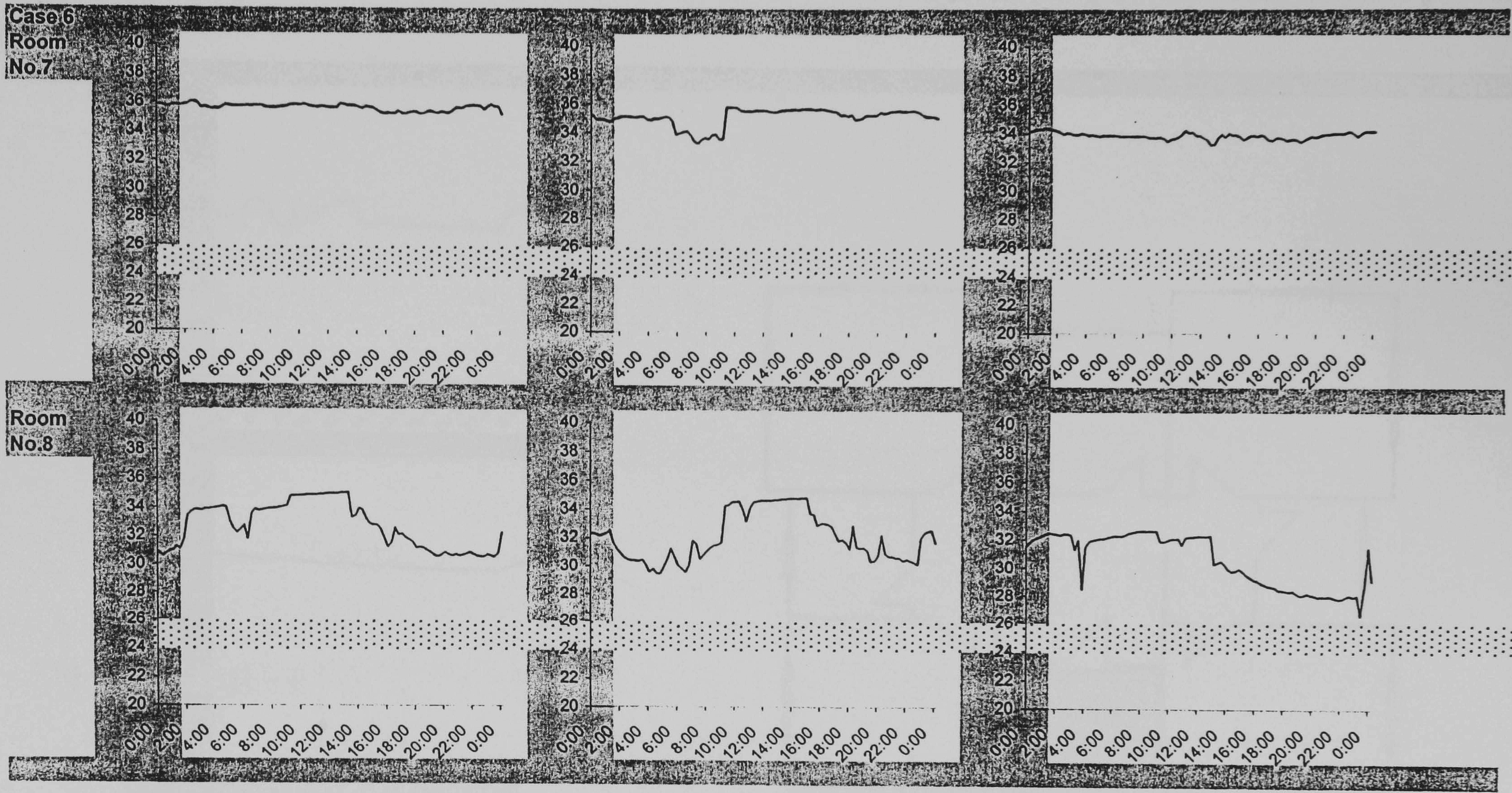
1- Reinforced concrete frame structure
2- Red burnt clay brick, the envelope covered with sand cement rendering
3- Single glazing windows with wooden frame
4- Exposed roof

Notes :

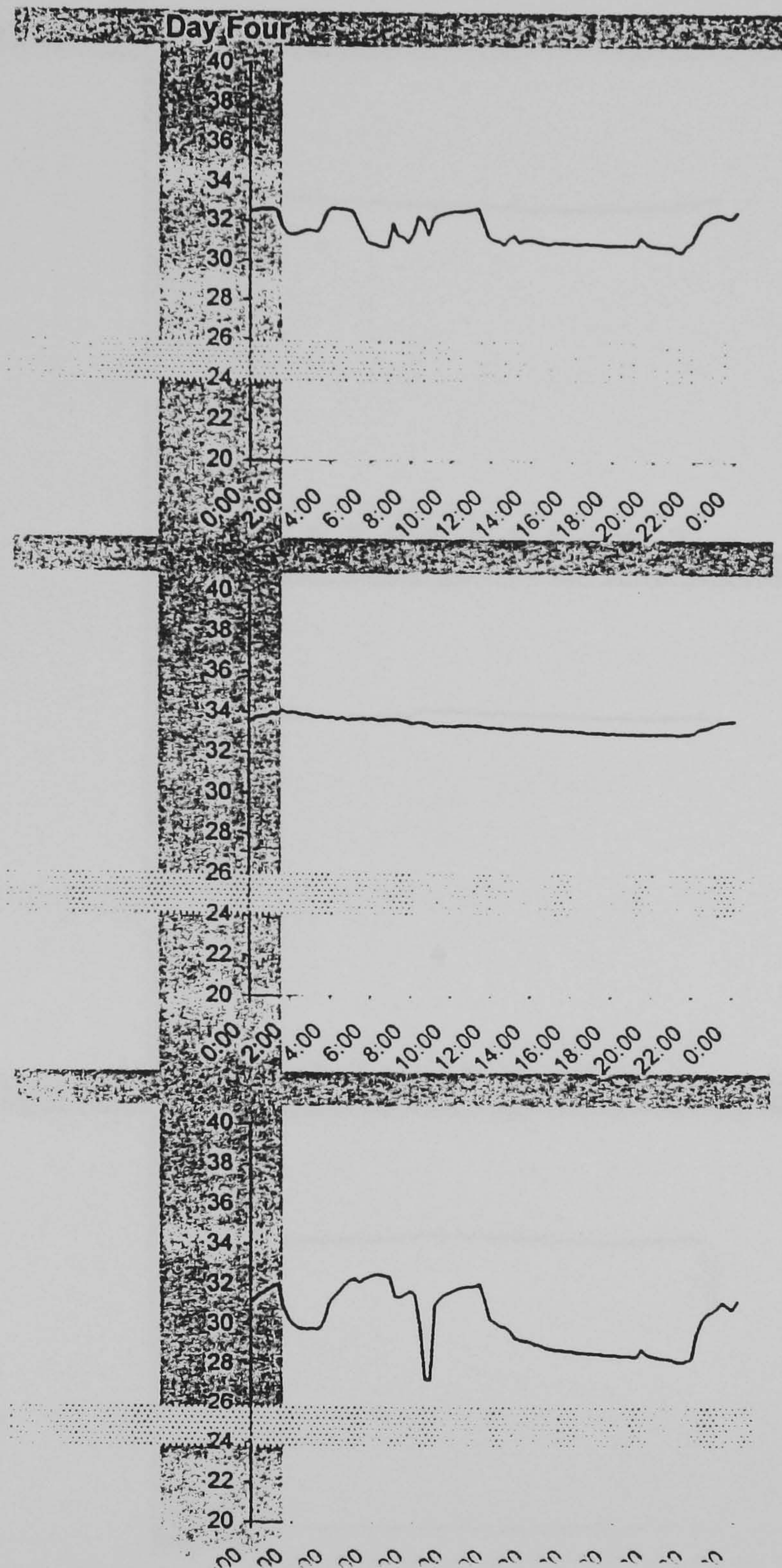
- Three Aduls + 2 children
- All windows are with curtains
- The occpancy rate for the living room is 10-12 hours
- All rooms have a window type A/C units

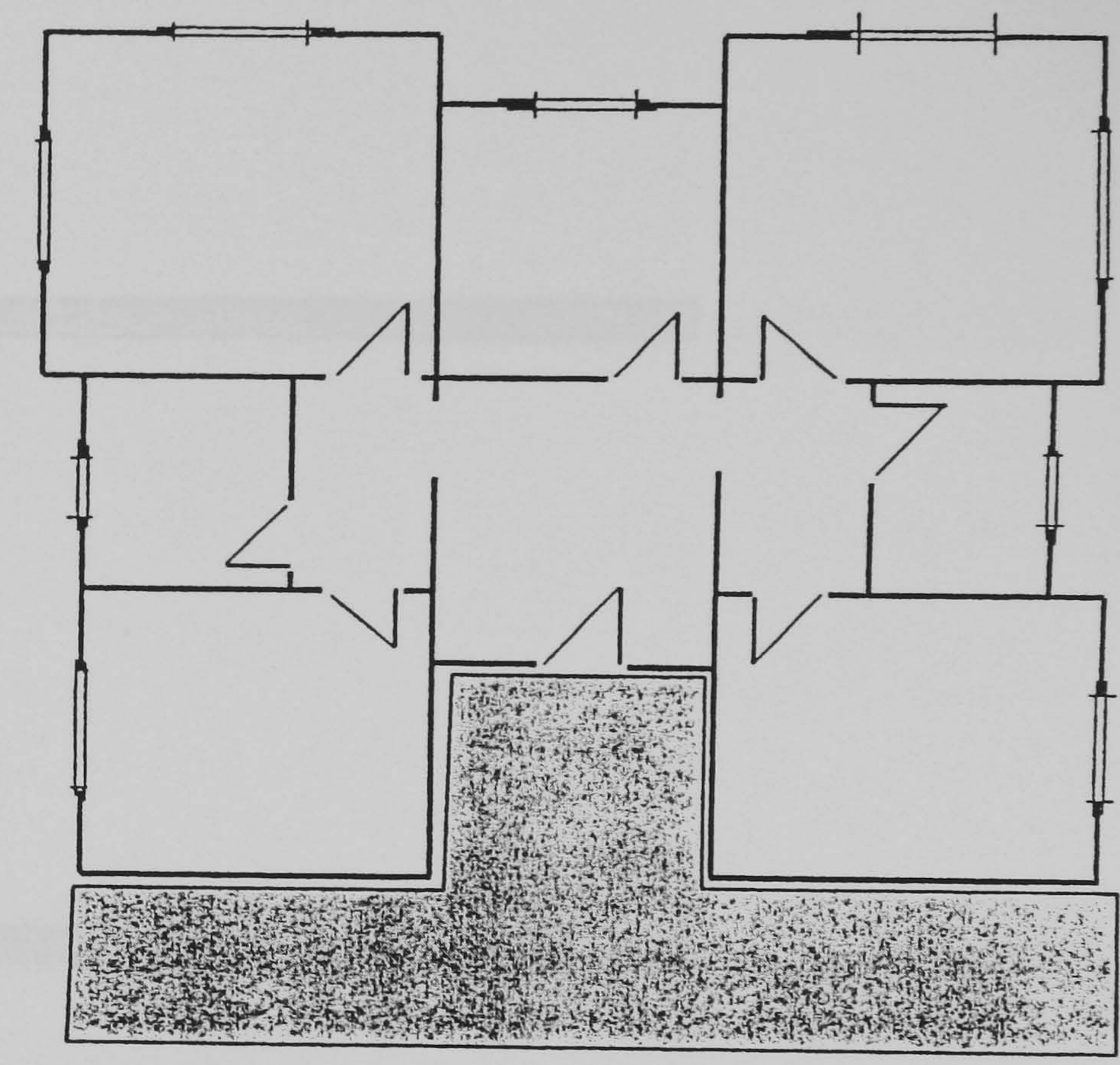

Case 6
Room No.1
Room No.2
Room No.3
Day One
Day Two
Day Three
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00


Case 6
Room No.4
Room No.5
Room No.6
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00

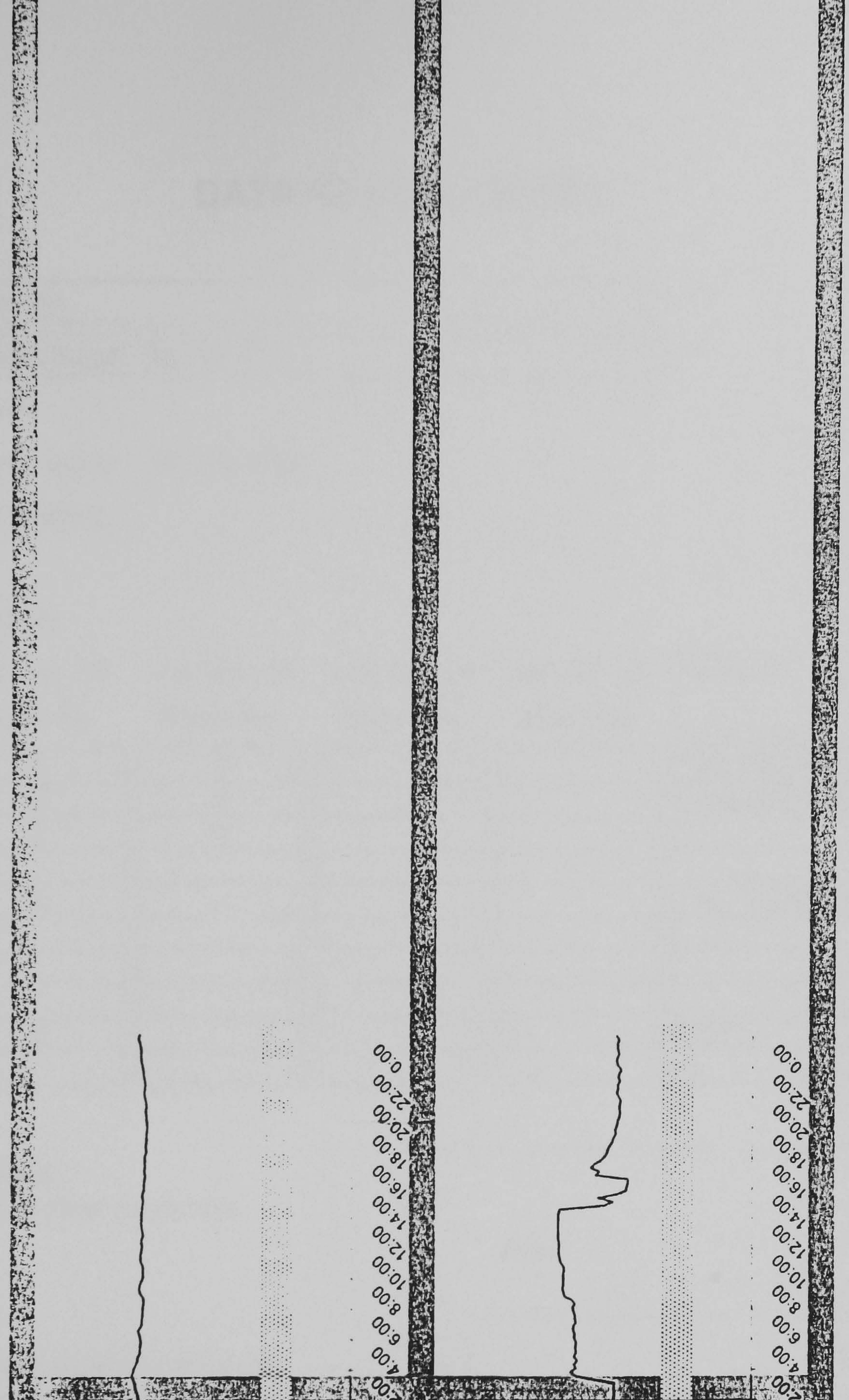

Case 6
Room
No.7
Room
No.8
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00

35


Day Four
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00




40 38 36 34 32 30 28 26 24 22 20
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00 0:00



DATA RECORD SHEET

Case no. : Seven
Apartment reference: Mr. O. H.

Date of record:

Start Logging : 19 July 1998

End Logging :

Logging Details:

Probe No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1	1	4			* No CO2 test due to
2	3	5			uncontrolled air spaces
3	2	6			
4					
5	2				* A/C current probe
6					
7					
8					
9	2				* RH%
10					

Building Details :

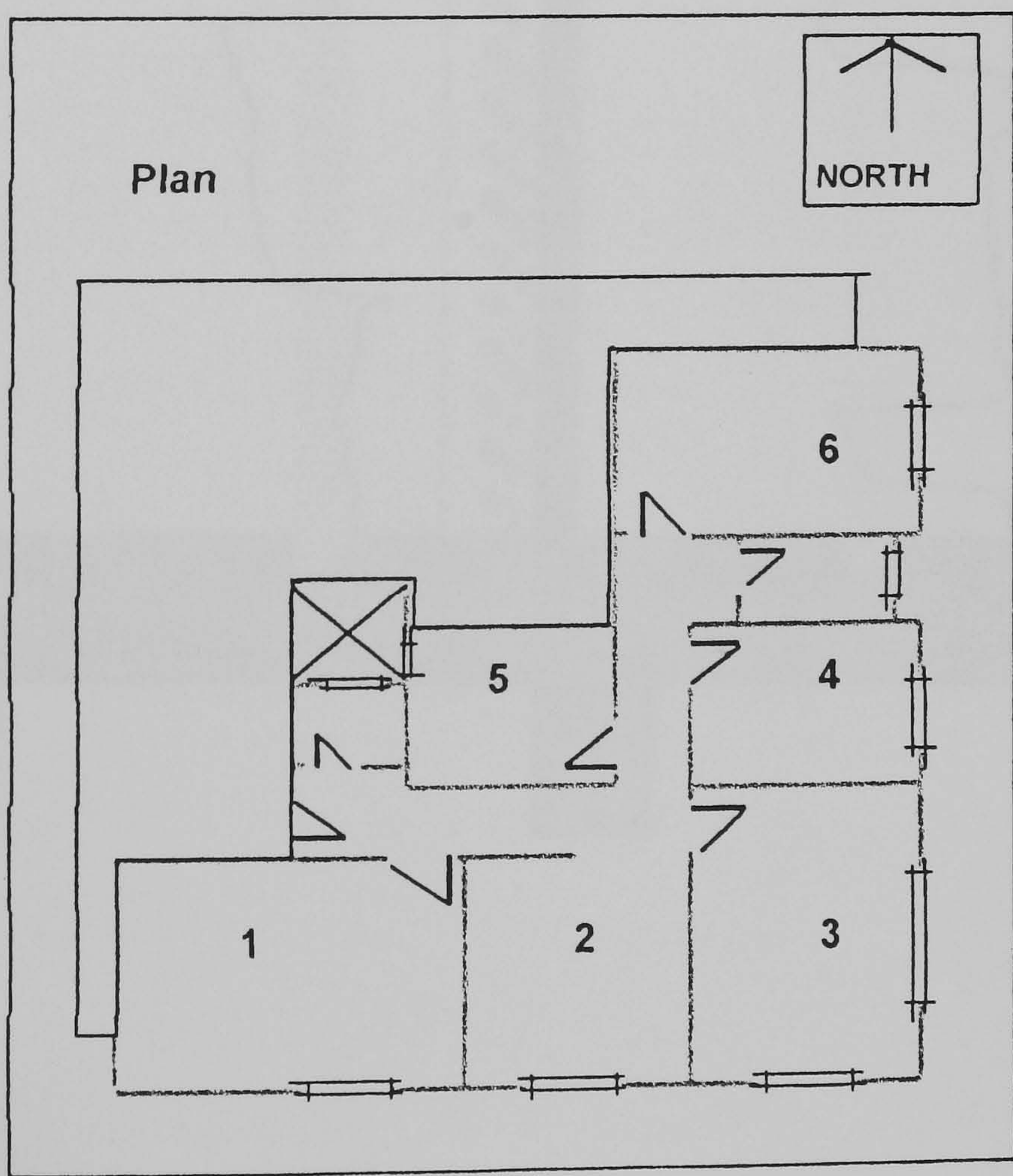
Location : Middle Floor Apartment

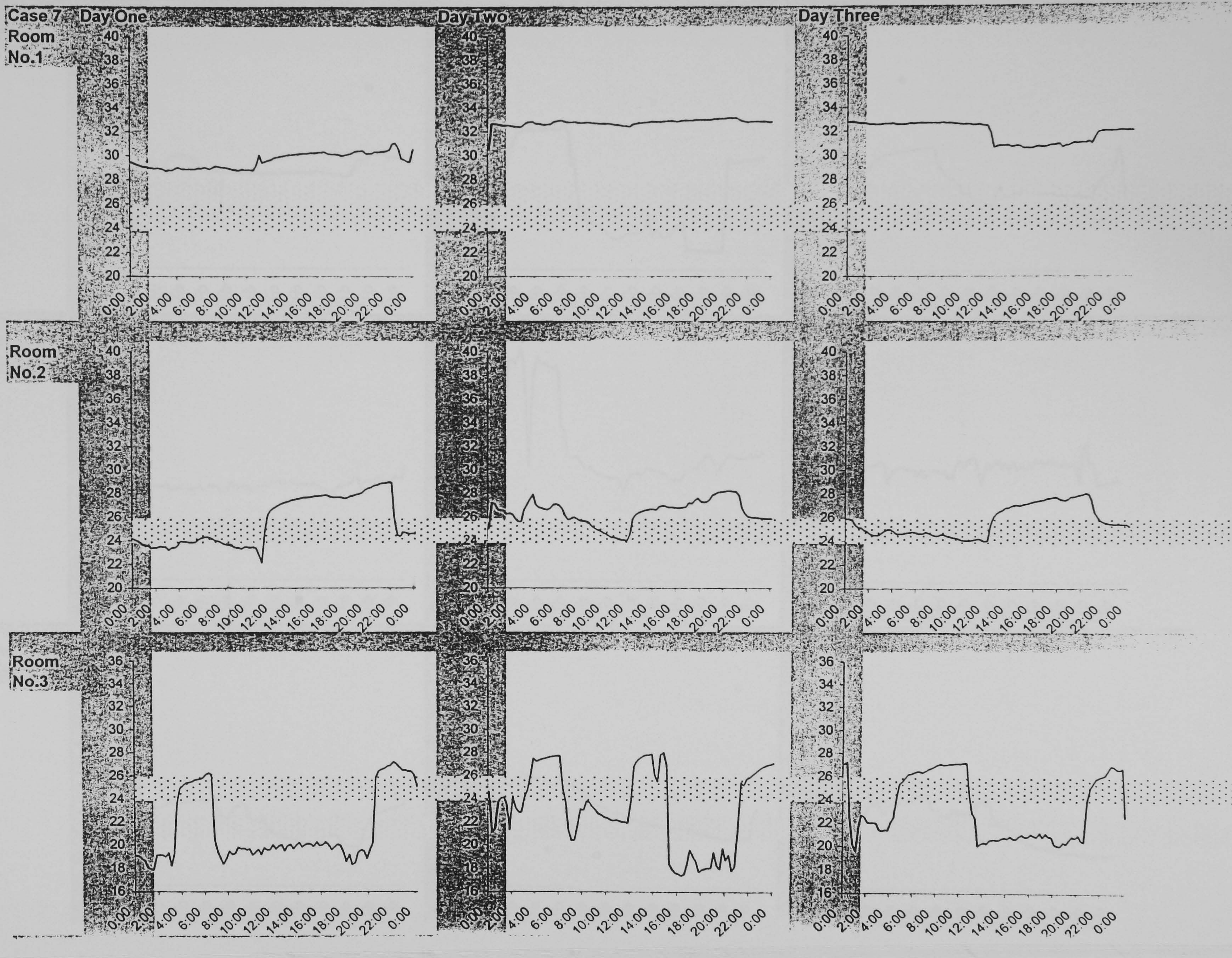
Construction :

1- Reinforced concrete frame structure
2- Hollow ceramic block for the envelope covered with sand cement rendering
3- Single reflective glazing windows with aluminum frame

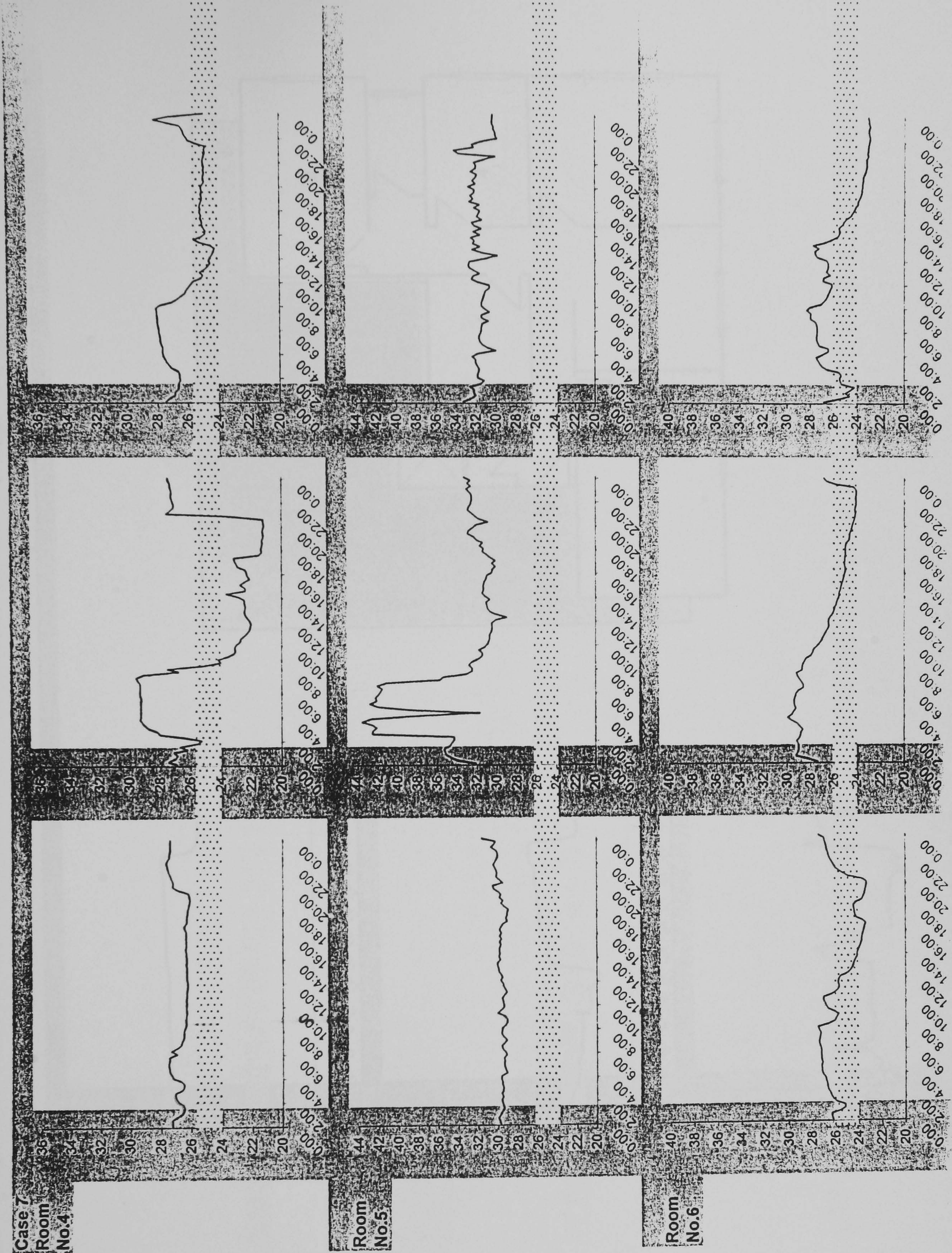
Notes :

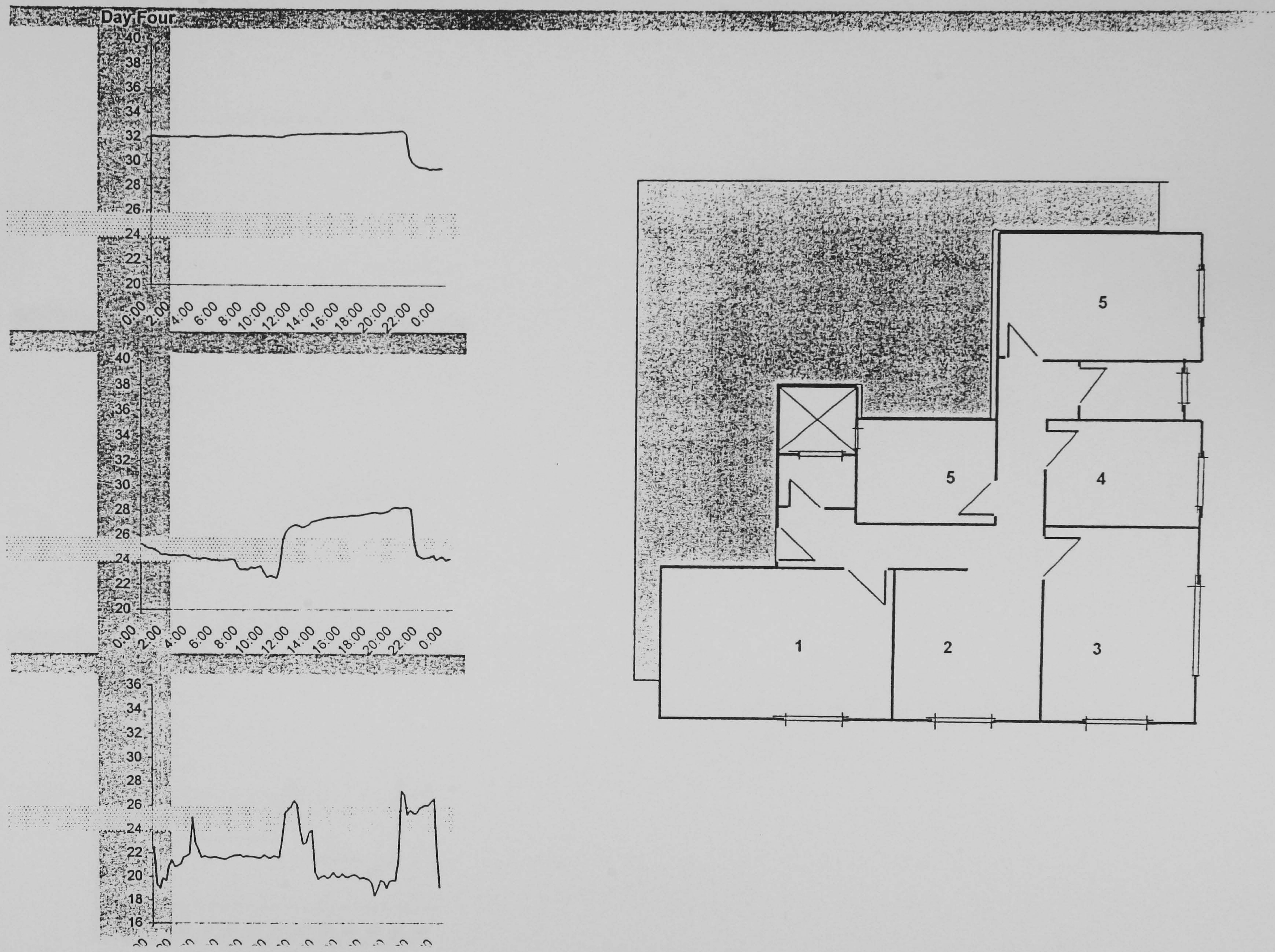
. Four adults + two children
. A/C split units are fitted in rooms 1&2, the rest are fitted with window type.
. All rooms are with curtains
. The occupancy rate for the living room is 14 hours

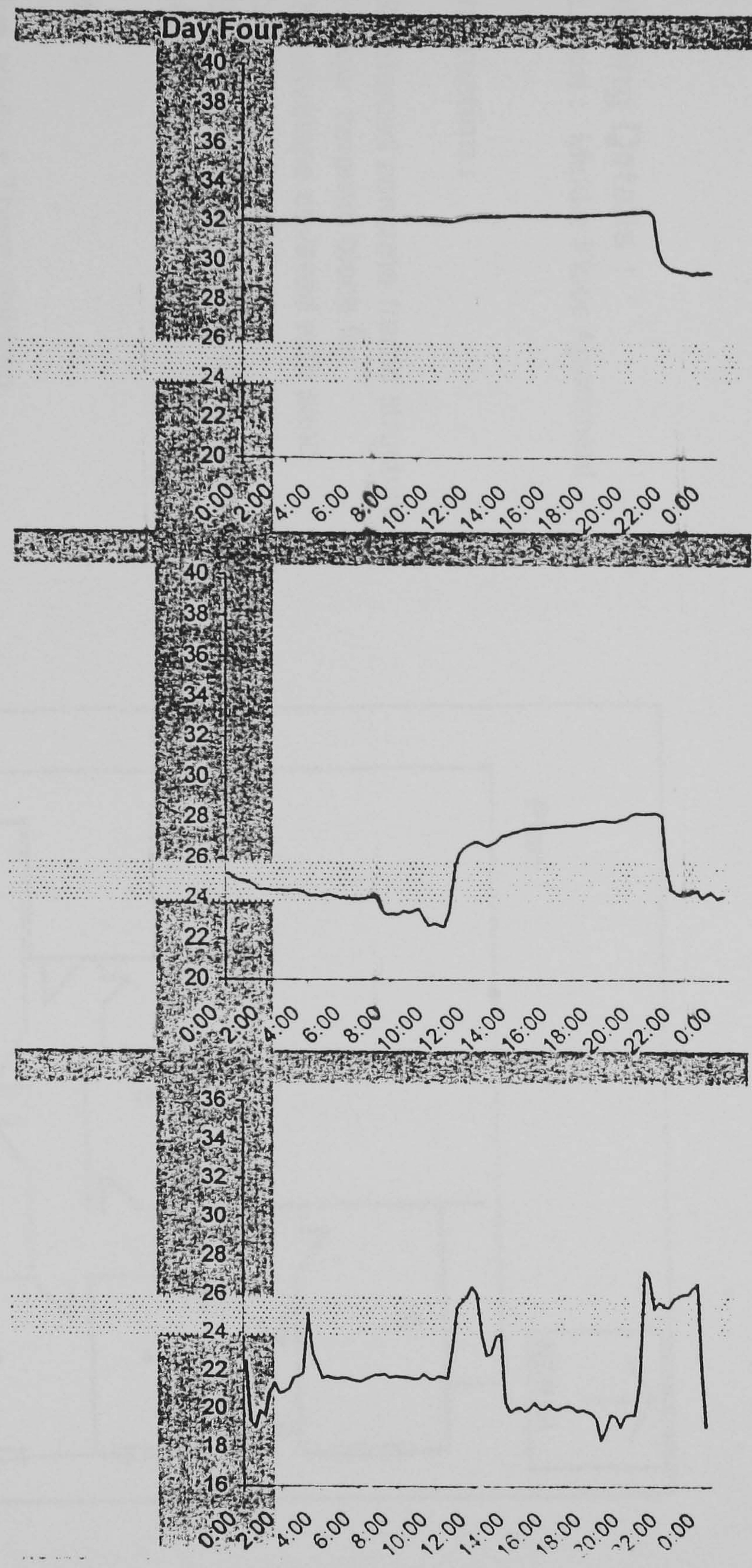


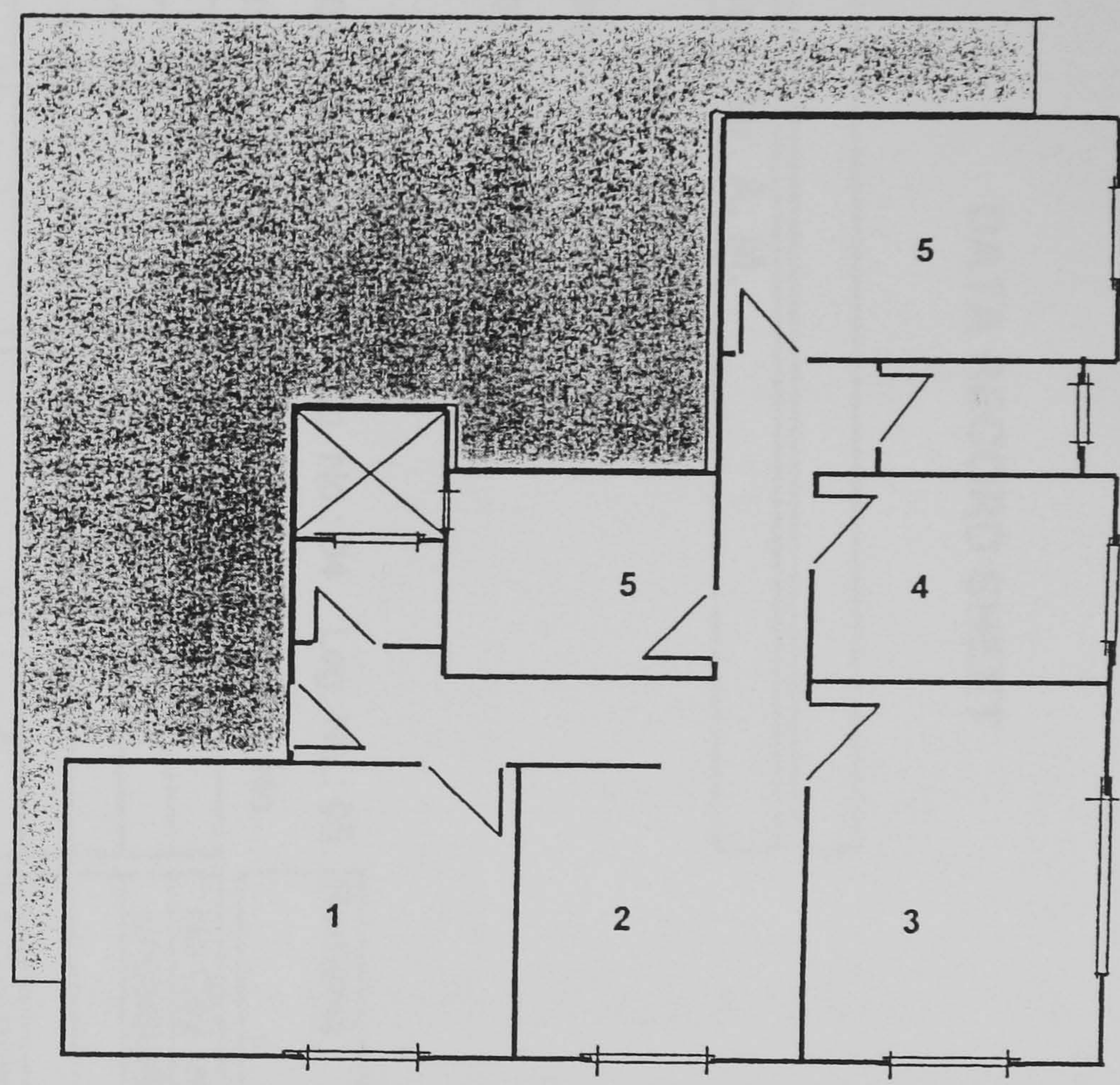


Case 7
Room No.1
Room No.2
Room No.3
Day One
Day Two
Day Three


Case 7
Room
No.4
Room
No.5
Room
No.6


Day Four
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
16
18
1
2
3
4
5


Day Four
40
38
36
34
32
30
28
26
24
22
20
16
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00


1
2
3
4
5
5

DATA RECORD SHEET

Case no. : Eight

Apartment reference: Mr. A. M.

Date of record:

Start Logging : 4 September 1998

End Logging :

Logging Details:

Probe No.	Log. No. :02 Room No.	Log. No.: 03 Room No.	Log. No.: 04 Room No.	Log. No.: 05 Room No.	Remarks
1			1	4	* No Co2 test due to
2			2	6	uncontrolled air spaces
3			3		
4			5		
5				4	* A/C current probe
6					
7					
8					
9			3		* RH%
10					

Building Details :

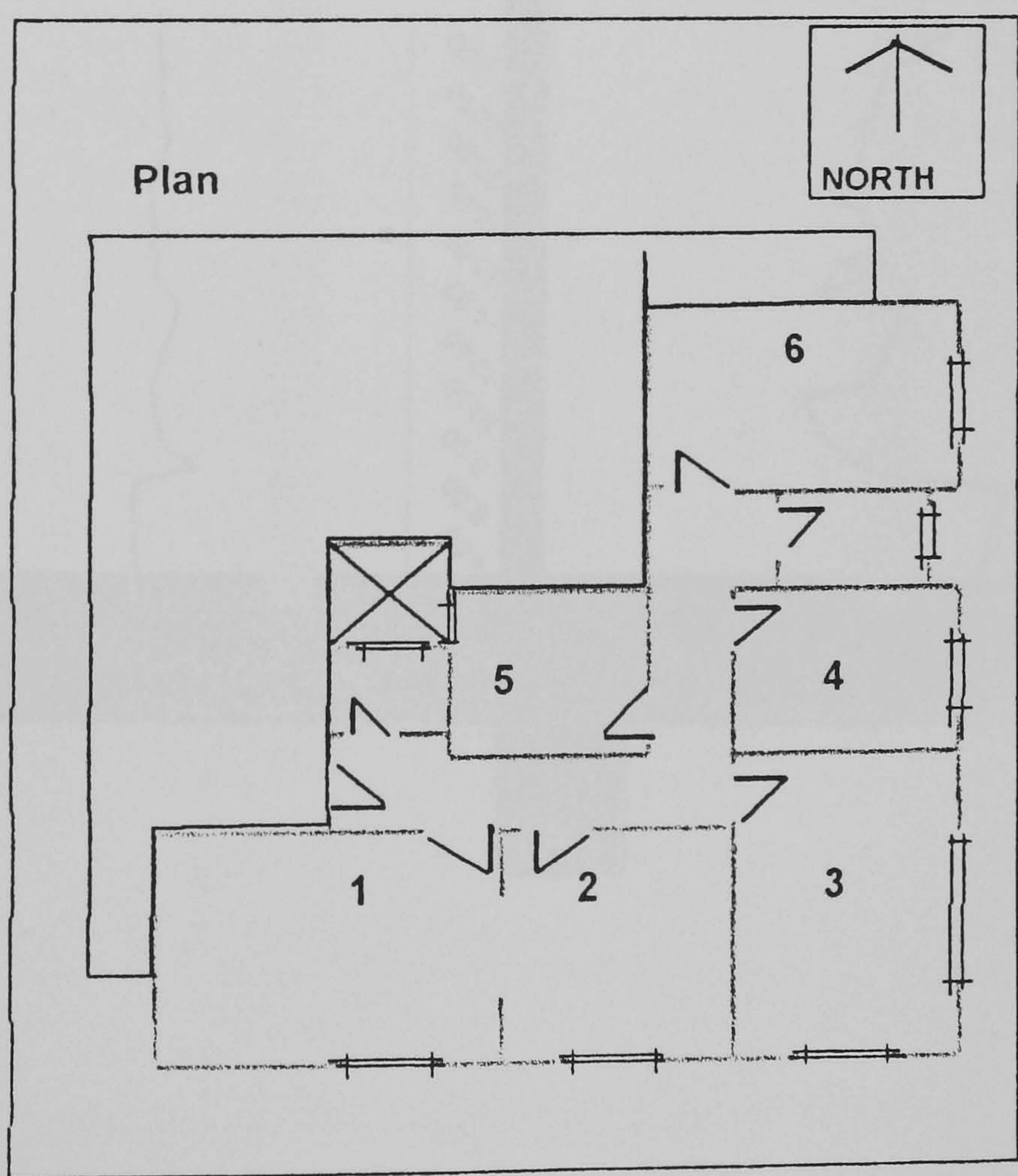
Location : Middle Floor Apartment

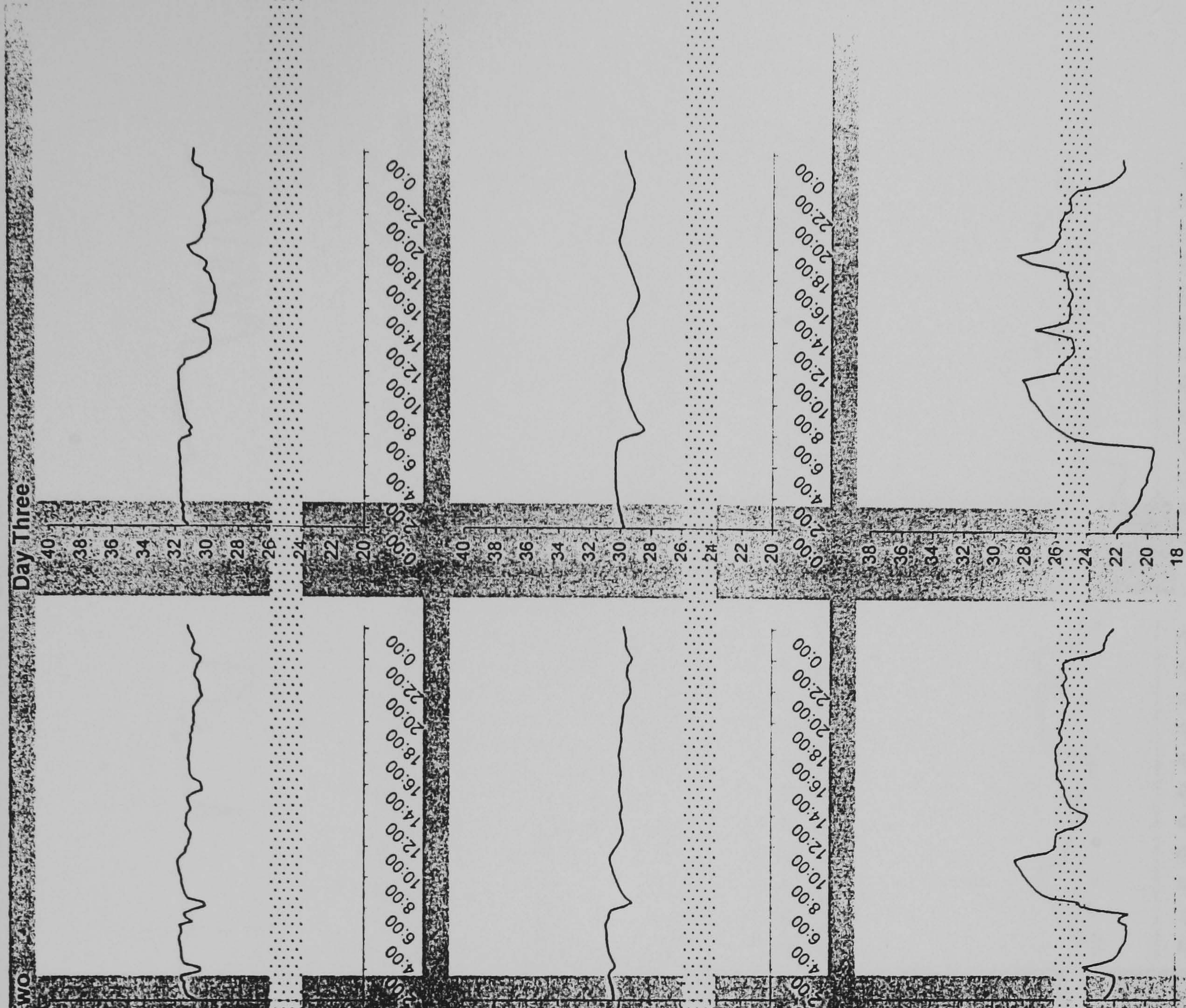
Construction :

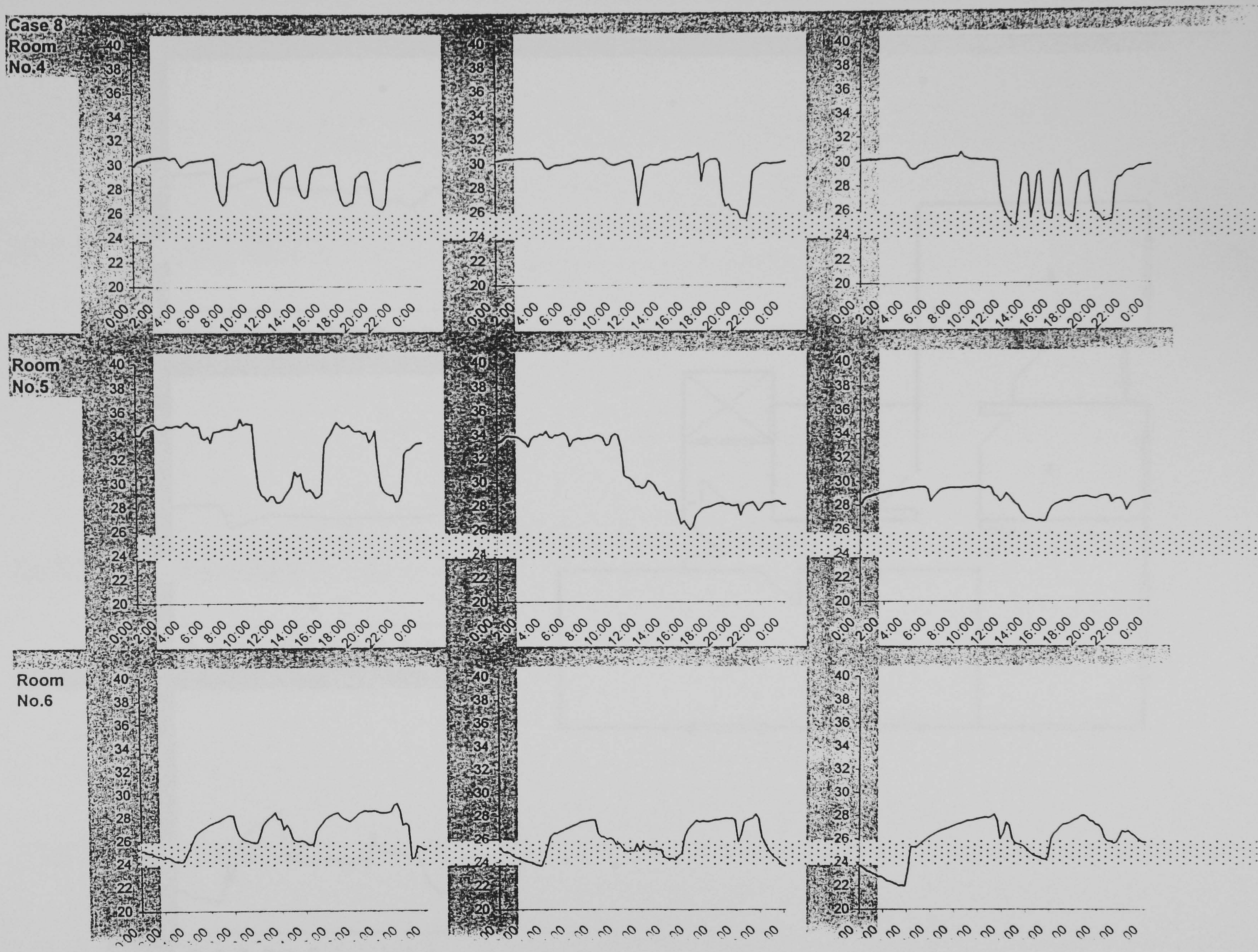
1- Reinforced concrete frame structure
2- Hollow ceramic block for the envelope covered with sand cement rendering
3- Single reflective glazing windows with aluminum frame

Notes :

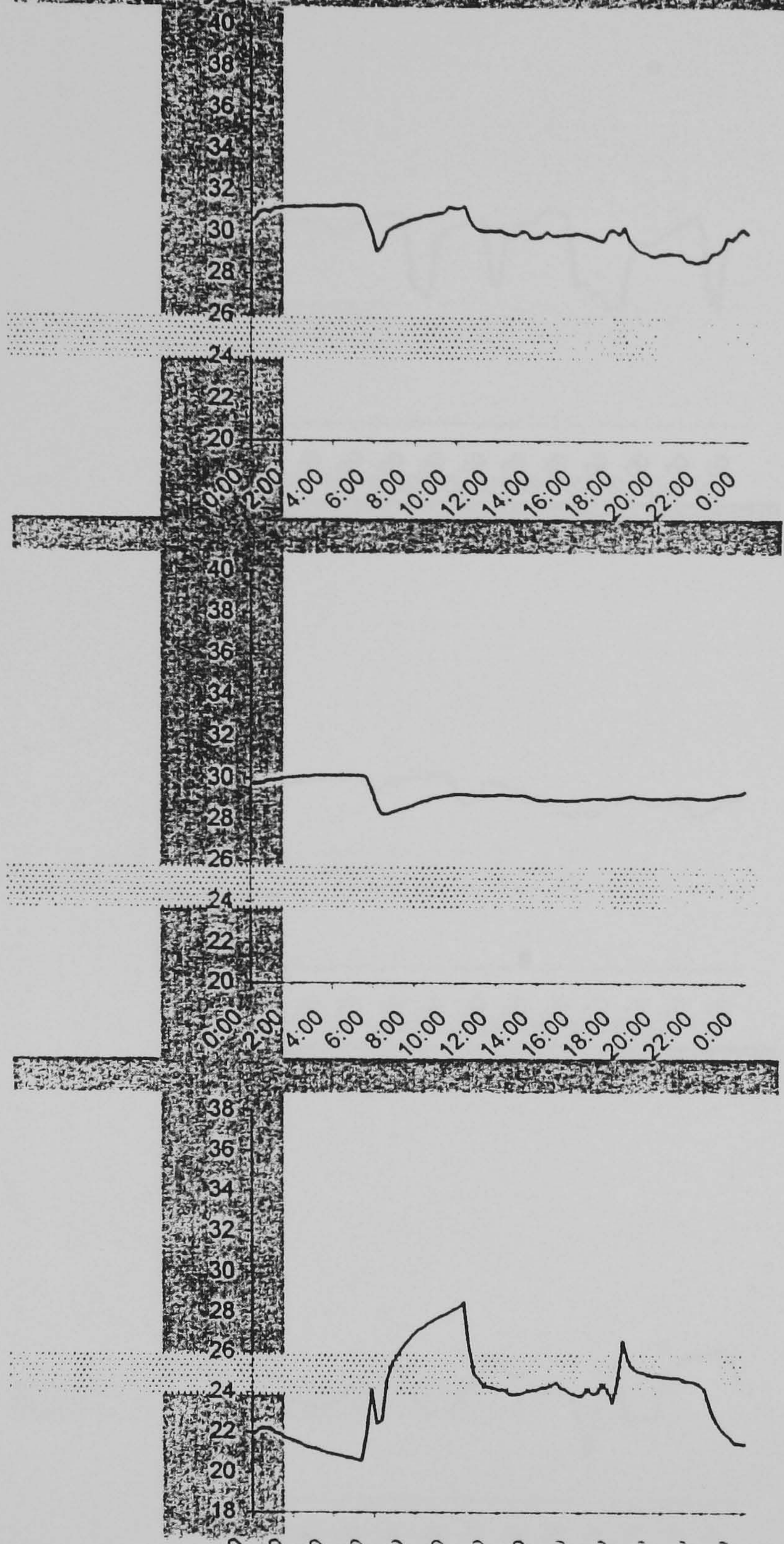
. Five adults + Three children
. All rooms are fitted with window type A/C units
. All rooms are with curtains
. The occupancy rate for the living room is 8-10 hours

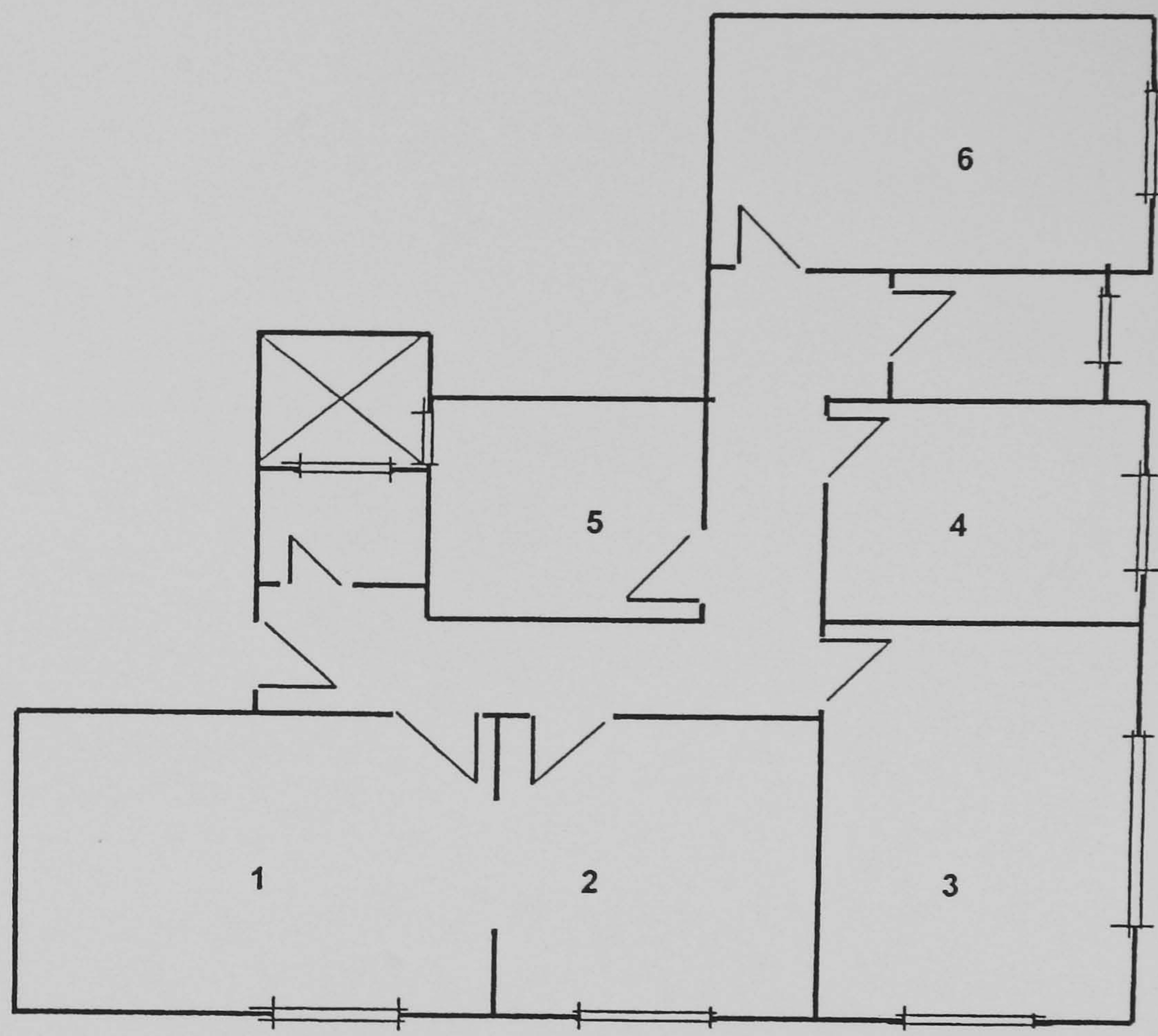


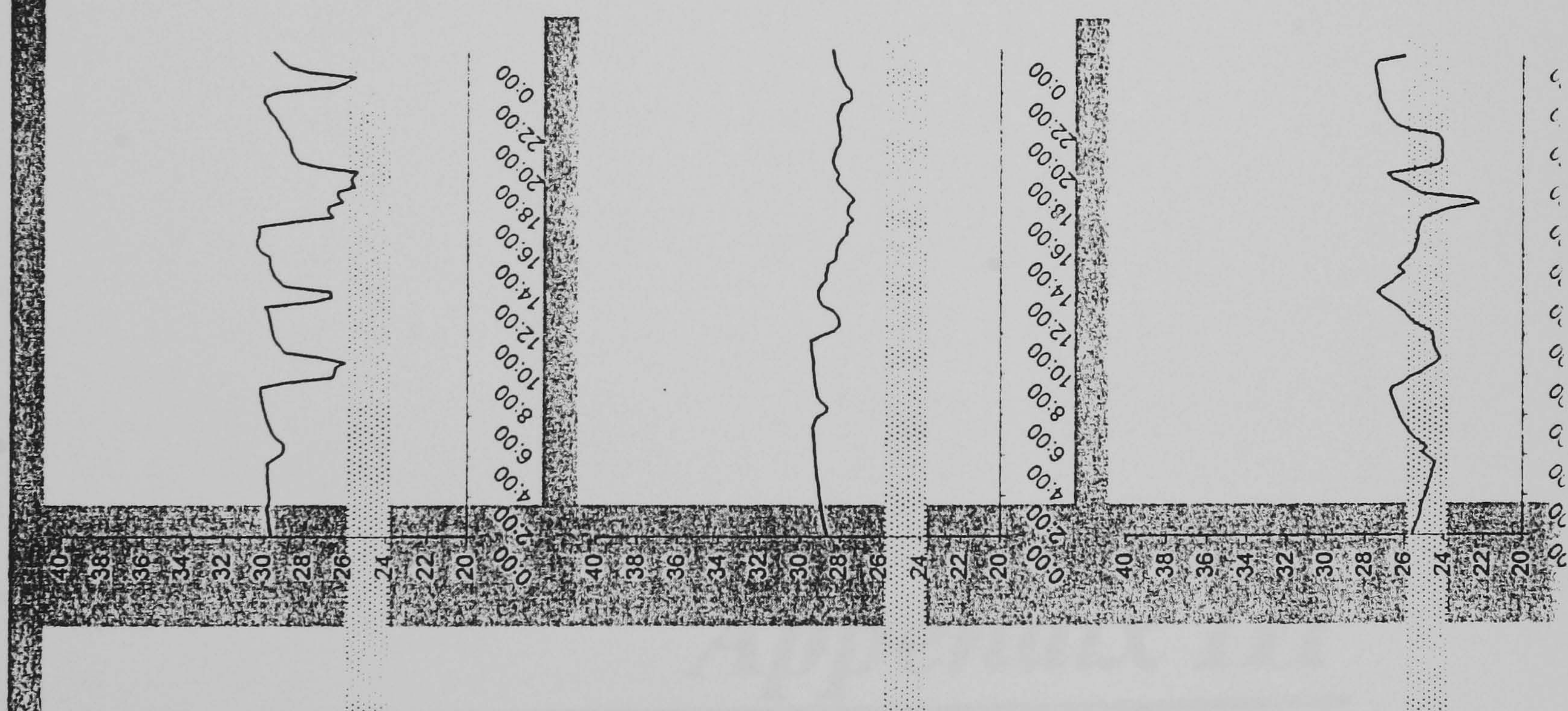

Case 8
Room No.1
Room No.2
Room No.3
Day One
Day Two
Day Three
40
38
36
34
32
30
28
26
24
22
20
18
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00


Case 8
Room
No.4
Room
No.5
Room
No.6
40
38
36
34
32
30
28
26
24
22
20
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00

Case 8 Day Four







40
38
36
34
32
30
28
26
24
22
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0:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00

Appendix III

Simulation Run Sample

B U I L D I N G   E N E R G Y   A N A L Y S I S   P R O G R A M

DEVELOPED BY

LAWRENCE BERKELEY LABORATORY/UNIVERSITY OF CALIFORNIA
WITH ASSISTANCE FROM
HIRSCH & ASSOCIATES, CAMARILLO, CA (805) 532-1045

WITH MAJOR SUPPORT FROM

UNITED STATES DEPARTMENT OF ENERGY
ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY
OFFICE OF BUILDING TECHNOLOGIES
BUILDING SYSTEMS AND MATERIALS DIVISION

AND ADDITIONAL SUPPORT FROM

SOUTHERN CALIFORNIA EDISON CO., PACIFIC GAS AND ELECTRIC CO.,
GAS RESEARCH INSTITUTE, ELECTRIC POWER RESEARCH INSTITUTE

LBL RELEASE JAN 1995 version : JJHirsch PC 2.1E-W83

This JJHirsch PC DOE-2.1E was released in July 1995.

```
$DOE-2.1E Input File
$Created by VisualDOE Jan 26, 2000
$
##write

TITLE
  LINE-1 = *VisualDOE*
  LINE-3 = *Construction 2 (HCMU)*
  LINE-4 = *BCASE2.GPH*
  LINE-5 = *VisualDOE Graphic Editor* ..
INPUT LOADS
    INPUT-UNITS METRIC
    OUTPUT-UNITS METRIC

ABORT ERRORS ..
LIST WARNINGS ..

RUN-PERIOD    JAN  1, 1995 THRU DEC 31, 1995 ..

BUILDING-LOCATION
$Building Azimuth is corrected for DOE2.1 by 180° (Entered Value = 0)
   AZIMUTH = 180
   HOLIDAY = NO
..

SET-DEFAULT
$Set window shade defaults
FOR WINDOW
MAX-SOLAR-SCH = SOLGAIN1-SCH
OPEN-SHADE-SCH = OPENSHADE1-SCH
VIS-TRANS-SCH = VISTRAN1-SCH
..

$Set window shade schedules
SHADE1-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24) VALUES = (0.8)  ..
SOLGAIN1-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24) VALUES = (30) ..
OPENSHADE1-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24) VALUES = (0.1)  ..
VISTRAN1-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24) VALUES = (0.6)  ..

$Apt/Lgt/Guest
SCH151 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.50,1.00,1.00,1.00,0.60)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.50,1.00,1.00,1.00,0.60)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.50,1.00,1.00,1.00,0.60)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.50,1.00,1.00,1.00,0.60)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.50,1.00,1.00,1.00,0.60)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.50,1.00,1.00,1.00,0.60)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.50,1.00,1.00,1.00,0.60)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.50,1.00,1.00,1.00,0.60)
..

$Apt/Eqp/Guest
SCH152 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.05,0.05,0.05,0.30,0.60,0.95,0.95,0.95,0.60)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
```

```
0.00,0.00,0.00,0.05,0.05,0.05,0.30,0.60,0.95,0.95,0.95,0.60)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.05,0.05,0.05,0.30,0.60,0.95,0.95,0.95,0.60)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.05,0.05,0.05,0.30,0.60,0.95,0.95,0.95,0.60)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.05,0.05,0.05,0.30,0.60,0.95,0.95,0.95,0.60)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.05,0.05,0.05,0.30,0.60,0.95,0.95,0.95,0.60)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.05,0.05,0.05,0.30,0.60,0.95,0.95,0.95,0.60)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.05,0.05,0.05,0.30,0.60,0.95,0.95,0.95,0.60)
..

$Apt/Occ/Guest
SCH150 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,1.00,1.00,1.00,0.50)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,1.00,1.00,1.00,0.50)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,1.00,1.00,1.00,0.50)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,1.00,1.00,1.00,0.50)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,1.00,1.00,1.00,0.50)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,1.00,1.00,1.00,0.50)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,1.00,1.00,1.00,0.50)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,1.00,1.00,1.00,0.50)
..

$Apt/Inf/Guest
SCH153 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(TUE) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(WED) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(THU) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(FRI) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SAT) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SUN) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(HOL) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
..

$Apt/Lgt/Bedroom
SCH172 = SCHEDULE
```

```
THRU DEC 31
(MON) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.45,1.00,1.00,0.50,0.50)
(TUE) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.45,1.00,1.00,0.50,0.50)
(WED) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.45,1.00,1.00,0.50,0.50)
(THU) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.45,1.00,1.00,0.50,0.50)
(FRI) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.45,1.00,1.00,0.50,0.50)
(SAT) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.45,1.00,1.00,0.50,0.50)
(SUN) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.45,1.00,1.00,0.50,0.50)
(HOL) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.45,1.00,1.00,0.50,0.50)
..

$Apt/Eqp/Bedroom
SCH173 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.05,0.05,0.05,0.05,0.05,
0.05,0.15,0.15,0.00,0.00,0.00,0.00,0.00,0.50,0.90,0.90,0.50)
(TUE) (1,24) VALUES =
 (0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.05,0.05,0.05,0.05,0.05,
0.05,0.15,0.15,0.00,0.00,0.00,0.00,0.00,0.50,0.90,0.90,0.50)
(WED) (1,24) VALUES =
 (0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.05,0.05,0.05,0.05,0.05,
0.05,0.15,0.15,0.00,0.00,0.00,0.00,0.00,0.50,0.90,0.90,0.50)
(THU) (1,24) VALUES =
 (0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.05,0.05,0.05,0.05,0.05,
0.05,0.15,0.15,0.00,0.00,0.00,0.00,0.00,0.50,0.90,0.90,0.50)
(FRI) (1,24) VALUES =
 (0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.05,0.05,0.05,0.05,0.05,
0.05,0.15,0.15,0.00,0.00,0.00,0.00,0.00,0.50,0.90,0.90,0.50)
(SAT) (1,24) VALUES =
 (0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.05,0.05,0.05,0.05,0.05,
0.05,0.15,0.15,0.00,0.00,0.00,0.00,0.00,0.50,0.90,0.90,0.50)
(SUN) (1,24) VALUES =
 (0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.05,0.05,0.05,0.05,0.05,
0.05,0.15,0.15,0.00,0.00,0.00,0.00,0.00,0.50,0.90,0.90,0.50)
(HOL) (1,24) VALUES =
 (0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.05,0.05,0.05,0.05,0.05,
0.05,0.15,0.15,0.00,0.00,0.00,0.00,0.00,0.50,0.90,0.90,0.50)
..

$Apt/Occ/Bedroom
SCH171 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,0.50,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,1.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00)
(TUE) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,0.50,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,1.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00)
(WED) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,0.50,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,1.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00)
(THU) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,0.50,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,1.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00)
(FRI) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,0.50,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,1.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00)
(SAT) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,0.50,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,1.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00)
(SUN) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,0.50,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,1.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00)
(HOL) (1,24) VALUES =
```

```
 (1.00,1.00,1.00,1.00,1.00,1.00,0.50,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,1.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00)
..

$Apt/Inf/Bedroom
SCH174 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(TUE) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(WED) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(THU) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(FRI) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SAT) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SUN) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(HOL) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
..

$Apt/Lgt/Kitchen
SCH182 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.95,0.30,0.30,0.30,0.30,0.30,
0.30,0.00,0.00,0.00,0.20,0.20,0.50,1.00,1.00,1.00,0.50,0.50)
(TUE) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.95,0.30,0.30,0.30,0.30,0.30,
0.30,0.00,0.00,0.00,0.20,0.20,0.50,1.00,1.00,1.00,0.50,0.50)
(WED) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.95,0.30,0.30,0.30,0.30,0.30,
0.30,0.00,0.00,0.00,0.20,0.20,0.50,1.00,1.00,1.00,0.50,0.50)
(THU) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.95,0.30,0.30,0.30,0.30,0.30,
0.30,0.00,0.00,0.00,0.20,0.20,0.50,1.00,1.00,1.00,0.50,0.50)
(FRI) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.95,0.30,0.30,0.30,0.30,0.30,
0.30,0.00,0.00,0.00,0.20,0.20,0.50,1.00,1.00,1.00,0.50,0.50)
(SAT) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.95,0.30,0.30,0.30,0.30,0.30,
0.30,0.00,0.00,0.00,0.20,0.20,0.50,1.00,1.00,1.00,0.50,0.50)
(SUN) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.95,0.30,0.30,0.30,0.30,0.30,
0.30,0.00,0.00,0.00,0.20,0.20,0.50,1.00,1.00,1.00,0.50,0.50)
(HOL) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.95,0.30,0.30,0.30,0.30,0.30,
0.30,0.00,0.00,0.00,0.20,0.20,0.50,1.00,1.00,1.00,0.50,0.50)
..

$Apt/Eqp/Kitchen
SCH183 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.10,0.10,0.10,0.10,0.10,0.10,0.95,0.50,0.50,0.50,1.00,1.00,
1.00,0.50,0.50,0.50,0.50,0.50,0.50,1.00,1.00,0.50,0.10,0.10)
(TUE) (1,24) VALUES =
 (0.10,0.10,0.10,0.10,0.10,0.10,0.95,0.50,0.50,0.50,1.00,1.00,
1.00,0.50,0.50,0.50,0.50,0.50,0.50,1.00,1.00,0.50,0.10,0.10)
(WED) (1,24) VALUES =
 (0.10,0.10,0.10,0.10,0.10,0.10,0.95,0.50,0.50,0.50,1.00,1.00,
1.00,0.50,0.50,0.50,0.50,0.50,0.50,1.00,1.00,0.50,0.10,0.10)
(THU) (1,24) VALUES =
 (0.10,0.10,0.10,0.10,0.10,0.10,0.95,0.50,0.50,0.50,1.00,1.00,
1.00,0.50,0.50,0.50,0.50,0.50,0.50,1.00,1.00,0.50,0.10,0.10)
(FRI) (1,24) VALUES =
 (0.10,0.10,0.10,0.10,0.10,0.10,0.95,0.50,0.50,0.50,1.00,1.00,
1.00,0.50,0.50,0.50,0.50,0.50,0.50,1.00,1.00,0.50,0.10,0.10)
(SAT) (1,24) VALUES =
```

```
 (0.10,0.10,0.10,0.10,0.10,0.10,0.95,0.50,0.50,0.50,1.00,1.00,
1.00,0.50,0.50,0.50,0.50,0.50,0.50,1.00,1.00,0.50,0.10,0.10)
(SUN) (1,24) VALUES =
 (0.10,0.10,0.10,0.10,0.10,0.10,0.95,0.50,0.50,0.50,1.00,1.00,
1.00,0.50,0.50,0.50,0.50,0.50,0.50,1.00,1.00,0.50,0.10,0.10)
(HOL) (1,24) VALUES =
 (0.10,0.10,0.10,0.10,0.10,0.10,0.95,0.50,0.50,0.50,1.00,1.00,
1.00,0.50,0.50,0.50,0.50,0.50,0.50,1.00,1.00,0.50,0.10,0.10)
..

$Apt/Occ/Kitchen
SCH181 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.20,0.20,0.50,1.00,1.00,
0.70,0.20,0.05,0.05,0.05,0.05,0.05,0.80,0.80,0.20,0.00,0.00)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.20,0.20,0.50,1.00,1.00,
0.70,0.20,0.05,0.05,0.05,0.05,0.05,0.80,0.80,0.20,0.00,0.00)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.20,0.20,0.50,1.00,1.00,
0.70,0.20,0.05,0.05,0.05,0.05,0.05,0.80,0.80,0.20,0.00,0.00)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.20,0.20,0.50,1.00,1.00,
0.70,0.20,0.05,0.05,0.05,0.05,0.05,0.80,0.80,0.20,0.00,0.00)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.20,0.20,0.50,1.00,1.00,
0.70,0.20,0.05,0.05,0.05,0.05,0.05,0.80,0.80,0.20,0.00,0.00)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.20,0.20,0.50,1.00,1.00,
0.70,0.20,0.05,0.05,0.05,0.05,0.05,0.80,0.80,0.20,0.00,0.00)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.20,0.20,0.50,1.00,1.00,
0.70,0.20,0.05,0.05,0.05,0.05,0.05,0.80,0.80,0.20,0.00,0.00)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.20,0.20,0.50,1.00,1.00,
0.70,0.20,0.05,0.05,0.05,0.05,0.05,0.80,0.80,0.20,0.00,0.00)
..

$Apt/Inf/Kitchen
SCH184 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(TUE) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(WED) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(THU) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(FRI) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SAT) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SUN) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(HOL) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
..

$Apt/Lgt/Living
SCH161 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(THU) (1,24) VALUES =
```

```
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
..
$Apt/Eqp/Living
SCH162 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(TUE) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(WED) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(THU) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(FRI) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SAT) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SUN) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(HOL) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
..
$Apt/Occ/Living
SCH160 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
..
$Apt/Inf/Living
SCH163 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(TUE) (1,24) VALUES =
```

```
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.15,0.15,0.15,0.15,
0.15,0.15,0.05,0.05,0.55,0.55,0.95,0.95,0.95,0.95,0.95,0.95)
..

$Apt/Eqp/Living
SCH162 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(TUE) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(WED) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(THU) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(FRI) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SAT) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(SUN) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(HOL) (1,24) VALUES =
 (0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.50,0.50,0.50,0.50,0.50,
0.80,0.80,0.50,0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
..

$Apt/Occ/Living
SCH160 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.20,0.20,0.30,0.30,0.30,0.30,
0.30,0.30,0.30,0.30,0.95,0.95,0.95,0.95,0.95,0.95,0.95,0.95)
..

$Apt/Inf/Living
SCH163 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
(TUE) (1,24) VALUES =
```

```
* 482 *  (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
* 483 * 1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
* 484 * (WED) (1,24) VALUES =
* 485 *  (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
* 486 * 1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
* 487 * (THU) (1,24) VALUES =
* 488 *  (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
* 489 * 1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
* 490 * (FRI) (1,24) VALUES =
* 491 *  (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
* 492 * 1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
* 493 * (SAT) (1,24) VALUES =
* 494 *  (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
* 495 * 1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
* 496 * (SUN) (1,24) VALUES =
* 497 *  (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
* 498 * 1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)
* 499 * (HOL) (1,24) VALUES =
* 500 *  (1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
* 501 * 1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00)

* 502 * ...............................................
* 503 * ...............................................  Skip *504 - *618

* 619 *
* 620 * $----------------------------------------------
* 621 * $Materials
* 622 * $ Cement, 2.54 cm Plaster w/ Sand
* 623 * CM03 = MATERIAL
* 624 * THICKNESS = .0254
* 625 * CONDUCTIVITY = .7212
* 626 * DENSITY = 1858.15
* 627 * SPECIFIC-HEAT = 837
* 628 * ..
* 629 *
* 630 * $ CMU Heavy Wt. 20.3 cm Hollow
* 631 * CB11 = MATERIAL
* 632 * THICKNESS = .2032
* 633 * CONDUCTIVITY = 1.0488
* 634 * DENSITY = 1105.28
* 635 * SPECIFIC-HEAT = 837
* 636 * ..
* 637 *
* 638 * $ Clay Tile, Hollow 25.4 cm 2 Cell
* 639 * CT05 = MATERIAL
* 640 * THICKNESS = .254
* 641 * CONDUCTIVITY = .6488
* 642 * DENSITY = 1121.3
* 643 * SPECIFIC-HEAT = 837
* 644 * ..
* 645 *
* 646 * $ Medium Wt. 15.2 cm
* 647 * CC25 = MATERIAL
* 648 * THICKNESS = .1524
* 649 * CONDUCTIVITY = .3605
* 650 * DENSITY = 1281.48
* 651 * SPECIFIC-HEAT = 837
* 652 * ..
* 653 *
* 654 * $ Cement, 2.54 cm Mortar
* 655 * CM01 = MATERIAL
* 656 * THICKNESS = .0254
* 657 * CONDUCTIVITY = .7212
* 658 * DENSITY = 1858.15
* 659 * SPECIFIC-HEAT = 837
* 660 * ..
* 661 *
* 662 * $ Clay Tile, Paver
* 663 * CT11 = MATERIAL
* 664 * THICKNESS = .0095
* 665 * CONDUCTIVITY = 1.8027
* 666 * DENSITY = 1922.22
* 667 * SPECIFIC-HEAT = 837
* 668 * ..
* 669 *
* 670 * $ Carpet with Fibrous Pad
* 671 * CP01 = MATERIAL
* 672 * RESISTANCE = .3666
* 673 * ..
* 674 *
* 675 * $-------------------------------------------------------------
```

```
$Constructions
$ 200mm Hollow concrete block
Asm113-LAYR = LAYERS
MATERIAL = (CM03, CB11, CM03)
INSIDE-FILM-RES = 0.12
..

$ 200mm Hollow concrete block
Asm113       = CONSTRUCTION
LAYERS = Asm113-LAYR
ABSORPTANCE =  .3
ROUGHNESS =  3
..

$ Ordenary Partition
PART-LAYR = LAYERS
MATERIAL = (CM03, CT05, CM03)
INSIDE-FILM-RES = 0.12
..

$ Ordenary Partition
PART          = CONSTRUCTION
LAYERS = PART-LAYR
ABSORPTANCE =  .3
ROUGHNESS =  3
..

$ Internal Floor
FRO-MASS-LAYR = LAYERS
MATERIAL = (CM03, CC25, CM01, CT11, CP01)
INSIDE-FILM-RES = 0.107
..

$ Internal Floor
FRO-MASS     = CONSTRUCTION
LAYERS = FRO-MASS-LAYR
ABSORPTANCE =  .3
ROUGHNESS =  3
..

$ External RC Roof
WR19-MASS-LAYR = LAYERS
MATERIAL = (CT11, CM01, CC25, CM03)
INSIDE-FILM-RES = 0.107
..

$ External RC Roof
WR19-MASS    = CONSTRUCTION
LAYERS = WR19-MASS-LAYR
ABSORPTANCE =  .4
ROUGHNESS =  4
..

$-----------------------------------------------------------------------
$Glazing Materials
$Single Clear 6 mm
  GT5_1_2 = GLASS-TYPE
  GLASS-TYPE-CODE = 1001
  FRAME-CONDUCTANCE = 17.233
  FRAME-ABS = 0.7
  SPACER-TYPE-CODE = 1 ..
```

GLAZING SELECTED FROM WINDOW LIBRARY--
TYPE: SINGLE CLEAR

G-T-C	LAYERS	U-SI	U-IP	SC	SHCG	TSOL	TVIS	GAP(mm)	GAS-FILL
1001	1	6.17	1.09	0.95	0.81	0.77	0.88	0.0	

```


$Guest-Room
"Guest-Room_C" = SPACE
  AREA = 20.0
  VOLUME = 70.0
  X = 0
  Y = 0
  Z = 0
  AZIMUTH = 0
  MULTIPLIER = 1
  FLOOR-MULTIPLIER = 1
  ZONE-TYPE = CONDITIONED
```

```
$Internal Loads
  LIGHTING-W/AREA = 10
  EQUIPMENT-W/AREA = 10
  INF-SCHEDULE = SCH153
  PEOPLE-SCHEDULE = SCH150
  LIGHTING-SCHEDULE = SCH151
  EQUIP-SCHEDULE = SCH152
  PEOPLE-HG-SENS = 67.4
  PEOPLE-HG-LAT = 55.7
  AREA/PERSON = 2.0
  LIGHT-TO-SPACE = .9
  LIGHTING-TYPE = REC-FLUOR-NV
$Infiltration
  INF-METHOD = AIR-CHANGE
  AIR-CHANGES/HR = 0.75
$Mass
  FLOOR-WEIGHT = 0
  FURNITURE-TYPE = LIGHT
  FURN-FRACTION = .85
  FURN-WEIGHT = 39
  TEMPERATURE = (26)
..
$ Wall1
Wall1 = EXTERIOR-WALL
  SHADING-SURFACE = NO
  CONS = Asm113
  X = 1.00
  Y = 5.00
  Z = 0.00
  HEIGHT = 3.50
  WIDTH = 1.00
  MULTIPLIER = 1.0
  INSIDE-VIS-REFL = 0.50
  TILT = 90.00
  AZ = .00
..
$ Wall2
Wall2 = EXTERIOR-WALL
  SHADING-SURFACE = NO
  CONS = Asm113
  X = 0.00
  Y = 0.00
  Z = 0.00
  HEIGHT = 3.50
  WIDTH = 1.00
  MULTIPLIER = 1.0
  INSIDE-VIS-REFL = 0.50
  TILT = 90.00
  AZ = 180.00
..
$ Wall3
Wall3 = EXTERIOR-WALL
  SHADING-SURFACE = NO
  CONS = Asm113
  X = 0.00
  Y = 5.00
  Z = 0.00
  HEIGHT = 3.50
  WIDTH = 5.00
  MULTIPLIER = 1.0
  INSIDE-VIS-REFL = 0.50
  TILT = 90.00
  AZ = 270.00
..
$ Window1
Window1 = WINDOW
GLASS-TYPE = GT5_1_2
  X = 1.8
  Y = 1.3
  HEIGHT = 1.4
  WIDTH = 1.4
  FRAME-WIDTH = 0.051
  MULTIPLIER = 1.0
 $Shading
```

```
* 831 *    SHADING-SCHEDULE = SHADE1-SCH
* 832 *    WIN-SHADE-TYPE = MOVABLE-INTERIOR
* 833 *    SUN-CTRL-PROB = 1
* 834 *    GLARE-CTRL-PROB = 1
* 835 * ..
* 836 *
* 837 * $ Part58
* 838 * Partition58 = INTERIOR-WALL
* 839 * NEXT-TO = "General_C"
* 840 *    CONS = PART
* 841 *    X = 4.00
* 842 *    Y = 5.00
* 843 *    Z = 0.00
* 844 *    HEIGHT = 3.50
* 845 *    WIDTH = 3.00
* 846 *    INSIDE-VIS-REFL = (0.50, 0.50)
* 847 *    TILT = 90.00
* 848 *    AZ = .00
* 849 * ..
* 850 *
* 851 *
* 852 * $ Part59
* 853 * Partition59 = INTERIOR-WALL
* 854 * NEXT-TO = "General2_C"
* 855 *    CONS = PART
* 856 *    X = 4.00
* 857 *    Y = 3.00
* 858 *    Z = 0.00
* 859 *    HEIGHT = 3.50
* 860 *    WIDTH = 2.00
* 861 *    INSIDE-VIS-REFL = (0.50, 0.50)
* 862 *    TILT = 90.00
* 863 *    AZ = 90.00
* 864 * ..
* 865 *
* 866 *
* 867 * $ Part60
* 868 * Partition60 = INTERIOR-WALL
* 869 * NEXT-TO = "General-out_C"
* 870 *    CONS = PART
* 871 *    X = 4.00
* 872 *    Y = 0.00
* 873 *    Z = 0.00
* 874 *    HEIGHT = 3.50
* 875 *    WIDTH = 3.00
* 876 *    INSIDE-VIS-REFL = (0.50, 0.50)
* 877 *    TILT = 90.00
* 878 *    AZ = 90.00
* 879 * ..
* 880 *
* 881 *
* 882 * $ Part61
* 883 * Partition61 = INTERIOR-WALL
* 884 * NEXT-TO = "General-out_C"
* 885 *    CONS = PART
* 886 *    X = 1.00
* 887 *    Y = 0.00
* 888 *    Z = 0.00
* 889 *    HEIGHT = 3.50
* 890 *    WIDTH = 3.00
* 891 *    INSIDE-VIS-REFL = (0.50, 0.50)
* 892 *    TILT = 90.00
* 893 *    AZ = 180.00
* 894 * ..
* 895 *
* 896 *
* 897 * $ Exterior Floor62
* 898 * Floor62 = EXTERIOR-WALL
* 899 *    CONS = FRO-MASS
* 900 *    X = 4.00
* 901 *    Y = 0.00
* 902 *    Z = 0.00
* 903 *    HEIGHT = 5.00
* 904 *    WIDTH = 4.00
* 905 *    INSIDE-VIS-REFL = 0.20
* 906 *    TILT = 180.00
* 907 *    AZ = .00
* 908 * ............................................ Skip *909 - *4052
```

```
$Apt/DHW/Bedroom
SCH175 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
..

$Apt/Fan/Guest
SCH192 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00,1.00,1.00,0.00,0.00)
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00,1.00,1.00,0.00,0.00)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,1.00,1.00,1.00,1.00,0.00,0.00)
..

$Apt/OAir/Guest
SCH158 = SCHEDULE
THRU DEC 31
(MON) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(TUE) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(WED) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(THU) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
```

```
(FRI) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(SAT) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(SUN) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
(HOL) (1,24) VALUES =
 (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
..

$Apt/PIUT/Guest
SCH205 = SCHEDULE
THRU DEC 31
(MON) (1,24) TEMP =
 (4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,
4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4)
(TUE) (1,24) TEMP =
 (4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,
4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4)
(WED) (1,24) TEMP =
 (4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,
4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4)
(THU) (1,24) TEMP =
 (4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,
4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4)
(FRI) (1,24) TEMP =
 (4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,
4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4)
(SAT) (1,24) TEMP =
 (4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,
4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4)
(SUN) (1,24) TEMP =
 (4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,
4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4)
(HOL) (1,24) TEMP =
 (4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,
4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4,4.4)
..

$Apt/HtT/Guest
SCH200 = SCHEDULE
THRU DEC 31
(MON) (1,24) TEMP =
 (17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,
17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8)
(TUE) (1,24) TEMP =
 (17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,
17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8)
(WED) (1,24) TEMP =
 (17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,
17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8)
(THU) (1,24) TEMP =
 (17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,
17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8)
(FRI) (1,24) TEMP =
 (17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,
17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8)
(SAT) (1,24) TEMP =
 (17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,
17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8)
(SUN) (1,24) TEMP =
 (17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,
17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8)
(HOL) (1,24) TEMP =
 (17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,
17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8,17.8)
..

$Apt/CtT/Guest
SCH196 = SCHEDULE
THRU DEC 31
(MON) (1,24) TEMP =
 (37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,
37.8,37.8,37.8,37.2,37.8,37.8,26.1,26.1,25.6,25.6,37.8,37.8)
(TUE) (1,24) TEMP =
 (37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,
37.8,37.8,37.8,37.2,37.8,37.8,26.1,26.1,25.6,25.6,37.8,37.8)
```

```
*4207 * (WED) (1,24) TEMP =
*4208 *  (37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,
*4209 * 37.8,37.8,37.8,37.2,37.8,37.8,26.1,26.1,25.6,25.6,37.8,37.8)
*4210 * (THU) (1,24) TEMP =
*4211 *  (37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,
*4212 * 37.8,37.8,37.8,37.2,37.8,37.8,26.1,26.1,25.6,25.6,37.8,37.8)
*4213 * (FRI) (1,24) TEMP =
*4214 *  (37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,
*4215 * 37.8,37.8,37.8,37.2,37.8,37.8,26.1,26.1,25.6,25.6,37.8,37.8)
*4216 * (SAT) (1,24) TEMP =
*4217 *  (37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,
*4218 * 37.8,37.8,37.8,37.2,37.8,37.8,26.1,26.1,25.6,25.6,37.8,37.8)
*4219 * (SUN) (1,24) TEMP =
*4220 *  (37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,
*4221 * 37.8,37.8,37.8,37.2,37.8,37.8,26.1,26.1,25.6,25.6,37.8,37.8)
*4222 * (HOL) (1,24) TEMP =
*4223 *  (37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,37.8,
*4224 * 37.8,37.8,37.8,37.2,37.8,37.8,26.1,26.1,25.6,25.6,37.8,37.8)
*4225 * ...........................................................
*4226 * .................................................. Skip *4227 - *4805

*4806 * ------------------------------------------------------------------------
*4807 * ------------------------------------------------------------------------

*4808 * $Description of Zone: Guest-Room
*4809 * "Guest-Room_C" = ZONE
*4810 *   ZONE-TYPE = CONDITIONED
*4811 *   SIZING-OPTION = ADJUST-LOADS
*4812 *   HEAT-TEMP-SCH = SCH200
*4813 *   COOL-TEMP-SCH = SCH196
*4814 *   DESIGN-HEAT-T = 20
*4815 *   DESIGN-COOL-T = 26
*4816 *   $No Zone Reheat
*4817 *   $Thermostat
*4818 *   THERMOSTAT-TYPE = TWO-POSITION
*4819 *   $Supply Air
*4820 *   MIN-CFM-RATIO = 1
*4821 *   AIR-CHANGES/HR = 0
*4822 *   $Outside Air
*4823 *   OA-CHANGES = 0
*4824 *   $No Exhaust Air
*4825 *   $No PIU
*4826 *   $No Baseboard Heating
*4827 *   $ No Refrigeration
*4828 *   ..
*4829 *
*4830 * $Description of Zone: Bed-Room
*4831 * "Bed-Room_C" = ZONE
*4832 *   ZONE-TYPE = CONDITIONED
*4833 *   SIZING-OPTION = ADJUST-LOADS
*4834 *   HEAT-TEMP-SCH = SCH199
*4835 *   COOL-TEMP-SCH = SCH197
*4836 *   DESIGN-HEAT-T = 20
*4837 *   DESIGN-COOL-T = 26
*4838 *   $No Zone Reheat
*4839 *   $Thermostat
*4840 *   THERMOSTAT-TYPE = TWO-POSITION
*4841 *   $Supply Air
*4842 *   MIN-CFM-RATIO = 1
*4843 *   AIR-CHANGES/HR = 0
*4844 *   $Outside Air
*4845 *   OA-CHANGES = 0
*4846 *   $No Exhaust Air
*4847 *   $No PIU
*4848 *   $No Baseboard Heating
*4849 *   $ No Refrigeration
*4850 *   ..
*4851 *
*4852 * $Description of Zone: Kitchen
*4853 * "Kitchen_C" = ZONE
*4854 *   ZONE-TYPE = CONDITIONED
*4855 *   SIZING-OPTION = ADJUST-LOADS
*4856 *   HEAT-TEMP-SCH = SCH202
*4857 *   COOL-TEMP-SCH = SCH207
*4858 *   DESIGN-HEAT-T = 20
*4859 *   DESIGN-COOL-T = 26
*4860 *   $No Zone Reheat
*4861 *   $Thermostat
*4862 *   THERMOSTAT-TYPE = TWO-POSITION
*4863 *   $Supply Air
*4864 *   MIN-CFM-RATIO = 1
```

```
   AIR-CHANGES/HR = 0
   $Outside Air
   OA-CHANGES = 0
   $No Exhaust Air
   $No PIU
   $No Baseboard Heating
   $ No Refrigeration
   ..

$Description of Zone: Living
"Living_C" = ZONE
   ZONE-TYPE = CONDITIONED
   SIZING-OPTION = ADJUST-LOADS
   HEAT-TEMP-SCH = SCH201
   COOL-TEMP-SCH = SCH195
   DESIGN-HEAT-T = 20
   DESIGN-COOL-T = 26
   $No Zone Reheat
   $Thermostat
   THERMOSTAT-TYPE = TWO-POSITION
   $Supply Air
   MIN-CFM-RATIO = 1
   AIR-CHANGES/HR = 0
   $Outside Air
   OA-CHANGES = 0
   $No Exhaust Air
   $No PIU
   $No Baseboard Heating
   $ No Refrigeration
   ..

$Description of Zone: General
"General_C" = ZONE
   ZONE-TYPE = CONDITIONED
   SIZING-OPTION = ADJUST-LOADS
   HEAT-TEMP-SCH = SCH209
   COOL-TEMP-SCH = SCH208
   DESIGN-HEAT-T = 20
   DESIGN-COOL-T = 26
   $No Zone Reheat
   $Thermostat
   THERMOSTAT-TYPE = TWO-POSITION
   $Supply Air
   MIN-CFM-RATIO = 1
   AIR-CHANGES/HR = 0
   $Outside Air
   OA-CHANGES = 0
   $No Exhaust Air
   $No PIU
   $No Baseboard Heating
   $ No Refrigeration
   ..

$Description of Zone: General2
"General2_C" = ZONE
   ZONE-TYPE = CONDITIONED
   SIZING-OPTION = ADJUST-LOADS
   HEAT-TEMP-SCH = SCH209
   COOL-TEMP-SCH = SCH208
   DESIGN-HEAT-T = 20
   DESIGN-COOL-T = 26
   $No Zone Reheat
   $Thermostat
   THERMOSTAT-TYPE = TWO-POSITION
   $Supply Air
   MIN-CFM-RATIO = 1
   AIR-CHANGES/HR = 0
   $Outside Air
   OA-CHANGES = 0
   $No Exhaust Air
   $No PIU
   $No Baseboard Heating
   $ No Refrigeration
   ..

$Description of Zone: General3
"General3_C" = ZONE
   ZONE-TYPE = CONDITIONED
   SIZING-OPTION = ADJUST-LOADS
   HEAT-TEMP-SCH = SCH209
   COOL-TEMP-SCH = SCH208
```

```
*4946 *    DESIGN-HEAT-T = 20
*4947 *    DESIGN-COOL-T = 26
*4948 *    $No Zone Reheat
*4949 *    $Thermostat
*4950 *    THERMOSTAT-TYPE = TWO-POSITION
*4951 *    $Supply Air
*4952 *    MIN-CFM-RATIO = 1
*4953 *    AIR-CHANGES/HR = 0
*4954 *    $Outside Air
*4955 *    OA-CHANGES = 0
*4956 *    $No Exhaust Air
*4957 *    $No PIU
*4958 *    $No Baseboard Heating
*4959 *    $ No Refrigeration
*4960 *    ..
*4961 *
*4962 * $Description of Zone: General-out
*4963 * "General-out_C" = ZONE
*4964 *    ZONE-TYPE = CONDITIONED
*4965 *    SIZING-OPTION = ADJUST-LOADS
*4966 *    HEAT-TEMP-SCH = SCH209
*4967 *    COOL-TEMP-SCH = SCH208
*4968 *    DESIGN-HEAT-T = 20
*4969 *    DESIGN-COOL-T = 26
*4970 *    $No Zone Reheat
*4971 *    $Thermostat
*4972 *    THERMOSTAT-TYPE = TWO-POSITION
*4973 *    $Supply Air
*4974 *    MIN-CFM-RATIO = 1
*4975 *    AIR-CHANGES/HR = 0
*4976 *    $Outside Air
*4977 *    OA-CHANGES = 0
*4978 *    $No Exhaust Air
*4979 *    $No PIU
*4980 *    $No Baseboard Heating
*4981 *    $ No Refrigeration
*4982 *    ......................................................
*4983 *    .......................................... Skip *4984 - *5334
*5335 *
*5336 * $Description of System: Guestzone
*5337 * "Guestzone" = SYSTEM
*5338 * SYSTEM-TYPE = PTAC
*5339 * ZONE-NAMES = ("Guest-Room_C")
*5340 *    RETURN-AIR-PATH = DUCT
*5341 * $Air-to-Air Heat Pump
*5342 *    HEATING-EIR = 0.25
*5343 *    DEFROST-TYPE = REVERSE-CYCLE
*5344 *    DEFROST-CTRL = ON-DEMAND
*5345 *    DEFROST-T = 4.4
*5346 *    HP-SUPP-SOURCE = ELECTRIC
*5347 *    HP-SUPP-HT-CAP = 0
*5348 *    MAX-HP-SUPP-T = 7.2
*5349 *    MIN-HP-T = -17.8
*5350 *    CRANKCASE-HEAT = 0
*5351 *    CRANKCASE-MAX-T = -17.8
*5352 *    COMPRESSOR-TYPE = SINGLE-SPEED
*5353 * $Cooling
*5354 *    MIN-SUPPLY-T = 12.8
*5355 *    COOLING-CAPACITY = 4000
*5356 *    COOL-SH-CAP = 3500
*5357 *    COOLING-EIR = 0.3681
*5358 * $No Economizer
*5359 *    OA-CONTROL = FIXED
*5360 * $No Evaporative Cooler
*5361 * $Supply Fan
*5362 *    FAN-SCHEDULE = SCH192
*5363 *    MIN-AIR-SCH = SCH158
*5364 *    SUPPLY-KW = .00021  $Fan energy included in EER (Cooling EIR)
*5365 * $Heating
*5366 *    MAX-SUPPLY-T = 40.6
*5367 *    $Temperature control not applicable for this system
*5368 *    HEATING-CAPACITY = 0
*5369 *    HEAT-SOURCE = HEAT-PUMP
*5370 * $No Heat Recovery
*5371 * $No Humidifier
*5372 * $No Hydronic Heat Pump
*5373 * $No Evaporative Precooler
*5374 * $No PreHeat
*5375 * $Zone Baseboard

*5376 * * STOP
```

Appendix IV

Simulation Result Sample

VisualDOE DOE-2.1E-W83 1/26/2000 18: 7: 5 LDL RUN 1
Construction 2 (HCMU) BCASE2.GPH VisualDOE Graphic Editor
REPORT- LS-E SPACE MONTHLY LOAD COMPONENTS IN MWH FOR Guest-Room_C WEATHER FILE- MAKKAH, 1980

(UNITS= MWH)		WALLS	ROOFS	INT SUR	UND SUR	INFIL	WIN CON	WIN SOL	OCCUP	LIGHTS	EQUIP	SOURCE	TOTAL
	HEATNG	-0.034	0.000	0.000	0.000	-0.003	-0.008	0.010	0.010	0.003	0.003	0.000	-0.018
JAN	SEN CL	-0.025	0.000	0.000	0.000	-0.002	-0.002	0.064	0.063	0.020	0.021	0.000	0.138
	LAT CL					0.013			0.069		0.000	0.000	0.082
	HEATNG	-0.024	0.000	0.000	0.000	-0.002	-0.006	0.007	0.007	0.002	0.002	0.000	-0.013
FEB	SEN CL	-0.021	0.000	0.000	0.000	-0.004	-0.001	0.071	0.058	0.018	0.019	0.000	0.140
	LAT CL					0.012			0.062		0.000	0.000	0.075
	HEATNG	-0.013	0.000	0.000	0.000	-0.001	-0.003	0.005	0.003	0.001	0.001	0.000	-0.007
MAR	SEN CL	0.078	0.000	0.000	0.000	0.005	0.014	0.101	0.069	0.021	0.023	0.000	0.313
	LAT CL					0.028			0.069		0.000	0.000	0.097
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
APR	SEN CL	0.159	0.000	0.000	0.000	0.009	0.026	0.112	0.070	0.022	0.023	0.000	0.420
	LAT CL					0.034			0.067		0.000	0.000	0.100
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAY	SEN CL	0.276	0.000	0.000	0.000	0.016	0.044	0.118	0.073	0.022	0.024	0.000	0.574
	LAT CL					0.042			0.069		0.000	0.000	0.111
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
JUN	SEN CL	0.317	0.000	0.000	0.000	0.017	0.049	0.112	0.070	0.022	0.023	0.000	0.611
	LAT CL					0.043			0.067		0.000	0.000	0.110
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
JUL	SEN CL	0.377	0.000	0.000	0.000	0.024	0.059	0.110	0.073	0.022	0.024	0.000	0.689
	LAT CL					0.043			0.069		0.000	0.000	0.112
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AUG	SEN CL	0.354	0.000	0.000	0.000	0.023	0.056	0.106	0.073	0.022	0.024	0.000	0.658
	LAT CL					0.053			0.069		0.000	0.000	0.122
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SEP	SEN CL	0.277	0.000	0.000	0.000	0.017	0.043	0.102	0.070	0.022	0.023	0.000	0.554
	LAT CL					0.062			0.067		0.000	0.000	0.129
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OCT	SEN CL	0.230	0.000	0.000	0.000	0.011	0.033	0.103	0.072	0.022	0.024	0.000	0.496
	LAT CL					0.046			0.069		0.000	0.000	0.115

NOV	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.149	0.000	0.000	0.000	0.007	0.020	0.083	0.070	0.022	0.023	0.000	0.374
	LAT CL					0.029			0.067		0.000	0.000	0.096
DEC	HEATNG	-0.018	0.000	0.000	0.000	-0.001	-0.004	0.006	0.005	0.002	0.002	0.000	-0.009
	SEN CL	0.029	0.000	0.000	0.000	0.001	0.003	0.067	0.067	0.021	0.022	0.000	0.211
	LAT CL					0.017			0.069		0.000	0.000	0.086
TOT	HEATNG	-0.089	0.000	0.000	0.000	-0.007	-0.020	0.026	0.026	0.008	0.009	0.000	-0.048
	SEN CL	2.199	0.000	0.000	0.000	0.124	0.344	1.149	0.828	0.256	0.277	0.000	5.178
	LAT CL					0.421			0.813		0.000	0.000	1.234

VisualDOE
Construction 2 (HCMU) BCASE2.GPH DOE-2.1E-W83 1/26/2000 18: 7: 5 LDL RUN 1
VisualDOE Graphic Editor
REPORT- LS-E SPACE MONTHLY LOAD COMPONENTS IN MWH FOR Bed-Room_C WEATHER FILE- MAKKAH, 1980

(UNITS= MWH)		WALLS	ROOFS	INT SUR	UND SUR	INFIL	WIN CON	WIN SOL	OCCUP	LIGHTS	EQUIP	SOURCE	TOTAL
JAN	HEATNG	-0.041	0.000	0.000	0.000	-0.002	-0.015	0.016	0.010	0.002	0.003	0.000	-0.028
	SEN CL	-0.011	0.000	0.000	0.000	-0.002	0.011	0.172	0.017	0.008	0.009	0.000	0.203
	LAT CL					0.011			0.018		0.000	0.000	0.028
FEB	HEATNG	-0.036	0.000	0.000	0.000	-0.002	-0.013	0.014	0.009	0.001	0.002	0.000	-0.023
	SEN CL	-0.006	0.000	0.000	0.000	-0.003	0.009	0.149	0.015	0.007	0.008	0.000	0.180
	LAT CL					0.010			0.016		0.000	0.000	0.026
MAR	HEATNG	-0.019	0.000	0.000	0.000	-0.001	-0.007	0.008	0.004	0.001	0.001	0.000	-0.013
	SEN CL	0.112	0.000	0.000	0.000	0.004	0.030	0.167	0.023	0.009	0.011	0.000	0.355
	LAT CL					0.022			0.025		0.000	0.000	0.047
APR	HEATNG	-0.001	0.000	0.000	0.000	0.000	-0.001	0.001	0.001	0.000	0.000	0.000	-0.001
	SEN CL	0.198	0.000	0.000	0.000	0.007	0.039	0.149	0.026	0.009	0.011	0.000	0.439
	LAT CL					0.027			0.027		0.000	0.000	0.054
MAY	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.340	0.000	0.000	0.000	0.013	0.066	0.143	0.027	0.010	0.012	0.000	0.611
	LAT CL					0.033			0.029		0.000	0.000	0.062
JUN	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.393	0.000	0.000	0.000	0.013	0.075	0.139	0.026	0.009	0.012	0.000	0.667
	LAT CL					0.034			0.028		0.000	0.000	0.062
JUL	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.473	0.000	0.000	0.000	0.019	0.094	0.140	0.027	0.010	0.012	0.000	0.774
	LAT CL					0.034			0.029		0.000	0.000	0.063
AUG	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.451	0.000	0.000	0.000	0.018	0.092	0.142	0.027	0.010	0.012	0.000	0.753
	LAT CL					0.042			0.029		0.000	0.000	0.071
SEP	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.362	0.000	0.000	0.000	0.014	0.076	0.155	0.026	0.009	0.012	0.000	0.653
	LAT CL					0.050			0.028		0.000	0.000	0.078
OCT	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.316	0.000	0.000	0.000	0.009	0.069	0.198	0.027	0.010	0.012	0.000	0.640
	LAT CL					0.037			0.029		0.000	0.000	0.066

	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NOV	SEN CL	0.216	0.000	0.000	0.000	0.006	0.049	0.194	0.026	0.009	0.012	0.000	0.512
	LAT CL					0.023			0.028		0.000	0.000	0.051
	HEATNG	-0.022	0.000	0.000	0.000	-0.001	-0.008	0.009	0.006	0.001	0.002	0.000	-0.014
DEC	SEN CL	0.061	0.000	0.000	0.000	0.001	0.021	0.186	0.021	0.009	0.010	0.000	0.310
	LAT CL					0.013			0.023		0.000	0.000	0.036
	HEATNG	-0.120	0.000	0.000	0.000	-0.007	-0.044	0.048	0.030	0.005	0.008	0.000	-0.080
TOT	SEN CL	2.904	0.000	0.000	0.000	0.100	0.629	1.932	0.289	0.111	0.132	0.000	6.098
	LAT CL					0.336			0.309		0.000	0.000	0.645

VisualDOE DOE-2.1E-W83 1/26/2000 18: 7: 5 LDL RUN 1
Construction 2 (HCMU) BCASE2.GPH VisualDOE Graphic Editor
REPORT- LS-E SPACE MONTHLY LOAD COMPONENTS IN MWH FOR Kitchen_C WEATHER FILE- MAKKAH, 1980

(UNITS= MWH)		WALLS	ROOFS	INT SUR	UND SUR	INFIL	WIN CON	WIN SOL	OCCUP	LIGHTS	EQUIP	SOURCE	TOTAL
	HEATNG	-0.029	0.000	0.000	0.000	-0.001	-0.011	0.010	0.003	0.002	0.012	0.000	-0.015
JAN	SEN CL	-0.009	0.000	0.000	0.000	-0.002	0.007	0.137	0.028	0.013	0.089	0.000	0.263
	LAT CL					0.008			0.031		0.000	0.000	0.039
	HEATNG	-0.026	0.000	0.000	0.000	-0.001	-0.010	0.009	0.003	0.002	0.011	0.000	-0.013
FEB	SEN CL	-0.003	0.000	0.000	0.000	-0.002	0.006	0.125	0.025	0.011	0.080	0.000	0.243
	LAT CL					0.007			0.028		0.000	0.000	0.035
	HEATNG	-0.013	0.000	0.000	0.000	-0.001	-0.005	0.004	0.001	0.001	0.005	0.000	-0.008
MAR	SEN CL	0.098	0.000	0.000	0.000	0.003	0.024	0.143	0.030	0.014	0.096	0.000	0.408
	LAT CL					0.017			0.032		0.000	0.000	0.049
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
APR	SEN CL	0.172	0.000	0.000	0.000	0.005	0.033	0.131	0.030	0.014	0.098	0.000	0.483
	LAT CL					0.020			0.032		0.000	0.000	0.052
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAY	SEN CL	0.289	0.000	0.000	0.000	0.010	0.057	0.130	0.031	0.015	0.101	0.000	0.633
	LAT CL					0.025			0.033		0.000	0.000	0.058
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
JUN	SEN CL	0.329	0.000	0.000	0.000	0.010	0.065	0.127	0.030	0.014	0.098	0.000	0.673
	LAT CL					0.026			0.032		0.000	0.000	0.058
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
JUL	SEN CL	0.395	0.000	0.000	0.000	0.014	0.082	0.131	0.031	0.015	0.101	0.000	0.769
	LAT CL					0.026			0.033		0.000	0.000	0.058
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AUG	SEN CL	0.380	0.000	0.000	0.000	0.014	0.080	0.132	0.031	0.015	0.101	0.000	0.752
	LAT CL					0.032			0.033		0.000	0.000	0.065
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SEP	SEN CL	0.307	0.000	0.000	0.000	0.010	0.065	0.135	0.030	0.014	0.098	0.000	0.658
	LAT CL					0.037			0.032		0.000	0.000	0.069
	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OCT	SEN CL	0.269	0.000	0.000	0.000	0.007	0.057	0.161	0.031	0.015	0.101	0.000	0.639
	LAT CL					0.027			0.033		0.000	0.000	0.060

	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NOV	SEN CL	0.183	0.000	0.000	0.000	0.004	0.040	0.149	0.030	0.014	0.098	0.000	0.517
	LAT CL					0.017			0.032		0.000	0.000	0.049
	HEATNG	-0.016	0.000	0.000	0.000	-0.001	-0.006	0.005	0.001	0.001	0.006	0.000	-0.008
DEC	SEN CL	0.053	0.000	0.000	0.000	0.001	0.015	0.142	0.029	0.013	0.095	0.000	0.348
	LAT CL					0.010			0.032		0.000	0.000	0.042
	HEATNG	-0.085	0.000	0.000	0.000	-0.004	-0.032	0.028	0.008	0.006	0.034	0.000	-0.045
TOT	SEN CL	2.463	0.000	0.000	0.000	0.074	0.531	1.642	0.353	0.166	1.156	0.000	6.386
	LAT CL					0.253			0.381		0.000	0.000	0.633

VisualDOE
Construction 2 (HCMU) BCASE2.GPH
REPORT- LS-E SPACE MONTHLY LOAD COMPONENTS IN MWH FOR Living_C

DOE-2.1E-W83 1/26/2000 18: 7: 5 LDL RUN 1
VisualDOE Graphic Editor
WEATHER FILE- MAKKAH, 1980

(UNITS= MWH)		WALLS	ROOFS	INT SUR	UND SUR	INFIL	WIN CON	WIN SOL	OCCUP	LIGHTS	EQUIP	SOURCE	TOTAL
JAN	HEATNG	-0.040	0.000	0.000	0.000	-0.003	-0.009	0.009	0.014	0.004	0.008	0.000	-0.016
	SEN CL	-0.022	0.000	0.000	0.000	-0.002	-0.002	0.069	0.080	0.027	0.042	0.000	0.191
	LAT CL					0.013			0.081		0.000	0.000	0.094
FEB	HEATNG	-0.028	0.000	0.000	0.000	-0.002	-0.006	0.007	0.010	0.003	0.006	0.000	-0.010
	SEN CL	-0.019	0.000	0.000	0.000	-0.004	-0.001	0.075	0.075	0.025	0.040	0.000	0.192
	LAT CL					0.012			0.075		0.000	0.000	0.087
MAR	HEATNG	-0.015	0.000	0.000	0.000	-0.001	-0.003	0.004	0.004	0.001	0.002	0.000	-0.007
	SEN CL	0.075	0.000	0.000	0.000	0.005	0.014	0.104	0.090	0.030	0.048	0.000	0.366
	LAT CL					0.028			0.087		0.000	0.000	0.116
APR	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.153	0.000	0.000	0.000	0.009	0.024	0.112	0.091	0.030	0.049	0.000	0.468
	LAT CL					0.034			0.087		0.000	0.000	0.121
MAY	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.273	0.000	0.000	0.000	0.016	0.043	0.119	0.094	0.031	0.051	0.000	0.627
	LAT CL					0.042			0.090		0.000	0.000	0.132
JUN	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.316	0.000	0.000	0.000	0.017	0.049	0.116	0.091	0.030	0.049	0.000	0.669
	LAT CL					0.043			0.087		0.000	0.000	0.130
JUL	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.378	0.000	0.000	0.000	0.024	0.060	0.119	0.094	0.031	0.051	0.000	0.757
	LAT CL					0.043			0.090		0.000	0.000	0.132
AUG	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.355	0.000	0.000	0.000	0.023	0.057	0.115	0.094	0.031	0.051	0.000	0.726
	LAT CL					0.053			0.090		0.000	0.000	0.143
SEP	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.275	0.000	0.000	0.000	0.017	0.043	0.106	0.091	0.030	0.049	0.000	0.611
	LAT CL					0.062			0.087		0.000	0.000	0.149
OCT	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	0.226	0.000	0.000	0.000	0.011	0.032	0.105	0.094	0.031	0.051	0.000	0.551
	LAT CL					0.046			0.090		0.000	0.000	0.135

	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NOV	SEN CL	0.143	0.000	0.000	0.000	0.007	0.019	0.081	0.091	0.030	0.049	0.000	0.420
	LAT CL					0.029			0.087		0.000	0.000	0.116
	HEATNG	-0.019	0.000	0.000	0.000	-0.001	-0.004	0.004	0.006	0.002	0.004	0.000	-0.009
DEC	SEN CL	0.024	0.000	0.000	0.000	0.001	0.002	0.069	0.088	0.029	0.047	0.000	0.260
	LAT CL					0.017			0.086		0.000	0.000	0.103
	HEATNG	-0.101	0.000	0.000	0.000	-0.007	-0.022	0.023	0.035	0.010	0.020	0.000	-0.041
TOT	SEN CL	2.177	0.000	0.000	0.000	0.124	0.340	1.191	1.075	0.355	0.576	0.000	5.838
	LAT CL					0.421			1.037		0.000	0.000	1.458

SYSTEM NAME	SYSTEM TYPE	ALTITUDE MULTIPLIER	FLOOR AREA (M2)	MAX PEOPLE
Guestzone	PTAC	1.000	20.0	10.

SUPPLY FAN (M3/H)	ELEC (KW)	DELTA-T (C)	RETURN FAN (M3/H)	ELEC (KW)	DELTA-T (C)	OUTSIDE AIR RATIO	COOLING CAPACITY (KW)	SENSIBLE (SHR)	HEATING CAPACITY (KW)	COOLING EIR (KWH/KWH)	HEATING EIR (KWH/KWH)	HEAT PUMP SUPP-HEAT (KW)
841.	0.000	0.1	0.	0.000	0.0	0.000	4.000	0.875	0.000	0.37	0.25	-2.377

ZONE NAME	SUPPLY FLOW (M3/H)	EXHAUST FLOW (M3/H)	FAN (KW)	MINIMUM FLOW RATIO	OUTSIDE AIR FLOW (M3/H)	COOLING CAPACITY (KW)	SENSIBLE (SHR)	EXTRACTION RATE (KW)	HEATING CAPACITY (KW)	ADDITION RATE (KW)	MULTIPLIER
Guest-Room_C	841.	0.	0.177	1.000	0.	4.00	0.87	3.66	-5.89	-2.39	1.0

SYSTEM NAME	SYSTEM TYPE	ALTITUDE MULTIPLIER	FLOOR AREA (M2)	MAX PEOPLE
BedZone	PTAC	1.000	16.0	2.

SUPPLY FAN (M3/H)	ELEC (KW)	DELTA-T (C)	RETURN FAN (M3/H)	ELEC (KW)	DELTA-T (C)	OUTSIDE AIR RATIO	COOLING CAPACITY (KW)	SENSIBLE (SHR)	HEATING CAPACITY (KW)	COOLING EIR (KWH/KWH)	HEATING EIR (KWH/KWH)
795.	0.000	0.1	0.	0.000	0.0	0.000	4.000	0.875	0.000	0.37	0.37

ZONE NAME	SUPPLY FLOW (M3/H)	EXHAUST FLOW (M3/H)	FAN (KW)	MINIMUM FLOW RATIO	OUTSIDE AIR FLOW (M3/H)	COOLING CAPACITY (KW)	SENSIBLE (SHR)	EXTRACTION RATE (KW)	HEATING CAPACITY (KW)	ADDITION RATE (KW)	MULTIPLIER
Bed-Room_C	795.	0.	0.167	1.000	0.	4.00	0.87	3.46	-2.33	-2.35	1.0

VisualDOE
Construction 2 (HCMU) BCASE2.GPH
REPORT- SV-A SYSTEM DESIGN PARAMETERS KitchenZone

DOE-2.1E-W83 1/26/2000 18: 7: 5 SDL RUN 1
VisualDOE Graphic Editor
WEATHER FILE- MAKKAH, 1980

SYSTEM NAME	SYSTEM TYPE	ALTITUDE MULTIPLIER	FLOOR AREA (M2)	MAX PEOPLE
KitchenZone	PTAC	1.000	12.0	3.

SUPPLY FAN (M3/H)	ELEC (KW)	DELTA-T (C)	RETURN FAN (M3/H)	ELEC (KW)	DELTA-T (C)	OUTSIDE AIR RATIO	COOLING CAPACITY (KW)	SENSIBLE (SHR)	HEATING CAPACITY (KW)	COOLING EIR (KWH/KWH)	HEATING EIR (KWH/KWH)
787.	0.000	0.1	0.	0.000	0.0	0.000	4.000	0.875	0.000	0.37	0.37

ZONE NAME	SUPPLY FLOW (M3/H)	EXHAUST FLOW (M3/H)	FAN (KW)	MINIMUM FLOW RATIO	OUTSIDE AIR FLOW (M3/H)	COOLING CAPACITY (KW)	SENSIBLE (SHR)	EXTRACTION RATE (KW)	HEATING CAPACITY (KW)	ADDITION RATE (KW)	MULTIPLIER
Kitchen_C	787.	0.	0.165	1.000	0.	4.00	0.87	3.42	-3.34	-3.35	1.0

VisualDOE DOE-2.1E-W83 1/26/2000 18: 7: 5 SDL RUN 1
Construction 2 (HCMU) BCASE2.GPH VisualDOE Graphic Editor
REPORT- SV-A SYSTEM DESIGN PARAMETERS LivingZone WEATHER FILE- MAKKAH, 1980

SYSTEM NAME	SYSTEM TYPE	ALTITUDE MULTIPLIER	FLOOR AREA (M2)	MAX PEOPLE
LivingZone	PTAC	1.000	20.0	5.

SUPPLY FAN (M3/H)	ELEC (KW)	DELTA-T (C)	RETURN FAN (M3/H)	ELEC (KW)	DELTA-T (C)	OUTSIDE AIR RATIO	COOLING CAPACITY (KW)	SENSIBLE (SHR)	HEATING CAPACITY (KW)	COOLING EIR (KWH/KWH)	HEATING EIR (KWH/KWH)
809.	0.000	0.1	0.	0.000	0.0	0.000	4.000	0.875	0.000	0.37	0.37

ZONE NAME	SUPPLY FLOW (M3/H)	EXHAUST FLOW (M3/H)	FAN (KW)	MINIMUM FLOW RATIO	OUTSIDE AIR FLOW (M3/H)	COOLING CAPACITY (KW)	SENSIBLE (SHR)	EXTRACTION RATE (KW)	HEATING CAPACITY (KW)	ADDITION RATE (KW)	MULTIPLIER
Living_C	809.	0.	0.170	1.000	0.	4.00	0.87	3.52	-2.72	-2.73	1.0

VisualDOE DOE-2.1E-W83 1/26/2000 18: 7: 5 SDL RUN 1
Construction 2 (HCMU) BCASE2.GPH VisualDOE Graphic Editor
REPORT- SS-A SYSTEM MONTHLY LOADS SUMMARY FOR Guestzone WEATHER FILE- MAKKAH, 1980

	COOLING						HEATING						ELEC	
MONTH	COOLING ENERGY (MWH)	TIME OF MAX DY	HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KW)	HEATING ENERGY (MWH)	TIME OF MAX DY	HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KW)	ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	0.03633	19	21	23.C	19.C	1.971	0.000					0.000	72.	1.130
FEB	0.04468	2	21	25.C	22.C	2.131	0.000					0.000	69.	1.200
MAR	0.08154	23	21	27.C	23.C	3.064	0.000					0.000	89.	1.560
APR	0.08585	27	21	29.C	23.C	3.285	0.000					0.000	89.	1.849
MAY	0.10776	25	21	32.C	23.C	4.198	0.000					0.000	99.	2.044
JUN	0.14223	1	21	32.C	24.C	4.390	0.000					0.000	113.	2.131
JUL	0.11956	6	22	31.C	27.C	4.428	0.000					0.000	106.	2.174
AUG	0.13207	10	22	33.C	24.C	4.397	0.000					0.000	111.	2.133
SEP	0.12346	21	21	30.C	24.C	4.241	0.000					0.000	104.	2.104
OCT	0.10269	12	21	29.C	26.C	3.755	0.000					0.000	97.	1.810
NOV	0.09741	2	21	29.C	24.C	3.636	0.000					0.000	93.	1.757
DEC	0.06015	7	21	27.C	22.C	2.793	0.000					0.000	81.	1.442
TOTAL	1.134						0.000						1122.	
MAX						4.428						0.000		2.174

VisualDOE DOE-2.1E-W83 1/26/2000 18: 7: 5 SDL RUN 1
Construction 2 (HCMU) BCASE2.GPH VisualDOE Graphic Editor
REPORT- SS-A SYSTEM MONTHLY LOADS SUMMARY FOR BedZone WEATHER FILE- MAKKAH, 1980

	C O O L I N G						H E A T I N G						E L E C	
MONTH	COOLING ENERGY (MWH)	TIME OF MAX DY	TIME OF MAX HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KW)	HEATING ENERGY (MWH)	TIME OF MAX DY	TIME OF MAX HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KW)	ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	0.15996	22	15	31.C	24.C	1.793	0.000					0.000	125.	0.810
FEB	0.14359	2	15	28.C	21.C	1.384	0.000					0.000	113.	0.656
MAR	0.29875	27	15	38.C	22.C	2.466	0.000					0.000	181.	1.207
APR	0.39072	9	15	34.C	24.C	2.249	0.000					0.000	216.	1.043
MAY	0.53209	31	23	33.C	26.C	2.622	0.000					0.000	277.	1.348
JUN	0.58024	1	15	38.C	27.C	2.632	0.000					0.000	295.	1.287
JUL	0.66922	6	15	35.C	27.C	2.697	0.000					0.000	336.	1.358
AUG	0.65372	5	23	34.C	24.C	2.665	0.000					0.000	329.	1.357
SEP	0.57366	20	15	36.C	27.C	2.707	0.000					0.000	288.	1.253
OCT	0.55332	31	15	35.C	26.C	2.577	0.000					0.000	279.	1.176
NOV	0.43671	14	15	34.C	24.C	2.497	0.000					0.000	231.	1.134
DEC	0.26222	1	15	30.C	23.C	2.154	0.000					0.000	166.	0.942
TOTAL	5.254						0.000						2837.	
MAX						2.707						0.000		1.358

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REPORT- SS-F ZONE DEMAND SUMMARY IN BedZone FOR Bed-Room_C

DOE-2.1E-W83 1/26/2000 18: 7: 5 SDL RUN 1
VisualDOE Graphic Editor
WEATHER FILE- MAKKAH, 1980

	- - - -D E M A N D S- - - - -		- -B A S E B O A R D S- - -		- -T E M P E R A T U R E S- -		- -L O A D S N O T M E T- -	
MONTH	HEAT EXTRACTION ENERGY (MWH)	HEAT ADDITION ENERGY (MWH)	BASEBOARD ENERGY (MWH)	MAXIMUM BASEBOARD LOAD (KW)	MAXIMUM ZONE TEMP (C)	MINIMUM ZONE TEMP (C)	HOURS UNDER HEATED	HOURS UNDER COOLED
JAN	0.13558	0.000	0.00000	0.000	26.1	24.0	0	0
FEB	0.12125	0.000	0.00000	0.000	26.1	24.0	0	0
MAR	0.26122	0.000	0.00000	0.000	26.2	23.0	0	0
APR	0.34460	0.000	0.00000	0.000	26.2	26.0	0	0
MAY	0.48046	0.000	0.00000	0.000	26.7	26.0	0	0
JUN	0.52954	0.000	0.00000	0.000	26.6	26.0	0	0
JUL	0.61559	0.000	0.00000	0.000	26.8	26.0	0	0
AUG	0.59716	0.000	0.00000	0.000	26.5	26.0	0	0
SEP	0.51511	0.000	0.00000	0.000	26.2	26.0	0	0
OCT	0.50013	0.000	0.00000	0.000	26.2	26.0	0	0
NOV	0.39169	0.000	0.00000	0.000	26.2	26.0	0	0
DEC	0.22981	0.000	0.00000	0.000	26.1	24.0	0	0

VisualDOE DOE-2.1E-W83 1/26/2000 18: 7: 5 SDL RUN 1
Construction 2 (HCMU) BCASE2.GPH VisualDOE Graphic Editor
REPORT- SS-A SYSTEM MONTHLY LOADS SUMMARY FOR LivingZone WEATHER FILE- MAKKAH, 1980

MONTH	COOLING ENERGY (MWH)	COOLING TIME OF MAX DY	COOLING TIME OF MAX HR	COOLING DRY-BULB TEMP	COOLING WET-BULB TEMP	MAXIMUM COOLING LOAD (KW)	HEATING ENERGY (MWH)	HEATING TIME OF MAX DY	HEATING TIME OF MAX HR	HEATING DRY-BULB TEMP	HEATING WET-BULB TEMP	MAXIMUM HEATING LOAD (KW)	ELEC- TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	0.24110	22	17	29.C	24.C	1.819	0.000					0.000	222.	0.985
FEB	0.23951	24	17	26.C	17.C	1.569	0.000					0.000	208.	0.883
MAR	0.44510	27	17	36.C	22.C	2.930	0.000					0.000	295.	1.545
APR	0.56994	23	17	31.C	25.C	2.685	0.000					0.000	338.	1.396
MAY	0.75130	31	18	40.C	19.C	3.259	0.000					0.000	419.	1.792
JUN	0.80592	1	18	35.C	27.C	3.417	0.000					0.000	441.	1.783
JUL	0.90329	22	19	34.C	27.C	3.402	0.000					0.000	488.	1.777
AUG	0.87105	8	18	36.C	28.C	3.489	0.000					0.000	474.	1.742
SEP	0.75130	2	17	35.C	27.C	3.118	0.000					0.000	412.	1.612
OCT	0.68689	2	17	33.C	28.C	2.847	0.000					0.000	388.	1.447
NOV	0.53408	1	17	32.C	25.C	2.622	0.000					0.000	326.	1.337
DEC	0.33960	1	17	28.C	24.C	2.122	0.000					0.000	257.	1.099
TOTAL	7.139						0.000						4270.	
MAX						3.489						0.000		1.792

81