THE POTENTIAL FOR ENERGY CONSERVATION IN RESIDENTIAL BUILDINGS IN DAMMAM REGION, SAUDI ARABIA

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A B S T R A C T

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The rapid housing and building development in the Dammam region of Saudi Arabia has transformed the region into a progressive urban area. The contemporary buildings which have spread all over the region in a short period have failed to provide acceptable comfort conditions inside the house, leading to the widespread use of mechanical cooling systems. The combination of poor thermal design and the rise in electricity prices has resulted in high annual fuel bills for running the air conditioning systems.

This study investigates the potential for energy conservation in residential buildings in Dammam region. It aims to identify the problem of high energy consumption in contemporary buildings and to study the relationship between the energy used and the thermal performance of the building.

This study reviews the socio-economic characteristics of Dammam region's inhabitants and the traditional and contemporary building materials cooling systems used in the region. It also presents a survey analysis of 500 houses and provides a thermal comparison and assessment of six case study houses.

A computer model has been developed and validated by the author to predict the annual amount of energy used in cooling the house. This model has been used to predict the various energy savings that can be achieved by modifying the building envelope elements and using lower U-values. Finally, some recommendations have been derived from the analysis.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

1.1 The Background of the Development of Building in Dammam Region

The development of towns and villages in Saudi Arabia has been phenomenal over the last fifty years. Thousands of square kilometres of vacant land have been converted into urban areas. In the 1920's Dammam region was one of these vacant areas, but by the year 1980 it had become one of the most developed regions in Saudi Arabia[1]. Dammam region is one of five geographical regions in Saudi Arabia, situated in the east of the country along the shores of the Arabian Gulf at longitude 50^{o} 06'E and between the latitudes of 26^{o} 06' and 26^{o} 30'North (see map 1). It mainly consists of three major cities, Dammam, Alkhobar, and Dhahran; Dammam and Alkhobar Cities are mainly residential whereas Dhahran is an industrial city, the headquarters of the oil company. The climate is generally hot in summer and quite cold for the rest of the year. The presence of the Arabian Gulf increases the relative humidity in the region and ameliorates the variation in day and night temperatures. The average annual temperature in the region is 36.6^{o} centigrade.

In the early twentieth century, the demand for buildings in Dammam region and the Gulf States was largely satisfied by the use of simple construction methods and traditional local materials, incorporating knowledge of the local climate. Traditional buildings were a true reflection of the cultural values of a society and well suited to the predominant climatic conditions. They always reflected an understanding of the sun's movement, power, generosity, and harshness. Traditional people in the Arabian Gulf states learned by trial and error the influence of solar energy on their dwellings. They orientated their buildings with respect to the sun and tried their best to utilize the wind more effectively by using cooling techniques such as wind catchers and mushrabiyah.

Despite the simple technology of building construction that was available and the low standard of living due to the lack of amenities, traditional buildings represented the most comfortable and rational design for the hot climate. Their design and construction was mainly based on the use of natural sources of energy for maintaining the levels of comfort inside the house. The people who were living in these houses were very highly satisfied by the achieved internal environment that provided comfortable conditions and respected social and cultural values.

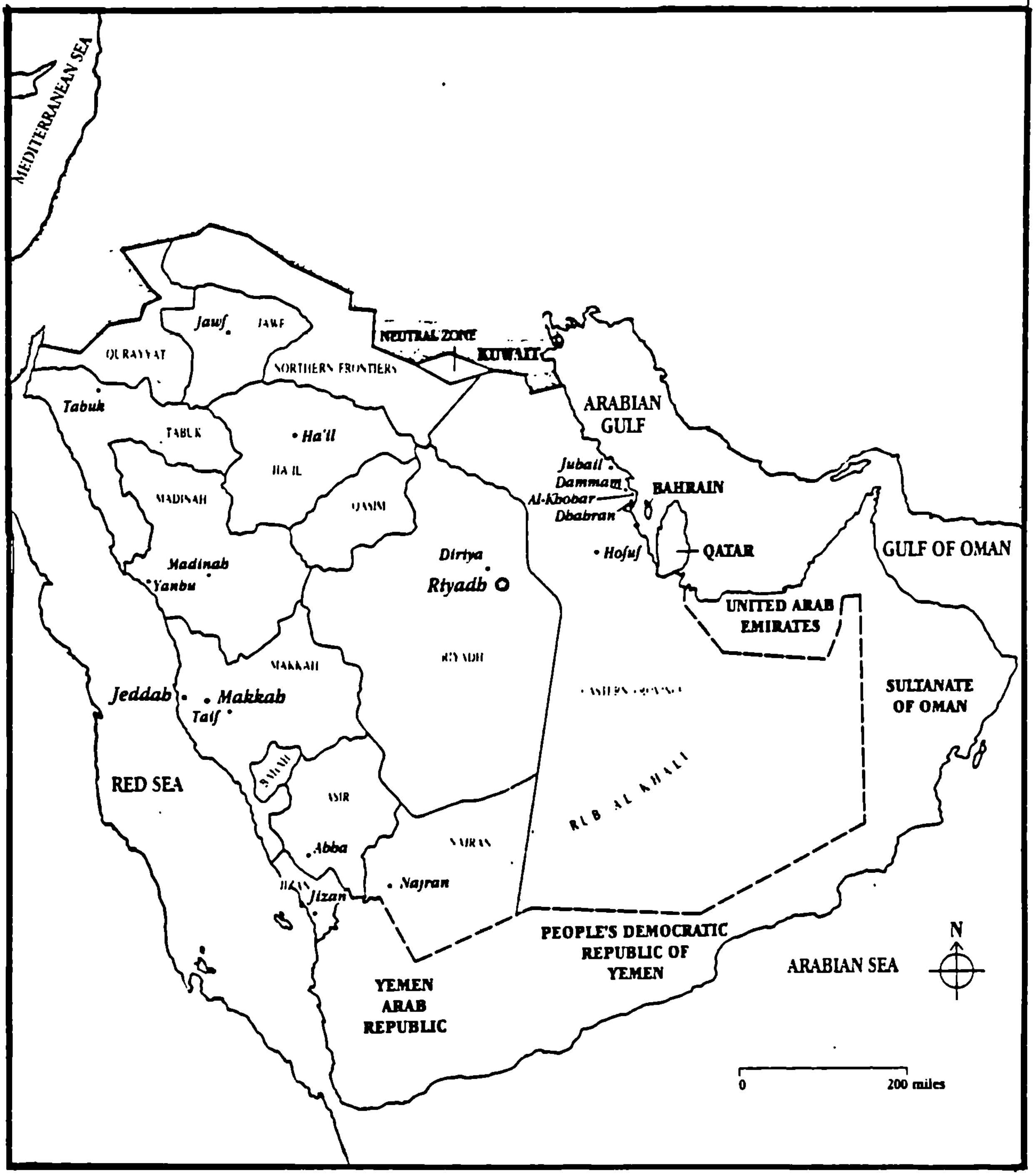
In 1964, after oil production had become of a commercial quantity, the country faced rapid development which created a severe housing shortage and an increase in rents. This shortage was aggravated by the influx of foreigners interested in renting what was available from the existing housing stock. The traditional buildings failed to accommodate the high increase of population and the people developed particular interest in the new building construction because, using these techniques, houses were able to be erected quickly. The growing pressure from the increasing housing shortage and the uncontrollable increase in rents attracted the attention of the Government which, in order to overcome this problem, made significant progress through several housing programme initiatives.

In the Second National Five Year Development Plan in 1974 the Government approved the formation of the Real Estate Development Fund (REDF)[2]. The aim of the Government was to reduce the housing demand in a short time and to enable every Saudi in the Kingdom to have a decent and secure house. The system by which the REDF helped the public was through providing interest-free loans to citizens so that they could build their own houses. The maximum loan was SR 300,000m, which is equivalent to 50,000 pounds sterling, repayable over a 25 year period[3]. However, although the programme was very successful in cutting down the shortage of housing as well as the increase of rents, it produced buildings of very poor quality thermally and increased the load on services.

After the REDF started issuing interest-free loans, the country faced a huge increase in the demand for building construction, with a corresponding high demand for construction materials and labour. The scarcity of building materials and the limited number of skilled labourers, architects and contractors was inadequate to meet the large demand of construction. As a result the costs of building materials increased greatly and caused inflation in the building market, also most contractors were encouraged to take on several projects more than their capacity, producing poor quality buildings due to inadequate supervision. Moreover, unskilled contractors took the opportunity of participating in the development and they produced poor quality buildings. In the light of previous circumstances the resulting buildings were very poorly built and inadequately designed.

Nowadays, contemporary buildings are designed with little attention paid to the selected building materials or the climatic characteristics of the area. Despite their high cost of construction they appear to be inefficient in modifying the external climate to provide a pleasant and comfortable environment inside the building. The only way that they can provide comfortable conditions inside the building is by the use of costly mechanical cooling systems. Thus many people at the present time are suffering from the running cost of energy needed to provide the necessary comfort conditions throughout the year. It is important to note here that the house that requires the least amount of mechanical cooling and the least amount of energy to operate the system to provide comfortable conditions, is the house designed with climatological considerations in mind and a careful selection of building materials.

With regard to energy sources, Saudi Arabia and the Gulf states are mainly dependent on oil for the production of electricity. Energy consumption in Saudi Arabia is of a very high level and is constantly increasing. The huge increase in energy demand is reflected by the statistical figures released by the Ministry of Planning, which show an increase in the annual consumption of electricity per subscriber from 2,600 kwh in 1970 to 16,140 kwh in 1983[4]. Also it shows that the sales of electricity jumped from 1.7 billion kwh in 1970 to 33 billion kwh in



MAP 1 : THE KINGDOM OF SAUDI ARABIA

1983 (see figure 1.1). The situation in Saudi Arabia is that energy is heavily subsidised by the government, which has had to give a grant of $2.77 billion towards energy costs to keep the consumer prices as low as they are[5].

1.2 The Problem

Dammam region is currently developing at an amazing rate and transforming itself to a progressive developed area. Modern buildings are increasing day after day, being deployed all over the region and replacing the traditional buildings. They have failed to cope with the external climate and to provide comfortable conditions inside the building without the extensive use of air conditioning cooling systems. This is due to the fact that modern buildings are normally built with less thermal capacity than the traditional buildings, and they leak through every square metre of walls and roofs. They do not leak water or gas, but energy in the form of heat, and this is really the heart of the problem, that energy is wasted so easily. Therefore, the increase in the number of new buildings is actually an increase in energy wasted and the amount of money subsidised by the government. The main problem appears to be the continuing increase in energy consumption due to the poor thermal performance of the building materials.

The demand for energy in Saudi Arabia is increasing as development continues. As a result of the high increase in energy consumption and governmental subsidy, the Saudi government stated in the Summer of 1984 that the electricity subsidisation would be reduced and the prices to the consumer would go up[6]. Immediately there was public objection to the proposed increase in electricity prices and the government backed down. However, the hint given by the government that it would reduce electricity subsidisation shows how serious this high level of energy consumption is to the government and how political is the whole issue of energy conservation.

As far as Dammam region is concerned, the total electricity sales during 1986 amounted to about 21,137 million kwh, as compared to 17,543 million kwh during 1985, reflecting an increase of 20.5% (see figure 1.2)[7]. The government subsidised the consumed energy for the year of 1986 by the amount of 904 million SR, to cover the difference between the consumer cost of 0.115 SR/KWH and the production cost of 0.45 SR/KWH[8]. Most of the consumed energy in Dammam region, as well as in the whole country, is due to the use of air conditioning systems for cooling buildings. The figures above reveal an enormous drain on the economy in the form of electricity subsidies due to inappropriate design and the use of inadequate building materials.

It would seem that conservation of energy in Dammam region and the whole country is urgently needed, as almost half of the energy produced is wasted quite needlessly. However, if the problem is not being tackled now, then the next generation will have an even bigger problem to deal with, which may be beyond their capabilities. Mr A M Bashawri, Vice President of the Saudi Government Railroad Organisation said in the International Railway Journal in 1981, that

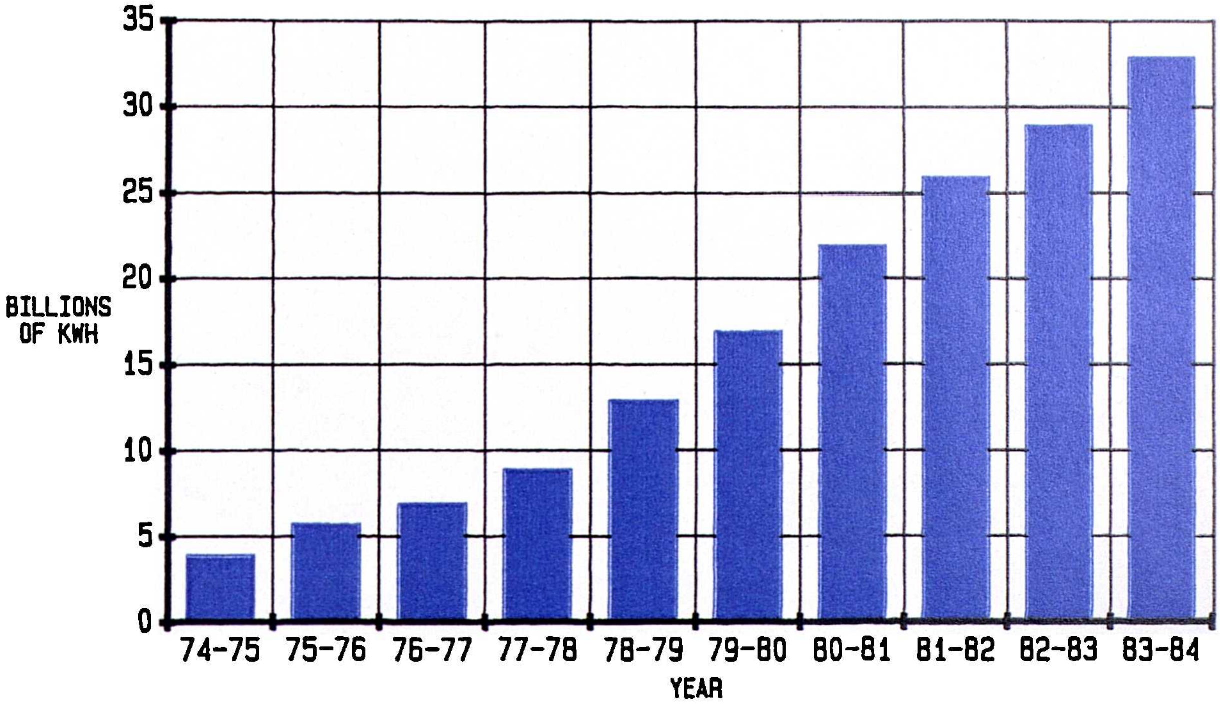
> "Despite our oil reserves we in Saudi Arabia are conscious of the need to conserve energy"[9]

1.3 The Aims and Objectives of the Study

It is clear from the previous discussion that energy is being wasted through the new residential buildings and the government subsidisation of energy is increasing dramatically. In concentrating on reducing the housing shortage in a short period of time, the final result has been a poor thermal housing stock. The government and the residents of these buildings are in urgent need of energy conservation and good quality buildings. Therefore, the thesis will focus on the potential for saving energy in the housing stock.

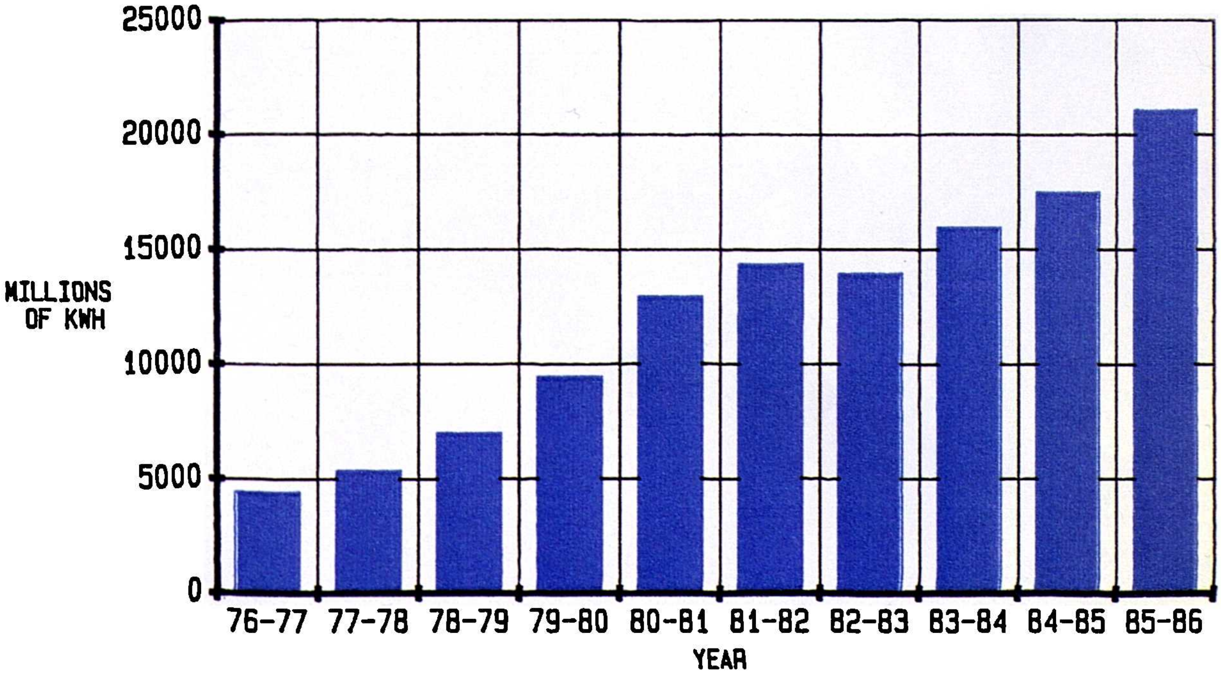
The purpose of this thesis is to study and analyse energy consumption in the residential buildings in Dammam region that have been built

FIGURE 1.1: THE GROWTH OF ELECTRICITY DEMAND IN SAUDI ARABIA
BETWEEN 1974 AND 1984



SOURCE: THE BIG ENERGY QUESTION, ARAB ENERGY,
JULY 1985

FIGURE 1.2: THE GROWTH OF ELECTRICITY DEMAND IN DAMMAM
REGION BETWEEN 1976 AND 1986



SOURCE: SAUDI CONSOLIDATED ELECTRIC COMPANY
IN EASTERN PROVINCE: ANNUAL REPORT 1986

between 1975 and 1985, and to demonstrate the potential for energy conservation. The aims of the study are as follows:

1. To provide a reasonable analysis of the thermal and physical factors of the external environment and its effect on the internal environment of the building, in order to provide an adequate thermal knowledge of the buildings in Dammam region.

2. To highlight the problem of high energy consumption and the effect of the occupants' behaviour on the thermal performance of the building and its consequences for energy consumption.

3. To develop a simple computer thermal model based on the findings of the above information for predicting the monthly energy consumption of the building, to enable the architect to select the most appropriate building materials and cooling systems.

4. To investigate the potential for saving energy in buildings and the relationship between energy savings and the thermal performance of the building materials.

1.4 Methodology and Structure of the Study

The thesis consists of three main parts, each of which depends on the findings of the previous one (see figure 1.3). These parts are structured in ten chapters and can be briefly summarised as follows (see figure 1.4).

The first part is mainly concerned with the study of the problem and its extent in Dammam region. The section is divided into three chapters apart from Chapter One, which is the main introductory chapter.

Chapter Two discusses the demographic and socio-economic characteristics of the region's inhabitants, the traditional and existing building materials used in a maritime climate with particular reference to

Dammam region, and the problems resulting from the rapid development. Chapter Three reviews and evaluates the traditional and contemporary cooling systems used in the region and the neighbouring Gulf states, and their applicability for cooling residential buildings.

Chapter Four investigates the climatological and meteorological features of the maritime climate and their effect on design, materials, and the configuration of houses in the region. Also, it discusses the comfort zone of the region and the different passive cooling strategies.

The second part of the study is concerned with conducting the survey and the analysis of the results. The study covers a literature review, observations, a questionnaire and physical surveys. This part of the study is divided into three chapters (Five, Six and Seven).

Chapter Five attempts to review heat transfer and the thermal properties of the building materials. It also discusses some examples of the different solutions and approaches adopted by the most developed countries in facing similar problems. Lastly, it surveys the different thermal studies that have used thermal modelling and the process of producing the thermal model.

Chapter Six analyses and evaluates the survey results, to study the different energy conservation parameters, such as the physical properties of the building materials, user behaviour and energy behaviour. The survey is conducted on 500 houses spread all over Dammam region, mainly from Dammam and Al Khobar cities. The method by which the survey is conducted is by obtaining the necessary information by means of questionnaires, observation and interviews. The survey analysis specifies the different houses need to be studied in detail to represent the surveyed houses.

Chapter Seven recodes the detailed measurements that were required for simulating the case study houses, These case study houses represent three categories, each category being represented by two houses. The analysis of the detailed measurements and the evaluation of the results are based on the urban configuration, the house conditions, the materials of the building envelope, the inhabitants' daily activities, and the houses' detailed measurements in order to find out the different problems involved in the high level of energy.

The third part of the study is devoted to the simulation procedures and the tabulation of the results. The study in this section comprises of the model development procedures, the analysis of saving energy and the achieved recommendations. The structure of this part is as follows:

Chapter Eight is allocated to building and validating the thermal computer model for use in predicting the energy consumption in buildings. The model is developed several times using the sol-air temperature to cover all possible heat gain parameters. The computer model is validated by comparing the predicted energy consumption against the measured data in six real buildings using Dammam region's climatic data. After the validation procedures, the model is used to predict the energy consumption of the buildings and the possible energy savings.

Chapter Nine is devoted to studying the potential for energy savings in housing in Dammam region. It demonstrates the modification of the envelope of the building by using lower u-values. The results of the simulation are analysed and evaluated in order to arrive at optimum solutions. The cost effectiveness of the different simulated building elements is studied sensitively in the light of net benefit for both occupants and government, and the best solution is based on the most cost effective building element for each category.

Chapter Ten provides a comprehensive conclusion for the whole thesis, summarising the findings of the different chapters of the thesis, and setting out the overall recommendations derived from the analysis of the thesis. Finally, the thesis is concluded with a few subjects recommended for further research.

Figure 1.3 : The General Overview of the Thesis Methodology showing the Relationship between its various sections

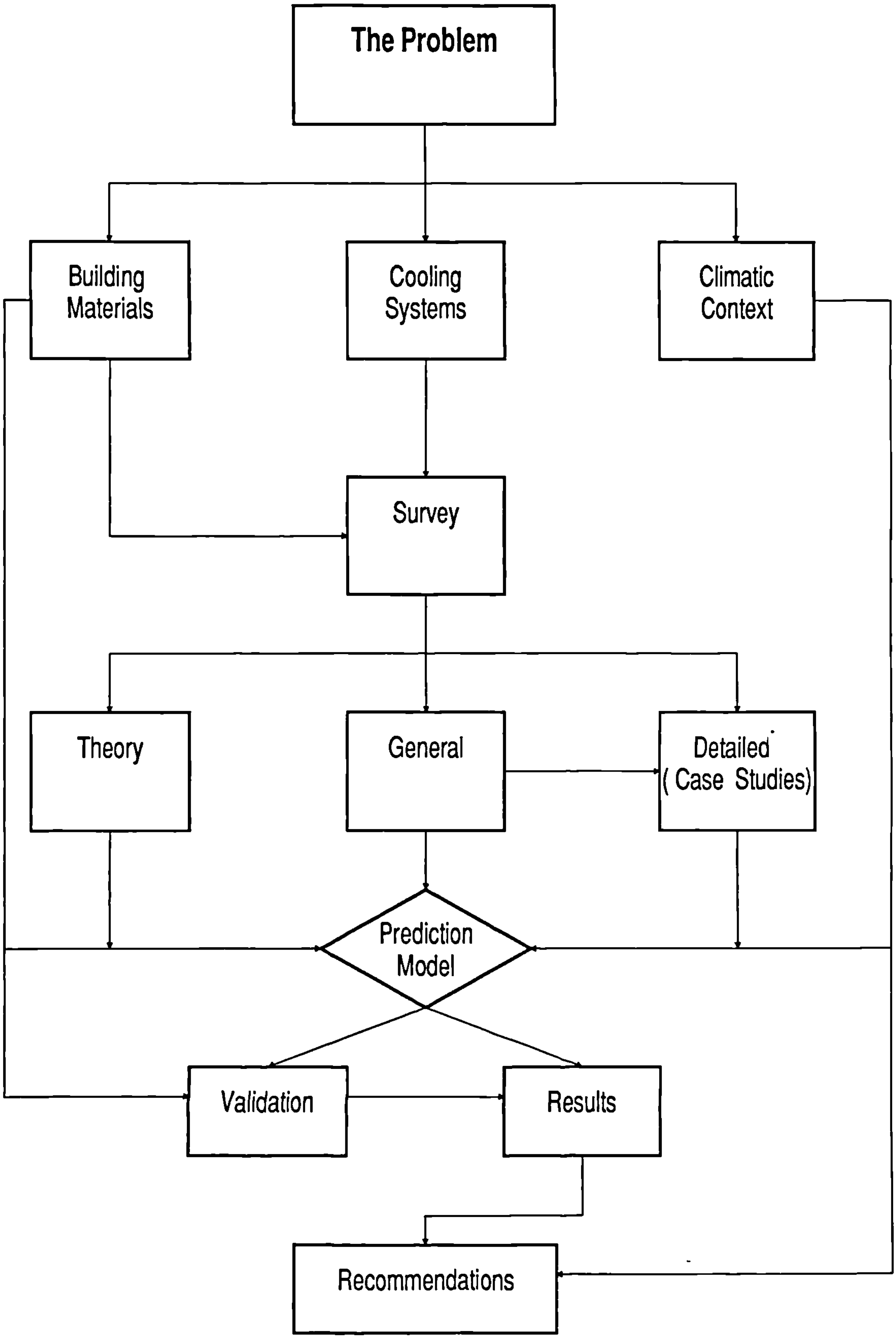
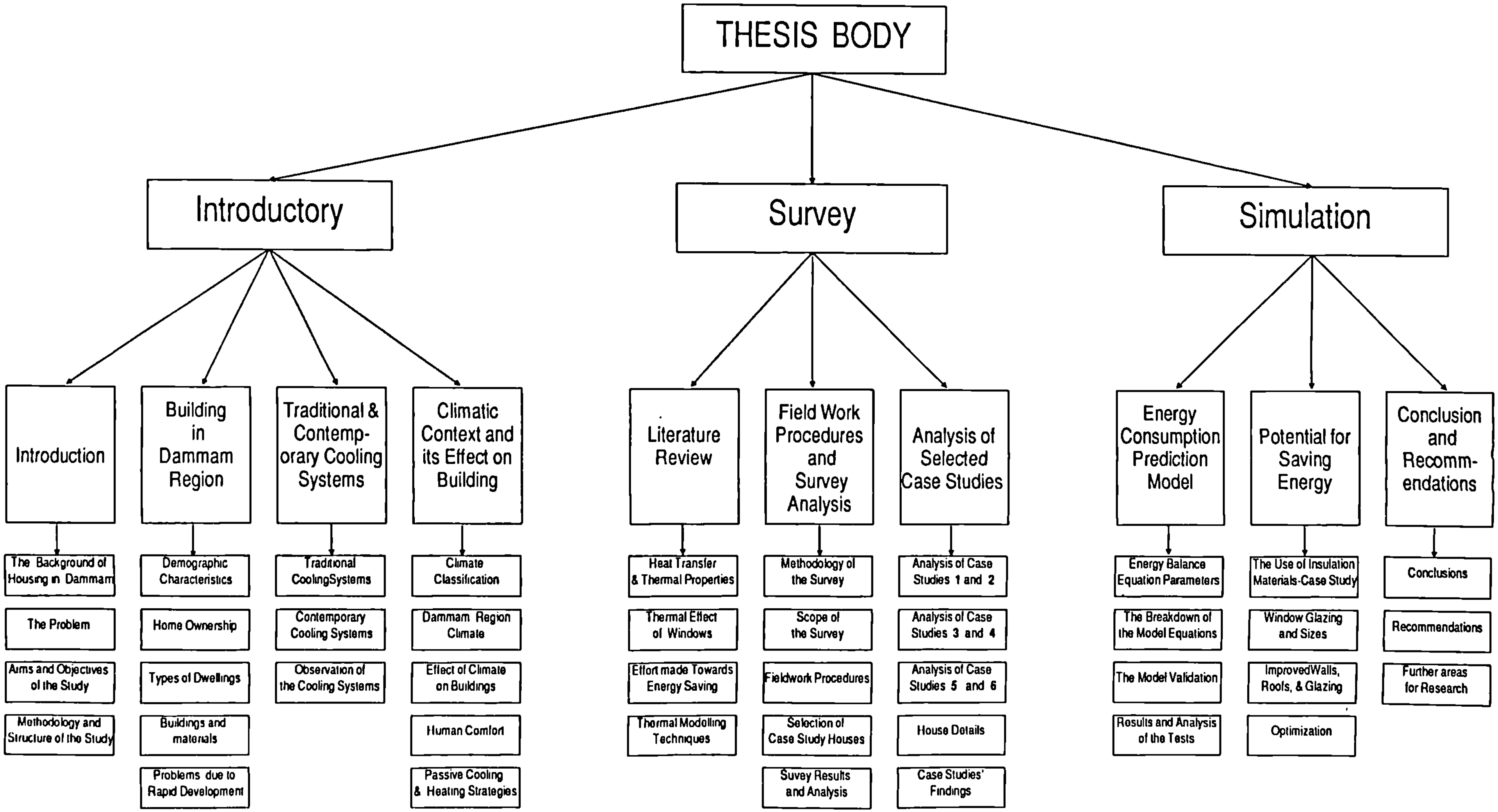


Figure 1.4 : Thesis Structure



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CHAPTER 2

C H A P T E R 2

BUILDING IN DAMMAM REGION, A MARITIME CLIMATE

BUILDING IN DAMMAM REGION, A MARITIME CLIMATE

2.1 Introduction

Buildings are defined according to their functions, but they can also be classified according to their building materials and other factors associated with the climate and technology. Buildings in areas with a hot climate are traditionally built to shelter the people and protect them from the severe environmental conditions. However, the contemporary buildings in hot climate areas are products of a new way of design, largely dependent on the use of imported building materials. As a result of using new building materials without adequate knowledge and experience, people began to suffer more from the climatic conditions. In order to solve this problem, the people started to use mechanical cooling systems, which are easier to use but are more expensive, and which have side effects on the overall environmental conditions as they increase the heat around the building.

This chapter aims to give a reasonable background to the main research of this study, and is devoted to the discussion of four main subjects. The first subject concerns the demographic and socio-economic characteristics of the people in the region. The second subject deals with the common types of residential buildings which have existed in the Dammam region. The third subject in this chapter is allocated to a discussion of the building materials used in the region, past and present. The final section dicusses the problems resulting from the rapid development.

2.2 Demographic Characteristics

During the nineteenth century the Eastern Province was an essential route for the pearl trade between Asia and North Africa. By the time of the proclamation of the Kingdom of Saudi Arabia in 1932, the importance of the province had declined since its earlier period. The migration to Dammam region was almost none in early times due to the large desert that covered most parts of the region, and due to the absence of sources of income. At that time, in the 1930's, the most active and populated areas in the Eastern Province were the oases, of Hafuf and Qatif, and the harbour, Darin and Jubail. The first immigrants in 1932 were 3000 members of the Doassar tribe who came from Bahrain and settled on the nearest seashore in the Eastern Province, which was named later Dammam, after the garrisons of Dammam (meaning drum). Also a few members of this tribe settled in Al Khobar in the 1930's and built a cluster of less than 30 houses. Six years later, in 1938, oil was discovered and the province started to regain its importance. However, the growth of the province was mainly concentrated on Dammam and Al Khobar Cities, especially when the government constructed the deep water port in 1951 and the roadline to Riyadh, coupled with the move of the provincial capital from Hofuf to Dammam in 1952.[1] As a result Dammam region attracted many people and created considerable mobility from outside the region as well as within the region. Thus, the rapid growth has tended to reflect the movement of the population in response to the new employment opportunities and perceived environmental amenities.

2.2.1 Population Growth

The population growth is a consequence of the net increase of the birth rate over the death rate, and also immigration from other countries, other regions, and other places. To estimate the population growth in Dammam region, the rates of birth and death and migration to the region were surveyed by several consultant departments such as the Central Department of Statistics. Accurate statistical data about birth and mortality for the whole country, as well as the region, are very hard to obtain, due to the fact that children under the age of ten, particularly those less than one year old, tend to be under-reported, despite the large fine the government charge for late registration; not only that but it is also very difficult to get accurate information about the nomadic people. However, in December 1977 at the 41st session of the International Statistical Institute, New Delhi, a paper was presented on "Multipurpose Survey", whereby the preliminary estimates were given of the crude birth and death rates.[2] These estimates are summarised in Table 2.1 as follows:

Table 2.1 : The Crude Birth and Death rates for Saudi Arabia, 1977

	Cities	Towns	Villages	Total
Live Birth Rate	0.041	0.054	0.061	0.054
Crude Death Rate	0.006	0.016	0.018	0.014

Additional analysis carried out by the staff of the Central Department of Statistics after December, 1977 has revealed that the final estimates of the birth rate will be at least 10 to 15% lower than the 1977 estimates, and that the final crude death rate will be 10 to 20% lower than the 1977 estimate.[3] Roughly, if a 15 per cent reduction is assumed in birth rate and in death rate, then the birth rate in the cities will become 0.035 and the death rate will become 0.005, a natural rate of population growth for the region, excluding immigration can be calculated at 3.0 per cent.

Migration

The availability of work in Dammam region attracted many people from different parts of Saudi Arabia and the neighbouring countries. Since the discovery of oil, the population of Dammam region is facing a rapid growth due to the immigration from different parts of the country. By 1953 the population had reached 25,000, initially consisting of traders, service workers, and employees of Arabian and American oil company (ARAMCO)[4]. The population of Dammam quickly surpassed that of Alkhobar, and the estimates in 1962 showed that there were 40,000 people in Al Khobar and 44,000 in Dammam City. By 1974 the national census reported that Dammam city had reached 125,000, an average annual growth rate of 8.4%, whereas Al khobar had reached 71,000 with an average annual growth rate of 4.5%.[5]

In 1979, CH2M Hill International and Consultant Engineering Group conducted a statistical survey in the region and reported that the in-migrant households, within a period of fifteen months, from the Eastern Province and the remainder of the kingdom to Dammam region, were 51 and 49 respectively, suggesting an annual rate of 41 from each area.[6]

2.2.2 Population characteristics

The characteristics of the people in a region where most of its population are immigrants derive from the interaction of the different components of the population with different social and cultural values. Not only that but also they derive from the family and household composition.

Composition of the population

The population of Dammam region comprises two major groups, Saudi and non-Saudi; the Saudi form 70 per cent of the region's population and the non-Saudis form 30 per cent. The Saudi population is comprised of two groups, those born in the Dammam region and those born in other parts of the kingdom. Roughly 35 per cent of the Saudi population was born in the Dammam region, another 35 per cent elsewhere in the Eastern Province, the balance being more or less equally distributed among the other provinces of the kingdom. On the other hand, the non-Saudi population is composed of people from other Arab countries and other Asian, European and American countries. The nationals of other Arab countries comprise almost one half of the expatriate population (47 per cent), and the people from other Asian countries form 24 per cent of the non-Saudi population and the remaining 29 per cent of the non-Saudi population are from European and American countries.[7] The presence of large non-Saudi population in the region may produce social and cultural differences within the region.

Family and household composition

The information gathered and processed by the same consultants indicates that the average household size in Dammam region is 6.74 persons for Saudis and 4.58 persons for non-Saudis. Saudi households generally have these characteristics: the majority, about 85%, are either nuclear or extended families. Groups of single persons living together form the remaining 15% as a single person Saudi household does not exist. The typical Saudi family household consists of six to seven persons - husband and wife, one or two children older than 12 and three younger children.

The typical expatriate family household comprises four persons, husband and wife and two children; however larger families tend to have some relatives living with them.

2.2.3 Income and Wealth

The economy of the Dammam region is dominated by the production for export of crude oil. Income from oil production and refining has averaged more than 94 billion Saudi Riyals (14 billion pounds) between 1972 and 1977, forming over 70 per cent of the national total Gross Domestic Product.[8] This source could contribute very effectively towards financing the manpower and technological input needed to develop new income sources in order to establish a self-sustaining economy.

The main income of people in Dammam region comes from salaries and wages, these are the predominant source of income. 79 per cent of Saudis and 97 per cent of non-Saudis gain their income on a salary and wages basis.[9] Only a small percentage of Saudis gain their income from different trade activities such as providing the necessary food and clothes for the people in the region and providing the necessary building materials for the builders. Trading is the commonest occupation of Saudis who are earning more than 1500 pounds per month. Trade also contributes to the strength of government employment where it takes up to 47 per cent of the labour force. Furthermore, a significant number of Saudis have more than one income source; where they work as employees and earn additional income from rental properties, such as housing or shops. This phenomenon contributes to an increase in poor quality building due to the quick construction.

Generally the average income of a Saudi household is slightly lower than that of an expatriate. As noted in the CH2M Hill report, the lowest monthly income for a Saudi family is about £300 pounds, representing about 10 per cent or the population in the Dammam region.

2.3 Housing Stock and Ownership

Traditionally, in Saudi Arabia, when a piece of waste land is developed by someone, it becomes his property. In fact during the early growth of Dammam region the development was not planned in an orderly fashion, and as the population grew, people took over any available land and built basic shelter and fences of local materials. But when the rate of physical development began to increase substantially in the mid 1940's, the government realised the need for a controlled layout. So, in 1947 the government asked for assistance from ARAMCO in laying out both Dammam and Al Kobar cities. In response, the oil company's surveyors subdivided the land and staked out the streets and plots on the ground.[10] From this time the government started to control land ownership and the size of plots.

In accordance with the local custom and tradition, people aspire to have their own dwelling for the purpose of privacy and freedom. The census conducted by CH2M Hill in 1979 revealed that 51 per cent of Saudi householders were owners of their own dwellings, 45 per cent were renters, the balance living free of rent under other arrangements, as bedouin or as squatters[11]. Private ownership enabled some people to play a valuable role in solving housing problems by letting some of their premises for rent, assisted indirectly by the government which made available interest-free loans to citizens to enable them to build their houses. On the other hand the public sector has a very limited role in providing housing directly for rent or sale as can be seen in Table 2.2, the distribution of owners in each group is relatively high even for the lower incomes.

Table 2.2 : Percentage of Saudi Owners by Income group, bearing in mind that the non-Saudi is not eligible to own any property

	Under 2000 SR	2000-5000 SR	5,000 10,000 SR	Over 10,000 SR
Dammam	42	45	47	72
Al Khobar	43	53	58	55
AVERAGE	42	48	51	69

2.4 Types of dwelling in Dammam Region:

In the past there were very few types of dwelling in Dammam region where almost all houses were traditionally built with local materials. In recent years, however, the region has been highly influenced by the rapid development of the economy and the rural-urban and urban-urban migration; this huge migration has caused a remarkable influence in the adoption of new types of housing. This influx into the urban areas even affected the traditional centres and the emergent building industry, and a whole new range of housing settlement patterns appeared. Nowadays, several types of housing can be found in Dammam region; most of the traditional courtyard houses have been replaced by modern dwellings and where they still survive they are now only inhabited by low income people and some immigrant workers.

The pace of housing development is evident from the fact that 90 per cent of the housing in Dammam region is less than 20 years old, and 36 per cent was built within a five year period.[12] In general, and according to the chronological development of Dammam region, there are three main housing types, each of which will be discussed in detail. The three common types of houses in Dammam region are:

1. Traditional courtyard house
2. Transitional houses (shanty dwellings)
3. Contemporary dwellings including:
   Modern villas
   Apartment buildings
   Company compounds' housing

2.4.1 Traditional courtyard house

Traditional planning and design was not based on pre-planned concepts. It was a result of the people's actual needs. Traditional planning reflected the interaction between many variables, such as economic, religious and cultural constraints, and climatic conditions. The traditional house in Dammam region played a unique role in accommodating the people's needs and in ameliorating the harshness of the climatic conditions. Sadly, a large number of courtyard houses in Alkhobar and Dammam were destroyed during the 1960's to make way for commercial buildings and multi-storey apartment buildings. The few remaining traditional houses are in danger of being demolished as they are abandoned by their owners. The remaining courtyard houses form only 7 per cent of the total housing stock in the region and they are inhabited by low income people and immigrant workers (see figure 2.1).[13]

Design and construction

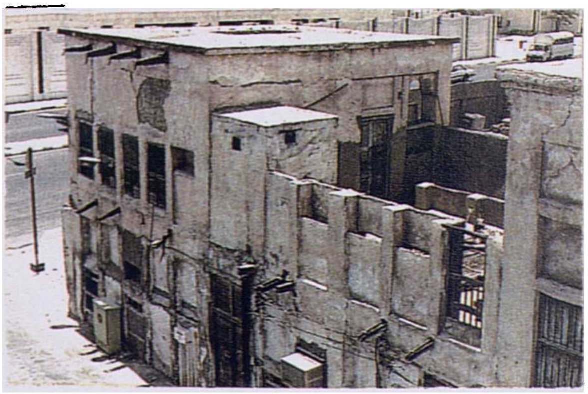
The design of such houses is similar in the different parts of the Eastern Province, Qatif, Jubail, Darin, Dammam and Al Khobar. They have almost the same cultural and religious background, share a similar climate and use similar building materials. Therefore, there are certain indigenous features which appear in almost every house, which either have a structural function or are introduced in order to meet and cope with the hot climate. However, the most common traditional house design comprises several features reflecting the region's climate and the people's social life. These features are:

1. Every house consists of two main parts, the private part, where the family's activities occur, such as sitting, eating and sleeping, and the semi-private part where the guests are entertained; both parts have lavatory facilities.

2. All rooms are oriented towards a courtyard and the whole house has an inward looking layout.

3. A covered aisle or gallery surrounding the courtyard connects the different rooms, though in some houses there is only one aisle along one side of the courtyard. Also there is a covered iwan or outside sitting area between two rooms, providing a cool and shady place, usually used in the afternoon.

4. Wind vents are located on the parapet wall of the roof, which is flat and is used mainly for sleeping purposes, to allow cross



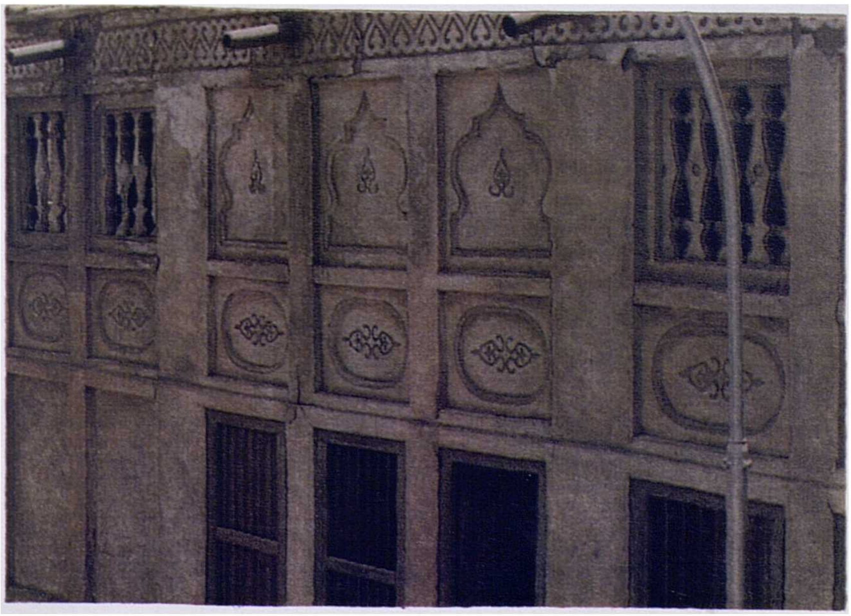


FIGURE 2.1 : EXAMPLES OF TRADITIONAL COURTYARD HOUSES IN DAMMAM AND ALKHOBAR CITIES.

ventilation. These wind vents are controlled by adjustable shutters to allow the regulation of cross-ventilation.

5. In some houses, balconies with wooden screens (Mushrabiyah) are found and they are used to cool and filter the air; they are also used to provide additional shade for the windows.

The traditional type of dwelling found in Dammam region was originally built with a local traditional system which was a skeleton structure system consisting of bearing and non-bearing elements. The bearing elements of the dwelling were the columns, walls, and the beams which carried all the load to the ground. The non-bearing elements were the shutters, windows, doors, partitions and vents. This system used local available materials such as coral stone, coral slab from the sea, palm beams, palm leaves, mud, and mortar.

2.4.2 Transitional houses

As a result of the rapid development in the 1950's and 60's, the need for housing increased dramatically and the government could not cope with it during its early stages. However, the people started to adapt themselves and built temporary houses which were mainly wooden houses using the wooden containers thrown by ARAMCO. The urgent need for a place to live in, coupled with the cheapness and quickness of building timber shacks, helped in spreading this system of building in the region.

The transitional house or shack is a small building built by an unprofessional builder, often the person who will live in the house himself. It is often built of materials which are not actually intended for housing construction, such as old packing crates, cardboard, or oil drums. It is not meant to be a permanent structure and is usually a one storey building (see Figure 2.2).

A few years later, after the introduction of the concrete block, the people built their houses with a combination of concrete blocks and

FIGURE 2.2 : EXAMPLES OF TRANSITIONAL HOUSES IN ALKHOBAR CITY.

wood. They used concrete block for the main structure and external walls and they used wood for the roof. These houses were built of more modern construction materials; usually concrete blocks and cement. Mostly they were built one storey high, with the exception of some dwellings of two storeys. They were built by unprofessional builders, but unlike shacks they were meant to be permanent structures. However, this system of building did not last long before the government issued the free interest loan and encouraged the people to build new buildings for a better standard of living. This type of housing has almost vanished and does not exist any more in the urban areas, but can be found in some of the rural areas.

2.4.3 Contemporary Dwellings

Dammam region has been transformed from a fishing village to a contemporary town developed in accordance with a modest plan prepared early in 1947 by ARAMCO, followed by another plan in 1979 by CH2M Hill International Consultant Engineering. This transformation was accompanied by urban development including roads and houses.

Dammam region has faced an accelerated growth of booming proportions in the last decade. The City has spread in all directions, including along the seaside, where the construction of the streets has been followed immediately by extensive residential development in both cities. In the south-west section of Dammam City, and on the south section of Alkhobar City, large scale residential complexes known as " rush programmes", sponsored by the Ministry of Housing, have been constructed. Also, the Real Estate Development Fund interest-free loans and the oil company (ARAMCO) homeowners' programme speeded up the development and increased the residential area fourfold. As a result of the rapid development, and due to the many foreign architects in the region, several types of dwelling house have been introduced. These types include the modern villa, apartment buildings and company compound housing.

2.4.3.1 The Modern Villas

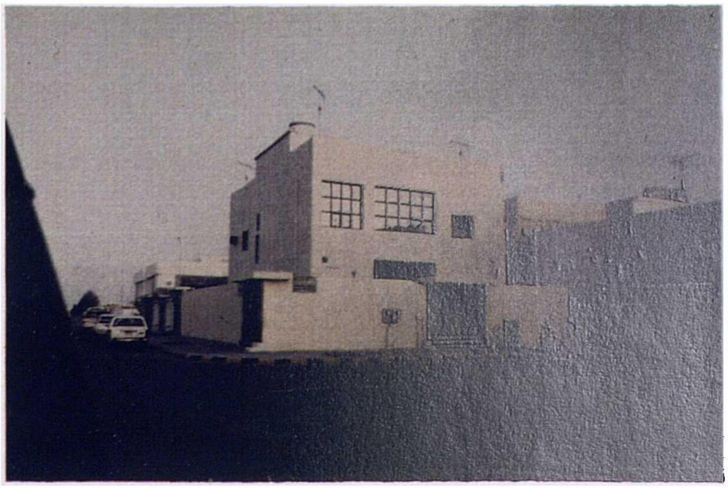
In the early 1950's, the modern villa house appeared in Saudi Arabia, especially in Dammam region. The transition to the type of a villa house was clearly a result of the social and economic changes that resulted from the rapid development. The growth of population, the expansion of cities, and the use of cars and streets led to the development of new residential areas and helped the adoption of the new villa house type. In the city the shortage of land has resulted in an ever-increasing subdivision of land owned by individuals. Additionally, the building regulations issued to ensure that each house obtains light from four sides and is separate from neighbouring houses have resulted in a box structure assembled in the middle of a walled plot.[14] The function of this wall has become that of an enclosure defining the land ownership all round, and forming an outside courtyard as a substitute for the traditional courtyard.

The villa type house is built by professional builders of modern materials. It may stand by itself, or it may be attached to other similar houses, but always there is open space on the outside of the building, sometimes this being planted with trees, bushes or grass. The villa usually consists of one or two storey buildings (see figure 2.3).

The common characteristic of the villa type is that rooms are grouped and surround a large hall used mainly as a family sitting area or for internal circulation. The size of the villa and the number of rooms and their functions depends on the family income and social status. Usually external walls are not shared with neighbours, allowing the house to have large windows all around which are unprotected from the hot sun. This type of villa house represents about 90 per cent of the total housing stock in Dammam region.[15] The building materials used are mainly reinforced concrete, cement, and hollow blocks.

2.4.3.2 The Apartment Building

The social and religious customs of the Arab's and Muslim's culture and way of life, are not always aided by living in apartment blocks, unless they are very carefully designed. This is due to the provision of



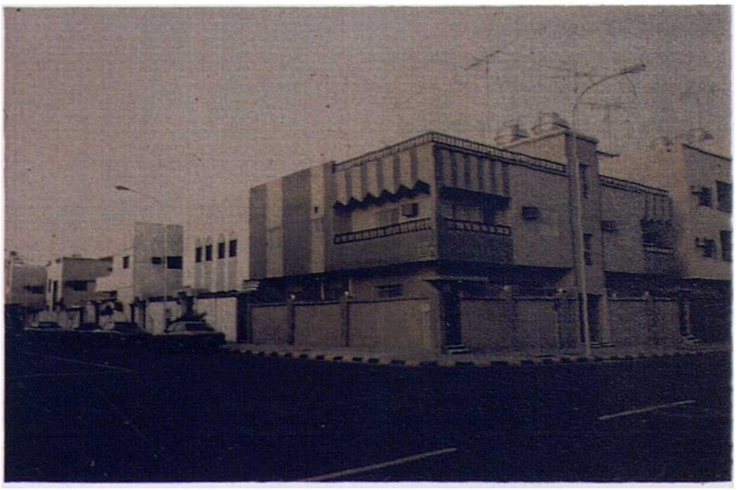


FIGURE 2.3 : EXAMPLES OF CONTEMPORARY VILLA HOUSES IN ALKHOBAR CITY SHOWING THE EXTERNAL WALL WHICH DEFINES THE LAND OWNERSHIP AND FORMS THE EXTERNAL COURTYARD.

shared spaces such as entrances, corridors, stairs and lifts. Also there are problems with elderly and children, as well as noise and the lack of privacy. However, although the flats are not popular with the local families they seem to be appreciated by foreigners and single men. Multi-storey buildings are mostly found in the centre of the city where the population density is high and also the land value. Even so there are not many multi-storey buildings in Dammam region due to the fact that the government is in favour of horizontal expansion rather than vertical. Thus the government has encouraged people to build their houses in the newly designed communities by making plots available to them.

Apartment buildings constructed in Dammam region are built by both sectors, private as well as public. The private sector apartment buildings are usually built for profit with retail shops on the ground floor and residential flats on the upper floors. In fact, the large fall in rents in the large cities such as Jeddah, Riyadh, Dammam and AlKhobar due to the large switch by the foreign companies from renting to building their own compounds, have slowed down the apartment building activity and driven people towards constructing more beneficial apartment building projects such as shopping centres. On the other hand, in 1973 the public sector, which is represented by the Ministry of Housing and Public Works, began an intensive building programme to supply the large cities in Saudi Arabia with high rise buidings to cut down the shortage in housing.[16] This programme, which is called the Rush Housing Programme, produced enormous high rise buildings in Dammam as well as in Alkhobar which have not been occupied yet, bearing in mind that these buildings were either completed or work was stopped on them about six years ago. This type of projects has discouraged the Ministry from building any more unwanted buildings. However, the total private and public apartment buildings in Dammam represent a very small percentage of the housing stock. Examples of private and public apartment buildings are shown in Figure 2.4.

2.4.3.3. The companies' compounds housing

Since the rapid development started in Dammam region in the early 1960's, many foreign companies showed their interest and moved into

FIGURE 2.4 : GENERAL VIEW OF THE GOVERNMENT HIGH-RISE RESIDENTIAL BUILDINGS IN DAMMAM AND ALKHOBAR CITIES.

the region. However, this movement created a housing shortage and increased rents very dramatically, which urged the government to ask the different companies to build compounds to house their own employees. Usually, the government often provides the land and the company builds the houses. Such compounds vary in size, but most of them are built with prefabricated systems. Most of these compounds were designed with recreational facilities such as swimming pools, tennis courts, and cafeterias, where the foreign employees live a self-contained life inside the compound.

Compound types and supported services are very much related to the status of the residents; generally there are three types of compounds. The first type is a luxurious compound made up of several large detached houses of two to four bedrooms, with a community centre providing a clinic, kindergarten and recreational facilities. This type of compound is occupied by professional people, mainly senior staff, and it is very well maintained and landscaped. The second type of compound is that provided for semi-professionals or technicians. In such compounds limited services and recreational facilities are available, and a small supermarket is built in the compound. The third type of compound is the low standard compound, which consists of portable buildings and mobile homes and prefab units. This compound is generally occupied by semi-skilled and unskilled workers. The unmarried employees share accommodation in these compounds which are primarily built to provide cheap collective facilities for a large number of lower-income workers.

The company compounds are mostly occupied by foreign employees who are thus generally isolated from the local community and the general melee of life. These company compounds actually represent a very small percentage of the housing stock in Dammam region, and they are also decreasing due to the final departure of some of the foreign companies; examples of these compounds can be seen in Figure 2.5.

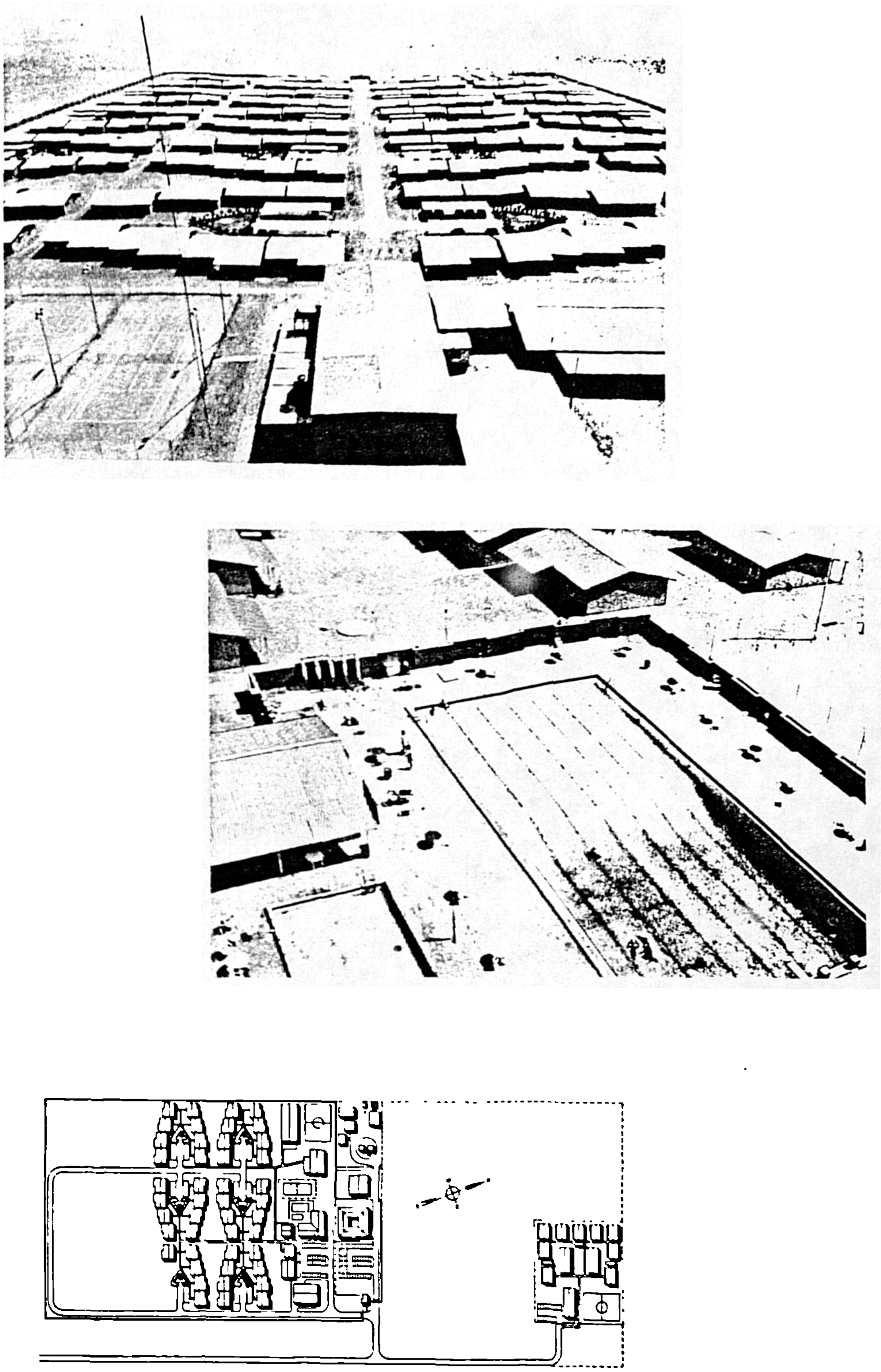


FIGURE 2.5 : PRE-FABRICATED HOUSING FOR COMPANY COMPOUNDS IN DAMMAM CITY.

Source: Shelter in Saudi Arabia, Kaizer, T.

2.5 Building Materials

The building materials used in the traditional house construction were mostly local. The use of these materials depended mainly on the availability, suitability and adaptability of these materials to the existing environment. However, there was a clear relationship between the availability of the building materials and the nature of the region's climate and topography, upon which the selection and use of materials depended. For instance, the five different provinces in Saudi Arabia used different traditional building materials due to the difference in climate and topography. Nowadays, because of the vast population increase and the need for a better standard of living, the traditional building materials have failed to satisfy all the needs and demands emerging from these factors, due to the limited resources of traditional materials and the lack of skilful traditional builders. Also the availability of alternative materials such as concrete, brick, and many other new industrialised materials, has helped the abandonment of the traditional materials. In this section an attempt has been made to discuss and analyse the traditional, contemporary, and innovative building materials used in Dammam region and their types and availability.

2.5.1 Traditional building materials

Building materials used in the past can be seen very clearly in the traditional buildings mostly found in the rural areas and the old part of the city. The traditional building materials proved that they were very successful in providing adequate protection from the severe climate and that they were durable and capable of surviving for a long time. The most common material used in the Arabian Gulf was mud, juss (gypsum), lime, stone, wood, reeds, straw, palm trunks and many others. These building materials were mostly produced locally but a few others such as mangrove poles were imported from East Asia and Africa. However, in order to review the most traditional materials most properly, the different traditional construction elements, foundations, columns, beams, walls, floor and roofs, are discussed in detail as follows:

1. Foundation

The most commonly used foundation in the early systems of house construction was the continuous strip foundation, which was shallow and simple but very competent. The foundation was usually constructed from the available local materials and excavated in a continued way under the walls intended to be built. The depth of the foundation varied from one part to another in the same region, depending upon their closeness to the seashore and on the soil type. The most common foundation size was roughly 1.2 metres (4 feet) deep by 0.9 metres (3 feet) wide, filled and compacted with coral stones and sea rocks.

Mainly there were three types of filling materials used in the strip foundation, each of which were successfully used. The first type of foundation materials used were stones and small rocks. The stones were laid in the excavation in an interlocking way where the void spaces in between were filled with stones and rocks, very tightly fitted and compacted very well in order to give it more strength. The second kind of foundation materials were stones and mortar. In this type, the stones were partly cemented and laid in the same way as in the first type. However, the upper level of excavation, which was about 0.4 metres (18 inches thick) was cemented with mortar to strengthen the foundation and level the surface. The third type of foundation materials were stones with cementing materials. The stones were sunk in the mortar throughout the whole foundation. This type of foundation was usually used for houses of more than four storeys. Actually, different types of mortar were used in cementing the foundation. The most commonly used mortars were juss (gypsum), mud with straw, a combination of mud and juss and a mixture of mud ash and lime.

2. Columns

The columns were used as main structural elements in the traditional housing and they transferred the loads from different levels to the foundation. This system of construction was used very extensively in the traditional houses along the coastal shores of the Arabian Gulf. The column was constructed generally as a square, rectangular, circular, or hexagonal section; it was placed every 1.00 metres up to 3.00 metres in various parts of the country.[17] However, this type of column, especially the tall ones, were usually supported by intermediate beams to reduce their slenderness ratio. These intermediate beams were after used as display shelves (see Figure 2.6).

The materials used for constructing the column were rocks, juss, mortar, wood and stone. Actually three types of columns were found in the region; the rock column, the wood column, and the stone column. The rock column was usually constructed by bonding the rocks together by juss mortar and this type of column was very widely used. The wooden column was not widely used due to the limited supply of timber in the region. The stone column was used mainly in conjunction with mud houses, where the stones were placed in position using mud or juss mortar for cementing the joints, and then the columns covered and plastered with mud.

3. Beams

Beams were used in many parts of the traditional house construction. They were used as structural components to span openings, supports, floors and roofs, to tie the columns together and to strengthen the filling walls. The main material used in the beam was wood, where it was used to span between two supports, and it was covered with protective layers of juss mortar. The construction of the beams was by laying down a number of mangrove poles placed over the opening and between two supports, where the upper side was filled with small stones and cemented together by juss mortar, and the two sides of the beam were plastered and smoothed with juss mortar (see Figure 2.6).

Generally, various types of wood were used in beam construction including date palm trunks, mangrove poles, tamarisk trunks and raw timber which were often obtained in many localities. The date palm trunks were cut into four quarters when used as material for beams, and were usually used in short span beams due to their low tensile strength. The mangrove poles and tamarisk trunks were widely used in most of the building beams.

4. Walls

The wall types used in the traditional buidings were mainly load bearing walls and filling walls. The load bearing walls were built as a structural element to carry the imposed loads from the different components of the structure and to support its own weight. The load bearing walls were solid, heavy and very thick. They were usually constructed from dressed stone or rubble and had a very thick base reducing to a smaller thickness as the height increased.

The dressed stone wall had a great structural capability, especially if the cementing materials used were of good quality and very strong. The stone walls were used as reinforcing elements in the lower levels of the house, which was infilled with mud brick. Although this type of wall had many good characteristics, its use in the region was very limited due to its difficulty in building and due to the great attention required during the construction process. Rubble wall construction was used more than the dressed stone wall, for reasons of economy. The rubble walls functioned as structural components for buidings of not more than two storeys. The durability of the wall depends upon the thickness, the kind of stone used and the kind of mortar used (see Figure 2.6).

The second wall type is the non-bearing wall type, the infill wall, which was used to fill the space between the columns in the post and beam construction system. The use of in-filling walls allowed more freedom in placing the opening at any place in between the columns. The non bearing walls were usually constructed of thin coral slabs which were cemented together by juss mortar.

The construction of this type of wall started by positioning the coral slabs by hand in the actual location, and then applying juss mortar to form the joints as the work proceeded. The completed wall was then plastered on both sides with lime and white wash. The type of infill wall was usually recessed on the exterior by about 5cm (2 inches) from the face of the column (see Figure 2.7). Also the interior was always decorated with various types of forms of frames and solid arches.

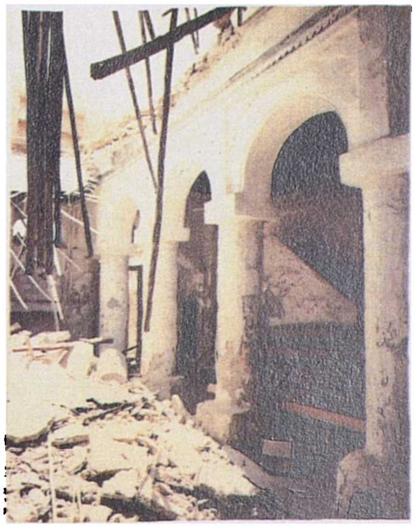
5. Floor and Roof

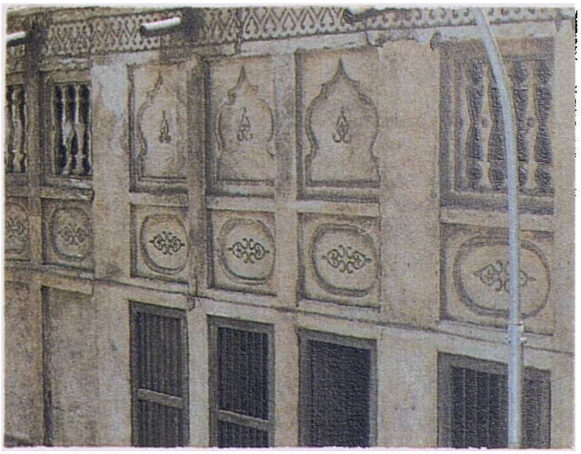
In the traditional house construction system the floor and the roof were built similarly, with a slight variation in the roof construction, where an additional layer of mud was added to increase its thickness and to reduce the leakage of rainwater. Since the construction and the materials used in both cases were the same it is suitable to limit the discussion to the roof construction only.

In general the roofs of early systems of roof construction were flat and they played an important part in the families' lives, as they used the roof during the hot summer nights. The construction of the roof consisted of imported mangrove poles as major beams spanning the shortest distance of the area to be covered, and then those beams were topped with various local materials, such as palm wood, as a secondary beam. Various local timber were used for joists, including date palm trunks, cut logs, and tamarisk trunks. This type of structural material give a maximum of 3.00 metres span, which limited the room width. Finally they were painted with bright colours before laying them over the mangrove poles, to give the ceiling different colour schemes (see Figure 2.6).

2.5.2 Contemporary building materials

The progressive growth in the national economy, combined with the industrial development provided more motivation for other development





Farosh (rubble stone)

FIGURE 2.6 : EXAMPLES OF TRADITIONAL STRUCTURAL ELEMENTS SUCH AS COLUMNS, WALL AND ROOFTS AND BUILDING MATERIALS SUCH AS FAROSH MANGROVE POLES AND WOVEN MATTING IN DAMMAM REGION.

to occur in the region, such as the development of the building materials industry. Actually, the development of the economy led to the transformation of the early system of house construction into the modern system which utilises different materials and uses new methods and techniques of construction that have been used in the most developed countries. However, the use of the industrialised materials as well as the adaptation of the new building techniques was brought in to the region to cope with the huge rapid development and to solve the shortage in housing, in order to provide modern, convenient and satisfactory living conditions.

However, today the most common system of house construction that is employed throughout the region is the reinforced concrete frame. It is used extensively as the major constructional system for the different types of buildings due to its durability, flexibility, and quickness in construction. The reinforced concrete structure is a simple system of reinforced concrete columns and beams, with concrete blocks or bricks in between to form the external walls and internal partitions. The roof and floors are usually constructed from reinforced concrete slabs or reinforced concrete ribbed floors (as shown in Figure 2.7). However, since the material used in the different structural components of the building, including foundations, columns, beams, floors and roofs, is almost all reinforced concrete it is appropriate to discuss the ingredients of reinforced concrete and the other material which could be used in constructing the building.

Nowadays most of the building materials are processed and manufactured in the region using either available or imported raw materials. These building materials include cement, concrete, plaster, gypsum, marble, and steel. These materials will be discussed briefly to complete the review of the building materials in Dammam region.

1. Cement

The dominant material used in the building is cement, and it has been found in almost every structural and non structural element. It is the essence of the contemporary buildings, even the steel

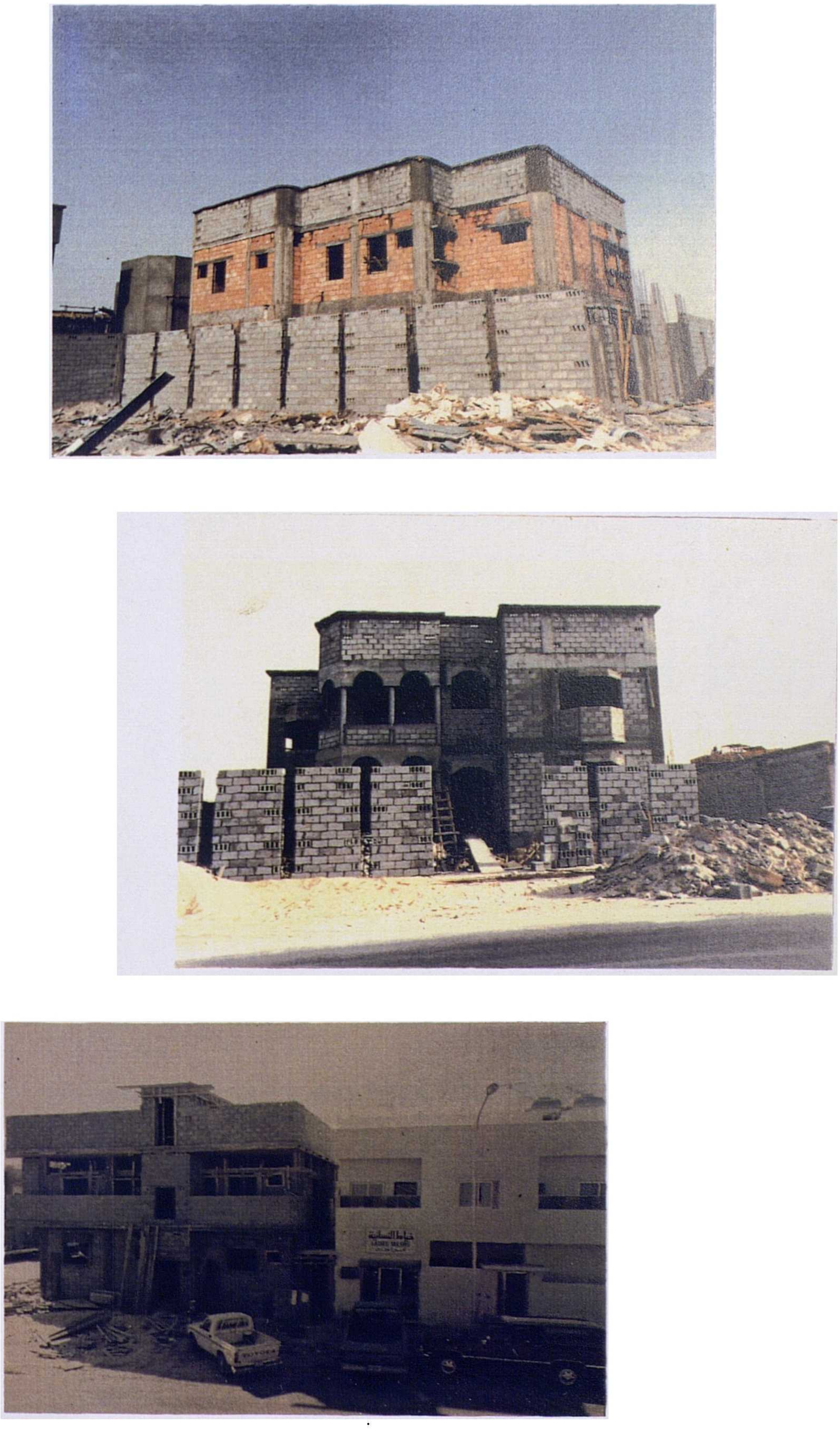


FIGURE 2.7 : CONVENTIONAL BUILDING MATERIALS IN CONSTRUCTING RESIDENTIAL BUILDINGS IN DAMMAM REGION.

structural buildings. However, while this essential building material is manufactured locally in large quantities, still there is a fair amount of cement imported due to the great demands for this material.

In 1961 the Saudi Cement Company, which is situated in Alhasa Region, started to produce this important building material, cement, with an output of about 100,000 tons per year. However, as a result of the increase in demand, the cement plant increased its production more than four times to reach about 504,000 tons per year.[18] Despite this production the region still faces a shortage of this material. The raw materials used in manufacturing the cement are limestone and clay, which are obtained from the area around the plant in Alhassa area. Other additive raw materials, such as iron ore and gypsum, are mined in other places and transported to the plant.

2. Concrete

Concrete is a new building material introduced recently into the region as a substitute for the traditional building materials. The use of concrete has provided more freedom to the architects and engineers to construct long spans and to build high-rise buildings. This material is a combination of sand, gravel, cement and sometimes reinforcing materials such as steel. It is used in almost all the building elements, foundations, columns, beams, floors, and roofs. However, while concreting at high temperatures, which is the case in the Dammam region, creates problems of shrinking and cracking, it still plays a major role in the building process and is used extensively in the region. Many studies have been done on the use of concrete material in countries overseas in order to improve its performance and to specify the most reliable way of concreting; such a study has been done by the British Research Establishment in 1981. Actually, there are many concrete products manufactured locally in many areas in the region. These products include concrete blocks, floor tiles, concrete pipes, and precast slabs.

The concrete blocks are produced in different shapes and sizes to satisfy the different construction needs. The types most commonly used in the region consist of three sizes, eight inch hollow load-bearing concrete blocks, six inch hollow load bearing concrete blocks and four inch hollow non-load bearing concrete blocks. The hollow concrete blocks are usually manufactured out of normal weight concrete by adding crushed stone as a coarse aggregate, and sand as a fine aggregate.

The concrete blocks are mainly used for external walls, and sometimes are used for internal walls as partitions. The eight inch load bearing concrete blocks are often used on the ground and first floors and walls, whereas the six inch load bearing concrete blocks are used on the upper floors. However, many types of concrete blocks are made for use on floors and roofs. They are laid to form a ribbed concrete floor.

Flooring tiles are produced in a very simple process and in many varieties of geometrical forms. They are made by pressing the mixed concrete onto a simple machine which forms the tiles into many shapes and sizes by pressure and vibration. The materials used in making the concrete tiles are sand, fine crushed stones, cement and water, and the face of the tile is polished and coloured with colour cement matrix. The concrete tiles are usually used for the floor and sometimes used for the roofs for better surface finish.

3. Plaster and Gypsum

Plaster and gypsum are local building materials used in traditional houses as well as in contemporary houses. Their production in the past was very expensive due to the large number of labours required and the long processing period. Nowadays, however, there are many local factories which produce these materials in commercial quantities. They were used in the traditional houses as binding mortar for the stone units and as a plastering for walls and ceiling in order to give a smooth texture and white surface.

The use of these two materials in the contemporary houses is limited to the floor and roof tiling as a mortar and as a decorative finish for the ceiling. Generally, these two materials are not durable because of their tendency to absorb moisture. They expand and shrink immediately after they have dried and create cracks in the building. Therefore the people try to avoid using these materials due to the high level of protection required for their use.

4. Marble

The only marble quarries in Saudi Arabia are limited to the Mekka area and along the Medina road. However, many marble factories are spread all over the kingdom to supply the different regions. The production process starts with cutting large blocks of marble into vertical sections, then these sections are processed as needed through the machines. The marble is still an expensive material to use and its uses are mainly in tiles and some facade finishes.

5. Steel

Steel in Saudi Arabia is mainly manufactured in the form of sheets, bars, and pipes. It is introduced to the building to carry the tension forces to allow long spans and high buildings. It is successfully used for the reinforced concrete, windows, and doors. however, steel used to be imported from other countries, mainly European countries, but now it is manufactured locally by several governmental establishments, such as Petromin and Sabic establishments.

2.6 Developed Building Materials

The production of the newly developed building materials has recently been given attention by private companies in Saudi Arabia. Building materials have been improved to cope with the hot climate and to provide satisfactory performance for a longer time. Actually, Saudi Arabia has achieved considerable improvement in its national building industry over the last five years, by allowing foreign companies to enter the building market under the supervision of a Saudi Citizen. However, producing adequate building materials does not come from the highly sophisticated technology alone, but this technology can also be used to make improvements to the local available raw materials. Many factories and plants have been constructed in the Dammam region to manufacture and improve the local building materials. Some of these specialise in the production of calcium silicate bricks, blocks, tiles and thermal bricks, while others are specialised in producing insulation materials. Such factories are the Construction Materials Company Limited (CMC), Alyammamah factory for red brick and clay products, Al-hajry Insulation Industries, Arabian Fibreglass Insulation and Energy Saving Systems Company (ESSCO).

2.6.1 Calcium Silicate products

Calcium silicate products are from an old material which was invented and appeared in Great Britain in 1886 and was developed more commercially in Germany in 1890.[19] As the demand increased for calcium silicate products many industries were established in many countries, such as Germany, Holland, USSR, USA, Australia, United Kingdom and most of the Middle East countries. In 1978 a calcium silicate product factory was established in the Dammam region to supply the housing development with the needed materials. The main products of calcium silicate are brick blocks and tiles with the specification of British Standards 187, calcium silicate bricks and blocks of the American National Standard A821 Designation C677-73, and American National Standard A781 Designation C73 - 75.[20]

Calcium silicate products are new building materials introduced to the region with many varieties in terms of colours and sizes. The produce can be used as load bearing or non-load bearing in internal and external walls. They can also be used in low-rise and high rise domestic dwellings, and in industrial and commercial buildings. The basic ingredients of the products are approximately 90 per cent sand and 10 per cent quicklime, producing the natural colour, which is white. These raw materials are drawn from local sources. The characteristics considered in selecting the raw materials are, in the case of sand an absolute minimal sulphate content, and in the case of quicklime a high oxide content and a minimal magnesium content. Although calcium silicate products offer considerable advantages in both construction and finishes, their uses are limited to some of the private companies and a few public places, due to the skill required for building with such materials. Examples of buildings built with calcium silicate products are shown in Figure 2.8.

2.6.2 Red Clay bricks

Production of bricks in Dammam region began recently when the concrete blocks failed to satisfy the climatic conditions. Actually, the newly introduced technology has shown a great benefit of producing load-bearing brick housing in the traditional materials. The quality of the brick depends on the quality of the raw material and its content of salt and sulphur materials; it also depends on the specification of the produced materials.[21]

Recent studies in highly industrialised countries such as England have demonstrated that load-bearing brick construction, in buildings less than ten storeys high, can be twenty per cent more economical than using reinforced concrete. Also, the energy required in obtaining natural silt and transforming it to burnt brick is minimal in comparison with the production of steel and cement. However, the simplicity of the brick manufacturing remains the same, although it has been enhanced by the development of production knowledge and techniques. The increase of modern factories which are furnished with computerised equipment and sophisticated means of handling materials can easily cope with today's market demands, by adjusting their output with the fluctuation of the market needs.

The red clay brick provides an acceptable insulation for the different buildings, and also supplies building materials of many varieties of size and form. It is used for roofs and floors and load-bearing walls, as well as non-load bearing walls, as shown in Figure 2.8. However, the people in Dammam region have not used it very often due to their lack of knowledge about it.

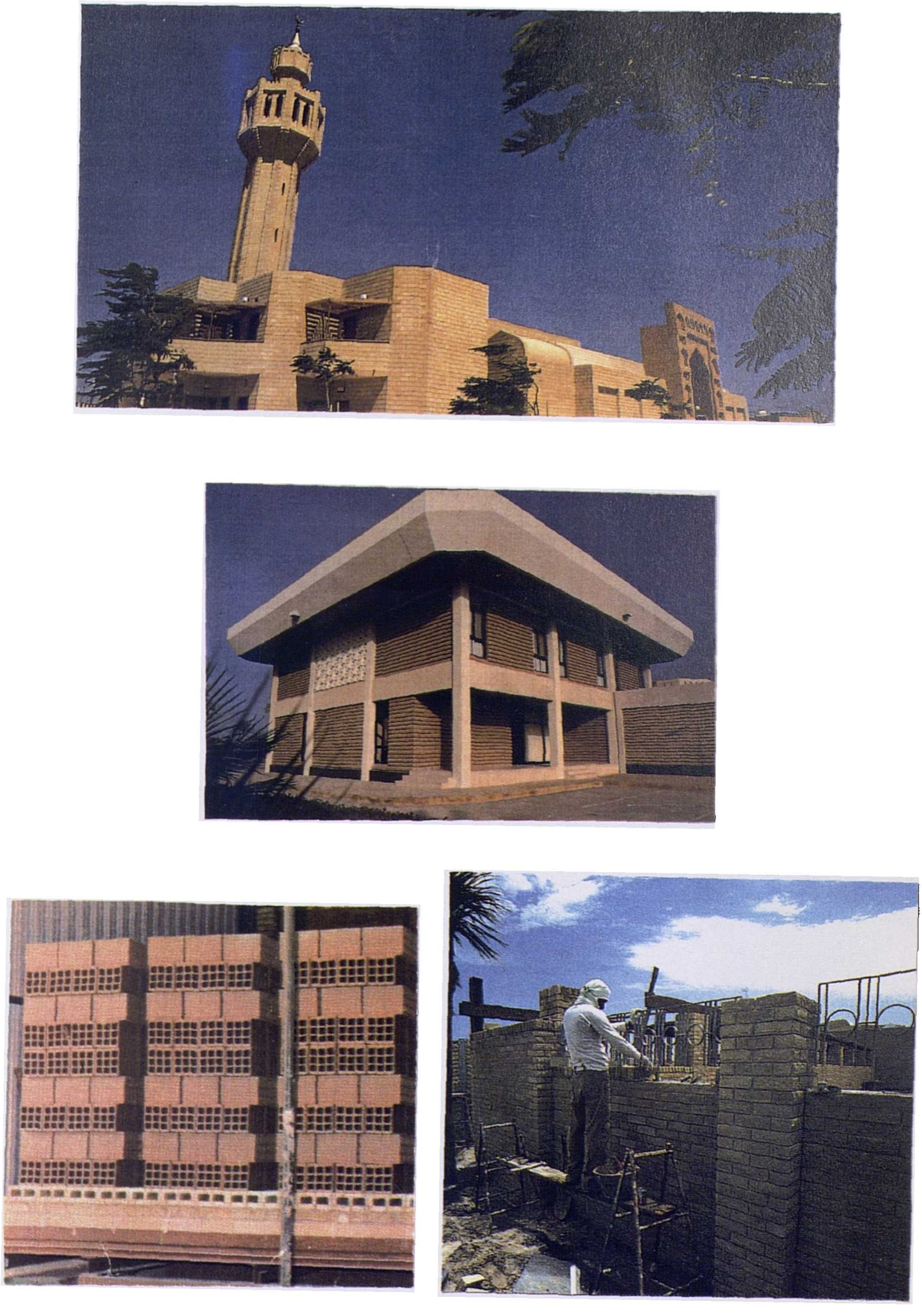


FIGURE 2.8 : EXAMPLES OF CONTEMPORARY BUILDINGS BUILT WITH CALCIUM SILICATE OR CLAY BRICKS AND BLOCKS.
MOST OF THESE BUILDINGS ARE EITHER MOSQUES OR COMPANY HEADQUARTERS.

2.6.3 Insulation materials

Thermal insulation materials are an essential factor in reducing the heat going through the external skin of the building. The use of such materials in the buildings improves the living situation and reduces the energy consumption. The high performance of these materials helps in maintaining the internal environment, so that it is cool for longer in hot climates.

In hot climates heat gain in respect of building materials is a serious problem. This has been so in Dammam region, where formerly there was a lack of insulation materials available, and where those used had a poor thermal performance. Lately, various types of insulation materials have been introduced to the region in order to cope with the need for better thermal insulation. Nowadays many varieties of insulation materials are available commercially in Dammam region with different forms and types. These include flexible insulation, fill insulation, reflective insulation, rigid insulation, and miscellaneous insulation.

Flexible insulation is composed of felted mats of mineral or vegetable fibres, wood fibre, and cotton.

Loose fill insulation is made of rock or glass products. It is available in bags and used conveniently in the walls of the hollow concrete blocks existing houses which were not originally insulated.

Reflective insulation is highly reflective material manufactured in the form of aluminium foil, sheet metal with tin coating, and paper products coated with a reflective oxide composition. Its main function is to reflect the solar radiation back to the environment in order to retard the heat transfer by the radiation. This type of insulation is very harmful for the environment, as it reflects the heat back to the streets adjacent to the building and to the passing people.

Rigid insulation is a fibre board material in sheet or other forms which is made of some inorganic fibre such as wood, sugar cane or other vegetable products. It can be found as fabricated board which may be used as wall board and roof decking and these type of boards can remain in place without being fastened. Also it can be found in the form of foamed polystyrene and urethane plastics and this insulation material can be used in the roof, walls and grounds. It is very light in weight and very durable in strength.

The thermal conductivity of the various insulation materials described above is shown in table 2.3.

Table 2.3 : Showing the Thermal Conductivity of some Insulating Materials

General Insulation Group	Specific Insulation Type	-range conductivity
Flexible Fill	1. Standard material	0.25 - 0.27
	2. Varmiculite	0.28 - 0.30
		0.45 - 0.48
Rigid	1. Insulating fibre board	0.35 - 0.36
	2. Sheathing fibre board	0.42 - 0.55
Foam	1. Polystyrene	0.25 - 0.29
	2. Urethane	0.15 - 0.17
Wood		0.60 - 0.65

Source : Housing Science Vol.7 No.3. pp.299, 1983.

2.7 Problems resulting from the rapid development

Due to the Government encouragement for people to build their houses, a rapid development took place. The Government controlled the development in the public sector, but failed to control it in the private sector. As a result, many problems occurred and people are still suffering from them. Those problems are:

1. The limited number of builders and designers was inadequate to absorb the huge demand for new buildings and that attracted foreign architects into the area. These architects participated in the design of the region's houses with no respect for traditional customs, religious values or climatic conditions, due to their lack of knowledge of them. Also draughtsmen had the opportunity of designing a house and then selling it to more than one client. As a result, a poor quality of house design was produced and western style houses were spread all over the region. Thus an unpleasant environment was created inside the house, as most of them look outward with large openings and almost all the exterior walls are totally exposed to the tremendously hot sun and receive radiation from different parts of the environment.

2. Due to the absence of professional building supervision by the municipality or by the REDF, buildings were built badly out of cheap and inferior materials. Also, owners did not have the knowledge to supervise their buildings and to select the appropriate materials. This situation led to a very poor quality of building and costly maintenance.

3. Building material prices went up very rapidly due to the huge demand to the use of imported materials and technology. Buildings were very inefficient thermally, due to the absence of the necessary insulation materials.

4. Apart from the poor thermal performance of buildings, the increase of paved areas and the absence of green areas around buildings

increased the cooling load on the house due to the indirect solar radiation from paved surfaces around the house, which in turn increased the energy consumption.

5. Due to the absence of public green areas in the community and to the fact that areas were totally occupied by buildings, children started to play in the streets and inside the house, which increased the heat input in the house.

6. Due to the common practice of excluding the air conditioning installation from the contract the window type air conditioning unit had become very common in the region. This type of cooling system increased the heat in the environment and on the exterior surfaces of the houses.

7. Privacy was not achieved by new housing, as neighbours could look over each other's yard and into each other's rooms from their balconies or through their windows. For most residents, overlooking problems were very serious and they closed their balconies with reflective glass or some other materials to ensure the privacy of their families from their neighbours. Unfortunately, this solution increased the heat inside the house and the balconies acted as heat storage units.

2.8 Summary

From the preceding study, it can be seen that Dammam region is one of the most rapidly developing regions with the highest increase in population rate in Saudi Arabia. This has been coupled with a rapid increase in the natural resources that have fuelled that development, i.e., oil. These two factors have spread development throughout aspects of life in the region, one of these aspects being housing.

The housing stock in Dammam region has been increased dramatically to accommodate the huge migration of people to the region. The government participated positively in the development by providing free interest loans for the people to build their own dwellings. However, it could not control the quality of the building, due to the huge number of houses constructed over a short period.

As a result, various communities and urban development of traditional significance, reflecting the culture of the region and the different solutions adopted to cope with the harsh climate, have come under the pressure of rapid urban growth. The intensive pressure caused by the rapid development has changed the pattern of the urban region's development from being organic and pedestrian oriented, to becoming geometric and vehicle oriented. In the process of change and urbanisation older communities are partially or totally destroyed and are often replaced with contrary housing form and layouts. The new houses are often based on a design of buildings built elsewhere or designed by architects who are not naturally concerned with the local culture of the region. Courtyard houses have been substituted by a box of concrete, with some passageways around it, to form the new villa house. Consequently, the new housing is climatically unsuitable, but with the availability of air-conditioning, climatic considerations in house design seem to be ignored.

Dwellings built with contemporary building materials are dominant in Dammam region. Although almost none of them incorporate resistive insulation materials such as loose fill, foam, or rigid board, they may incorporate capacitive insulating materials such as concrete blocks, sand, or stone. The typical, locally built modern houses have thinner walls and roofs, and as a result have poor thermal performances; in contrast the traditional buildings usually developed an acceptable time lag by increasing the thickness of the walls and roofs and because the materials they used had high thermal properties.

It appears that building materials in Saudi Arabia are not scarce, but the problems encountered may be the result of ignorance in selecting the appropriate material. Today many building material industries are established in the region, and almost no researches are being undertaken to discuss the possibility of reducing the heat gain through the fabric. Consequently, this study is devoted to the aim of reducing the energy consumption of the contemporary buildings, through the use of the newly developed materials to improve their thermal performance.

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CHAPTER 3

TRADITIONAL AND CONTEMPORARY COOLING SYSTEMS IN THE AREA

INTRODUCTION

3.1 Introduction

Traditional buildings demonstrate the complex inter-relationship that exists between their climatic environment and the rudimentary technology that has evolved in response to the need to provide protection from the harshness of the climate. In particular, in the arid regions, the more harsh the environment the more creative the response and techniques used. Much of the traditional housing in the Middle East has used various cooling systems which have evolved over many years, and the traditional buildings are extremely well adapted to the particular climatic conditions of the locality. Unfortunately, nowadays the traditional cooling systems are ignored by contemporary house builders.

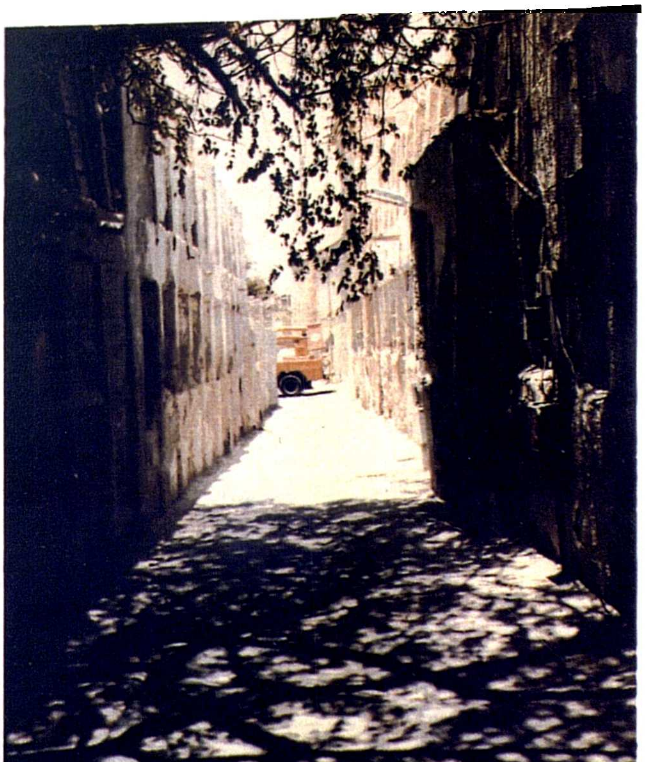
In Saudi Arabia the rapid development the Dammam region has faced over the last few decades, coupled with the availability of energy and the improvement of the economy have led people to abandon the traditional cooling systems and use mechanical cooling systems instead. Today the predominant cooling systems used in contemporary housing are the mechanical systems. To understand the different cooling systems used in the region over a period of time, this chapter is devoted to a discussion of the various cooling systems used by both traditional and contemporary buildings.

3.2 Traditional Cooling Systems

In hot climates, especially in the coastal regions of the Arabian Gulf any kind of cooling system or any type of structural element used to ameliorate the harshness of the climate is considered to be a cooling technique which provides welcome relief and blessing. Several types of cooling technique have been used traditionally in most parts of the region in order to cool the houses. However, since most of the major cities of the Eastern Province are coastal cities, they tend to utilize the cool breezes which exist even in the hottest period of the year. The main idea of the traditional cooling techniques is based on the movement of air by the cross-ventilation method, where air is permitted to flow freely into and out of the rooms. Furthermore, as a result of the importance of privacy in the house in the Islamic religion, houses were designed to be inward looking, and this has led to the construction of the courtyard house. The open courtyard house and the seasonal usage of the different parts of the house, participate very effectively in easing the harshness of the climate. However, special structural forms have been used to make habitation more comfortable; these structural elements include compact planning, air vent windcatchers, courtyards and Mushrabiyah.

3.2.1 Compact planning:

The planning of traditional housing in Dammam region and the Eastern Province, similar to that in the rest of Saudi Arabia, is comprised of compact clusters of adjacent houses, presenting the character of a dense mass of compartments and passageways (see figure 3.1). The compact planning creates a high population density grouped around a passageway which provides pedestrian circulation for the adjacent houses. The density indicates that houses share numerous common walls, which reduces the total exposed surface area and thus the total solar energy received by each house[1]. The normal pattern is that one side of the house faces the passageway and the other three sides are joined to the other houses. In regions such as Dammam region where the sunshine is very intensive, reducing the perimeter exposed to the sun, which is the case in the traditional communities, is very critical and very effective in keeping the heat out of the house.



(Qatif area)

FIGURE 3.1 : THE COMPACTED MASS OF COURTYARD HOUSES IN THE OLD SECTION OF DAMMAM CITY. IT SHOWS THE SHADED ALLEYWAYS AND WALLS.

Compact planning does not only reduce the exposed walls but also provides shade and passageways with a cool environment. The passageways connecting the contiguous houses are narrow, and are shaded by the high walls of the houses on either side. These passageways are perhaps cold in the winter, but provide comfort during the long summer season. The narrow width also provides greater protection from unpleasant wind and dust than is provided in wide streets. Moreover, apart from the climatic aids, compacted housing is conducive to social interaction and family relationships and, in the pre-modern Saudi society, occupants of adjacent and neighbouring houses were often relatives.

It is clear that the traditional model of compact planning suits the social, religious and physical requirement of contemporary Saudi society better than the modern villa design and the dispersed housing layout. However the compact planning and the traditional housing of the region has been rejected because (1) buildings of traditional construction in materials such as mud and plaster need regular maintenance; (2) they lack modern amenities, such as bathrooms, and services such as electricity and water; (3) the narrow winding streets are not suitable for cars;and (4) the dense configuration makes access difficult not only for cars but also for emergency vehicles and garbage collection. Therefore, people believe that traditional housing is associated with a low standard of living and the modern villa represents the desired standard of living. Unfortunately, this attitude shows a lack of experience and knowledge, whereby the traditional building as a whole is rejected and ignores the fact that some of the features of the traditional house could be adapted and used in the modern house to provide a nice comfortable living environment.

3.2.2 The Badgeer (wind catcher)

The badgeer, the second cooling system, is one of the most important cooling systems used in traditional houses. The main purpose of this system is to provide a means by which air can travel freely to the different rooms of the house. The badgeer was introduced to the

Arabian Gulf countries from Persia (Iran) where it has been used extensively over many years as a simple form of air conditioning. There are two main forms of badgeer and both of them were used extensively in the coastal cities and villages of the Arabian Gulf. These are: (1) the wind tower form and (2) the open recessed wall form.

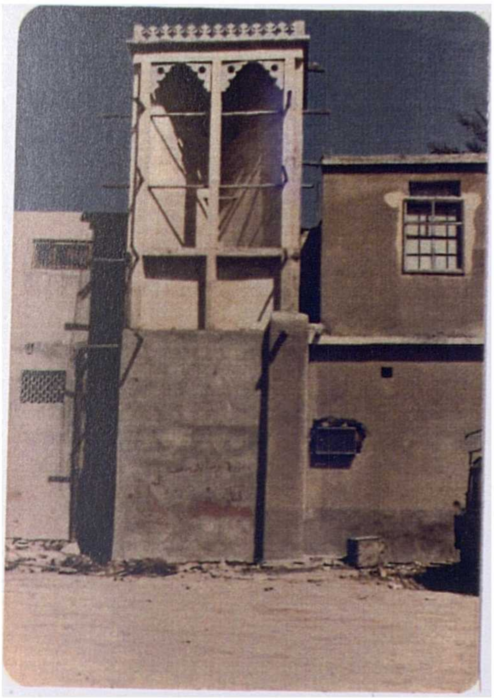
3.2.2.1 The wind tower badgeer

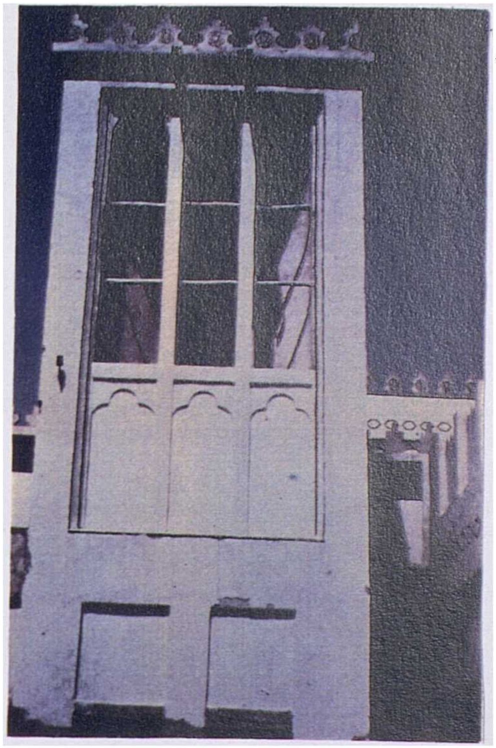
The wind tower is usually constructed a storey higher than the roof. This is simply a tall chimney which has openings to take in the air and convey it down into one or more rooms of the house. It consists of a tall square tower divided diagonally by walls in the form of the capital X. It is found on houses especially in Iran and the Gulf states, although it does occur in some of the cities of the Eastern Province of Saudi Arabia, such as Dareen and Qatif.

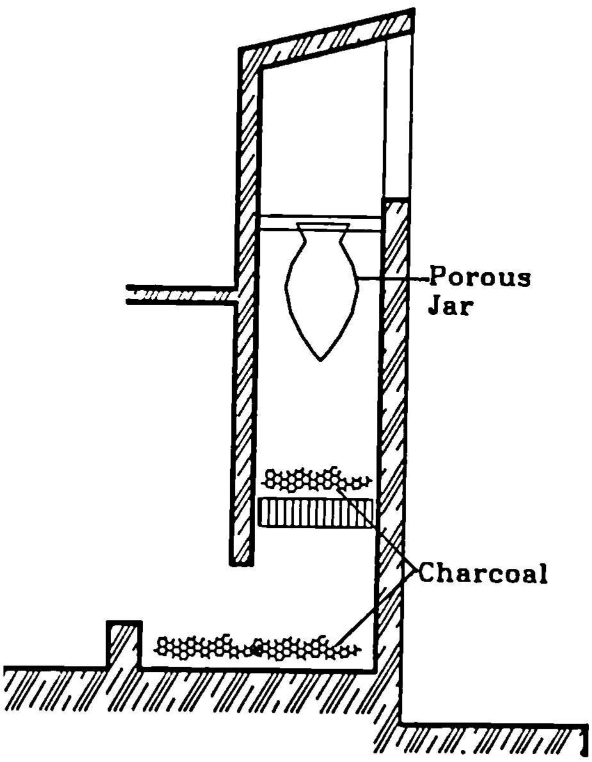
There are two main variations of the wind tower, depending on the regularity of the wind direction. If the wind in the region is variable, the wind towers are open on all sides to trap the breeze from any direction and deflect it downward into the house. If there is a predominant wind, the wind towers are open only in one direction, as in the wind towers in Iran and the Afghanistan border region. Usually in any region the wind towers are oriented toward the prevailing wind direction. Figure 3.2 shows various types of the badgeer, wind tower.

The wind tower can basically function in two ways to cool the house. The first way is by catching the prevailing breezes and forcing them down the tower. The second way is that when there is no wind, air descends down the wind tower in the early part of the day and it is cooled by being in contact with the tower walls which have cooled during the night; this process works only until the tower walls warm up or until their temperature becomes greater than that of the surrounding air.[2] Also, if there is no wind, a reverse upward flow is then created.

The breeze from the tower may enter directly into the room from which







Section: Water-jar Wind Tower.

Source:Danby, M.W.
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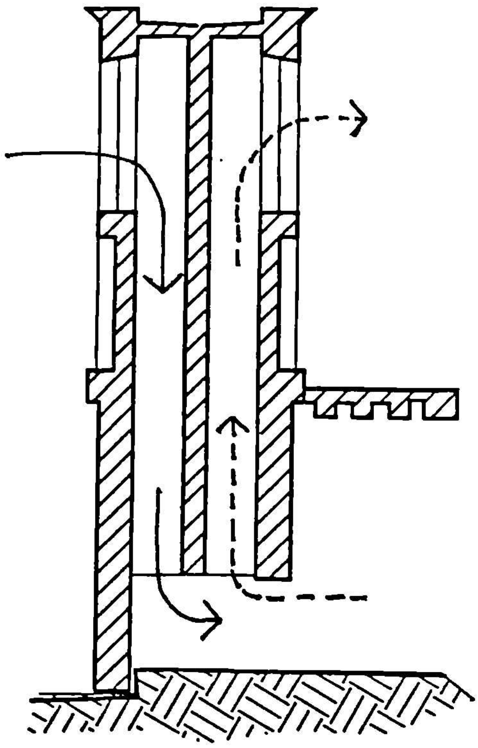


Section: Typical Wind Tower.

FIGURE 3.2 : VARIOUS TYPES OF AIR TOWERS (BADGEER) USED IN THE ARABIAN GULF COUNTRIES AS AIR COOLING SYSTEMS.

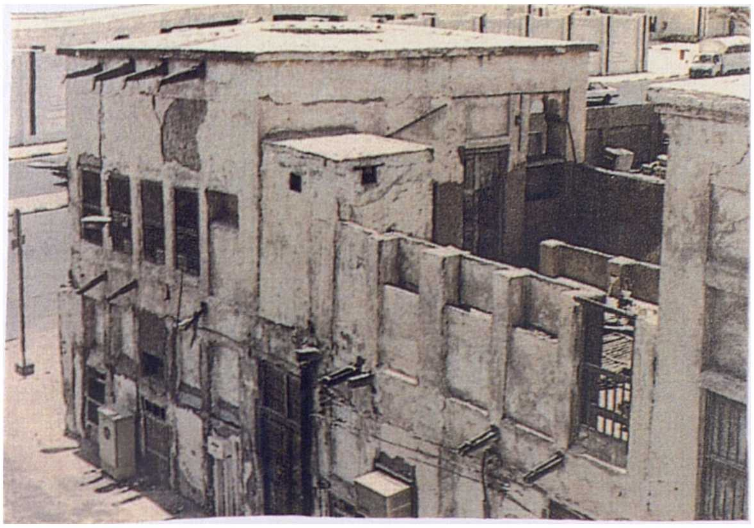
the tower rises, or it may be channelled through a square shaft to the open iwan, where the family usually sit together, or into separate rooms. The diverted air can be stopped temporarily by adjustable shutters used where the air enters the room. However, during the winter period the openings on the tower are closed up totally to stop the cold air coming in and to keep the warm air inside. Additionally some wind towers have mesh screens over the openings to keep out the birds and insects, also they have small ledges for the dust to settle as the air speed reduces, in order to trap the incoming dust.

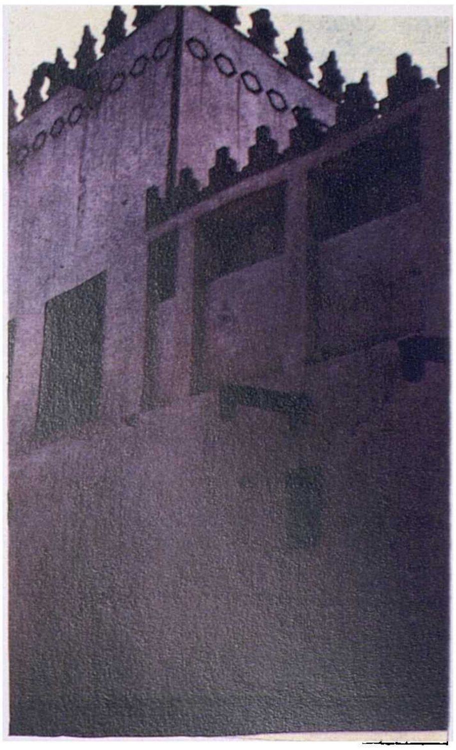
In some wind towers an evaporative cooling system is achieved by providing an additional feature to cool the air. The air is channelled from the tower over water jugs placed where the air flows into the rooms (see figure 3.2)[3]. In this system water evaporates into the air, increasing the humidity of the air and cooling it at the same time.

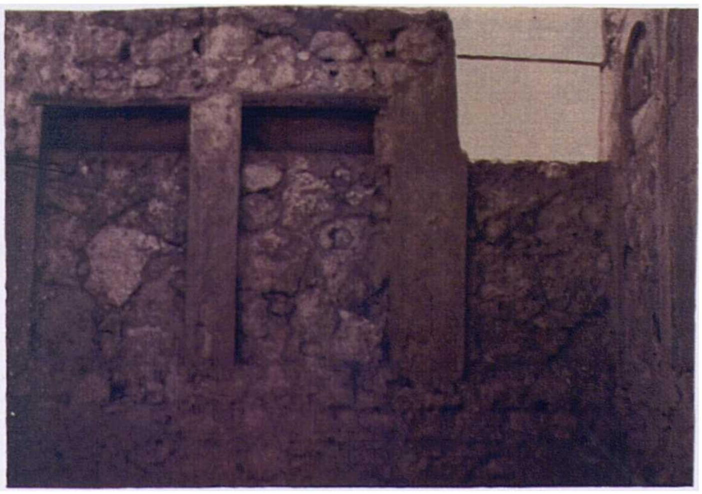
3.2.2.2 The open wall badgeer

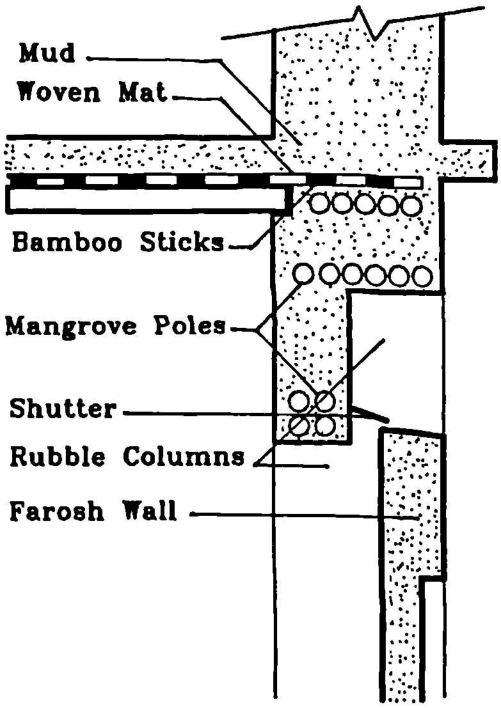
The most common passive cooling structure in Eastern Province and the Arabian Gulf countries is perhaps the open wall badgeer. Its main functions are to channel the breeze that blows in the direction of the wall by deflecting it downward into the rooms by the recessed wall, and to allow sufficient light to enter indirectly. The open wall badgeer is constructed by two recessed parts of the same wall constructed on top of each other and forming an opening of approximately 0.30 metres between the two parts of the wall. The lower part of the wall is about 1.20 metres high and the upper part starts where the lower part is terminated, as shown in figure 3.3 The flow of air through the opening is controlled by an adjustable horizontal wooden board which slides in and out of the same level of the opening.

This type of open wall badgeer is usually employed in the upper rooms, in some of the ground rooms, and in most of the roof walls. The open wall badgeer has three advantages on the regular window. Firstly, it has a greater area to deflect the breeze into the house; secondly it allows the breeze to enter the house and not the sun; lastly it keeps privacy of the house unobserved from the street or by neighbours.









Section through open wall badgee

FIGURE 3.3 : AT LEFT, GENERAL VIEW OF A TRADITIONAL OPEN WALL BADGEER IN ALKHOBAR CITY, AND A DETAILED SECTION THROUGH IT SHOWING ITS DIFFERENT PARTS: AT RIGHT, VIEW OF OPEN WALL BADGEER IN BAHRAIN

3.2.3 The courtyard

The third cooling system used traditionally is the courtyard which encourages heat loss from the living area of the house by the form of outgoing radiant heat (see figure 3.4). Despite the availability of the different types of courtyard its main concept remains the same. The courtyard conceptual design is of an internal enclosed space open to the sky with rooms and spaces arranged around it on two, three or four sides.[4] These rooms and spaces look inwards towards the court for natural daylight and ventilation. It could be of single storey or two or three storeys high and is used as an open space for the family to sit out in during spring and summer. Sometimes the courtyard accommodates most of the family activities, especially in the summer season.

The courtyard plays a major role in regulating the internal temperature of the traditional courtyard house by providing the surrounding rooms and spaces with the desired shade, especially in the summer period. However, the adequacy of the shade provided depends on the size of the courtyard dimensions; its length, width and height and their optimum proportions. As a matter of fact, the courtyard performs in three main functions during the summer period, taking advantage of the diurnal temperature changes.[5] Firstly, during the night, the cool air descends into the courtyard and flows into the surrounding rooms, displacing the hotter air. Consequently, the floor, the walls, the roofs, the ceilings and furniture are cooled at night and remain so until a late hour of the day. Secondly, when the sun directly strikes the courtyard floor, as a result of the direct radiation, the warmed air begins to rise creating convection currents in the rooms due to the leaks of air to the courtyard, which could provide further comfort. This process encourages the courtyard to act as a chimney by exhausting the hot air and replacing it convectionally by the cooler air drawn through the entrance lobby from the narrow street. This function cools the house by exchanging the cool air between the street and courtyard and the rooms surrounding the courtyard. Thirdly, when the sun sets the external air temperature drops and the courtyard starts to irradiate the heat to the clear blue sky allowing cooling air to flow and descend into the house.

In the short winter, the courtyard is usually vacant because it is exposed to the clear sky and becomes cold. However, the thick adobe construction achieves a form of balance by storing or dissipating heat during the diurnal changes of temperature. Nevertheless, the courtyard is a desirable place to sit in and enjoy the warmth of the sun especially around midday and during the afternoon. Daniel Dunham described the life in a courtyard as:

> "Life in a courtyard house can best be imagined as a life at the bottom of a rather comfortable and sometimes very elegant well, where the coolness and stillness are in delightful contrast to the dust, wind and heat of the surroundings.[6]

In addition to the courtyard having many functional aspects and visual characteristics, it can also be a planning and designing tool for reducing the size of the building plot and increasing the residential density of the community. However, the functional and non-functional aspects of the courtyard should be analysed and evaluated rationally and objectively in order to incorporate it into the design of new house types, taking into consideration the changing needs and the new desires of the inhabitants. Finally, the couryard seems to meet most of the Arab demands very effectively as far as the environment, religion and social and cultural needs are concerned.[7] The introverted courtyard acts as the key for improving the environmental conditions, turning its back, as it does, to the dust, glare and noise of the street. The courtyard house was very common among the arid and semi arid regions where the exclusion of heat from the buildings is a major problem.

3.2.4 The Mushrabiyah

The fourth traditional cooling system, the Mushrabiyah, was developed in response to the hot-humid climate where cross-ventilation is very effective in improving the internal conditions of the building. However, from the necessity of cross-ventilation and the desire for privacy, arose the design of Mushrabiyah and other types of louvered or screened windows. The Mushrabiyah is a decorative wooden screen forming an

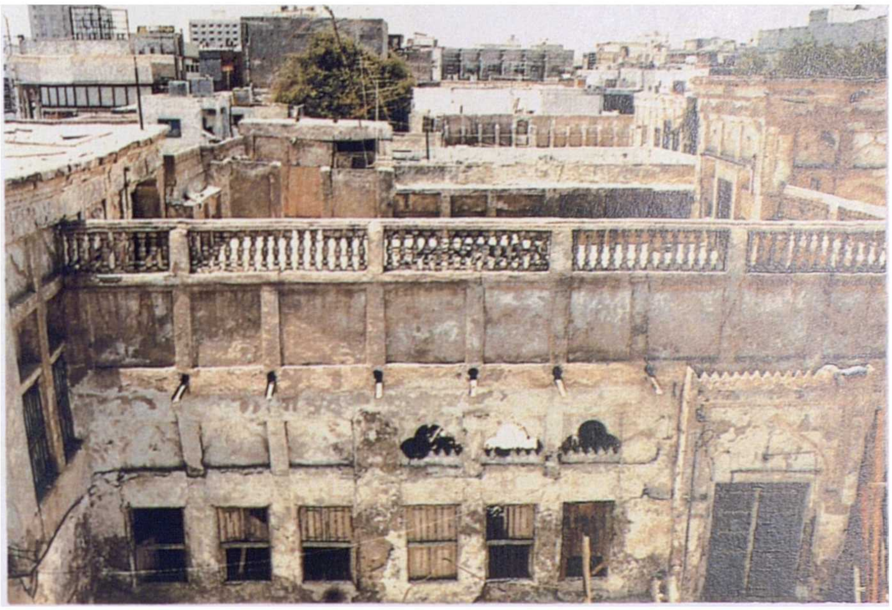


FIGURE 3.4 : TYPICAL TRADITIONAL COURTYARDS IN DAMMAM AND ALKHOBAR CITIES.

enclosure to protect windows or balconies (figure 3.5). It is usually constructed at different floor levels with teakwood and ornamented with simple wooden lattice work. Some of the Mushrabiyah's woodwork is beautifully turned or carved with great display of detail and an attractive finish of fine design.[8] It became decorative over a period of time especially during the period of Ottoman occupation and achieved popularity and honour on the west coast, where the Egyptian artisans worked, and on the east coast, where the skilled artisans came from the Indian sub-continent. However, later on and during the last period of the Ottoman occupation, the quality of materials used and the superiority of skill and technology improved the performance and the appearance of the Mushrabiyah on the west coast of Saudi Arabia.

The Mushrabiyah fulfils three main functions; it allows cross-ventilation to penetrate through the wooden screen, it provides adequate privacy for family life from the outside, while allowing residents within the house to look through it and it provides a cool space for storing drinking water. When the direct breeze blows it enters the room through the Mushrabiyah as a result of the slight pressure difference between the inside and outside of the room; however this slight pressure difference ensures the continuous circulation of cool air. The pressure difference and the flow of air can be achieved by proper orientation and design of the doors and windows within the rooms which have the Mushrabiyah. Furthermore, the Mushrabiyah acts sometimes as an evaporative cooler when a clay water jar filled with water is placed inside the Mushrabiyah. During the day, humidity of air coming through the Mushrabiyah starts to increase after it contacts the water in the jar and evaporates water on the surface. When the air passes through the Mushrabiyah and contacts the water in the jar, the water loses some of its heat and utilized for drinking water, and the relative humidity of the air is increased due to the evaporated water.

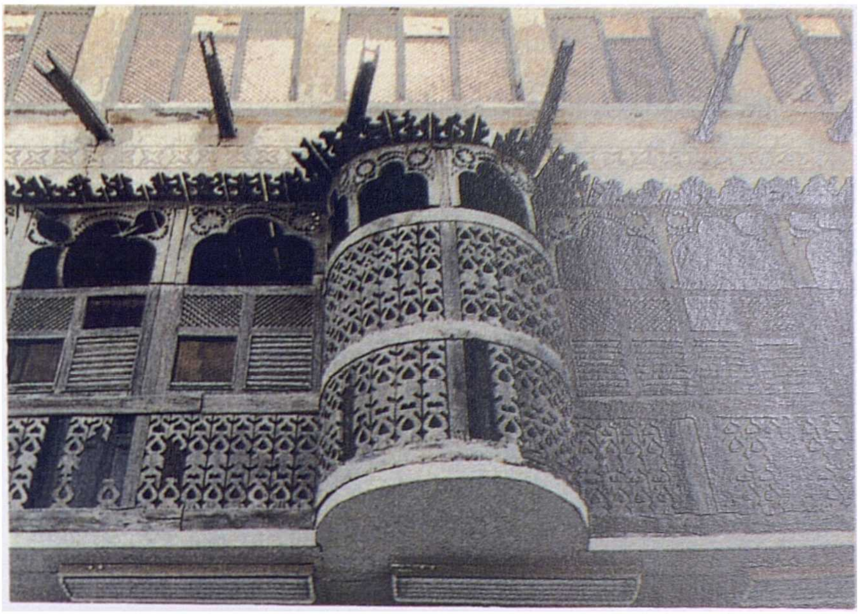


FIGURE 3.5 : DECORATIVE MUSHRABIYAH OF TRADITIONAL HOUSES IN ALKHOBAR CITY.

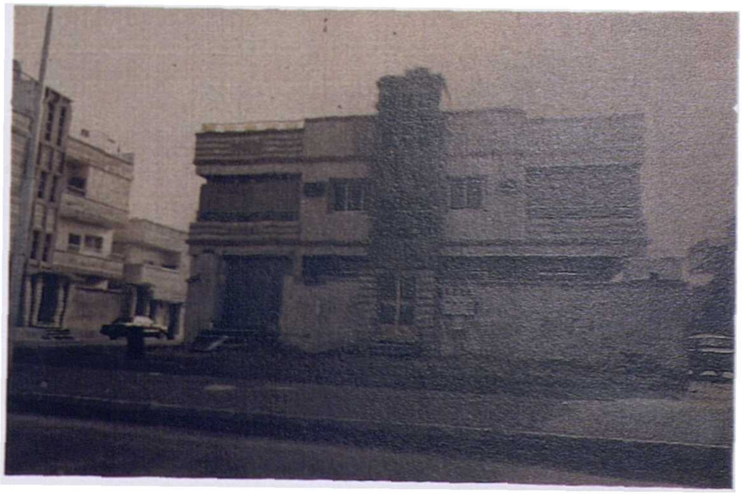
3.3 Contemporary Cooling Systems

In traditional buildings the necessity for easing the harshness of the climate was largely satisfied by employing traditional cooling systems which incorporated knowledge of the local climate and the physical environment. On the other hand, in contemporary buildings rapid urbanisation, coupled with the availability of the latest technology, encourage the designer and the client to use the modern technology and materials. The present stock of contemporary buildings in Dammam region is the result of the explosion of economic growth during the past thirty years. During this explosion, the building practices of neighbouring countries and many western countries were introduced to the Dammam region with little regard for the local environment and design requirements. As a result of this, the villa type house has become the dominant dwelling in the region and probably the greatest influence on the built environment. In order to combat the extreme summer weather conditions, the new villa type house introduced elements such as the balcony and terrace, the outer courtyard, and mechanical air conditioning, as contemporary cooling systems.

3.3.1 The balcony and terrace:

Generally, in most countries the balcony is designed to allow more ventilation into the room, provide an outside sitting space on the upper floors, and shade for the windows on the floor(s) below.

When the balconies were used in the traditional buildings they were enclosed by wooden screens and called Mushrabiyah. They were very sufficient in providing cross-ventilation through the room and humidifying the breeze, as well as securing privacy. However, the contemporary balcony is designed for the same purpose as the traditional balcony, but due to the use of unsuitable building materials it does not perform properly. Additionally, the balcony is misinterpreted by the new housing stock and causes problems for the inhabitants. These problems include the lack of privacy, the trapping of dust and the danger to children of falling from the balcony. The



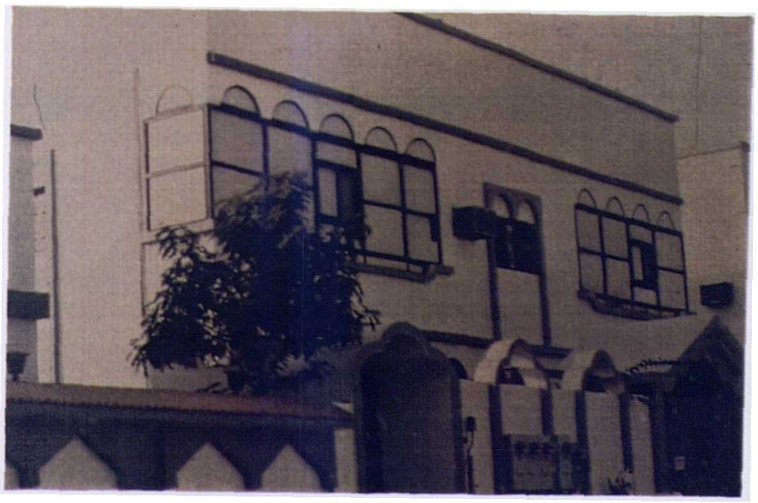


FIGURE 3.6 : TYPICAL CONTEMPORARY BALCONIES USED WIDELY IN DAMMAM AND ALKHOBAR CITIES: SOME OF THEM SCREENED BY GLASS AND OTHERS BY SOLID PLYWOOD TO PROVIDE PRIVACY.

caused by the balcony causes the inhabitants to close their balconies with reflective glass or solid plywood to ensure privacy (see figure 3.6). Unfortunately, the use of glass on the balcony converts its function from being a cooling system to a storage heater: the use of glass enables the short wave radiation to penetrate into the balcony and prevents the long wave radiation from draining out, causing an accumulative heat trap which consequently increases the cooling load of the house. In fact, the balcony is one of the major problems people should consider when seeking to improve their building's performance in energy conservation.

3.3.2 The extroverted courtyard

The second cooling system incorporated in the design of contemporary housing is the extroverted courtyard. The extroverted courtyard (or set back) has resulted from the application of the new building regulations which require all buildings to be set back a specific minimum distance from the plot boundaries, thereby ensuring passageways around the house, daylight from four sides, and separation from neighbouring houses.[9] These regulations have produced contemporary courtyard houses totally opposite to the traditional form, where the introverted courtyard house is replaced by the extroverted villa, and the dense mixed-use urban pattern is substituted by the mono-zoned suburban grid-iron layout (see figure 3.7).

From the climatic point of view the extroverted courtyard allows the heat generated by air conditioning machines to escape from the house, and enables the house to have more windows on all sides in order to get more light and ventilation. However, although the extroverted courtyard succeeds in exhausting the heat generated by the air conditioning machine, and in providing adequate light and adequate ventilation, but its capacity for passive cooling is very limited, making mechanical air conditioning essential if the house is to provide a comfortable interior climate. Furthermore, there is the lack of privacy due to the problem of being overlooked by the neighbouring houses, as instead of opening into an internal courtyard, the windows look across

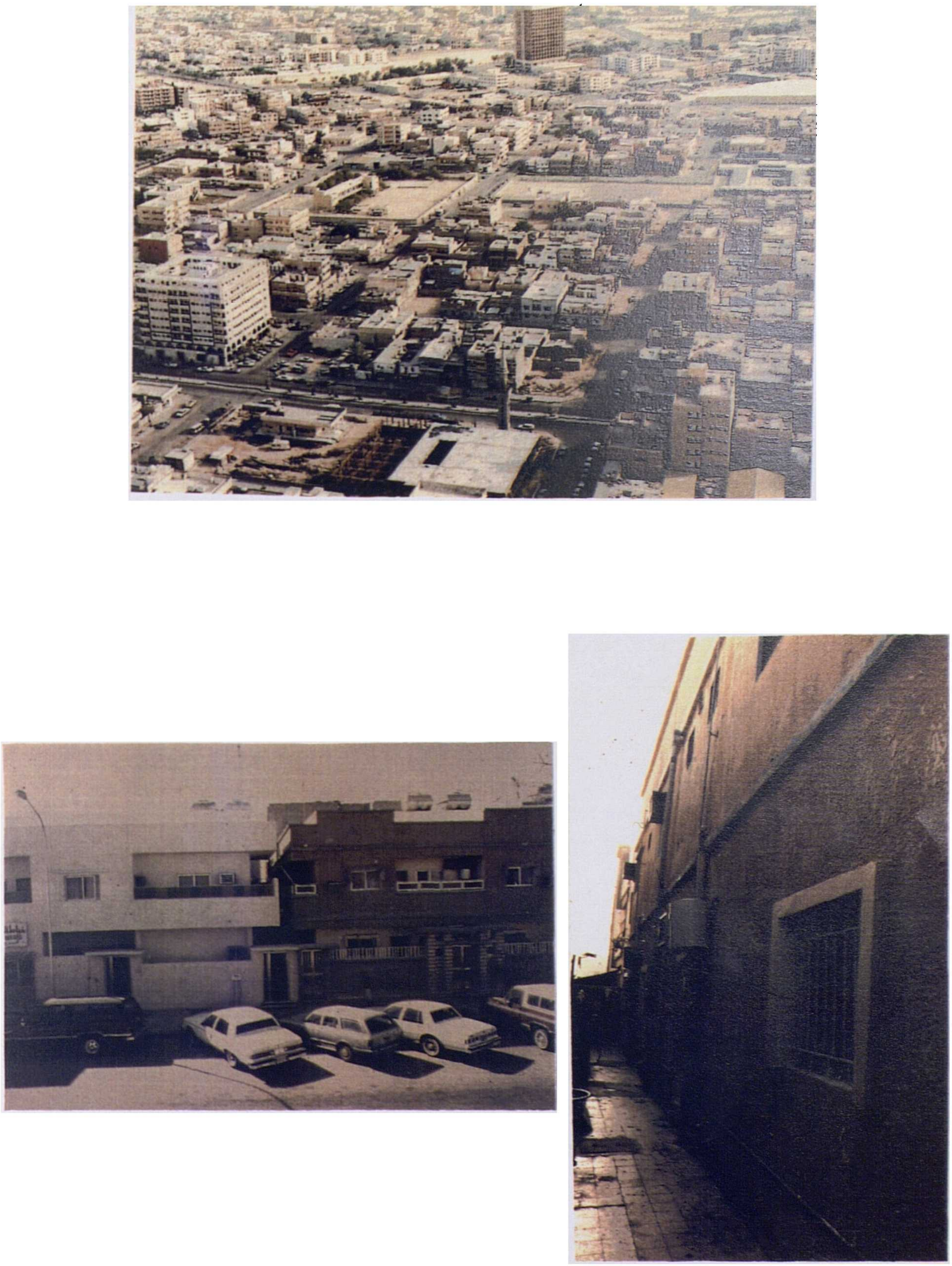


FIGURE 3.7 : EXAMPLES OF THE COMMON EXTROVERTED COURTYARD (SET BACK) THAT HAS REPLACED THE TRADITIONAL COURTYARD IN ALKHOBAR CITY.

an exterior courtyard towards the neighbouring house. Because of the lack of privacy, the extroverted courtyard cannot be used for the daily activities, neither can it be planted because it is very narrow, and it cannot be fully used as an external circulation area for the house. The concept of the extroverted courtyard has exposed the four walls of the house to direct solar radiation which increase the heat gain through the fabric, thus - the extroverted courtyard participates in heating the house rather than cooling it.

3.3.3 Mechanical cooling systems

The creation of a comfortable environment is of major importance for the productivity and well-being of man. In Dammam region and throughout Saudi Arabia, as well as in the neighbouring countries, air conditioning plays an important role in providing comfortable conditions inside the house. Almost all the new housing in Dammam region is extensively dependent on air conditioning units for cooling purposes.[10] The introduction of air conditioning units has resulted in the most radical change to the design of houses. This change was accompanied by the use of new building materials and construction techniques, architects and engineers who were not necessarily concerned with the local context, and relatively inexpensive electrical energy costs due to the government's subsidisation of the energy costs.

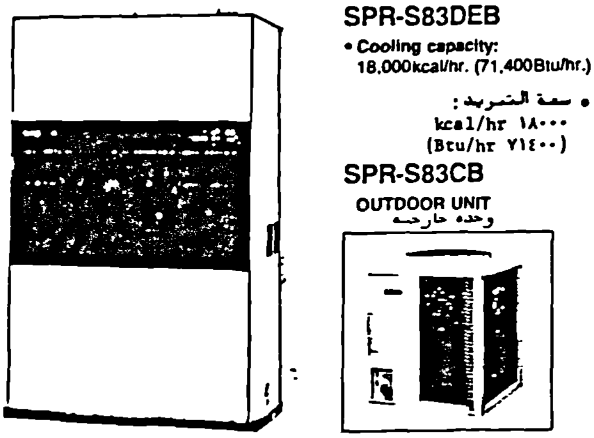
A typical new building in Dammam region, consists of a well built structure, with heavy construction materials, a solid exterior wall, large window areas, and some form of mechanical air-conditioning system to keep the internal environment comfortable. There are several types of cooling system used throughout the region; these are central air-conditioning, split unit air-conditioning and window type air-conditioners.

The central air-conditioning cooling system is not commonly used among the houses built through the Real Estate Development Fund, due to its high purchase cost and maintenance problems: indeed, it is rarely used in the region except for governmental buildings and the wealthier houses.

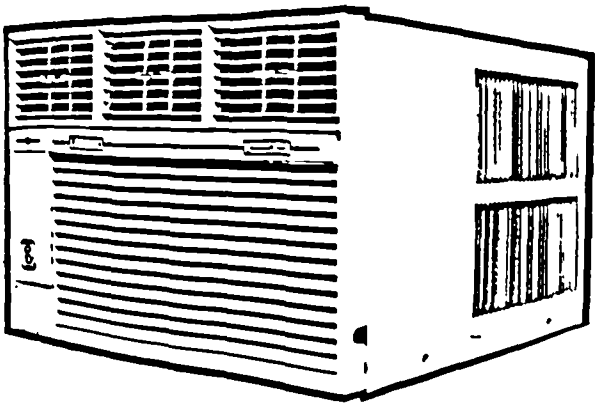
The second type of mechanical cooling system used is the split unit air-conditioning; this has recently been introduced to the region and it competes highly with the window type air-conditioning unit. It is mostly used in some of the newly built houses, though not in all of them due to the people's uncertainty about its performance and due to its high cost. Generally, the split unit cooling system consists of a condensing unit placed outside the room for noise and heat reasons, and a blower-coil unit placed inside the room to supply the room with cool air, (see figure 3.8); these two split units are connected together with liquid line and a suction line for supplying the cooled air and sucking out the returned air.[11]

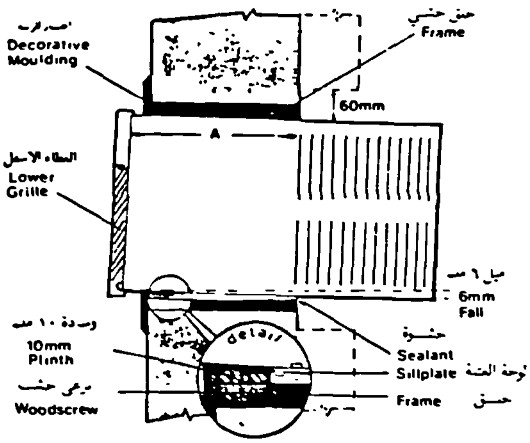
The third mechanical cooling system is the window type air-conditioning unit. This is very widely used in the contemporary housing in Dammam region, due to its lower installation cost compared with the other two systems discussed above. It is a compact refrigerating machine placed across the wall, having the outlet inside the room for supplying cold air and keeping the inlet outside the room to exhaust the heat produced by the system (see figure 3.8).

Despite the popularity of the window type unit, the split unit air-conditioning has more advantages than the window type. These advantages are that the split unit air-conditioning does not produce noise during its operation, which is the case with the window type unit, because the indoor unit operates with whisper-quiet efficiency and employs a noiseless fan. The split unit system also does not exhaust heat at the same place of cooling because the condensing unit is away from the room. Therefore, the split unit cooling system is more efficient in cooling the space and consumes less energy than the window type cooling system.



Split Unit





Window type unit

FIGURE 3.8 : CONVENTIONAL MECHANICAL COOLING SYSTEMS USED

3.4 Observation of Traditional and Contemporary Cooling Systems

The elements of the traditional cooling systems developed within Dammam region and the neighbouring countries are evidence of the people's response to the impact of the physical environment and its interaction with cultural, religious and economical factors. However, the development of these elements was not limited by physical or political boundaries but by cultural and climatic boundaries, as can be seen in the Eastern Region of Saudi Arabia where the architectural and the climatic solutions are similar to those found in the Arabian Gulf and Iran. The traditional cooling systems which were commonly used in the region did not require any mechanical system to operate in order to cool or heat the spaces. The basic principles of these cooling systems were based upon the maximum utilisation of the movement of the sun and the prevailing wind. Also, the people adapted themselves by certain behavioural habits, where they performed most of their activities outdoors during the summer and transferred their activities to indoors during the winter season.

Before the introduction of electricity and automobiles the traditional buildings in Dammam region and the gulf countries represented the most comfortable and sensible house design for the hot arid maritime climatic region. The use of compact planning, windcatchers, open courtyards and the Mushrabiyah in simplifying the climate indicated the deep knowledge of the people of their local environment. Also the high windowless walls facing the streets and alleyways, and the separation between the guest room and the family activity area reflected the high consideration paid to the society's values and needs during the design processes. Moreover, the design and construction of traditional houses relied heavily on local building materials and the utilisation of the sun's motion and the wind directions.

On the other hand, the contemporary cooling systems were introduced in the Dammam region as a result of the adaptation of the new villa type, which is often based on designs of buildings built elsewhere or designed by architects who are not necessarily concerned with the local climatic context and the availability of cheap power. By themselves these contemporary cooling elements, which are the balcony and the extroverted courtyard, failed to provide a cool environment inside the house. In fact, these two cooling elements participate in increasing the heat gain inside the house due to the use of glass in the balcony and the larger area of wall exposed to the sun. The contemporary cooling system which seems to be most welcomed and widely used in the region is mechanical air conditioning. This system is very effective in improving the internal environment of the house, but it consumes too much energy and drains out heat into the extroverted courtyard.

There are many lessons to be learned from the traditional building techniques, as the buildings used to be designed in response to the values and needs of the people as well as being adapted to the environment. Naturally, this does not mean that people should go back to the pre-industrial technology but it means that traditional housing should be studied carefully and aspects such as windcatchers, open courtyards, and Mushrabiyahs should also be investigated deeply to determine the aspects which can be adopted and combined with the forms and systems of contemporary housing. However, it is very obvious that the universal use of the motor car, and the provision of full infrastructure services makes it impossible to reproduce the traditional compact planning and introverted designs, but it should be possible to utilise the traditional principles to develop contemporary solutions that avoid the problems that have resulted from the adaptation of western building techniques, house designs and planning layouts. Even though it would be unrealistic to expect all houses to be cooled passively and the use of mechanical cooling systems to be completely abandoned, yet it is possible to minimise the cooling load to reduce energy consumption, and to spend more money initially for providing low energy consumption building, bearing in mind that this building will save more money in the long run through its high energy saving.

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CHAPTER 4

CHAPTER 4

THE CONTEXT OF THE CLIMATE AND ITS EFFECTS ON BUILDING

4.1 Introduction

4.2 Climate Classification

4.3 Characteristics of the Climate of Dammam Region and Its Factors

- 4.3.1 Solar radiation
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- 4.3.4 Prevailing wind
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4.8 Summary

THE CONTEXT OF THE CLIMATE AND ITS EFFECTS ON BUILDING

4.1 Introduction

The climatic conditions of any region depend on a number of geographical factors including the region's latitude, its position with respect to land and water, and its elevation above sea level. For climate there are no political boundaries, but there is almost an agreement among various people as to whether the climate is acceptable, good or bad. This variation in judgement depends upon the person's attitude, past experience and comfort level. Therefore the scale of good and bad differs from one place to another; for instance the people like the Eskimo find the climate along the fringe of the Arctic ocean agreeable, whereas nomads of the desert like the desert climate. Many people in the modern world are adapting to the climate of their regions and feel uncomfortable when they are removed from them.

Climate plays a very important part in affecting people's daily life as well as the whole environment. Climate affects human behaviour, human health, human energy, national agricultural production and national energy consumption. Climate is a very complex concept, consisting of five different factors, each one of which depends on the other. The different climatic factors are solar radiation, air temperature, air humidity, wind, and precipitation.

Architects are usually interested in the factors of the climate which directly affect human comfort and building usage. These factors are expressed in the form of averages, changes and extremes of temperature, the temperature differences between day and night, relative humidity, wind speed and direction, incoming and outgoing radiation, and rainfall and its distribution. The records of the climatic factors can be collected from different sources such as airports and meteorological stations.

4.2 Climate Classification

Climate classification is an important issue which determines the most appropriate types of building materials and natural products for each climatic zone. Scientists have discussed this issue very widely, leading them to similar results with some variations.

The numerous combinations of climatic variables may be classified according to many different criteria, depending on the purpose of the categorisation. Since the purpose of this study is to reduce energy consumption and improve the thermal performance of the building, the necessary climatic controls are entirely different in hot and in cold conditions. Therefore, these differences provide a basic distinction for climate classification - usually, the thermal effect of materials in buildings without using air-conditioning units in hot and warm climate depends on the diurnal temperature range, which depends on the vapour pressure level. In this case temperature and humidity are interconnected in determining the type of climate.

The first attempt at climate classification was made between 1835 and 1842 by a young British scientist, R.B. Hinds[1]. He classified the climatic zones into four categories according to the air temperature only. In 1953 the second attempt was made by G.A. Atkinson, who classified the climatic zones in a very clear way. He based his classification on the major weather factors which affect human comfort, air temperature and relative humidity. He divided the tropical regions into three major climatic zones and each zone was divided into two sub-groups. Table 4.1 summarises Atkinsons' climatic zones as well as the climate of Dammam region; also it reveals that the climate of Dammam is similar to the maritime desert climate. Therefore, any recommendations or experiments which have been done to improve the energy consumption in a similar climate could be applied to Dammam region, with special consideration to the region's micro-climate and to the users' behaviour.

Table 4.1

Summary of the Different Climatic Zones Classification as Reported by G.A. Atkinson

ZONES	WARM-HUMID EQUATRIAL CLIMATE		HOT-DRY CLIMATE		COMPOSITE CLIMATE		DAMMAN REGION CLIMATE
SUB GROUPS	Warm-humid climate	Warm-humid island climate	Hot-dry desert climate	Maritime desert climate	Composite or climate	Tropical upland climate	
Daytime mean maximum	27-32	29-32	43-49	38	32-43	24-30	36-40
Nightime mean minimum	21-27	18-24	27-32	24-30	21-27	10-13	26-30
Diurnal mean range	narrow	8^oC	17-22	9-12	11-22	11-20	8-12
RH Range %	55-100	55-100	10-55	50-90	20-55 55-95	45-99	60-99
Vapour pressure N/m^2	2500-3000	1750-2500	750-1500	1500-2500	1300-1600 2000-2500	800-1600	1200-2500
Direct	low	strong	strong	strong	vary	strong	strong
Diffuse	strong	low	very low	strong	vary	fair	fair
Precipitation mm	2000-5000	1250-1800	50-155	50-155	500-1300	above 1000	less than 130
Wind	weak	6-7m/s	dusty	breezy	dusty	> 15M/s	breezy
Vegetation	rich	fair	poor	poor	*fair*	*fair*	*poor*

Source: Man and His Environment, Gates, D.M.

4.3 Characteristics of the Climate of Dammam Region and its Factors

The region of Dammam, the present capital of Eastern Province and its largest settlement, experiences a fairly complex climate which can be considered as a maritime composite climate. This region is situated along the Arabian Gulf coast at a longitude of $50^{o}06'$ and between the latitudes of $26^{o}06'$ and 26^{o} 30' N. The area is bounded by the Arabian Gulf on three sides, north, south and east, and extends inward towards the desert from the west. The climate of the region is generally hot in the summer and moderately warm for the rest of the year. Sadly, the summer period, represented by the harshness of July and August temperatures of $42^{o}C$ average with low humidity, dominates most of the year, whereas the winter period, represented by the pleasant months of December and January of $22^{o}C$ average with increased humidity, only accommodates a few months of the year[2].

Every creature needs energy to survive and to stay within certain temperatures to live, and the energy usually tries to maintain the required temperature conditions. The climatic factors of significance in this energy flow are, solar radiation, ambient air temperature, air humidity, prevailing wind, and precipitation.

4.3.1 Solar radiation

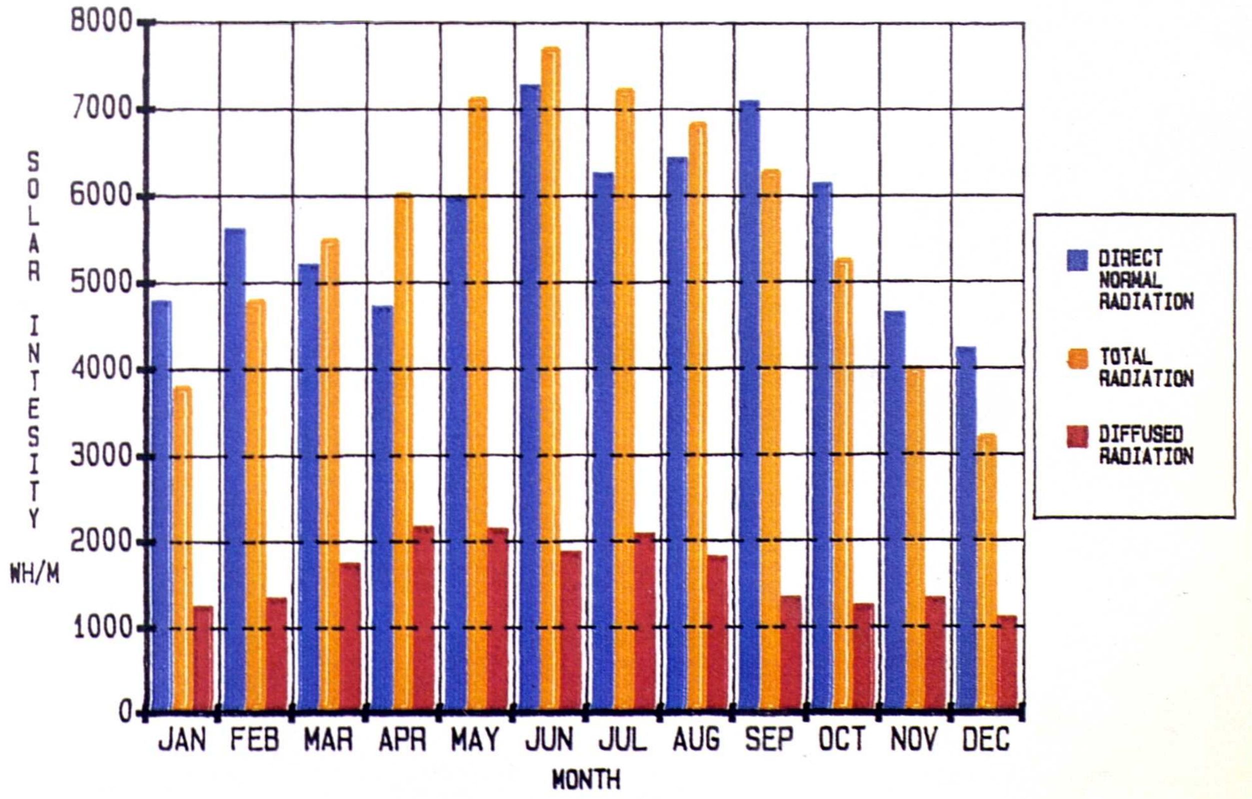
Solar radiation is a form of energy which is propagated as an electromagnetic wave through space, or through a medium such as air or water. The sun supplies the earth with almost all of its energy in the form of radiation; therefore, the sun is the dominating influence on climates and lighting. The reception of solar energy varies with altitude, this variation being caused by the filtering effect of the atmosphere.

Solar radiation falling on Dammam region affects most of the climatic patterns of the region. The amount and intensity of solar radiation depend on the time of the year and the time of the day; they also

Table 4.2: Mean monthly solar radiation intensity,Dammam region.
source: King Fahad University of Petroleum and minerals (KFUPM)

MONTHS	DIRECT NORMAL RADIATION	TOTAL RADIATION	DIFFUSED RADIATION
JANUARY	4815	3830	1273
FEBRUARY	5646	4830	1367
MARCH	5239	5530	1764
APRIL	4748	6056	2184
MAY	6010	7160	2162
JUNE	7309	7744	1893
JULY	6291	7270	2106
AUGUST	6466	6873	1832
SEPTEMBER	7123	6323	1359
OCTOBER	6167	5288	1270
NOVEMBER	4064	4626	1348
DECEMBER	4249	3246	1132

FIGURE 4.1: THE DIRECT NORMAL, THE TOTAL, AND THE DIFFUSED SOLAR RADIATION INTENSITY IN DAMMAM REGION



depend on the area's altitude as well as the clearness of the sky from cloud and air pollution. Since Dammam region is situated between latitudes $26^{o}06'$ and $26^{o}30'$ north, the sun's rays are almost vertical during the summer period, especially on 21st June. Therefore, the period of intense solar radiation extends for about six to seven months between 21st March up to 21st October. The sky is mostly clear in this period due to the high sun heat.

The daily average amounts of solar radiation for each month for the whole year is enough to indicate the climatic conditions of the region. For specific detailed design, however, solar radiation should be recorded in hourly totals, or even as hourly average intensity. The different intensity of solar radiation falling on Dammam region is summarised in Figure 4.1, as well as Table 4.2.

4.3.2 Ambient air temperature

Ambient air temperature is affected mainly by the amount and intensity of the solar radiation falling on the earth, the clearness of the sky and the period length of the solar radiation. At night, the ambient air temperature drops down gradually, due to the absence of solar radiation despite the continual flow of earth long-wave radiation to the atmosphere.

In the past, the ambient air temperature within the cities and towns may have been lower than today. The present ambient air temperature is elevated by the heat coming from the black paved streets, the smoke of vehicles, air conditioning units, and some other heat released by the consumption of energy. All add more heat into the air and delay the quick release of absorbed heat during the night, which reduces the diurnal temperature range.

Analysis of the climatic data for the year 1987 in Dammam region shows that the presence of the Arabian Gulf cuts down the variation in day and night temperatures. The analysis shows that the daily temperature is very high for most of the year, with some reasonable temperatures in few months. From the meterological data, it can be seen that the hot period in the region, considered as the summer season, extends from the middle of April until the end of October, whereas the winter runs from late December until the end of February. The average annual temperature in Dammam region recorded by King Fahad University of Petroleum and Minerals is 36.6^{o}C.

The maximum temperature during the hot period reaches a peak of about 46^{o}C in July and August, and the minimum of the coldest months, January and February is 12^{o}C (see Figure 4.2 and Table 4.3).

4.3.3 Air humidity

The humidity involves three types, absolute humidity (AH) saturation-point humidity (SH) and relative humidity (RH). The absolute humidity is the amount of moisture actually present in unit mass or unit volume of air; it is measured in g/kg and (g/m^3) respectively[3]. The saturation-point humidity is the amount of moisture the air can hold depending on the air temperature. The relative humidity, which is most important to this study, is the ratio of the actual amount of moisture present (AH), to the amount of moisture the air could hold at the given temperature (SH).

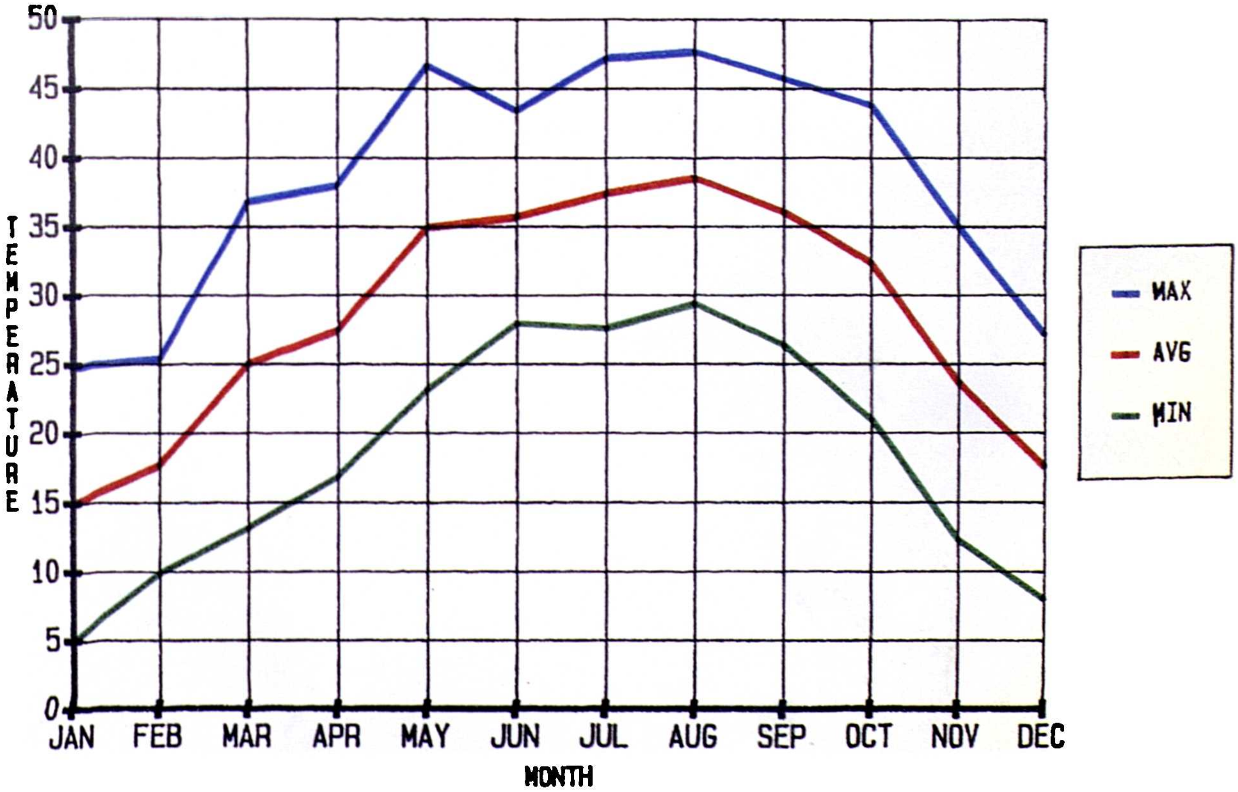
$$RH = \frac{AH}{SH} \times 100$$

The dry bulb temperature (DBT) and the wet bulb temperature (WBT) are used to calculate the relative humidity inside a building which is required for the calculation of the building's thermal performance. The difference between the two readings gives the rate of evaporation, which leads to the determination of the relative humidity by using the psychrometric chart. Usually, the monthly mean maximum and mean minimum relative humidity values for each of the twelve months would give a reasonably accurate picture for the designer to carry out his work. However, this is not quite enough for detailed study unless it is associated with some more information to clarify the other parameters, such as solar radiation, air temperatures, precipitation and wind speed. The relative humidity in Dammam region is relatively high due to the

Table 4.3: Mean monthly maximum, average, and minimum air temperature, Dammam region. source:KFUPM

MONTHS	MAXIMUM	AVERAGE	MINIMUM
JANUARY	24.8	14.85	4.9
FEBRUARY	25.4	17.65	9.9
MARCH	36.8	25.0	13.2
APRIL	38.0	27.45	16.9
MAY	46.7	34.95	23.2
JUNE	43.4	35.7	28
JULY	47.2	37.4	27.6
AUGUST	47.7	38.55	29.4
SEPTEMBER	45.7	36.05	26.4
OCTOBER	43.8	32.4	21.0
NOVEMBER	35.0	23.65	12.3
DECEMBER	27.1	17.55	8.0

FIGURE 4.2: THE MEAN MONTHLY MAXIMUM, AVERAGE, AND MINIMUM AIR TEMPERATURE IN DAMMAM REGION



large surface of exposed water of the Arabian Gulf. Usually in maritime climates the relative humidity in the indoor spaces is lower or equal to the relative humidity outside, due to the evaporation of the sweat of the inhabitants of these spaces and due to the poor thermal protection provided by the building.

The highest average relative humidity on the eastern coast occurs during the winter months. Although humidity is relatively lower during the summer than the winter, it is uncomfortable when the temperature is high. The presence of the Arabian Gulf, while contributing to the relatively high humidity, provides occasional fresh on-shore breezes, making the conditions more pleasant along the coastal strip.

The highest relative humidity recorded in Dammam region in 1987 occurred in January and reached 99.9%, while the lowest maximum was 35.9% in July of the same year. Relative humidity ranges from 99.9% to 40.2% in January and from 69.9% to 29.8% in July (see Figure 4.3 and Table 4.4).

4.3.4 Prevailing wind

Wind is a major factor of the climate and affects the whole city as well as the individual houses. It is essential to determine the speeds and directions of the wind for every month, as well as to recognise the daily wind pattern, in order to identify the prevailing wind direction and make use of most of it. Nevertheless, it is important to determine whether the area is subjected to storms, hurricanes or tornados by giving them special consideration.

In a maritime composite climate, the winds sometimes are accompanied by very fine sand. Therefore, the impact of the wind on the size of the building openings and building orientation is worth considerable attention from the point of view of passive design.

The prevailing winds in Dammam region are usually north and north west between 290^{o} and 360^{o}. The wind prevails within the fourth sector almost throughout the year. Since 1970 the prevailing winds have been from the north and north west for about ten months, and for

Table 4.4: Mean monthly maximum, average, and minimum relative humidity, Dammam region. source: KFUPM

MONTHS	MAXIMUM	AVERAGE	MINIMUM
JANUARY	99.9	57.15	14.4
FEBRUARY	96.0	61.0	26.0
MARCH	96.5	58.05	19.6
APRIL	96.5	59.55	22.6
MAY	90.1	56.6	23.1
JUNE	95.7	61.3	26.9
JULY	97.4	60.85	24.3
AUGUST	98.7	56.5	14.3
SEPTEMBER	97.1	63.05	29.0
OCTOBER	98.5	62.4	26.3
NOVEMBER	98.5	71.05	43.6
DECEMBER	99.9	62.85	25.8

FIGURE 4.3: THE MEAN MONTHLY MAXIMUM, AVERAGE, AND MINIMUM RELATIVE HUMIDITY IN DAMMAM REGION

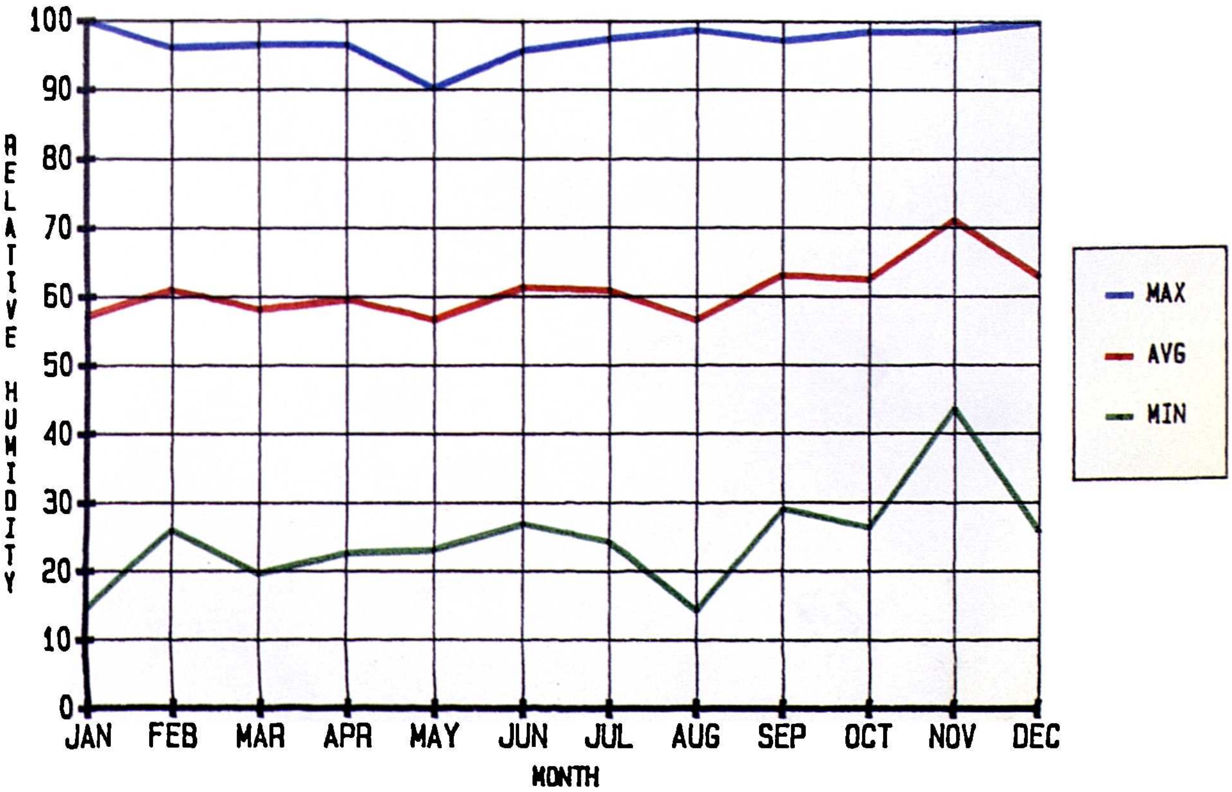
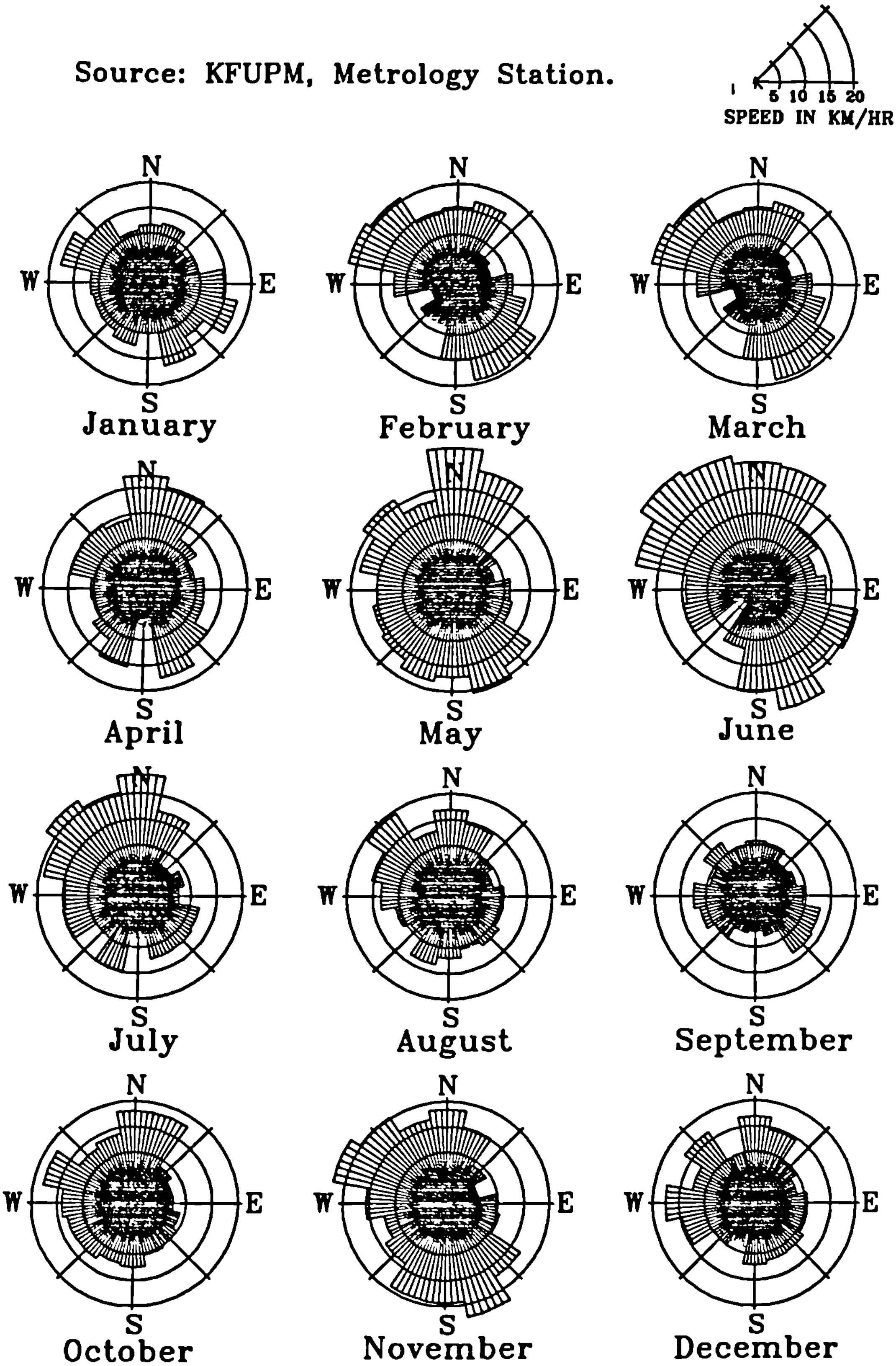


Figure 4.4: Prevailing Wind Directions and Speed for Dammam Region.

Source: KFUPM, Metrology Station.



only two months were from the other directions[4]. The absolute maximum wind velocity in the region recorded is 37 knots during January 1974. The high velocity dust storms called "Al-Shammal" which are from the north usually occur during late spring and early summer (see Figure 4.4).

4.3.5 Precipitation

Precipitation is a word which is used for any form of water descending from the atmosphere like rain, snow and hail. It is important for the designer to know about the precipitation types as well as the maximum amount for any 24 hour period for the whole year; this knowledge is essential for the design of surface drainage and roof slopes.

The precipitation in Dammam region is no more than rainfall, and it is very slight and extremely irregular. The period from June to October is totally dry, while the rain is expected to occur during the rest of the year in irregular patterns. The following table shows the monthly and yearly variation in the amount of rainfall in the Dammam region, see table 4.5.

Table 4.5
Distribution of amount of Rainfall by Months (mm)

	1981	1982	1983	1984	1985	1986	1987
Jan	16.3	2.9	N/A	7.2	9.2	N/A	T
Feb	0.9	42.9	N/A	T	T	N/A	0.6
Mar	26.8	208.5	N/A	T	T	N/A	26.2
Apr	T	1.2	N/A	2.0	2.0	N/A	4.4
May	T	1.0	N/A	2.9	3.1	N/A	53.0
June	0.0	0.0	N/A	0.0	0.0	N/A	0.0
July	0.0	0.0	N/A	0.0	0.0	N/A	0.0
Aug	0.0	0.0	N/A	0.0	0.0	N/A	14.4
Sept	0.0	0.0	N/A	0.0	0.0	N/A	3.1
Oct	0.0	1.9	N/A	0.0	0.0	N/A	39.9
Nov	T	51.5	N/A	9.3	11.1	N/A	0.0
Dec	T	19.9	N/A	38.4	42.5	N/A	0.0
	44.0	329.8	93.9	60.2	67.9	N/A	141.6

Source: Statistical Year Books, 1981, 82, 84, 85-87.
N/A = Not available
T = Trace
Source : Statistical Year Book, Table 1-8, 1971-1975.

* Not available.

4.4 Climatic Assets

The climatic factors denoted by solar radiation, air temperature, relative humidity, wind speed and direction, and cloud cover may affect the climatic conditions either negatively or positively, depending upon the locality and the season. Accordingly, in hot-humid areas the crucial problem is how to cool the space and keep it cool during the summer rather than how to heat it and keep it warm in winter. Usually in these areas the periods of fall, winter and spring, are very short, with a dominant summer period.

The initial climatic asset is that the use of adequate building materials that attenuate the effect of extreme high temperature on interior spaces can reduce the over heating problem as well as the diurnal range.

Despite the reduction in long wave night radiation due to the moderate to high humidity, it helps, especially in summer, in decreasing the intensity of the falling solar radiation and causing a noticeable drop in the sensible heat of the air.

Utilising the occasional breeze coming from the sea in cooling the house during the summer time may contribute significantly to saving energy.

In winter, the intense solar radiation and insulation of buildings promise to provide reasonable thermal comfort condition inside the house. Also, adjustable and controllable shading devices could be designed in such a way as to prevent any over-heating problem in the space during the summer period and allow more heat into the house during the winter period.

4.5 The Effect of Climate on Building

4.5.1 Air motion and its effect on comfort

Air motion is a vital factor in affecting the comfort condition inside buildings. The air movement, measured in terms of velocity and direction, determines the convective heat exchange of the body and also affects the evaporative capacity of the air which results in the cooling efficiency of sweating. It plays a major role in air infiltration within a building; therefore, it is important to consider the dynamics of outside air motion and its impact on a building. Usually, on the wind side, a positive pressure is built up due to the compressed air resulting from the blockage of the structure facade. Also, on the leeward side, a negative pressure is created due to the suction of air away from that side of the building[5]. As a result of the positive and negative pressures around the building, there must be an inlet and an outlet for the air to travel through the building in order to circulate the air and cool the building. Usually, the air enters from the positive pressure side through windows and cracks and exits from the negative pressure side. The rate of the air movement within the building depends on the wind velocity and the size of the openings.

Therefore, utilising the air movement by providing proper ventilation in the house becomes an important factor which should be considered in the overall design of any house. Most often, in some regions when the summer winds are cold and properly directed within the building, they can contribute very generously in minimising the use of mechanical cooling systems, especially in the early days of the summer season when the cooling requirement is small. On the other hand, the cold winds could be harmful for the building's internal conditions where the cold winds increase the surface conductance of the building's exterior walls and thereby increase its heat loss. But the problem of heat loss during the winter season could be significantly reduced by careful selection and combination of building materials, and attention to the design and shape orientation of the building. In order to provide pleasant air movement within the house, the size and location of windows should be selected carefully; also the proper wind and sun barriers such as trees and vegetation can slow the winter wind reaching the house and speed up a summer breeze to increase comfort in the dwelling[6].

4.5.2 Orientation and its effect on comfort

One of the vital elements that has a direct influence on the thermal performance of the building is its orientation in relation to the sun. The envelope of any building, usually composed of various materials, each of which has different thermal characteristics, is affected by the quantities of solar radiation falling on its different surfaces at different times. However, in winter, at higher latitude areas, the south wall of the building receives much more solar radiation than the east or west walls. In summer, the solar radiation falling on south and north walls is about half of that absorbed by the east and west walls. In the areas of lower latitude, the ratio of solar radiation falling on the building facades in summer and winter is relatively different to that in the higher latitudes. Consideration of this phenomenon during the design phase can easily mean the difference between comfort and discomfort in the indoor environment of the house. Therefore, due to the variations in the solar radiation intensity falling on the walls at different times, the arrangement of rooms and spaces within the building should be designed with respect to the motion of the sun to take the best advantage of the sun's radiation in the winter and to avoid it in the summer.

The most suitable orientation of a house depends upon the actual needs for cooling or heating. Other factors such as winds can also influence the selection of orientation; it is important to remember that the optimum orientation in one region may be the worst orientation in another region. In other words, the optimum orientation of dwellings varies in different climatic regions and building sites. For example, in the hot-arid region Olgyay recommends orientations from south to 25^{o} east of south, while in hot-humid climates, only 5^{o} east of south. Admitting that, the most suitable orientation of a building with respect to the sun's motion tends to improve the interior climate of the building; also there are other elements, such as infiltration and external surface temperature, that are affected by orientation and which consequently influence the house comfort[7].

4.5.3 Effect of orientation on external surface temperature

Different surfaces of a building receive different amounts of solar radiation depending on the various surface orientations. The quantitative effect of the sun's radiation depends mainly on the surface colour, the temperature and air speed close to the external surface. Actually, the thermal effect of almost any solar radiation intensity varies positively with the darkness of colour and inversely with the air velocity. The amount of heat penetrating into the house is very strongly influenced by the colour of the external walls and roofs, the dark colours tending to absorb more solar heat than light colours. However, the thermal effect of the exterior walls' colours is an important factor in the amount of the absorbed heat, especially when little or no insulation is used, having less effect as the insulation materials increase[8]. The external surface temperature of a building envelope depends also on the ambient air temperature and the amount of solar radiation. In the absence of sun due to cloud or sunset, the temperature patterns of wall surfaces in any orientation are almost the same as the outside air temperature. However, during exposure to solar radiation whether direct, diffused, or reflected, the temperatures of the wall surfaces vary proportionally according to the degree of the absorbed solar radiation. For instance, when the colour of the surface is light, its absorbtivity is low, hence the ambient air temperature may have more thermal effect than the incident radiation, whereas with dark colours the effect of solar radiation is greater.

4.6 Human Comfort

The response of the human body to the thermal environment does not depend on air temperature alone, but depends also upon humidity, radiation and air movement. However, the human body gains heat from solar radiation and from the process of digesting food; it loses heat too through evaporation, convection, conduction and radiation. Of the energy produced in the body only about 20% is utilised, and the remaining 80% is surplus heat and must be released to the environment[9]. So the living human body is always increasing the heat of the environment. The heat generated in this way varies from one person to another according to the activity, and the greater the activity the greater the heat loss to the environment.

Preception of human comfort usually varies from culture to culture and from person to person according to the physical conditions and the physical activities. The acceptable comfort range also varies for the same individual throughout the year, but there are obvious limits to the range of temperature, humidity and natural ventilation within which human comfort can be maintained. However, there are many subjective and individual factors influencing thermal preferences and due to the different interacting variables which affect human comfort. Scientists have expended a great deal of effort trying to define a truly accurate comfort zone.

4.6.1 Definition of human comfort

Surveying the different definitions of human comfort in different countries is an important factor for comparison and evaluation. In the United States of America, for instance, in the 1920's American scientists established a physiological measurement, called the effective temperature scale (ET), by combining the effects of temperature, humidity and air movement. Since the effective temperature scale came into existence, the lower limits of the desirable living temperature have been ranged from $62^{o}F$ ($16.7^{o}C$) up to the present day design standard of $75^{o}F$ ($24.4^{o}C$). In the 1950's the effective temperature scale was re-examined by ASHRAE and replaced with a new comfort design scale which allowed a design temperature range of 6^{o}, from $72^{o}F$ ($22.22^{o}C$) to $78^{o}F$ ($25.6^{o}C$), and from 20 to 60% relative humidity, and established the stable indoor comfort standard for today[10].

The research corporation at the American Institute of Architects (AIA) has defined human comfort as the sensation of complete physical and mental well-being. They also said that the total sum of the body's heat gain and heat loss should be equal to zero, which means that the rate of heat production should be equal to the rate of heat loss. When the body's heat is more than its corresponding heat loss, an uncomfortable feeling will occur and sweating will begin[11].

McKellar, of the University of Melbourne, Australia, carried out experiments in hot humid regions to test the tolerance of people, in order to define the limits of the comfort conditions. The resulting definition gives the limits of comfort condition for minimum standards of design as an average figure of 75°F (24.4°C) dry-bulb temperature or 79.5°F (26.4°C) effective temperature[12].

The different comfort zones mentioned previously cannot be used in this study for several reasons. Firstly, the climatic conditions of these countries are totally different from the climate of Dammam region. Moreover, comfort condition is associated with the physiology, psychology and sociology of the people rather than just physiological acclimatisation, which, according to the reports of some medical authorities, takes a few weeks to achieve. The physiological and sociological factors that make the people in Dammam region tolerant of their environment are different from those in European and American countries, due to their difference in skin colour, ability for drinking liquids and retaining water, and blood pressure. Secondly, people in different countries are used to adapt themselves to the climate by different means. Some people leave the cities and go to the farm areas during the summer time, some go to the seashore very often and others travel abroad to other cool areas during the summer periods. However, Victor Olgyay stated that for regions other than approximately 40° latitude, the lower perimeter of the summer comfort line should be elevated about 3/4°F for every 5° latitude change towards a lower latitude. Therefore, by applying the Olgyay statement and from the previous analysis of the comfort zone in the different countries, the suggested Dammam comfort zone ranges from 70°F (21.1°C) dry-bulb, with relative humidity of 30% to 80%, to 82°F (27.77°C) dry-bulb with relative humidity of 30% to 45%. This range suggests that the human would be comfortable indoors within this given zone (see Figure 4.5).

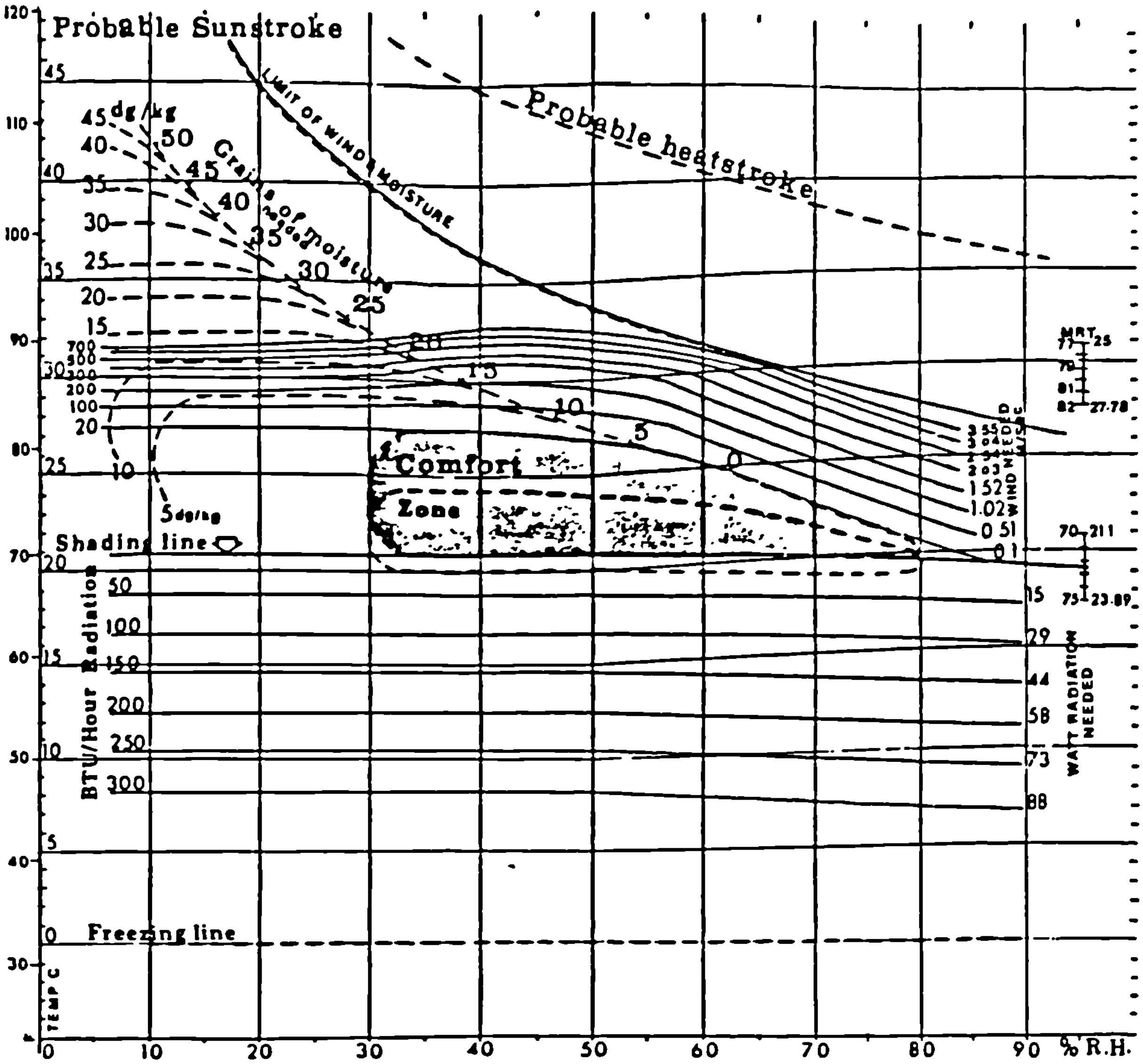


FIGURE 4.5: THE BIOCLIMATIC CHART SHOWING DAMMAM COMFORT ZONE AS OLGYAY SUGGESTED.

4.6.2 Defining human comfort and design strategies by using the building bioclimatic chart

Various authors have developed more or less definite definitions of the comfort zone as well as the different climatic design strategies. An actual definition of the comfort zone and the design strategies for Dammam region is concluded by reviewing Milne and Givoni and H.R. Bensons' works in the bioclimatic chart.

Milne and Givoni's building bioclimatic chart is an extension of Olgyay's work during the 1960's by Givoni. In order to establish a comfort zone limit and strategies, Givoni proposed a method based on the psychrometric chart correlating climatological data with building design strategies. Each strategy is shown by generalised average limits of 1 or 2^{o}F or of a few percentage points relative humidity. This chart gives the design an accurate representation of the environmental control strategies in order to achieve human comfort in buildings. Givoni's comfort limits are between 68^{o}F (20^{o}C) dry-bulb with relative humidity of 20% to 80% to 80^{o}F (26.7^{o}C) dry-bulb with a relative humidity of 20% to 50%[13].

On the other hand, the results of tests similar to those of Givoni were conducted by H.R. Benson* in Dhahran city, which is part of Dammam region and only 15km away from Dammam city, and reflect the residents' tolerance to the heat. These results determined the limits of comfort in Dhahran city, which is 69^{o}F (20.55^{o}C) dry-bulb with relative humidity of 30% to 80%, to 80^{o}F (26.7^{o}C) dry-bulb with relative humidity of 20% to 50%.

As a result of the analysis of the previous two experiments one can conclude that the comfort zone limits in Dammam region are 69^{o}F (20.5^{o}C) dry-bulb temperature, relative humidity of 30% to 80%, to 80^{o}F (26.7^{o}C) dry-bulb temperature with relative humidity of 20% to 50%. (See Figure 4.6) This concluded comfort zone is the same as DHAHRAN city comfort zone.

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* Harold R Benson, Facilities Planning Department, Arabian American Oil Company (ARAMCO), Dhahran, Saudi Arabia.

4.7 Comfort Zone Limits and Heating and Cooling Strategies

In this part, the climatic designs, consisting of three main zones, using, in a theoretical sense, the world 'zone' to desribe any particular range of temperature and humidity which can be shown graphically in the psychrometric chart are reviewed. Firstly, they are reviewed as comfort and dehumidification zones where the natural ventilation would keep the interior conditions comfortable; secondly as used for heating the building to maintain the interior comfort, especially when the air temperature is below comfort zone; thirdly as used for cooling the building to achieve the comfort zone by either mass structure, ventilation, evaporative cooling or air conditioning. These climatic design strategies are discussed in more detail below.

4.7.1 Comfort and dehumidification design strategies

Zone A-I : Comfort Zone

The comfort zone is the range of climatic conditions where the thermal comfort is experienced by the sedentary workers in the shade. The limits of the comfort zone in Dhahran area, which is part of Dammam region and about 15km from Dammam and 8km from Alkhobar cities, were conducted by tests carried out by H.R. Benson at King Fahad University of Petroleum and Minerals on volunteers in temperature climates which reflect the residents' tolerance to the heat. The limits are $69^{o}F$ ($20.5^{o}C$) dry-bulb with relative humidity of 30% to 80%, to $80^{o}F$ ($26.7^{o}C$) dry-bulb with relative humidity of 20% to 50% (see Figure 4.7).

Zone A-II : Dehumidification Zone

In this zone the dry-bulb temperature range is perfect, but the relative humidity is too high. In this case, the ventilation is very effective during these periods; but this means that if the natural ventilation does not help, the only practical choice is to use mechanical cooling (see Figure 4.7).

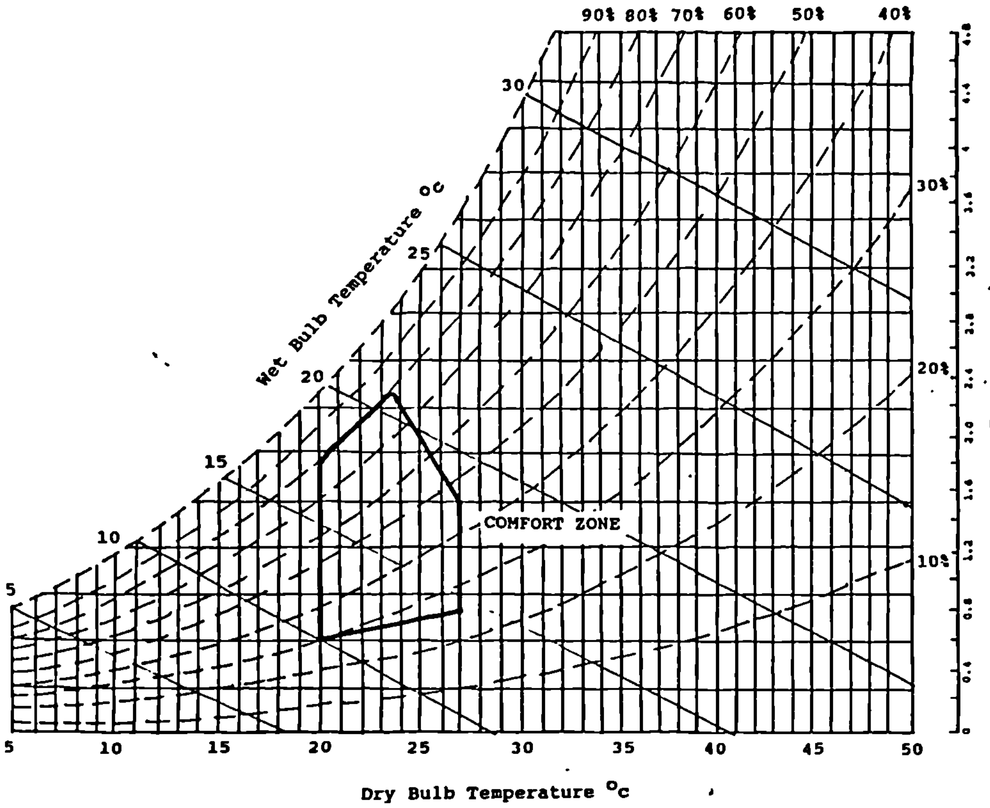
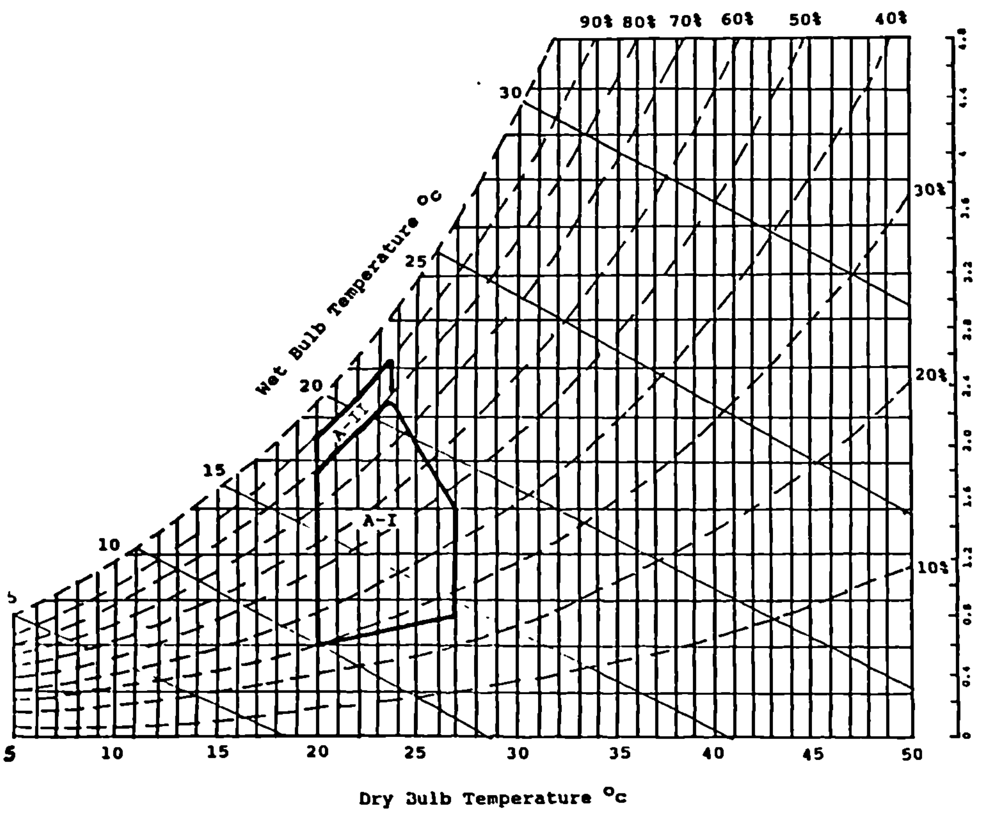


FIGURE 4.6: THE CONCLUDED COMFORT LIMITS IN BUILDING BIOCLIMATIC CHART FOR DAMMAM REGION.



A-I Comfort zone.
A-II Dehumidification zone.

FIGURE 4.7: SUMMARY OF THE COMFORT AND DEHUMIDIFICATION ZONES.

4.7.2 Heating design strategies

The passive design strategies of heating have been determined by Givoni and Milne in the bioclimatic chart. This bioclimatic chart summarised the different zones and types of energy needed to achieve the comfort level. There are several ways proposed for heating the buildings. Firstly, by allowing the sunlight to fall on materials of high thermal mass which store the heat and then give it back during the night-time, like the traditional adobe walls. Secondly, by accomplishing heat storage by the use of masonry or by placing water in containers behind a window wall. Thirdly, by using plastic bags on the roof to store and re-radiate the heat back later. Fourthly, by providing glass to trap solar energy through the greenhouse effect, where the glass is transparent to short wave solar radiation and opaque for the long wave radiation which will be emitted by the interior building materials[14].

Heating strategy zones

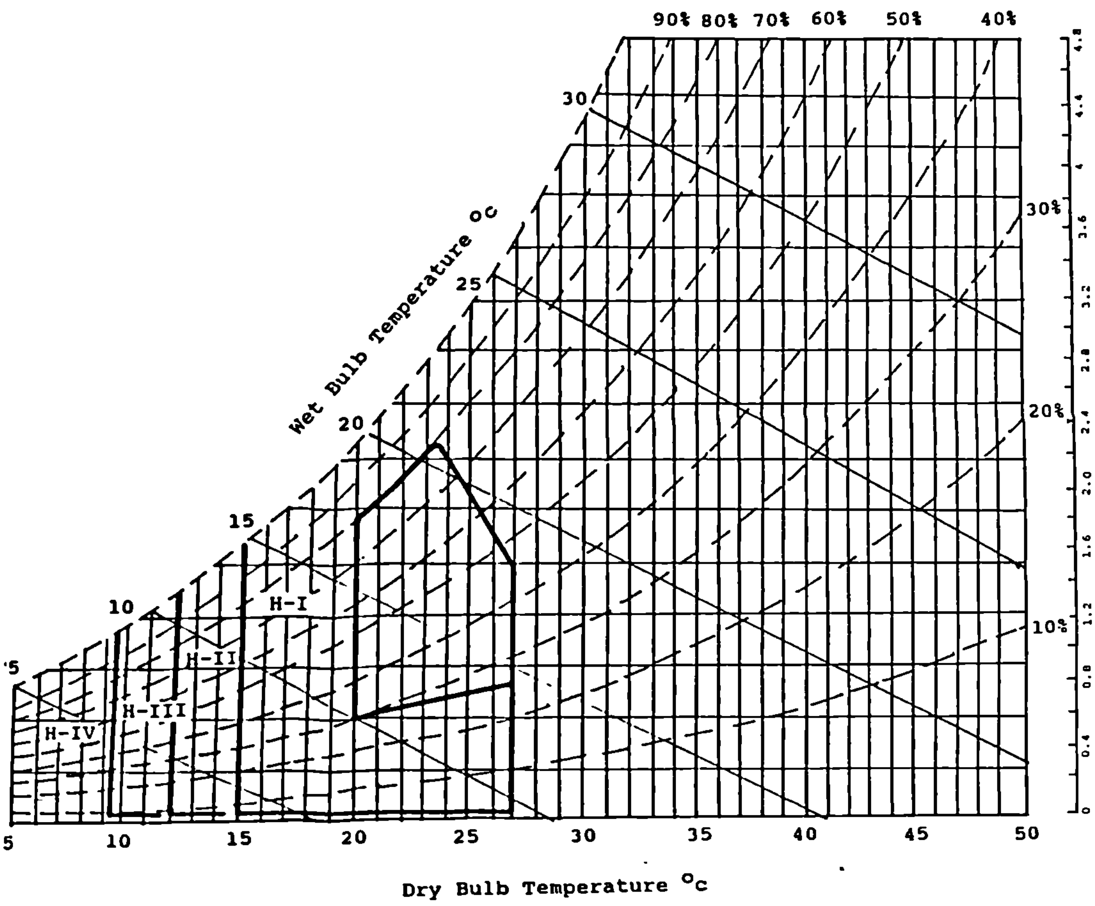
These zones have lower air temperatures than the comfort zone. They require some means of heating, either passively or actively. The initial treatment is to minimise conductive infiltration heat losses and to utilise the thermal mass of the surroundings, walls, floors and roof. These zones are categorised as follows into four zones due to the amount of heat needed to achieve the comfort zone temperature (see Figure 4.8).

Zone H-I

In this zone the temperature range requires relatively little heat gain and this can be gained through the passive solar heating. Furthermore, comfortable conditions can be achieved by using clothing during the day time. This zone's temperatures range between 59-68°F (15-20°C).

Zone H-II

The temperatures of this zone range between 54-59°F (12-15°C).



H-I 20°c - 15°c heating zone.
H-II 15°c - 12°c heating zone.
H-III 12°c - 9.5° heating zone.
H-IV 9.5°c- and less heating zone.

FIGURE 4.8: SUMMARY OF THE HEATING DESIGN STRATEGIES ZONES.

Comfortable conditions can easily be achieved by using passive solar heating systems. Clothing and blankets might help in increasing the temperature a little, but not for achieving the comfort level.

Zone H-III and H-IV

These heating zones are the ranges of lower temperatures in which both passive solar and active heating systems are required in order to be in the comfortable zone. The ranges of temperature in Zone H-III are 49°F (9.5°C) to 54°F (12°C) and in Zone H-IV the temperature ranges are less than 49°F (9.5°C).

4.7.3 Cooling design strategies

Cooling strategies and systems are the major concern of the people in Dammam region. Cooling the buildings can be achieved by two major means, passive cooling and active cooling.

I. PASSIVE COOLING STRATEGIES :

The passive cooling is limited to a few zones. These zones indicate the extensions of the comfort zone in the hot climate. There are three strategies which the scientists have found to be successful in saving energy in cooling and in thermal effectiveness[15]. These strategies can be used alone or in combination with the other two (see Figure 4.9).

Zone C-I : High mass structure (thermal mass zone)

This is the range of climatic conditions where the mass of the building should have a very high time-lag. This time-lag can be increased by improving the insulation of the walls, floors and roofs. Therefore, the indoor air temperature can be maintained very easily by closing the door and windows during the day-time to reduce infiltration.

Zone C-II : (1) Natural ventilation

Natural ventilation can be used when the daily temperature and humidity readings fall in the natural ventilation zone as shown in Figure

4.9. In this zone, it is possible to achieve the comfortable indoor conditions by orienting the buildings' openings towards the prevailing breezes and to insulate the building envelope very well. Also, if the breeze is great enough, it can cool the body by convecting the heat and by evaporating the perspiration.

Zone C-II : (2) High mass and night-time ventilation for cooling

This zone occurs when only the night temperature falls in the comfort zone. In this zone the high mass building should be ventilated to cool the interior with night-time breezes, then close the ventilation during the day-time heat. In extreme cases, mechanical ventilation is necessary to move enough night-time air through the building.

Zone C-III : Evaporative cooling zone

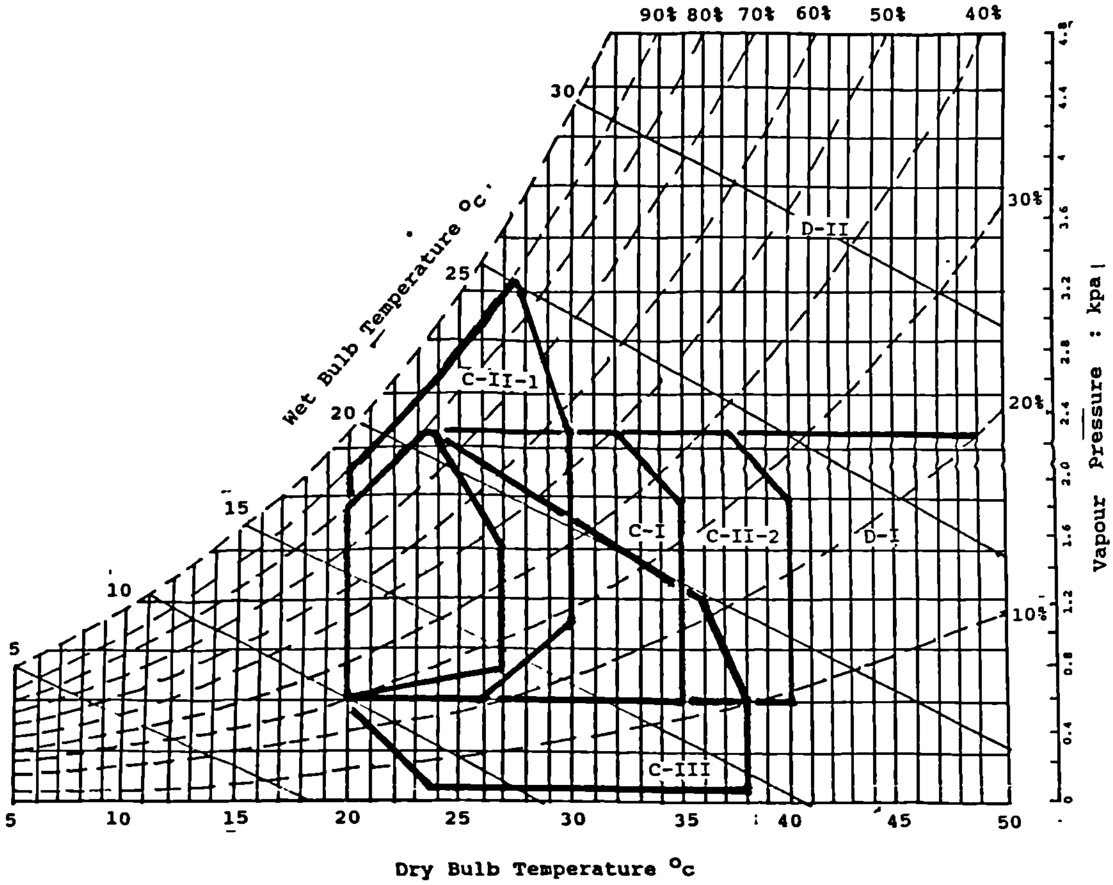
This is the range of conditions when the air temperature is too high and the humidity is low. The evaporative cooling is a process of moisturising the air to reduce its temperature before it enters the interior of the building. This is typically done by blowing the dry air through a wet cloth mesh or porous fibre mat or by blowing pin mist into the air. Also moisturising the air might be done by spraying or dripping water through a specially designed chamber.

II. ACTIVE COOLING AND DEHUMIDIFICATION ZONES

The active cooling and dehumidification zones are located beyond the reach of passive cooling systems. In these zones, the residential buildings cannot be made comfortable without the use of mechanical cooling or air conditioning systems (see Figure 4.10).

Zone D-I : Mechanical cooling zone

Here is the range in which the heat only should be removed from the air without affecting the humidity directly; this could be achieved by mechanical air coolers.



C-I High mass structure zone.
C-II-1 Natural ventlation zone.
C-II-2 High mass and night time ventlation zone.
C-III Evaporative cooling zone.
D-I Mechanical cooling zone.
D-II Mechanical cooling and dehumidification zone.

FIGURE 4.9: SUMMARY OF THE COOLING DESIGN STRATEGIES ZONES.

Zone D-II : Mechanical cooling and dehumidification

This is where both heat and humidity should be removed from the air to achieve the comfortable conditions. A conventional refrigerant air conditioning system is required in this zone.

4.7.4 Initial strategies of thermal control for Dammam region

Combining the strategies of climatic design with the daily temperature of Dammam region would help in specifying the appropriate system to be used in achieving the comfort level. For that reason, the bioclimatic chart was superimposed over the psychrometric chart of Dammam region in Figure 4.11. The coincidence of zones with the climatic conditions of Dammam region indicated the adequate system or combination of systems required to attain the comfort level. The combined chart showed that most months fall in the cooling zone and few fall in the comfort zone, but only two or so fall in the heating zone. Actually Figure 4.11 showed some potential for cooling the houses in Dammam region passively, but at the same time it showed that the need for active cooling systems to achieve the comfort conditions at all times of the year, bearing in mind that achieving comfort level passively requires considerable effort and major changes in the building materials.

Within the passive cooling zone, where most of the months fall, the most effective strategy is thermal mass building, cross ventilation, fans and evaporative cooling. Thermal mass building provides the internal conditions with adequate protection from the outside climatic fluctuations; cross ventilation cools the space by exhausting the accumulated heat during the day-time and allowing fresh air to take its place. Fans are usually used to circulate the inside air within the house and reduce the demand on the active system. Evaporative cooling is essentially the same as ventilation, but its applications have been developed within the Arabian Gulf regions and it has been used rarely due to the high humidity.

For the months which fall into the active zone, the use of mechanical systems is the only way for cooling and for dehumidification. The cooling period is not limited to the day-time, but extended to the night-time; this is also due to the low difference between the day temperature and the night temperature.

Finally, all the previous strategies are just initial suggestions; they are affected by several factors such as social and cultural aspects, occupants' behaviour, wind quality and availability of insulation materials. The possible adequate cooling strategy will be discussed later on after detailed study of people's behaviour and building materials in respect to the climate.

FIGURE 4.10: SUMMARY OF THE OVERALL DESIGN STRATEGIES IN RESPECT TO DAMMAM REGION'S COMFORT ZONE.

A-I	Comfort zone.
A-II	Dehumidification zone.
H-I	$20^{o}c$ - $15^{o}c$ heating zone.
H-II	$15^{o}c$ - $12^{o}c$ heating zone.
H-III	$12^{o}c$ - 9.5^{o} heating zone.
H-IV	$9.5^{o}c$- and less heating zone.
C-I	High mass structure zone.
C-II-1	Natural ventlation zone.
C-II-2	High mass and night time ventlation zone.
C-III	Evaporative cooling zone.
D-I	Mechanical cooling zone.
D-II	Mechanical cooling and dehumidification zone.

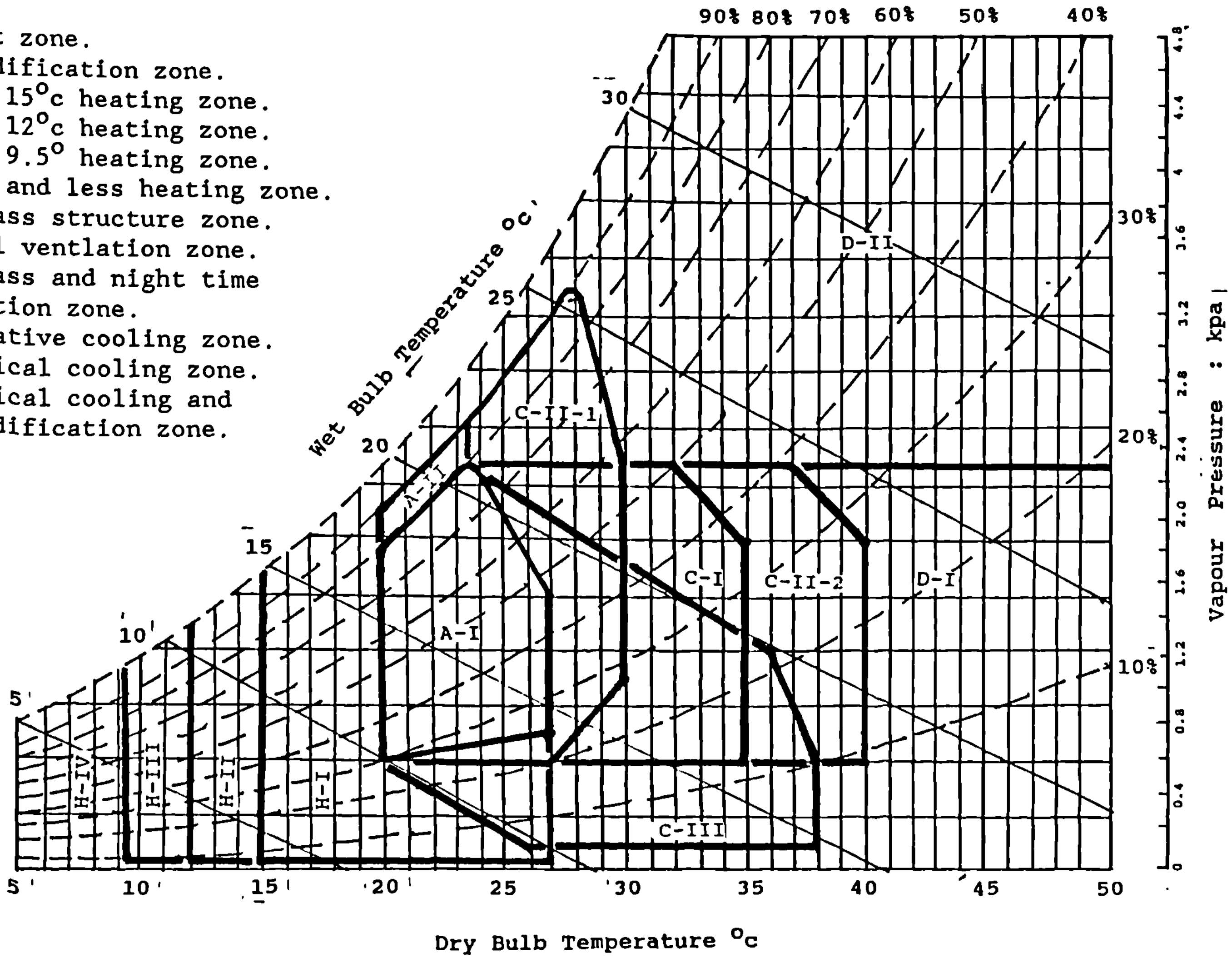
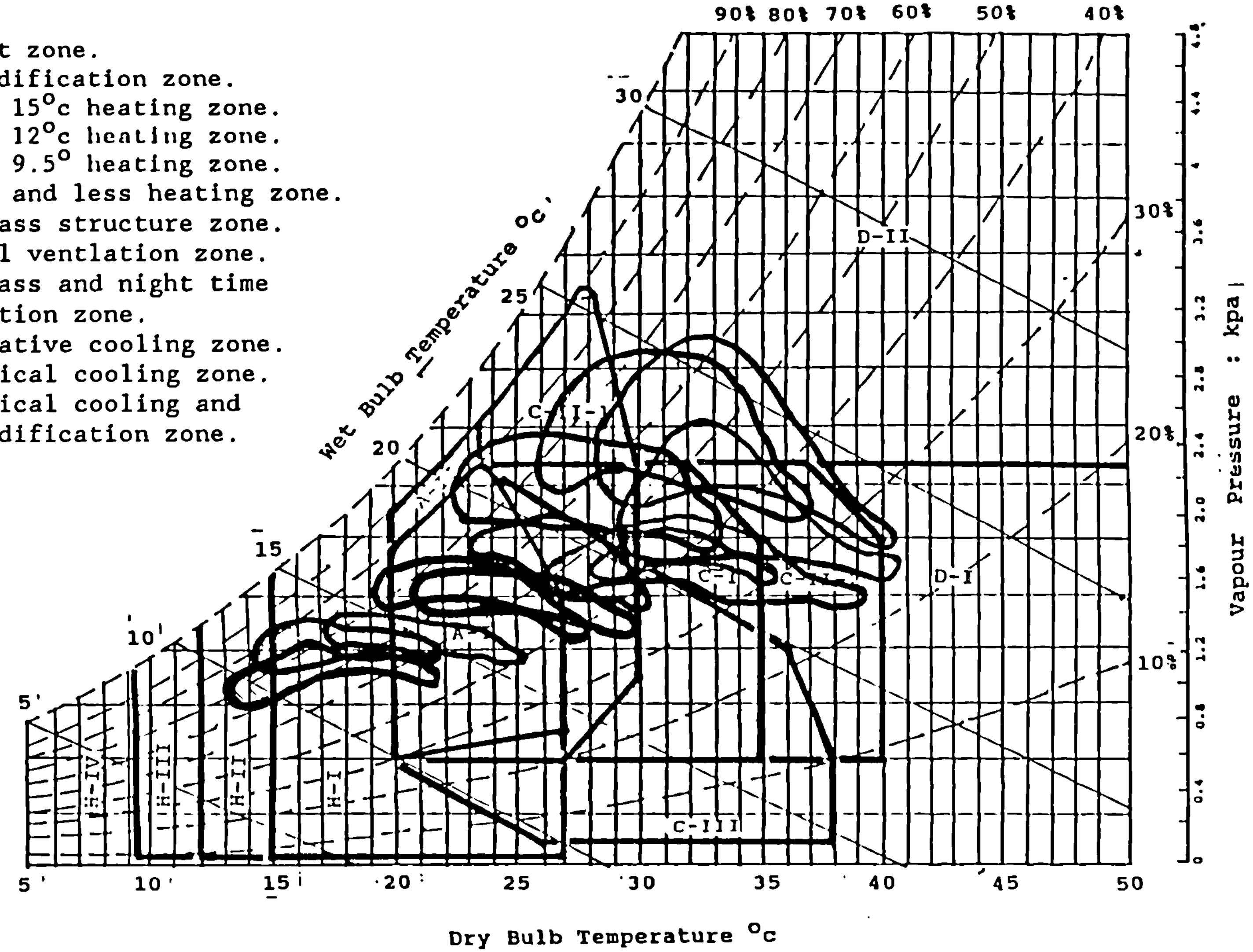


FIGURE 4.11: SUMMARY OF THE PSYCHROMETRIC AND THE BIOCLIMATIC CHARTS FOR DAMMAM REGION.

A-I	Comfort zone.
A-II	Dehumidification zone.
H-I	$20^{o}c$ - $15^{o}c$ heating zone.
H-II	$15^{o}c$ - $12^{o}c$ heating zone.
H-III	$12^{o}c$ - 9.5^{o} heating zone.
H-IV	$9.5^{o}c$- and less heating zone.
C-I	High mass structure zone.
C-II-1	Natural ventlation zone.
C-II-2	High mass and night time ventlation zone.
C-III	Evaporative cooling zone.
D-I	Mechanical cooling zone.
D-II	Mechanical cooling and dehumidification zone.



4.8 Summary

Understanding the climatic profile of Dammam region is very important for evaluating the thermal performance of the building and comparing the harshness of the climate with people's discomfort. The climate of this region is fairly complex, but could be considered as a desert maritime climate because it is hot and partially humid due to the presence of the sea. Two main seasons may be distinguished, hot summer and mild winter. The hot summer season spans over seven months, while the mild winter is only two to three months. Solar radiation, air temperature and humidity all participate in increasing the hot environment in the region due to the clear sky, black paved streets and lack of greenery.

Building orientation affects the indoor climate in two respects, by its response to these two clear climatic factors, solar radiation and ventilation. The solar radiation influences the indoor climate by its heating effect on walls and rooms facing different directions, the ventilation poses problems associated with the relation between the direction of prevailing winds and the orientation of the building. Consideration of these two factors may result in some contradictory requirements, where in some hot climate areas one orientation may provide lower air temperatures while the other orientation may provide more prevailing winds. The final decision of such a situation should be based on evaluation of the quantitative physiological advantage of each factor, which is mostly determined by the ambient air temperature and humidity.

The climatic design strategies were discussed in detail to assess the potential of cooling the house passively for most of the year. The strategy was clearly presented on the bioclimatic chart and also the daily temperature for the whole year was plotted on the psychrometric chart. The result of superimposing the bioclimatic chart over the psychrometric chart indicated that there is a good chance of saving energy by applying these strategies. The way of applying these strategies and the possibility of saving energy will be discussed later on in the final chapter, where all recommendations and conclusions are presented. However, it is clear from figure 4.11 that the passive cooling alone could not provide a comfort condition inside the house; therefore, the use of active or mechanical cooling system is necessary for achieving the comfort level.

FOOTNOTES

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CHAPTER 5

CHAPTER 5

LITERATURE REVIEW

LITERATURE REVIEW

5.1 Introduction

The obvious way to learn about certain phenomena is by being cognizant with the work that others have done concerning these phenomena. Well constructed research usually surveys and reviews the literature written about the researched subject; not only that but it also surveys the significant experiments done in the field of study. However, the review of the thermo-physical properties of materials usually gives a clear picture of the heat exchange mechanism between the outside and inside environment of the building. In fact, the calculation of heat transfer represents the key factor for thermal design and the analysis of the thermal performance of buildings, especially in a hot climate. Also, the survey of various methods employed by the developed countries in order to save energy and the different ways of modelling the energy consumption in the building would give a wider view to the different dimensions of the energy problem. Therefore, this chapter has been devoted to the review of the principles of heat transfer and thermal properties of building materials. It will also discuss some examples of the different solutions provided by the more developed countries in facing the energy problem, and will finally survey possible thermal studies by way of thermal modelling and the method used to link the various factors in the process of producing the thermal model.

5.2 Heat Transfer and Thermal Properties of Building Materials

The indoor climatic condition of a building is generally a controlled environment separated from the outdoor environment. However, this controlled environment is very much influenced by the degree of heat gain and heat loss that the building experiences. This heat gain or heat loss process mainly takes place in three different forms[1]. Principally, heat is a thermal energy, transferred between two objects due to the difference between their temperatures, and the direction of the heat flow is always from the higher to the lower temperature. The rate of heat transferred between two objects is proportional to their temperature difference where the higher the temperature differences, the greater is the rate of heat transfer.

In the case of houses, heat is transferred across the various elements of the building fabric under the influence of air temperature difference between inside and outside, and due to radiation exchange with the external environment. During the heat flow process, solar energy reaches a wall in the form of radiation and is absorbed by the external surfaces of the wall, flowing across the wall materials by conduction into the internal environment. However, if there is an air space in the wall then the heat flows across the air space by convection and radiation and continues its flow by conduction then radiation and convection in the space. Therefore, the thermal properties of the building materials are essential in calculating the heating and cooling load of the building. However, in designing the size of heating or cooling apparatus, the designers should be aware of the thermal properties of the building materials to enable them to calculate the heating and cooling load. The major thermal properties of the building materials which affect the rate of heat flow in and out of the dwelling and the indoor thermal conditions, are thermal conductivity, density and specific heat.

5.2.1 Thermal Resistance (R)

The thermal resistance of a building element or airspace expresses the capability of that material to resist the flow of the heat. The thermal resistance is calculated by dividing the thickness of the element by its conductivity (λ), or by multiplying the material's resistancy (r), which is the reciprocal of the material's conductivity, by its thickness[2].

$$R = \frac{L}{\lambda} = rL \quad \ldots\ldots 5.1$$

where R = thermal resistance of the material m^2C/W
L = material thickness m
λ = thermal conductivity of the material W/Mc^o
r = thermal resistance of the material MC^o/W

The resistance of a wall consisting of more than one layer where the layers are in contact element is the total sum of the resistance of each layers. Thus:

$$R = R_1 + R_2 + \ldots . R_n = \frac{L_1}{_1\lambda^1} + \frac{L_2}{_2\lambda^2} + \ldots\ldots \frac{L_n}{_n\lambda^n} \quad \ldots\ldots 5.2$$

5.2.1.1 Surface characteristics

The external surfaces of a building envelope usually consist of different

materials, each of which behaves differently according to its individual properties. The external surface of a material has three characteristics which influence its behaviour with respect to radiant heat. These characteristics are absorptivity, reflectivity and emissivity. The absorptivity is the ratio of the amount of solar radiation absorbed by a surface to that which falls on it; the reflectivity is the ratio of the amount of solar radiation reflected by a surface to that which falls on it; the emissivity is the ratio of the thermal radiation from unit area of a surface to the radiation from unit area of a perfect black surface (full emitter)[3].

Most surfaces absorb part of the incident radiation and reflect the remaining part. However, in some surfaces the falling radiation on an opaque surface is totally absorbed, which is the case with perfect black surface, or it is totally reflected, as is the case with a perfect white surface. In every case, the sum of the absorptivity which is denoted by (a) and the reflectivity, denoted by (r), should be equal to one.

Hence r= 1 - a 5.3

The emissivity of a surface is its relative ability to emit radiant energy. The emissivity (E) and absorptivity (a), sometimes they are numerically equal for any specific wavelength, but they may differ for different wavelengths. All surface emit radiation and the intensity of that radiation depends on their surface temperature.

E = a = 1 - r 5.4

The absorption or reflection of heat is very much affected by the colour of the building surfaces, so that the use of light colours is effective in reducing the heat gain in the building. Even though the colour of a surface gives a good indication of its absorptivity for solar radiation, it does not indicate the behaviour of a surface with respect to long wave radiation. Black and white surfaces have a different absorptivity for solar radiation, (where the black surface absorbs more heat than the white surface during their exposure to the sun), but they have similar emissivity for long wave radiation. Cooling by exposure to the night is therefore similar for both black and white surfaces.Considering the different surface characteristics of opaque materials, it is important to use a light colour material for the exterior surfaces of buildings in hot arid regions.

5.2.1.2 Surface Resistance

The external envelope of the building forms a barrier between the external environment and the internal environment of the building. The heat transfer from the outside environment to the inside environment is affected by three main factors. The first factor is the climatic condition on which the amount of heat transfer at the external surface is dependent; the second factor is the thermal conductivity of the material in which the heat is transferred through; the third factor is the condition of the internal environment, with which the internal surface is in contact. Also there are three modes, radiation, convection and conduction, in which the heat transfer through the building envelope from the outside environment to the inside environment takes place[6]. Those modes are influenced by the emissivity of the surfaces, the rate of air movement, and the direction of heat flow. The surface resistance is a function of the heat transfer coefficient on either side of the building envelope. Values of surface resistance are calculated in the IHVE Guide as follows:

$$R_2 = \frac{1}{Eh_r + h_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.5$$

where R_s = surface resistance.................... M^{2o} c/W
E = surface emissivity factor for normal radiation
h_r = radiation heat transfer coefficient ... $W/m^{2o}c$
h_c = convection heat transfer coefficient .. $W/m^{2o}c$

5.2.1.3 Surface Coefficient

The inside and outside air films adjacent to the wall influence the performance of the exterior wall. The air film which is attached to a surface gives an appreciable resistance to the heat flow across that surface. The reciprocal of the resistance of the air film is known as the surface coefficient, which determines the heat flow from the surface of the building envelope to the surrounding air, and the radiation exchange with the other surface[5]. Thus the surface coefficient is comprised of two factors, radiative and connective heat exchange. The radiative heat exchange is basically dependent on the surface emissivity and on the mean temperature of the surface exchanging radiation. The connective coefficient depends primarily on the velocity of the air adjacent to the surface. The actual surface coefficient is the sum of the radiative and connective coefficients and is expressed by h in w/M^2k or h_i for internal surface and h_e for an external surface.

5.2.1.4 Thermal Resistance of Airspace

The transfer of heat between surfaces separated by an airspace occurs by radiation, convection and conduction. The airspace in modern buildings is often used to insulate and protect the internal environment from the effect of the external environment by increasing the envelope layers and reducing the heat flows through it. The resistance of a sealed airspace is defined as the reciprocal of the quantity of heat transferred in the steady state in unit time between unit area of the boundary surfaces when their temperatures vary by one degree[6]. The thermal resistance of air space depends mainly on the emissivity factor (E) of the surfaces enclosing the airspace, the thickness of the airspace in the cavity, the amount of ventilation of the airspace cavity and the direction of the heat flow.

The surface emissivity has a direct effect on the airspace resistance where the use of different materials can increase or decrease the airspace resistance. For instance, airspaces lined with low emissivity material such as aluminium foil have a much higher resistance because of radiation is largely prevented from occurring. The thickness of the airspace in the cavity influence the quality of the airspace resistance - the greater the thickness the greater the thermal resistance, until it reaches a virtually constant resistance. IHVE Guide (1970) reported that a vertical airspace of about 20mm thick provide an optimum resistance. The airspace ventilation also provides an additional heat flow path, which decreases the effectiveness of the airspace resistance. Furthermore, the horizontal airspace presents a higher resistance to downward than to upward heat flow because of the creation of convection currents due to the temperature difference across the space. However, the thermal resistance of the airspace is high due to its low thermal conductivity, but it is still less than that of many insulating materials. This is perhaps because a large amount of heat is transferred by radiation across the airspace, the remainder being by convection, [Van Straaten] (1967). The transfer of heat by both radiation and convection can be calculated theoretically by the following formulas:

1. Heat transfer by radiation

$$H_r = F_e A (T_1^4 - T_2^4) \quad \text{.......... 5.6}$$

and when T_1 comes close to T_2, the formula becomes

$$H_r = F_e A (T_1 - T_2) \quad \text{.......... 5.7}$$

where H_r is the radiation heat transfer, T_1 and T_2 represent the absolute temperature of surfaces, is Stefan-Boltzmanconstat, F_e is the emissivity of the surface, and A is the area of the surface.

2. Heat transfer by convection

$$H_c = h_c\ (\varnothing_1 - \varnothing_2) \quad \text{.......... 5.8}$$

where H_c is the convection heat transfer, h_c is the convection coefficient, and $\varnothing_1$ and $\varnothing_2$ represent the temperature of the inner leaf and outer leaf.

However, airspace resistance is the reciprocal of the heat transferred by radiation and convection.

$$R_c = \Delta\varnothing\ (H_r + H_c) \quad \text{.......... 5.9}$$

where R_c is the resistance of the airspace, $\Delta\varnothing$ is the mean temperature difference in Fahrenheit, and H_r and H_c represent heat transferred by radiation and convection respectively.

5.2.2 Thermal Conductivity (λ)

Thermal conductivity is an important property of building material which determines the rate of heat flow by conduction through the material for a given temperature difference across the surface. It is usually used in calculating the heat transfer through walls, floors, and roofs of the building in a dynamic state as well as in a steady state. The value of thermal conductivity varies considerably with the material types, the moisture content of the material, and the density of the material. With regard to building materials the thermal tends to decrease as the density decreases. This is because of the presence of air in the voids in the materials which has a low thermal conductivity value.

The thermal conductivity of a material (λ) defined as the heat flow in unit time through unit area of a unit thickness, with a unit of temperature gradient; it is expressed in (W/mc^{o})[7]. Thermal conductivity can be determined by two methods, the steady state method and the dynamic state method. The steady state method has been described by many scientists, such as Van Straaten (1967), Ball (1968), Loudon (1968), Arnold (1979) and many others. It consists of three plates of the same size, one of which is electrically heated and the other two are cold; the two cold plates are positioned on either side of the hot plate each pressing firmly two material samples between the hot plate and the other two cold plates. The temperature difference across each sample is monitored to within 0.01 deg C with two pairs of differentially connected thermocouples, one at each side of the plate[8]. The formula suggested by Straaten from this method is as follows:

$$Q = \frac{2\lambda A}{L}(t_1 - t_2) \qquad \text{5.10}$$

where Q = rate of heat transfer over test area
λ = thermal conductivity
A = test area
t_1, t_2 = temperatures of hot and cold plates
L = mean thickness of samples

The 2 represents the two samples supplied from the same heat source.

The second method of calculating the thermal conductivity is the dynamic method, which has the further advantage of being capable of measuring the effect of the moisture content of the material. It was first proposed by Vernotte (1937) and developed more by Clarke and Kingston (1950). Briefly, the principle of the dynamic method of measurement is to heat the sample for a short period by using constant power input and record the temperature rise with time[9]. From these readings the thermal conductivity is obtained using the theoretical temperature versus the time relationship calculated for the particular experimental arrangement. This experiment can be completed in a few minutes compared with the several hours required for the steady state method; despite that, the heat source in both experiments is similar. The formula applied for calculating thermal conductivity by the dynamic method is as follows:

$$\lambda = Q \log_e (t_2/t_1) \quad \Delta T \qquad \text{5.11}$$

where λ = thermal conductivity of the material
Q = heat input per metre (w/m)
$\log_e$ = logarithm
t_2, t_1 = finishing time and starting time respectively.

ΔT = the difference in temperature of the material (finishing and starting)

5.3 Thermal effect of windows

The extensive use of window glazing in the building facade has become one of the dominant features of contemporary buildings. It has caused considerable changes in the relationship between the exterior environment and the interior environment, causing an overheating problem which has become a major concern of the people, not only in hot regions but also in temperate and cold regions. The internal thermal environment of a dwelling in any climate is considerably dependent on the size and location of the window as well as the degree of shading devices provided. However, the development of new glazings and other new materials with different thermal properties in recent years has provided dwellings with more flexibility in terms of the design and size of their windows and better control of the internal thermal environment.

The thermal effect of a window on the internal environment depends mainly on its size, its orientation, the thermal property of its glass and the efficiency of the shading devices used. When the solar energy strikes on a window, the radiant energy is divided into three components. Some is reflected directly with no thermal effect on the glass material, a further part of the energy is absorbed by the glass and consequently by dissipated to either side, while the third part of the radiant energy is directly transmitted through the glass to the internal environment of the building[10]. The relative distributions of the energy amongst these three components are determined by the angle of incidence of the incoming solar radiation with the surface of the glazing and by the thermal property of the glass.

5.3.1 Thermal properties of glass

Glass is a very useful building material which has been used widely in building over the last few decades, possessing thermal behaviour which contributes considerably to passive solar house design, especially if used properly. One of the most important features of glass, especially for heating purposes, is that it is transparent for the shortwave radiation coming from the sun and opaque for the longwave radiation coming from the low temperature emitters; this process is known as the greenhouse effect[11]. However, the requirements of windows vary from hot regions to cold regions. The requirement of window glass in cold regions is to admit daylight, solar radiation and view, whereas in hot regions it is to provide daylight with the minimum heat gain and view. However, in practice, in both regions window glass transmits heat.

Nowadays, different types of glass with different thermal properties have been developed and produced. They vary according to the degree of their transmission, reflection and absorption of heat. Generally, all types of glass tend to absorb and reflect solar radiation, but heat-absorbing glass absorbs heat more than any other kind, whereas heat reflecting glass reflects more infra-red radiation than the ordinary clear glass. However, the heat absorbing glass breaks down the solar heat gain through that glass into two parts; first is the transmission of shortwave visible light and infra-red radiation, and the second is the inward heat flow by convection and longwave radiation from the heated glass surface. On the other hand, the heat reflective glass, produced by adding a very fine semi-transparent metallic coating onto the surface of the glass, reflects selectively a large portion of the infra-red radiation. Since the reflective coating is subject to scratching, it is usually protected by double glazed, or by a mesh screen. However, if the reflective glass is used as the outer sheet of the double glazing window, it is more effective than if it is used in the inside sheet. This is due to the fact that the reflective glass, which is coloured, absorbs more sunlight than the clear glass and this property increases its temperature. Therefore, if it is positioned as the outer sheet, then the absorbed heat can easily be despatched to the outside air. Lastly, the glass reflectivity depends mostly on the angle of incidence of the sun's rays; it is low when the sun's rays are perpendicular to the glass surface and increases as the angle of incidence increases.

5.3.2 Thermal efficiency of shading devices

Shading devices are very important elements in cutting down the radiation falling onto the glass. They affect the quantity of incident radiation and modify both the heat flow to the interior and the indoor temperature. Actually, protecting the windows with various types of shading devices reduces the amount of solar radiation penetrating through the glass into the interior environment. However, the degree of protection depends on the location of the shading devices with respect to the glass, whether they are inside or outside. For instance, if the shading devices are installed outside, they intercept the solar radiation before it reaches the glass; a portion of it is reflected outward, some is reflected inward, and the rest is absorbed by the shading devices, increasing their temperature, but none is transmitted. The result of placing the shading devices outside is that the heat flows by convection and radiation from the shade especially at night; heat is removed by convection due to the wind and barely affects the glass; the transparent materials are opaque to longwave radiation; therefore, only a small quantity of incident radiation penetrates through the external shading. In contrast, when the shading devices are installed in the interior of the building, such as cloth curtains, venetian blinds, and roller blinds, the solar energy is transmitted through the glass into the interior before being intercepted by the shadings. In this case the radiation heat absorbed by the shading materials is re-released to the interior and most of the penetrated heat remains in the interior space due to the opaqueness of the glass to the longwave radiation[12]. Therefore, the effectiveness of the external shading devices is much more than that of internal shades.

The external shading of windows can be achieved in many different ways, one of the most common being the use of vegetation such as trees around the dwellings and in front of the windows. This will considerably affect the internal thermal behaviour of the dwelling, as in the summer the leaves of the trees act as a heat filter and glare protection, and also absorb radiation. In winter the leaves of the trees fall and make no obstruction to the direct path of solar radiation, which may be needed for heating purposes. Furthermore, the use of trees does not provide shading only, it also provides a pleasant environment around the building. However, apart from this natural shading, there are many architectural features that can be used to protect windows from solar radiation when it is unwanted; these features include shutters, awnings, overhangs, and many types of louvers, fixed and adjustable. The adjustable shading devices are more effective than the fixed ones due to the possibility of adjusting the shading in accordance with the continuous changes of the direction of solar radiation. However, the functions of these shading devices differ widely in different climatic conditions.

5.4 Thermal transmittance, U Value:

The thermal transmittance of a structure is defined as the amount of heat transmitted in unit time through unit area of a given structure, divided by the difference between the environmental temperature on either side of the structure and expressed by U in (W/M^2C^o). The thermal transmittance of any building element can be obtained by adding the thermal resistance of its component parts together with the adjacent air layers and taking the reciprocal of that; this procedure is given in the following formula which is quoted from IHVE Guide (1970) 30 DK A, thus:

$$U = \frac{1}{R_{si} + R_1 + R_2 \ldots\ldots + R_a + R_{so}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.12$$

where U = thermal transmittance --- W/M^2C
R_{si} = inside surface resistance ---- M^2C/W
R_1, R_2 = thermal resistance of structural component M^2C/W
R_a = airspace resistance $M^{2o}C/W$
R_{so} = outside surface resistance $M^{2o}C/W$

The value of the thermal transmittance can be calculated, from the thermal resistance of the component of the materials, and can be measured practically by subjecting heat to the element and measuring the surface and air to air temperature difference across the element. The calculated values of the thermal transmittance were compared with measured values at British Research Station (BRS), Wall and Roof Laboratories, and it has been found that the measured values are about 12 per cent higher than those calculated[13]. Accordingly, measured U-values are not accepted as a standard value due to the fact that the conditions of the tests may not agree with the conditions assumed for the calculation. There are many references such as the IHVE Guide, ASRAE Handbook of Fundamentals and Building Research Establishment (BRE) Digest No.108, and many other published papers which give conductivity and U-values for a range of typical building materials and elements which can be used for further assistance during the calculation procedures.

5.5 Efforts Made Towards Saving Energy

The energy crisis in 1973 and the resulting escalation of energy costs acted as the trigger which prompted the awareness of both the governments and the public of the whole concept of energy usage and conservation. Governments are now actively considering energy use and the possibility of energy conservation in many different fields. Different countries have implemented various actions to tackle the problem of energy consumption. Some of them have introduced new building regulations to govern energy consumption while others take more energy conscious attitudes to design and reduction in comfort standard. In this study it is useful to look at some examples of the actions introduced by different countries having similar climates. Since most of the European countries have studied energy consciousness more than any other country, it is appropriate and beneficial to look at the effort made by some European countries.

5.5.1 Design for energy economy in France

The energy crisis in France was the beginning of a plethora of laws and regulations to reduce the national energy consumption. This crisis resulted in the government setting up agency, the Agency for Economies in Energy (AEE), a semi-private organisation and separately funded. The main aim of the government was to achieve by 1985, a national reduction of 45 million tonnes of equivalent oil consumption in energy usage per annum. The work of the *Agency is concentrated* on three main sectors; namely, the industrial and agriculture sector, the transport sector, and the residential and commercial sector.

However, the AEE concentrated its efforts on the residential sector where it achieved its greatest success due to the potential of introducing new techniques of saving energy. It introduced new requirements governing the use of energy as follows:

1. Lighting levels and energy consumption of domestic equipment is limited to certain levels.

2. Internal space temperatures during the heating season have been restricted to $20^{o}C$.

3. The individual thermostatic regulation is mandatory on a per dwelling basis.

4. In multi dwelling buildings, individual energy metering of each unit is compulsory.

5. The occupier is accountable for ex~~ac~~cess energy usage above an allowable average.

6. Thermal insulation materials and control systems have been installed in existing buildings as well as new buildings.

Consequently, the AEE development work has resulted in direct economies of 13400 tonnes equivalent of oil per annum, with a future potential of nearly 6 million tonnes per annum[14]. However, from the initial achievement, it would appear that the Agency is very successful in its approach.

5.2.2 New building regulations in Italy

In February 1978, and as an impact of the energy crisis, the Italian Government prepared and published their revised national regulations, governing the use of energy in buildings. Their published regulations were among the first regulations to come out in Europe and give an indication of trends in Europe[15]. These regulations consist of 25 articles, each of which discusses one aspect of the building components in more detail. However, in order to obtain approval of the design proposal, a set of documents should be submitted to the government, including the names of the approved laboratories agreed for conducting sample testing. Also the government should approve the following:

(a) the heat producing plant and equipment, burners, steam generators, hot water boilers;

(b) details of all equipment which is connected into the heating systems whether air/water heat exchanges, circulation pumps, proposed heat transfer system or radiators;

(c) the type and components of the automatic control systems, and heat metering equipment.

Moreover, the Government defines the external design temperatures, insulation requirements and maintenance instructions as follows:

1. The external winter design temperature is specified for the major towns and for the other areas not precisely specified.

2. The internal temperature is limited to $20^{o}C + 1^{o}C$ tolerance during the hours of operation during the heating season. Also all insulation having an installed load greater than 348 kw/h must have not less than two boilers.

3. The temperature of domestic hot water is limited to $48^{o}C$, with a tolerance of $5^{o}C$, and the heating plant which serve both the heating system and the domestic hot water.

5.5.3 Energy conservation regulation in Great Britain

The situation of facing the energy crisis in Great Britain is slightly different from that in some other European countries. In Great Britain many institutions, such as the Department of the Environment, the Chartered Institution of Building Services (CIBS), the Building Standards Institution (BSI), and many others, are encouraged to study the matter of energy conservation in building in more detail. Moreover, the government provides grants through some of these institutions for the different universities to study a certain phenomenon in residential building with the aim of further improvement. However, the procedures and techniques involved in saving energy are divided into two main categories, a compulsory category which is to fulfil the minimum requirement of the building regulations, and an optional category which is concerned about the optional recommendations.

A. Compulsory Category

The compulsory category includes the building regulations issued to govern the use of energy and the quality of building materials in respect to energy conservation. However, in order for the government to ensure the fulfilment of the required regulations, it does not issue any building permission unless the building fulfils the required building regulations. Literally, the compulsory building requirements governing energy saving (The Building Regulations 1985, Conservation of fuel and power) can be summarised as follows:

1. Resistance to the passage of heat through the external fabric; which imposes limitations on the maximum size of single glazed area, minimum allowable insulation thickness of the exposed walls, floors and roofs, and maximum allowable thermal transmission (U-values) for the different building components.

2. Space heating or hot water systems in buildings should be provided with automatic controls capable of controlling the operation and output of space heating systems and the temperature of stored water.

3. Hot water pipes and warm air ducts should have adequate thermal insulation unless these pipes are intended to contribute to the heating of a part of a building. Also, hot water storage should have adequate thermal insulation.

4. As a result of parliamentary action towards saving energy the internal temperature of a residential building is recommended to be $19^{o}C$ during the winter season and $20^{o}C$ during the summer season.

B. <u>Optional Category</u>

Apart from the compulsory requirements which are the minimum in the scale of energy saving, the government provides for the people many options for better energy saving. It encourages many institutions to research and improve the thermal performance of the buildings. These institutions give recommendations for the main procedures to be followed to obtain the efficient use of energy in the design and management of buildings. They provide guidance at the design stage of new buildings, including alterations and extensions to existing buildings, on the means of achieving economic usage of primary energy whilst maintaining satisfactory levels of internal environmental conditions for the occupants. The main objective of the optional category is to open the way for designers to plan for minimum primary energy usage by improving the efficiency of the system, exploiting techniques of heat recovery, and improving the thermal properties of the building materials. It concentrates on optimising the following aspects (Energy Design Guide by BSI, and Guidance Towards Energy Conserving Design by CIBS):

1. The thickness and type of thermal insulation of walls, roofs and floors.

2. The size and type of glazing on the external surfaces, and the adequate level of natural lighting.

3. The thermal transmittance (U-value) of the building envelope.

4. The appropriate level of natural ventilation to be allowed into the building.

5. The heating systems and the best way of operating and controlling them with the minimum use of energy.

5.5.4 A brief review of the various approaches

The different energy saving approaches of the different countries as a reaction to the energy crisis show the importance of energy conservation in these countries. The different solutions introduced by these countries indicate the great potential for saving energy in residential buildings. However, some of their solutions can be adapted and used in different countries with great attention to the local building materials, micro climate, and social lifestyle. Not only that, but also a researcher can learn from these solutions and develop a system to tackle the energy problem in his country or in any country, as long as the energy and heat transfer parameters are taken into consideration.

5.6 Different Approaches to Thermal Modelling of Building

The design of buildings in countries with a hot climate most often does not sufficiently consider the climatic factors. Not only that, but also the data available which can be applied to the prediction of the thermal behaviour of buildings are minimal. However, the energy behaviour in the buildings results from the complex interaction of climate, construction, internal gains, operating schedule, and user behaviour. Learning from the nature of this interaction, a massive building can use more or less energy for cooling or heating than a lightweight building, also the heating or cooling peak loads can be increased or decreased by the modification of the building envelope. Usually the building envelope alters the pattern of energy demand over the day, so building operating costs can be dramatically affected even when use is unchanged. This study covers the various aspects of modelling buildings for thermal purposes and energy measurements. There are two main techniques which might be followed for the thermal studies:

1. Theoretical techniques for modelling a real building
2. Empirical techniques for modelling a real building

5.6.1 Theoretical techniques for modelling a real building

The rising energy costs created demands for accurate methods for predicting energy consumption and heating and cooling loads. As a result, many methods for predicting energy consumption and heating and cooling loads have become available, ranging from simple rules of thumb to large dynamic thermal computer models. To select the most suitable technique, the user should be aware of the relative advantages and disadvantages of each modelling method. Therefore, this section of the study reviews a variety of schemes for estimating energy consumption and the heating and cooling loads for a building. Generally the available methods can be categorised into two main types;

(1) the steady state method, and
(2) the dynamic model

Both methods have the ability to specify all the variables interchanged within and around the proposed building studies, with some limitations on the steady state method. The different parameters that both methods consider in their calculations are as follows:

1. Construction aspects

   (a) Location and orientation of the building
   (b) Thickness of the various components of the building envelope
   (c) Size of the window openings and the type of shading devices used.

2. Fabric thermal properties

   (a) U-values of the fabric components
   (b) Surface heat transfer coefficients and thermal resistances
   (c) Thermal capacity of the fabric

3. Occupants in the building and their behaviour

   (a) Number of persons in the dwelling
   (b) The system in which the windows are operated and the rate of ventilation permitted.
   (c) Type and size of the heating and cooling systems used and their operational schedule.
   (d) Incidental heat gains from occupants and appliances.

4. Climatic elements

   (a) Solar radiation, global, direct and diffused

(b) External air temperature and the required internal temperature
(c) Relative humidity
(d) Wind speeds and directions

5.6.1.1 Steady State Method

The steady state method is normally used for calculating the rate of heat transmission through the building envelopes. Also, it gives a reasonable estimation of the monthly as well as the annual energy consumption and the peak loads of heating and cooling in the buildings. It is intrinsically appealing to designers for incorporation into energy design codes, such as CIBS building energy code.[16] Fortunately, advanced computer technology has brought the microcomputer well within the budget of small architectural and engineering practices, which has created demands for the steady state calculation procedures to be mounted into the computer machines. However, ASHRAE and CIBS have offered the annual energy use and peak loads. Examples of such methods are as follows:

ASHRAE, the American Society of Heating, Refrigeration, and Air-conditioning Engineers, has developed a set of calculation methods for estimating annual energy consumption. The ASHRAE method for predicting the air-conditioning cooling load is more elaborate than the heating load prediction method, and specifically addresses the building mass[17]. Actually, the ASHRAE Handbook of Fundamentals (1972) described two methods for calculating cooling loads, the first method being the Total Equivalent Temperature Differential (TETD). This was simply adding the various components of space heat gain together to get an instantaneous total sum of the space heat again, which was converted to an instantaneous space cooling load. The second method that ASHRAE developed was the Transfer Function Method; it was principally similar to the first method, but it employed entirely different weighting factors, all coefficients of room transfer functions, in converting heat gain to cooling load. However, ASHRAE sponsored a research project to develop the calculation procedures and to eliminate any discrepancy between the TETD and Transfer Function methods. The final results of the research project have resulted in a new calculation method called Cooling Load Factors (CLF) which calculates the cooling load in the space directly, unlike the previous methods which calculate the cooling load in a two step process. The, ASHRAE calculation procedures for cooling loads are described in detail in Issue 1981 Chapter 28, and the summary of these procedures are as follows:

$$Q_F = U \times A \times CLTD \quad \text{.......... 5.13}$$
$$Q_{so} = A \times SC \times SHGF \times CLF \quad \text{.......... 5.14}$$
$$Q_s = No \times Sens\ H.G. \times CLF \quad \text{.......... 5.15}$$

where Q_F, Q_{so}, and Q_s are the heat gain by fabric, solar radiation, and sensible gain respectively, and U is the steady state u-value, A is the element area, CLTD is the cooling load temperature difference, SC is the shading coefficient for the combination of glass and shading, SHGF is the solar heat gain factor for the specific orientation of the surface, CLF is the cooling load, No is the number of people in space, and sens.H.G. is the sensible heat gain from occupants.

Another prediction method is the admittance method which was originally developed in Britain to allow the prediction of summer temperatures in buildings without mechanical cooling. The calculation of that admittance method is based on the analytic formulation of building response to 24 hours cycle energy inputs, where the temperature swings resulting from energy inputs are determining the admittance of the mass elements[18]. In 1978 Axley developed the admittance method and wrote a general purpose computer program for building energy analysis which was mainly based on the admittance procedures. Further development was achieved by Steel in 1981 when he provided a method for deriving the dynamic heat capacity which represents all of the thermal mass elements of a building as a single capacitance. Also, in 1982, Subbarao presented a graphical method for determining the overall dynamic response of a building which could then be used as a correlation parameter to determine energy performance. Although the method procedures were developed originally for use in predicting design or peak conditions, its use is also applicable to non-design conditions including estimates of annual energy consumption; consequently, the energy balance equations as described in CIBS Guide Section A5 are as follows:

$$Q_u = \sum (AU)\ (t_{ei} - t_{ao}) \quad \text{.....} 5.15$$
$$Q_v = (pv\ (t_{ai} - t_{ao}) \quad \text{.....} 5.17$$
$$Q = 24\ (\sum AU)\ (t_{ei} - t_{ao}) + C_{pv}\ (t_{ai} - t_{ao})) \quad \text{.....} 5.18$$

where Q is the total transferred heat, Qu is the heat transferred through the fabric, Q_v is the heat transferred by ventilation, $\sum$ AU is the area-weighted sum of U-values of all external surfaces, C is the specific heat of air, p is the density of air and v is the volumetric air change rate, t_{ei} is the temperature of the internal environment, t_{ai} and t_{ao} are the air temperatures inside and outside respectively

5.6.1.2 The dynamic model

Dynamic thermal modellings are complex thermal models that require the power of large mainframe computers to run the fundamental equations governing the heat transfer through the building materials. They are unlike the steady state models and are capable of predicting the variations with time of internal temperatures, heat fluxes, and energy conditions for real zoned buildings[19]. In fact, a wider possible range of problems can be approached by the complex dynamic models, where their uses extend far beyond the scope of the steady state models. Unfortunately, despite the power and flexibility of the dynamic thermal models, they have some drawbacks for the potential user, where the software and the hardware to run the model are very expensive. Also, large volumes of data are required even for modelling the simplest buildings, which leads to a lengthy input procedure. Moreover, a great deal of time has to be devoted to the learning and the application of the processes. However, many dynamic thermal computer models have been reviewed by the author and one of them is briefly discussed as follows:

ESP Dynamic Thermal Model

The Environmental Systems Performance (ESP) is a dynamic computer model for building and plant energy simulation. The ESP computer package has been developed by Dr Joe Clarke, the system's progenitor, as part of his doctoral research, and from 1977 to 1980, the project was funded by the UK Science and Engineering Research Council (SERC).

In 1980 Dr Clarke was joined by Dr Don McLean and since then further grants from SERC and the European Economic Community (EEC) have enabled a move to dynamic systems simulation[20].

ESP is a system for simulating a transient energy and it is capable of modelling the energy and fluid flows within combined building and plant systems. The ESP package is comprised of 13 interrelating program modules facilitating input management, simulation, results recover and display, data base management, and several simulations support functions. Also it can simulate one or more zones within the building as well as the whole building by the interlocking of the different zones. Furthermore, the ESP is applicable to existing buildings and new designed buildings with or without advanced technology features. Basically, in ESP simulation procedures the different zones are defined in terms of geometry, construction, and usage profiles. However, the amount of data required to simulate only one small zone is very large and may take a long time to be collected. Apart from the detailed construction profile and the occupants' profile, the minimum required climatic data for any simulation includes the hourly values of dry bulb temperature, direct normal or total horizontal solar intensity, diffuse horizontal solar intensity, wind speed, wind direction and relative humidity. Finally, the ESP thermal model holds much promise for the future, despite its current high cost and the doubts designers have about its predictive accuracy inhibiting its widespread use.

5.6.2 Empirical techniques for modelling a real building

The thermal performance and the energy consumption of actual buildings can be measured in the real site as well as in the laboratories by a representative model. In the real site, the measurements of thermal performance and energy consumption are more accurate than those measured in the laboratory, due to the fact that the environmental conditions, the micro climate, and the occupants' heat input are hard to be represented accurately in the laboratory. However, the measurements in the real site require a great deal of effort and include the continuous reading of the different readings, recording any changes occurring in the building, and collaborating the instruments between now and then, and also require enough and sufficient instruments in order to get a successful and accurate experiment. Alternatively, unoccupied model buildings in various scales can be constructed on the research site or in the laboratory for thermal and energy measurements. However, both of these model buildings have been used recently to conduct results upon which the theoretical results can be checked and verified.

5.6.2.1 Real building measurements

The real scale building measurements may be considered as providing a straightforward technique for understanding the problem and are favourable for laboratory and theoretical work. Many researchers all over the world have used this technique for studying certain aspects of the behaviour of the house, such as ventilation, thermal performance of the envelope, window effect with respect to solar radiation, and so on. Some examples of the actual measurements carried out on the real buildings are mentioned below.

In 1979 J.K. Whittle did a study of three local authority two storey houses, each of which consisted of three bedrooms. These houses were constructed of timber framed units for the external walls, concrete blocks for the party walls, and plaster board units for the room partitions. Whittle measured on an hourly basis the indoor air temperature, the global solar radiation, and the wind speed. Also he measured the energy consumed by each house individually. The purpose of his study was to verify a computer model against the conducted data from occupied dwellings. Finally, he concluded that the simulations of the real houses enabled him to verify the computer model which could then be used for the general improvement of the local authority houses[21].

In 1979 an Egyptian researcher, M.M. Abdel-Aziz Nour, made measurements on a real courtyard house in Cairo, Egypt. He measured the temperature in the courtyard and compared it with the temperature measured on the roof. He also measured the air temperature inside the courtyard house rooms and compared this with the indoor air temperature of the modern house rooms. His aspiration was to find the difference between the thermal performance of the light and heavyweight constructions, and the traditional and modern dwellings. He concluded that the courtyard works as a temperature regulator and the traditional house design is more suitable than the modern design as far as the air temperature is concerned. However, this result can only be true if the traditional principles are applied as a system and not separately[22].

Christine E. Uglow (1982) surveyed 42 occupied dwellings ranging from small flats to large detached houses. The collected data was mainly based on external measurements of the dwellings and short questionnaires which established details of the dwelling and of its occupancy. The purpose of her survey and measurements was to investigate the validity of a method of predicting seasonal energy consumption in occupied dwellings mainly used for space heating. She concluded her study by indicating the accuracy of the model in predicting the full consumption for space heating[23].

5.6.2.2 Model building measurements

The actual buildings are sometimes represented by models to enable the researchers to study the different thermal phenomena, such as the effects of ventilation and light etc, in the internal environment of the building, in more detail. Various scales of building models can be built with the same construction materials and techniques used for building the real buildings. The model measurements in the laboratories are more convenient and easy to monitor compared with the measurements of real buildings. However, some examples of the measurements and experimental procedures on model buildings are as follows:

In 1976 Younis Mukhtar conducted an experimental work in Sudan, studying the thermal performance of the roof. He made model rooms of 2.0 x 2.0 x 1.5m with the same brick wall thickness of 22cm and with different roof materials such as concrete, Jack arch, corrugated sheet and traditional mud. He measured the internal and external surface and air temperatures, the solar radiation intensity on the horizontal surface and the wind speed and directions. He concluded his experiments, finding that the reinforced concrete roof with 50mm of expanded polystyrene of 100mm concrete slab gives the greatest reduction in both maximum slab temperature and its diurnal variations, followed by the brick jack and hollow tile roof and corrugated sheet roof. Finally, the conclusion he arrived at was that to improve the roof performance, white paint may be used on the external surfaces, ventilation used at night time, especially when the outdoor air temperature is less than the indoors air temperature, and that the use of external insulation and shading would maximise the delay in internal temperature[24].

Another type of model building is that which is built inside an environmental chamber, such as that studied by Burch, Peavy and Powel in 1975. The model was constructed of a timber-framed four bedroomed house, and measurement instruments were fully installed in the model. Surface and indoor air temperatures were measured, energy consumption observed, inhabitant, casual gains from appliances, light and operating the windows were all represented in the model. Also solar radiation was simulated. However, the aim of this experiment was to measure the energy consumption and thermal performance in order to compare it with the theoretical thermal model results[25].

5.6.3 Observation on the different approaches of building modelling

In recent years, the production of computer thermal models has been of interest to many individuals and organisations, especially in Europe and North America. As a result, the computer thermal models nowadays have become available in large numbers commercially and publicly. Since the different computer programs have originated from different calculation methods and use different data and assumptions, therefore, the accuracy of their methods is different and relative to the proper data and assumptions used. However, recently a survey has been conducted by M.T. Bowman and K.J. Lomas (1986) reporting that at least 200 methods are available, ranging from simple to large dynamic thermal computer models. Also, they describe the uncertainty of the accuracy of different computer programs, especially if each program dealt with different boundary conditions[26]. In fact, in 1972, a study conducted by Nevrala on various thermal computer models, showed that these computer models differ in their basic treatment of heat flow through and the thermal storage within the structure. Also, he found that some of these programs rely on empirical allowance, some employ crude approximation to the conduction process, and others attempt to use the fundamental equations and to take account of the heat exchange within the room[27].

On the other hand, the actual measurements of a real building are very useful and more accurate than any other measurements due to the presence of all the possible factors, such as occupants, microclimate and appliances' heat input, that might affect the accuracy of the measurements. The actual energy consumed due to cooling or heating can easily be measured, but this alone will not give a reliable indication of the thermal performance of the composing envelope materials. However, the building model can be investigated in detail and the thermal performance of the building envelope can also be measured precisely. However, measurement of energy in the building model is not certain because it is influenced by many parameters other than the thermophysical property of the building envelope materials, such as, users' behaviour, the number of occupants and appliances' and lighting heat input. Also, the possibility of changing the materials of the building envelope for further study and improvement is not achievable in the real building. Therefore, the most suitable way for measuring energy consumption and achieving adequate energy saving is to use both measurements of real dwellings and computer modelling. The procedures of doing this as follows:

1. Obtaining detailed measurements of the dwelling including:

   (a) Obtaining the characteristics of the building such as building materials, component size, external surface colours and detailed dimensions of each facade.

   (b) Determining the building location, orientation, external shading devices and shading from adjacent buildings.

   (c) Obtaining the appropriate weather data and selecting outdoor design conditions. Also obtaining internal measurements for the comfort conditions inside the building.

(d) Acquiring an adequate schedule of lighting, occupants, internal equipment, appliances and any processes that would increase the internal cooling load.

2. Developing a computer model which suits hot climate regions, for estimating the cooling load in the dwelling and the energy consumption.

3. Validating the computer model against the actual measured data to check the model accuracy.

4. Applying the validated model for further improvement of the building envelope and consequently the energy consumption.

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CHAPTER 6

C H A P T E R 6

SURVEY ANALYSIS AND FIELDWORK PROCEDURES

SURVEY ANALYSIS AND FIELDWORK PROCEDURES

6.1 Introduction

Environmental and behavioural studies have shown a rapid development in recent decades. The analysis of the relationship between human behaviour and the physical environment has attracted many researchers from many fields in the social sciences, such as psychology, sociology, geography and anthropology, and from the environmental design fields such as architecture, urban and regional planning, and interior design[1]. Research on environment and behaviour has often dealt with applied, real-world problems of environmental design as they have treated basic theoretical issues.

The basic goal of most of the social science and environmental design surveys is to produce an accumulating body of reliable knowledge identifying problems which cannot be solved by present day knowledge[2]. Such knowledge would enable the researchers to explain, predict and understand empirical phenomena that interest them. Furthermore, a reliable body of knowledge could be put to use to ameliorate the human condition and the standard of living.

The ultimate purpose of this survey is to produce reliable information about the existence of the energy consumption problems in the housing stock in Dammam region. The survey also aims to survey the different energy conservation parameters such as physical properties of the building, user behaviour and energy behaviour. Moreover, the study should enable the author to select a number of houses which can represent the housing stock in Dammam region for detailed investigation.

This chapter of the dissertation is devoted to the presentation of the survey conducted by the author on the housing stock in Dammam region. The method by which the survey was carried out, the scope of the survey, and the summary of the fieldwork procedures are discussed as are the results and analysis of the survey, and the computer programs used for analysis.

6.2 Methodological Elements of the Survey

Surveys and data analysis are very essential elements in most social science research. Usually social science data are obtained when investigators record observations about phenomena being studied; however, not all phenomena are accessible to the investigator's direct observation. Therefore the data should be collected through asking the people who have experienced certain phenomena to reassemble these phenomena. The obtained responses established the data upon which the finding of this study will be based. To attain the maximum possible information, this study has implemented the following survey research elements as sources of its data collection:

(1) Questionnaire
(2) Observing environmental behaviour
(3) Personal interviews

6.2.1 Questionnaire

This part of the study represents the main part of the methodology, where the answers could be sought from a group of users through the use of questionnaires. The selection of this type of survey was based on the fact that the questionnaire survey is the most widely used type of survey design. Also, it is one of the most important instruments in survey research; it provides useful data, especially when investigators begin with a very well defined problem, knowing what major concepts and dimensions they want to deal with.

The main foundation of the questionnaires is the question itself. Therefore, the question should be designed in a very clear and motivated way to encourage the respondents to understand it and answer it very easily[3]. The survey question could be concerned with many variables such as facts, opinions, attitudes and respondents' motivation. However, most questions can be classified into two general categories of factual questions or opinion and attitude questions.

As far as this study is concerned, most of its questions were based on factual questions. They were designed to elicit objective information from the respondents regarding their houses, their environment, their habits and the size of the families. The design of these questionnaires was initiated by reviewing some other questionnaires designed for similar study conducted on the Worcester Green buildings at Washington in the United Kingdom, considering the differences of social, cultural, and religious values. These questionnaires were developed many times to meet the author's objectives and the final draft was reviewed by Mr A.D.C. Hyland, Deputy Course Director of Housing for Developing Countries, and Professor A.C. Hardy, Head of Building Science Section. The translated version of the questionnaire was also reviewed by the statistician of the Department of Town and Regional Planning at King Faisal University, Dr Abusufian Salim for further improvement; samples of the English and Arabic versions of the questionnaire are presented in Appendix (A).

6.2.2 Observing environmental behaviour

Observing behaviour means systematically watching people use their environments: individuals, pairs of people, small groups and large groups. The observation should aim to answer and explain what the behaviour of the people? How do activities relate to one another? And how do spatial relations effect participants? Also, the observer of environmental behaviour should look at how a physical environment supports or interferes with behaviour taking place within it[4].

The main advantage of observation is its directness; it makes it possible to study behaviour as it occurs. Usually, in observation the researchers do not have to ask people about their own behaviour and the action of others; they can simply watch them doing and hear them saying things[5]. Sometimes observation is associated with some questions forwarded to people in order to clarify some of the vague behaviour. Also questions could be used to record some of the activities which cannot be observed directly due to privacy or inconveniences of people and time.

As an objective appraisal of the study, observation played a major part in reconnaissance of the actual environmental conditions as well as occupants' behaviour in the surveyed houses. These reconnaissances were made to generate information regarding (a) design characteristics such as social, climatic and economic conditions; (b) physical characteristics such as type and size of the dwelling, building materials, construction methods and equipment; (c) residents' characteristics such as age, family size, mix of people, and social and economic conditions; and (d) residents' behavioural characteristics, such as use of balconies and yards, children's play activities in the house, visual privacy, and social interaction. Actually, the observed information is narrowly discussed in this chapter, but widely discussed in the following chapter where the detailed analyses of the chosen case studies are discussed.

6.2.3 Personal interviews

The simple function of personal interviews is a face-to-face interpersonal role situation in which an interviewer asks respondents questions designed to obtain answers required for the research completion[6]. Most interviews are as a result of oral communication between the researcher and the respondent. Usually, the conclusion drawn from the interview conversation would directly answer and satisfy the researchers objective.

The interview section represents the unsystematic part of this study. In this section, data were collected by means of personal interviews and open informal discussions with public authorities, personal as well as practitioners including planners, architects and builders. Also the personal interviews were extended to include the residents of some of the surveyed houses. Some of these meetings were pre-arranged, while most of them happened as an unplanned meeting during the process of data collection. Although the interviews were not systematic, nevertheless, useful information was obtained through the use of open-ended questions which encouraged people to talk freely and lengthily. Such friendly talks were very helpful in reinforcing and complementing the data obtained from the resident survey.

6.3 The Scope of the Survey

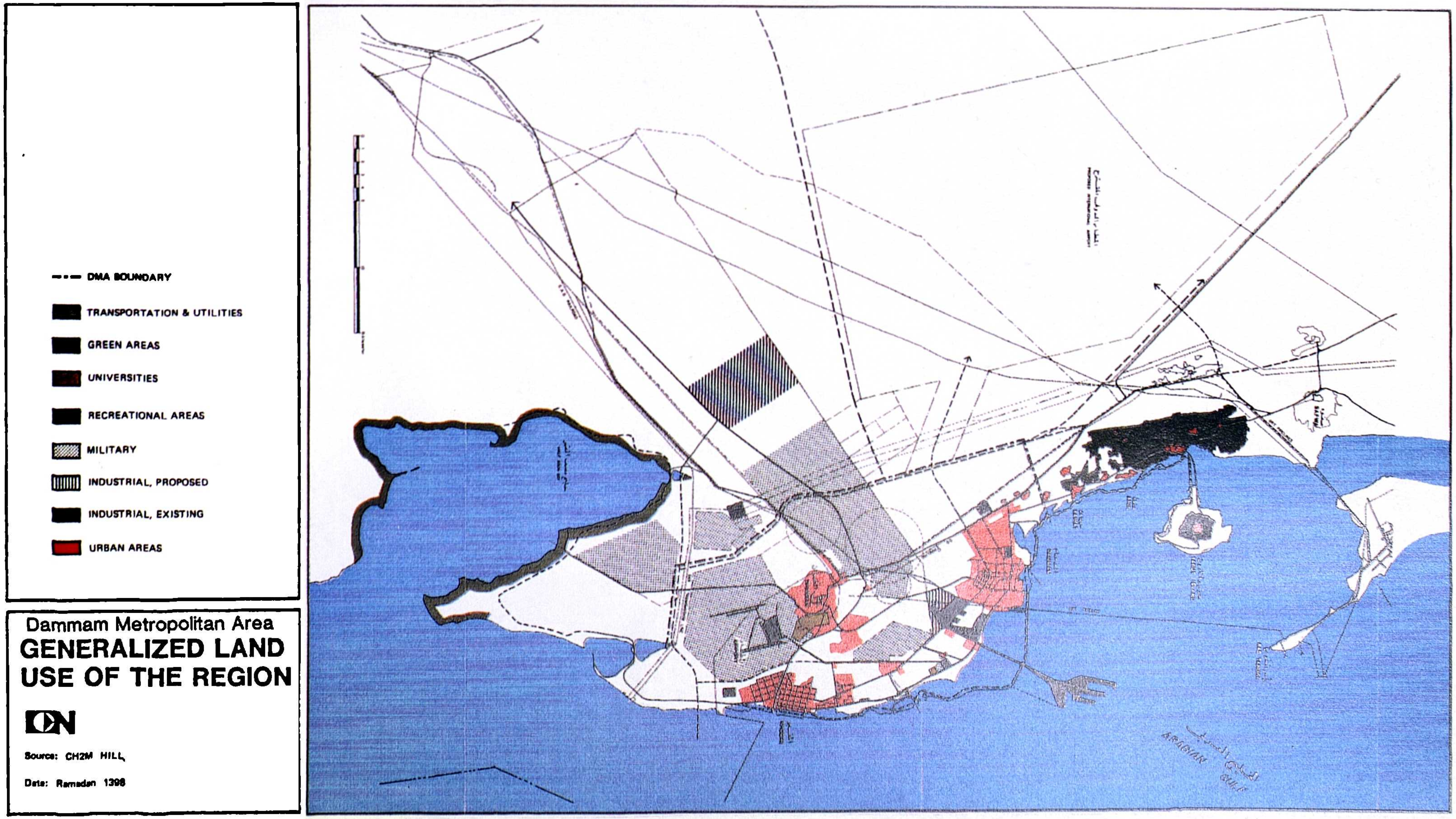
Usually data are collected in order to make generalisations about certain topics such as behaviour, attitudes or even the educational level of people. Only rarely does a study include observations of all respondents or even all events that are required for generalisations. In fact, it is almost impossible in a survey to interview or to question all possible respondents. Therefore, in this study, to arrive at accurate estimates of parameters, the following requirements were effectively dealt with: (1) the definition of the studied area, (2) the size of the sample, and (3) the sample frame.

6.3.1 Study area

One of the first problems which should be considered in any survey procedure is determining the size of the population involved in the survey. For this reason, the population of this study was defined precisely by specifying the area which the author would like to investigate. The study area was specified as Dammam region due to the rapid development which was experienced in the area, as mentioned previously, and due to the presumed high energy consumption. The study sample was drawn from two major cities in the region, which were Dammam and Alkobar cities. The selection of these two cities was motivated by the following: firstly, in terms of practicality, limiting the study population to particular areas rather than the whole city, makes it more feasible due to the limited resources and time; and, secondly and most importantly, is that these two cities were the most developed cities in the region and they accommodate most of the region's residential areas.

Both cities accommodate two types of residential areas, financed by two different housing programmes, the Arabian and American Oil company's (ARAMCO) housing programme. and the Real Estate Development Fund

MAP 2 : DAMMAM REGION URBAN GROWTH



(REDF) housing programme. The actual study area is concerned with the housing built through the REDF which forms most of the housing stock in Dammam region. However, this area is spread over nearly 120 square kilometres (see map 2).

6.3.2 Sample size

Once the study area has been defined, the sample that is required to represent the study area should immediately be drawn. Usually, adequate surveys require large sample sizes of varied characteristics that sufficiently reflect the variation which might exist in the total population. However, a large sample cannot be achieved in this study due to its scope and nature, especially if the limited availability of resources is considered. Nevertheless, practical and *thoughtfully* selected probability samples, in association with a well designed questionnaire, give the possibility of making a reasonable representation of the total population.

By employing some of the sampling techniques, a total of 500 houses were randomly selected from a total list of 14,000 houses obtained from the region's electricity company. The information supplied by the electricity company was quite useful, including detailed names, home addresses, and three months of energy consumption during the summer season of 1987. Out of the 500 names, almost 425 interviews were completed which represent about 85 per cent of the prospective respondents. However, the other 15 per cent of the respondents did not complete the interview for two possible reasons, either they refused or terminated the interview because the informant was not co-operative and he thought it was an invasion of his privacy, or it was not possible for the investigator to meet the head of the household.

With respect to the size of the sample, it was small enough to be examined within the time limits of the investigator, but also it was large enough to produce some potentially significant data about the occupants' behaviour as well as the energy behaviour.

6.3.3 Sample frame

The sampling frame is a systematic procedure involved in selecting a sample from a complete list of sampling units. Usually, in small scale studies, the sampling frame is based on telephone directories, city directories, or even private and public organisation lists. It is highly important that there should be some harmony between the sampling frame and the sampling population, due to the fact that the accuracy of the sample depends on the accuracy of the sampling frame. Actually, most of the sample design elements which are the population coverage, the sampling stages, and the actual selection process are effected by the sampling frame.

The structure of the sample frame in this study was based upon simple random sampling. Actually, this sampling method gives each of the sampling units of the population an equal chance of being selected. To ensure this requirement, tables of the random digits were used to determine the actual population to be sampled. The following steps show the processes in which the actual population was determined.

1. Dammam region was divided by SCECO company into four major districts, two of which represent the study area, Dammam City and Alkobar City. Also each major district was divided into several sub-districts.

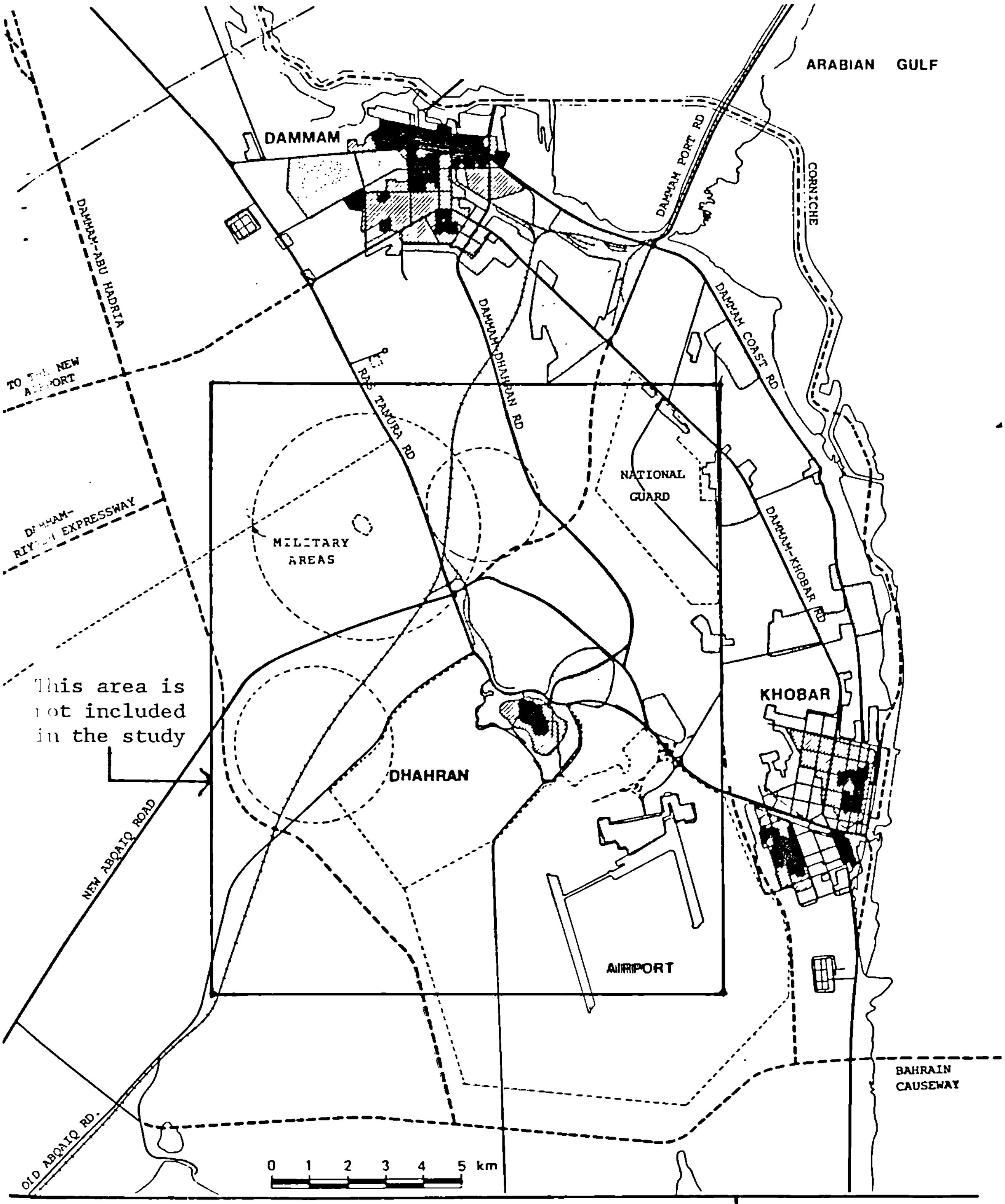
2. The study area was defined by omitting all other sub-districts such as commercial, industrial and Aramco's housing sub-districts from the major districts (see map 3).

3. Using the computer, a random sample of 14,000 houses including addresses and electricity bills, was drawn from the total housing stock in Dammam region. However, the 14,000 was the maximum sample the electricity company could release due to security matters.

4. All houses with zero energy consumption were omitted from the main sample, due to the fact that these houses could be unoccupied or still under construction.

5. Using the random digits table, a sample of 500 houses was randomly selected from the remaining main sample.

6. If the household head was not available or refused the interview, the following procedure was applied; the house adjacent on either side was chosen, and if this house was also not appropriate for the same reason the next adjacent house was chosen. Correspondingly, if this was not appropriate the next and so on.



DAMMAM METROPOLITAN AREA URBAN GROWTH

DAMMAM METROPOLITAN AREA

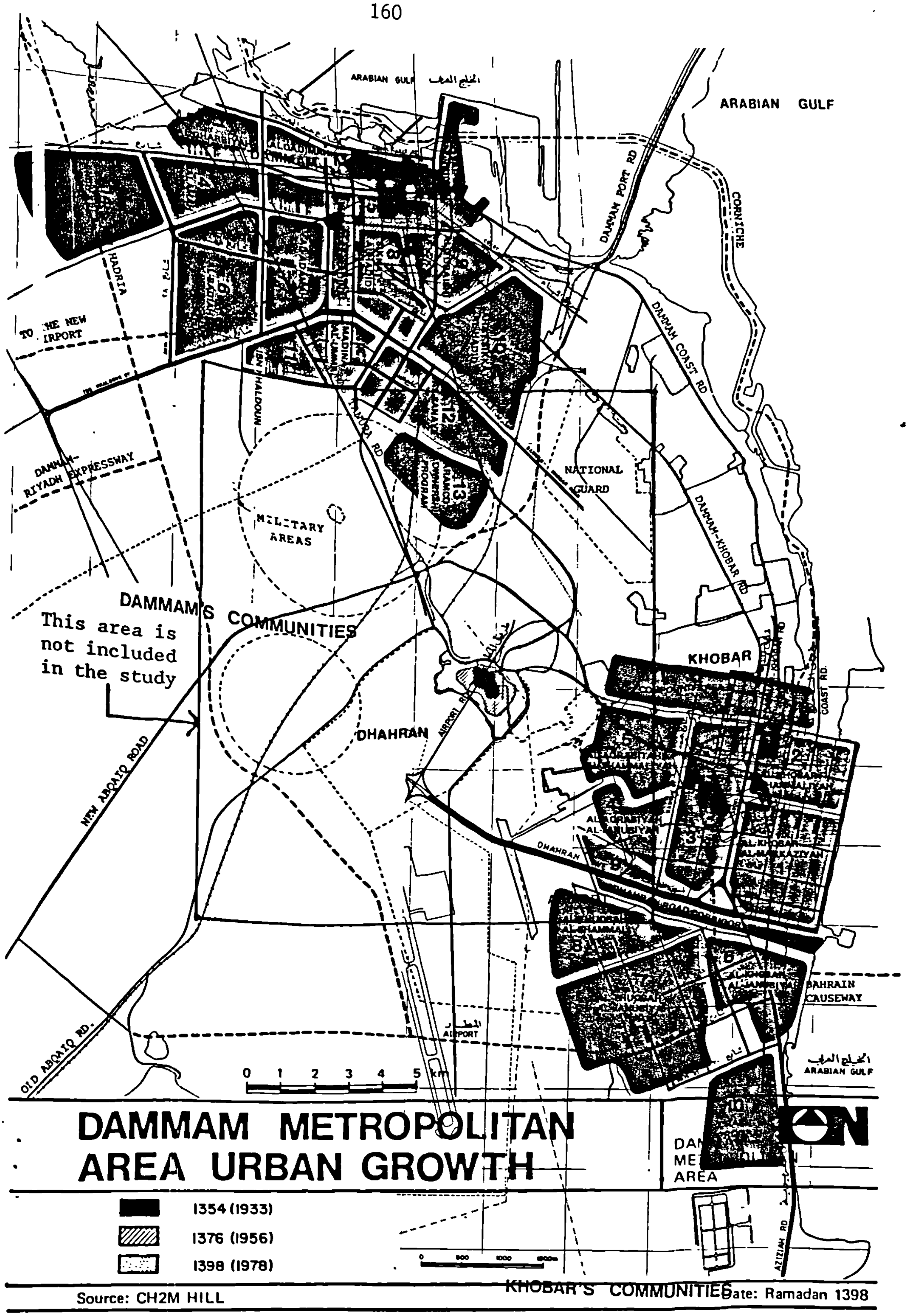
1354 (1933)

1376 (1956)

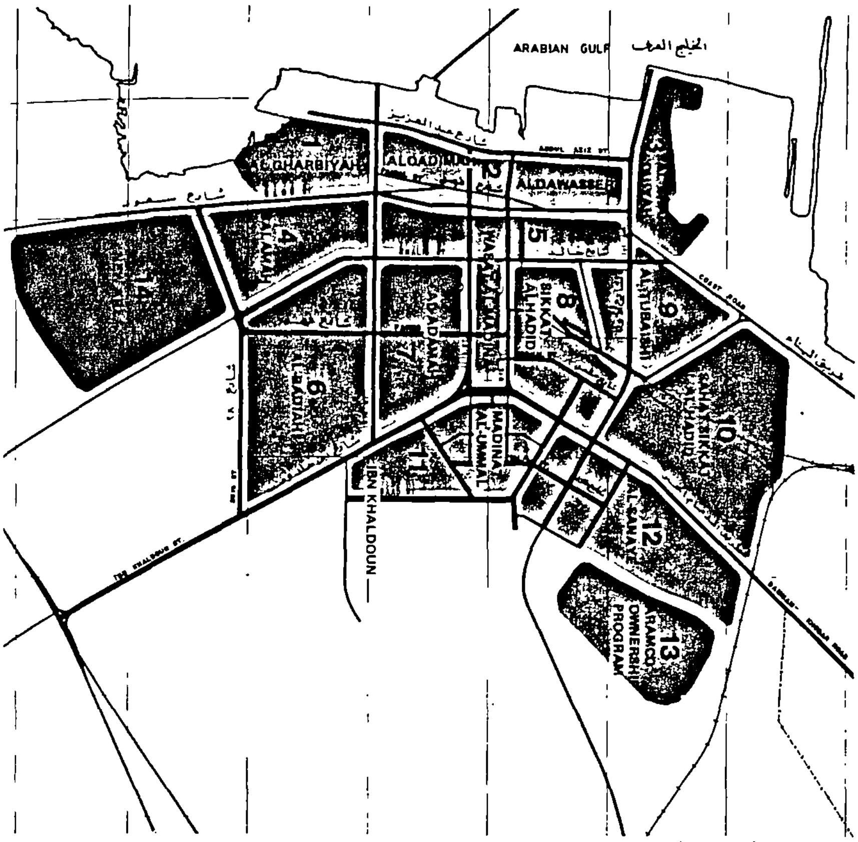
1398 (1978)

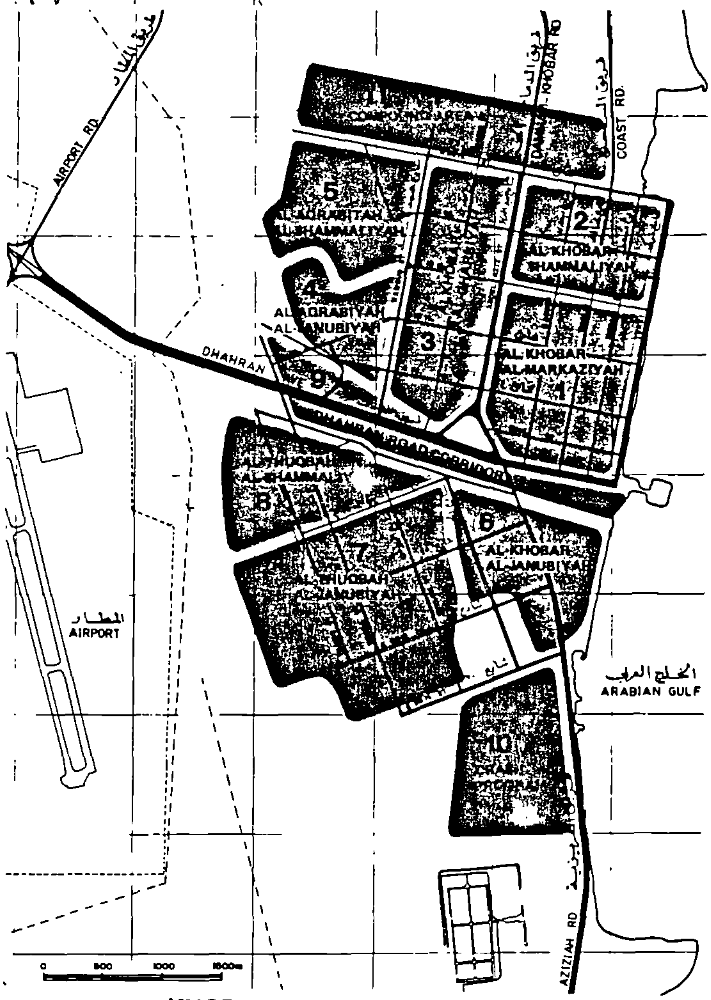
Source: CH2M HILL

Date: Ramadan 1398



MAP 3: DAMMAM REGION HOUSING DISTRICTS





MAP 3: DAMMAM REGION HOUSING DISTRICTS

6.4 Fieldwork Procedures

The survey was carried out by the investigator during the late summer of 1987, specifically from the 15th August until the 20th October. The actual fieldwork was divided into two major surveys, the general survey which was mainly concerned with collecting information about the main sample, and the detailed survey which was only concerned with the selected case studies.

Usually, practical experiments and social surveys are time consuming because of the overlapping procedures; however, a clear and well prepared procedure can reduce the time and effort required. The importance of the timing in this survey is vital due to the fact that this survey is concerned about the energy consumed by cooling the buildings as well as investigating the people's reaction towards saving energy, therefore, this survey should be conducted during the summer period. To save time and effort, the author believed that this survey needed a clear strategy of this fieldwork and an early preparation of the necessary aspects before the actual survey began.

6.4.1 The strategy of the fieldwork

The strategy of this fieldwork was established to achieve the author's objective in investigating the energy consumption parameters which are, the physical properties of the building, the typical house design, the user behaviour, and the energy behaviour. The strategy was structured by specifying the information needed to be collected, how it was going to be collected, and the purpose of collecting this information. It specified the way of conducting the general investigation as well as the detailed investigation as follows:

a) GENERAL INVESTIGATION

The general housing investigation was carried out on the houses which had been built in the period 1975 to 1985 (the boom year) and the range of houses which was investigated is about 500 houses.

	INFORMATION TO BE COLLECTED	HOW IT IS GOING TO BE COLLECTED	AIM & PURPOSE
A.	PHYSICAL PROPERTIES		
1.	Physical size of the house.	From the Presidency of Town and Rural Planning.	To know the different areas of the houses in order to group them in different groups.
2.	Type of the house's materials.	From REDF literature and physical observation.	To categorise the different houses according to their material type.
3.	Different houses' orientation.	From the region Municipality.	To get an overall idea of the different orientation in the region in order to get the common orientation.
4.	Different spaces of the house.	From the Questionnaire.	To survey the different spaces of the house which consumed energy.
B.	USER BEHAVIOUR		
1.	Number of Occupants	From the Questionnaire.	To discover the size of the household in order to categorise the house according to the relation of area and number of household.
2.	Users' reaction towards saving energy.	From the Questionnaire.	To discover the effort they made to save and the potential of saving.
3.	The users' behaviour towards opening and closing the window.	From the Questionnaire.	To discover whether they use natural ventilation or not and whether they are willing to open and close the windows.

C.	ENERGY BEHAVIOUR		
1.	How much energy is consumed by each house per month for the 12 months.	By reviewing the electricity company bills.	To calculate the average consumption per house and how much the summer season differs from the winter season.
2.	Type of energy used in each house.	From the Questionnaire.	To discover the energy used in cooling as well as in other uses.
3.	Different cooling systems used in the house.	From the Questionnaire.	To discover the different probabilities of energy consumption.
4.	Energy cost.	From the electricity company and the gas company.	To show the cost of cooling in relation to the other alternatives.

b) DETAILED INVESTIGATION

This investigation was conducted on six different contemporary houses. These houses were chosen from the evaluation of the questionnaires due to their differences which were based on:

(a) size of house area
(b) size of household
(c) number of appliances in the house

The house detailed investigation was conducted on each house of the six selected houses as follows:

	INFORMATION TO BE COLLECTED	HOW IT IS GOING TO BE COLLECTED	AIM & PURPOSE
A.	PHYSICAL PROPERTIES OF THE BUILDING		
1.	Physical size of the house in detail.	Physical measurements.	To find out the area of the house and the length of the different elevations in order to know the amount of the exposure on the house.

2.	Building materials.	Physical observation.	To determine the different types of materials used in the house in order to estimate the performance of the building.
3.	The house orientations and the design of different spaces.	Physical observation and interview.	To discover the different orientations of the house and where the different spaces are located in relation to the sun.
4.	Percentage of openings in each house.	Physical survey and measurements.	To survey the size of the openings and to obtain the percentage of the solid to the opening. Also to find out whether the windows are double or single glazed in order to calculate the heat gained through the windows.
B.	USER BEHAVIOUR		
1.	The exact number of the household.	Physical survey and Questionnaire.	To determine the relation between the family size and the energy consumed.
2.	Level of comfort.	Interview and physical measurements.	To calculate the energy consumption with respect to their level of comfort.
3.	Recording the daily activities of the users in the house.	Interview Questionnaire some observation.	To know when and where the activities occur and what type of activities they are.
C.	ENERGY BEHAVIOUR		
1.	Type of energy used in the house.	Physical survey.	To know the percentage of energy used in cooling with respect to the other.
2.	How much energy has been consumed precisely.	By reading the electricity meters and reviewing the previous bills for each month.	To determine the total energy used in the house to compare it with the cooling consumption only.
3.	Different cooling systems used in the house.	Physical survey and interview.	To consider the coefficient of performance of the cooling system in the calculation procedures.

6.4.2 The preparation of the fieldwork

The preparation of the fieldwork started with communications with the different governmental departments involved in the survey directly or indirectly, as follows:

1. An early communication was made with both the Saudi Arabian educational attache and King Faisal University to acquire their approval in supporting the fieldwork. This started four months preceding the survey, while the questionnaire was being developed, and was agreed two months prior to the survey.

2. The final agreed version of the questionnaire was translated into the Arabic language and five hundred and forty copies of eight pages each were made available for the surveyor to distribute.

3. A team of seven university students to be employed in the data collection was selected with the university authorities. Also an authorisation letter was issued to entitle the students to interview people; these letters which described the typology of the survey and illustrated the name and occupation of the investigator, were issued and signed by the Dean of the College of Architecture and Planning.

4. A flexible arrangement of data collection was employed due to the uncertainty of what was going to happen during the survey. There was a daily meeting with the students between nine and eleven o'clock in the morning to collect the previous day's finished questionnaires and to discuss and solve some of the problems that had arisen. In consequence of the students' understanding, few problems seemed to arise; the meetings were adjusted to be twice weekly, even though the questionnaires were received and revised daily and students were asked at the following meeting about the missing or the incorrect data.

To ensure a good quality of answered questionnaires and to spend more time with the respondents, each student was asked to complete not more than five questionnaires daily. The students were conducting the survey between five and eight o'clock at night to avoid meeting unqualified persons who might give irrelevant information and to guarantee the presence of the head of the household during this time. Even so, they faced many problems while interviewing the people, such as meeting an elderly person who was not keen to answer the questions properly, or sometimes due to the absence of the head of the household, when the remaining members of the household would not respond to the interview positively.

5. By using a systematic way of coding, which is a system of writing in numbers or letters to abbreviate the length of data, the daily received questionnaires were recorded on coding sheets. The data in the coding sheets was later transferred onto the mainframe computer through the data preparation section in the University of Newcastle upon Tyne; this consisted of raw data, data set, variable labels, and value labels (see appendix A).

   (a) Raw Data:
   It was a series of numbers and letters representing the actual survey to enable the computer to read it.

   (b) Data Set:
   It was presented in the form of cases and variables. The cases were the basic units of analysis, for instance, a person replying to a questionnaire was considered as one case. The variables were all the answers which were measured and recorded for each case (each questionnaire).

   (c) Variable Labels:
   The variable labels were used to assign some short labels for the extended descriptive labels due to the limited characters the computer can accept.

(d) Value Labels:

The value labels were the weight of the different questions on the questionnaires. These labels were used to provide descriptive labels for the values.

6.5 The selection of Case Studies

Since this study was concerned primarily with the energy consumed by the buildings built by REDF and the possibility of improving their performance, a considerable amount of time and effort was devoted to the precise investigation of the selected case studies that could be simulated in detail later on this study. However, the selection of one representative case study for a large number of houses was not possible at this stage due to the various variables which could not be covered by only one case. Therefore, all the surveyed houses were put into several groups in order to represent each group individually. Fortunately, the municipality of Dammam region had already categorised the houses into three categories according to their plot size, which saved investigation time in categorising them and establishing new grouping criteria. Using regression analysis, each group was represented by two houses, the highest energy consuming house and the lowest energy consuming house which gave a total of six case studies.

After the selection of the six case studies was made, official letters from King Faisal University were issued to the occupants of these houses. The purpose of these letters was to introduce the investigator to the occupants and to inform them about the importance of this study; also it asked them for their assistance to the investigator in collecting the data and conducting the physical measurements required. Furthermore, there was a signed letter by the investigator directed to the occupants to assure them of complete secrecy and confidentiality of all information received in their answers.

Due to the circumstances of privacy and personal secrecy, some of the occupants of the houses chosen for detailed study refused to be interviewed and did not allow any measurements to be taken. In such cases, where the first priority house refused the detailed measurements to be taken, the second priority house was selected for the detailed study. A collection of detailed drawings and measurements were obtained for each case study which will be presented in detail later on in the study.

6.6 Computers Used in the Analysis

The computer program used for the statistical analysis of this study was the powerful package SPSSX, which is the statistical package for social sciences. It is a large and powerful computer program which has many facilities for manipulating and analysing the data. Also, it was used in featuring many of the statistical procedures which range from simple descriptive measures such as mean, frequency distribution, cross-tabulations, and simple plot, to multivariate methods, such as multiple regression and multivariate analysis of variance. It can take the data from the file and turn it into meaningful information, illustrated by some graphical explanation.

The use of the SPSSX package required a set of commands to enable the computer to define, analyse and display the data. Actually the SPSSX procedures can only deal with data in the form of a rectangular file which is composed of rows and columns[7]. Therefore the data of the survey is converted onto a raw data file which contains numbers and letters by using the coding system. In order to make this raw data meaningful for the computer as well as for the final results, two things were constructed, the file definition, which provides basic information about the data file, and the variable definition which provides specific information about the location, structure and meaning of the data on the file.

The other computer package used on the analysis of this survey as an assistance to the main package SPSSX was Chart.

Chart package is a useful tool for creating different types of charts and graphs. The features offered by Chart program are not so different from the features offered by GIMMS program , but the main advantage of Chart or GIMMS is that the chart is direct and does not need any program to run it. Therefore the chart program was used very frequently in this study to illustrate most of the analysis results.

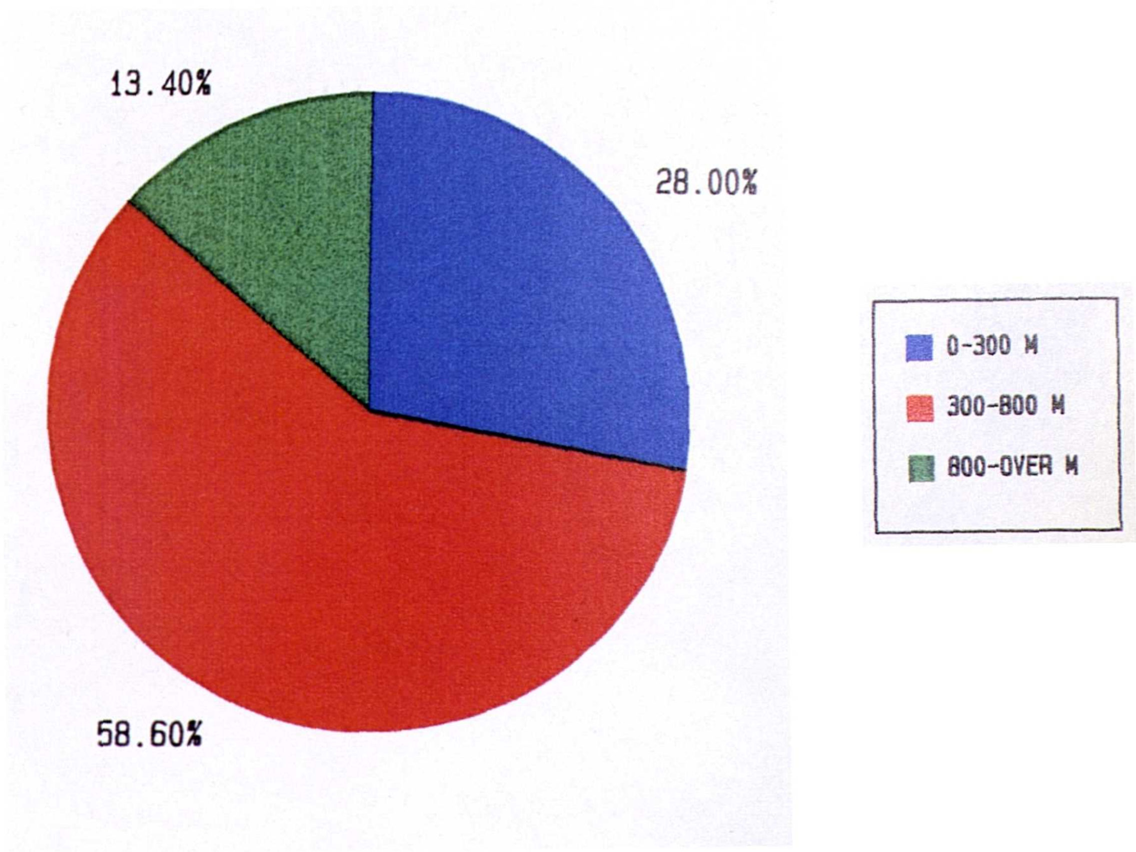
6.7 Results and Analysis of the Survey

The collected data from the survey were coded, built into computer files as discussed previously, and tabulated using SPSSX program. Analysis and presentation of the data comprised two main tabulations. Firstly was the simple descriptive tabulations to study the frequency and percentage distribution of the responses in order to define some of the characteristics of the housing stock, including the people's attitudes, and the occupants' behaviour in Dammam region. However, this simple tabulation was a very helpful process in presenting the data in a more simplified way to enable the non-researcher groups to understand it. Secondly, was the cross tabulation which was mainly used to test the relationship among different variables, for instance, to test the level of significance between the level of comfort and the orientation of the buildings. Thus the cross tabulation process represents the pattern analysis which led to indirect conclusions resulting from the type of relationship between two or more variables.

6.7.1 Area of houses surveyed

The housing stock in Dammam region has been categorised by the Municipality into three categories according to the plot size. Unfortunately, the percentage of the housing stock in each category has not been released by the local municipality yet, because it was in the process of constructing a comprehensive master plan for Dammam region. However, the questionnaires, which have been carried out to survey the energy consumption of the individual houses in Dammam region, show that the percentage of the medium plot size is almost twice that of the other two sizes. This result can be interpreted as that the random sampling may have, by some chance, picked more of the medium plot size and that of course increase the percentage of the medium plot size. The other possibility is that the survey reflects proportionally the actual housing stock in the region, which is the logical explanation due to the result of the random sampling. Finally, this survey shows that the medium plot size occupied about 58.6% of the surveyed houses

FIGURE 6.1: THE DISTRIBUTION OF THE TOTAL HOUSES SURVEYED



where the small plot size occupied 28% and the large plot size occupied only 13.4% of the surveyed houses as shown in figure 6.1.

6.7.2 Definition of housing categories

Most attempts to identify the important aspects of the environmental quality, revealed that the housing factor is a vital element of the quality of life. However, to enable the investigator to select representative case studies for each category, the different housing categories were defined in terms of average number of rooms, average number of appliances, and average household size

(a) Number of rooms per dwelling

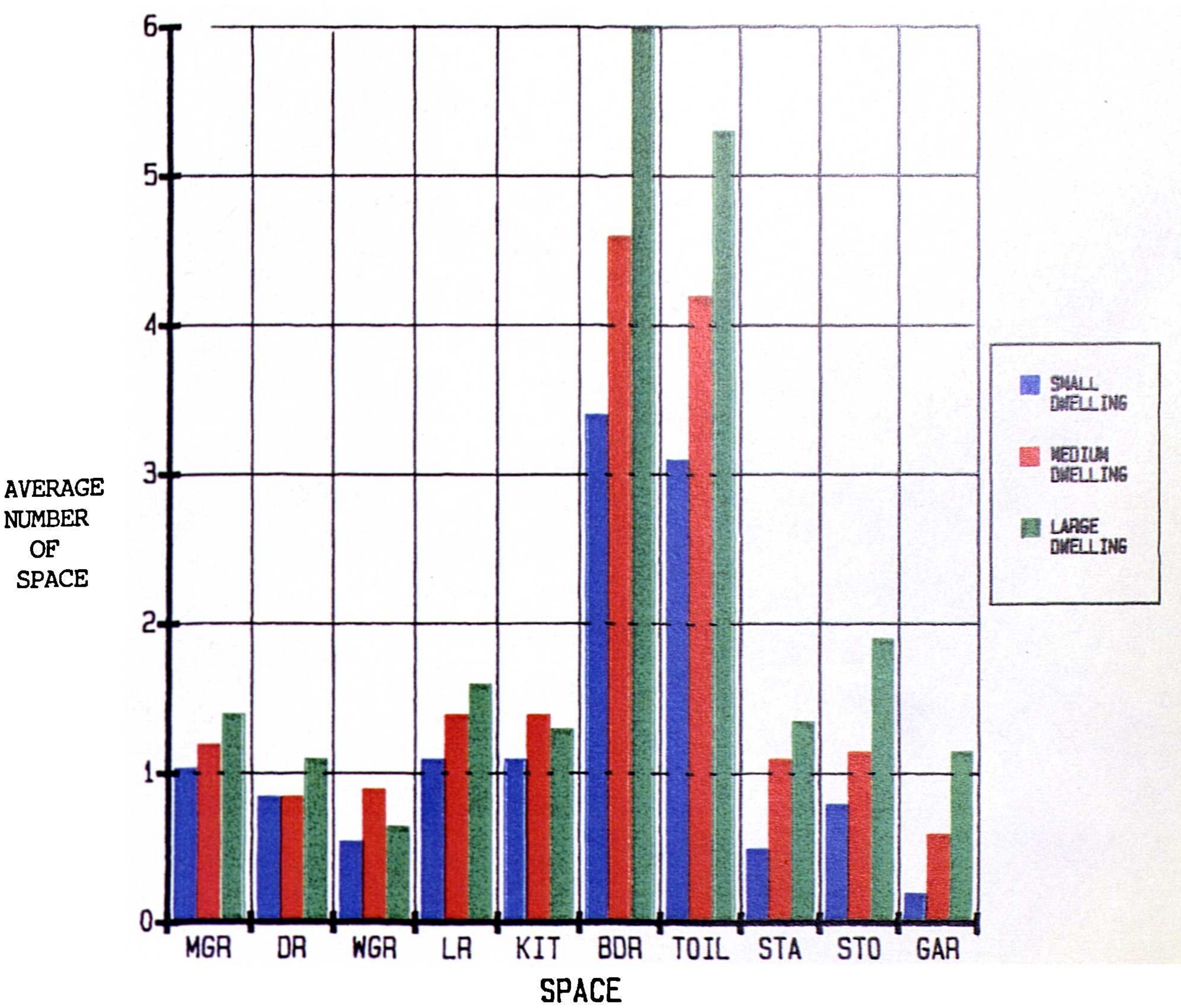
The housing stock built through the REDF in Dammam region is comprised of three housing categories, each having a different number of rooms relative to its size. The survey conducted on these three categories showed that they almost shared the same common rooms, which are the guest room, dining room, living room, bedroom, kitchen, toilet, storage and garage, with slight variations on their numbers and sizes due to the different dwelling areas. The average number of rooms per dwelling in each category resulting from the conducted survey is shown in Figure (6.2 a, b) and concluded in Table 6.1 as follows:

Table 6.1

The average number of rooms per dwelling in each category

ROOM	Average Number of Rooms per Dwelling Small Dwelling (0-300M^2)	 Medium Dwelling (300-800M^2)	 Large Dwelling (800 & over M^2)
Men's guest room (MGR)	1.04	1.2	1.4
Dining room (DR)	0.85	0.85	1.1
Women's guest room (WGR)	0.55	0.9	0.65
Living room (LR)	1.1	1.4	1.6
Kitchen (KIT)	1.1	1.4	1.3
Bedrooms (BDR)	3.4	4.6	6
Toilets (TOILET)	3.1	4.2	5.3
Staircase (STA)	0.5	1.1	1.35
Storage (STO)	0.8	1.15	1.9
Garage (GARAGE)	0.2	0.6	1.15

FIGURE 6.2: THE AVERAGE NUMBER OF ROOMS PER DWELLING



(b) Number of appliances per dwelling:

The energy consumed by any dwelling is very much influenced by the number of appliances and lighting available in the dwelling, due to their direct energy consumption and to the heat they generate inside the dwelling which, indeed, increases the cooling load of the dwelling. Therefore, in order to get a clear idea of the relationship between the energy consumed and the size of the dwelling, the number and size of the appliances were surveyed. From the evidence of the main survey carried out in 1987, figures 6.3 a, b illustrate the relative variations in the number of appliances in each category, which can be summarised in table 6.2 as follows:

Table 6.2

The average number of appliances per dwelling in each category

APPLIANCE	NUMBER OF APPLIANCES/DWELLING Small Dwelling	Medium Dwelling	Large Dwelling
Fridge & Freezer	1.3	1.6	1.5
Freezer	0.3	1.0	1.4
Gas oven	0.8	1.2	1.6
Electric Oven	0.2	0.4	0.6
Kettle	0.3	0.5	0.7
Washer	1.1	1.3	1.2
Dryer	0.7	0.75	0.8
Dishwasher	0.3	0.1	0.1
T.V.	2.0	3.0	4.0
Video	1.0	1.0	2.0
Air Conditioner	7.0	10.0	11.0

Note: Any appliances averaged below 0.55 will be equal to zero.

FIGURE 6.3a: THE AVERAGE NUMBER OF APPLIANCES PER DWELLING

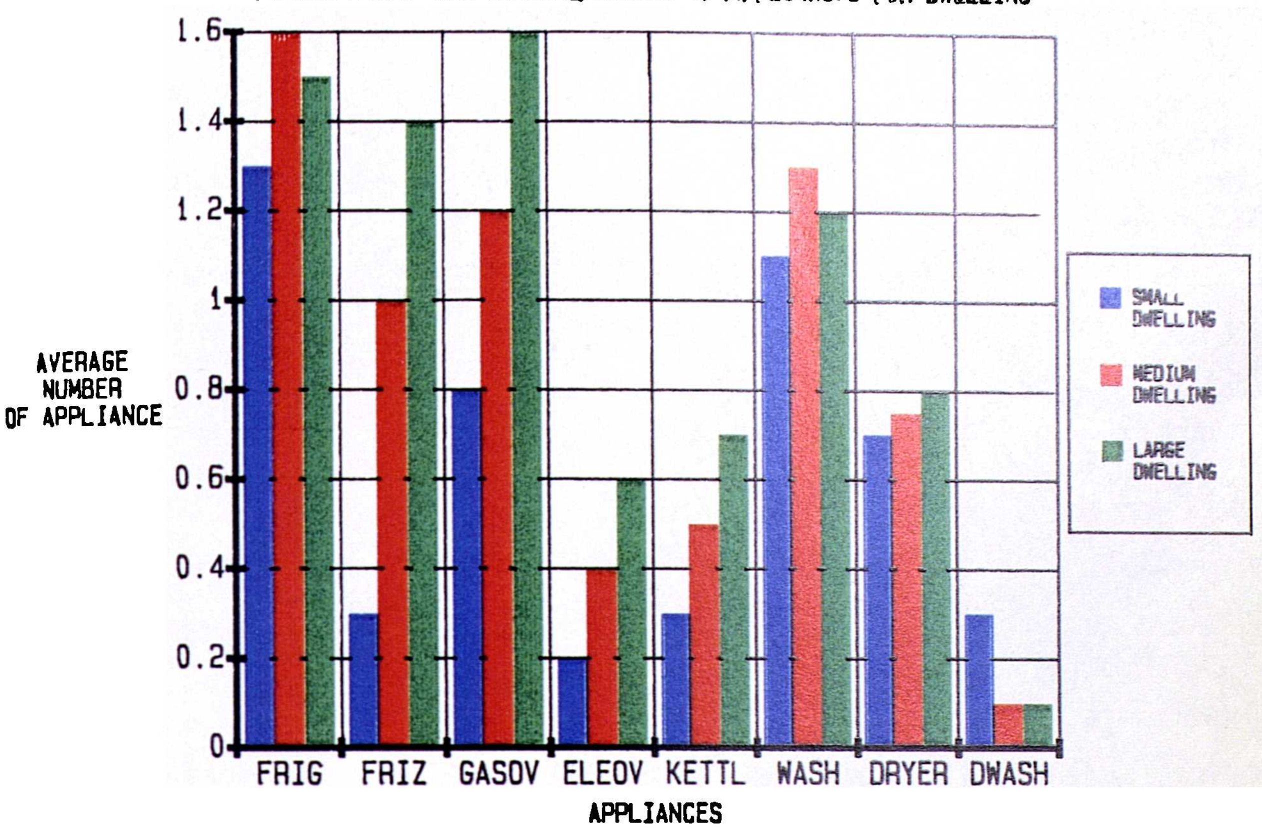
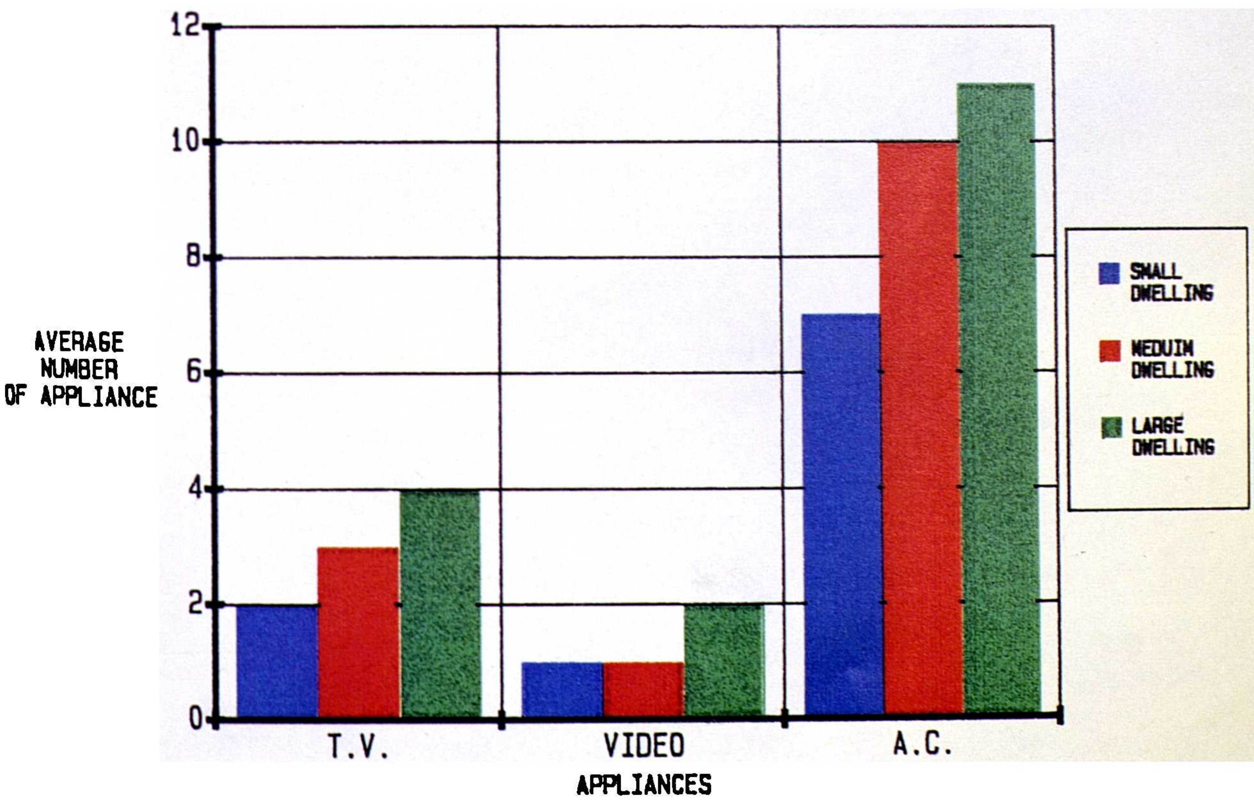


FIGURE 6.3b: THE AVERAGE NUMBER OF APPLIANCES PER DWELLING



(c) Average size of household per dwelling:

The necessity of surveying the size of the household was because of the importance of the amount of heat emitted by the occupants and their frequent use of the appliances and spaces. Usually, the persistent usage of appliances and spaces in the dwelling due to the large number of occupants lead to high energy consumption. Moreover, in a Saudi society where the extended family is very common, it is very hard to generalise or even to control the size of the household. For these reasons the household of each dwelling category was determined and averaged in order to specify the average number of occupants per dwelling in each category.

Table 6.3 presents the factual average number of occupants per dwelling category. The small, medium and large dwelling categories accommodate about 6.35, 7.99, 8.6 persons per dwelling respectively. These figures were averaged over the range of 2 to 9, 4 to 14 and 5 to 17 persons per dwelling respectively. Therefore, the number of households in the selected case studies should be not less than the specified average for each category, but it could be more than the average for more confidence.

Table 6.3

Average Occupants per dwelling in each category

CATEGORY	Average number of persons per dwelling		
	Mean	Mode	Median
Small house	6.35	4	6,000
Medium house	7.99	6,000	7,000
Large house	8.6	7,000	7,000
Overall	7.721	6,000	6,000

6.7.3 User behaviour

Among the important factors that affect the building's thermal performance are the users' behaviour and their attitude towards saving energy. In fact, the degree of saving energy is very highly related to the users' behaviour and their awareness of the necessity for reducing energy consumption. Therefore, the users' behaviour inside the dwelling was observed and recorded carefully with very high secrecy due to the protection of the people's privacy. Despite all the effort spent and the amount of information collected, only a few things, the cooling system usage time and type and the effort made to save energy, received the consent of the people for publishing.

(a) Cooling system usage time and type:

Generally, the different rooms in a dwelling are used for different activities and purposes, and also they are used at various times of the day for different periods of time. Therefore, in order to get a reasonable estimate of the energy consumed by the dwelling, the type of the cooling system used and the duration of usage were surveyed in this study. The survey showed that the cooling system usage time specified for each room is shared by almost all the surveyed dwellings, which makes the usage time common among all three categories, due to the high percentage result from the analysis in figure 6.4. The similarity in the usage time among the various dwellings could be a result of the uniformity of the people's working hours and social values. Actually, the survey summarised the common cooling system usage time in different parts of the surveyed dwellings as follows:

	Room	The Time the Cooling System is Used
1.	Men's guest room	"evening" between 17-23 hours
2.	Dining room	"evening" between 20-22 hours
3.	Women's guest room	"morning" between 10-12 hours
4.	Living room	"most of the day" between 8-23 hours
5.	Kitchen	"afternoon & evening" between 12-14/ 18-20 hours
6.	Bedroom	"afternoon & night" between 12-16/23-8 hours
7.	Staircase	"all day" 24 hours ventilation
8.	Storage	"all day" 24 hours ventilation

FIGURE 6.4: THE PERCENTAGE DISTRIBUTION OF THE DIFFERENT ROOMS' COOLING TIME

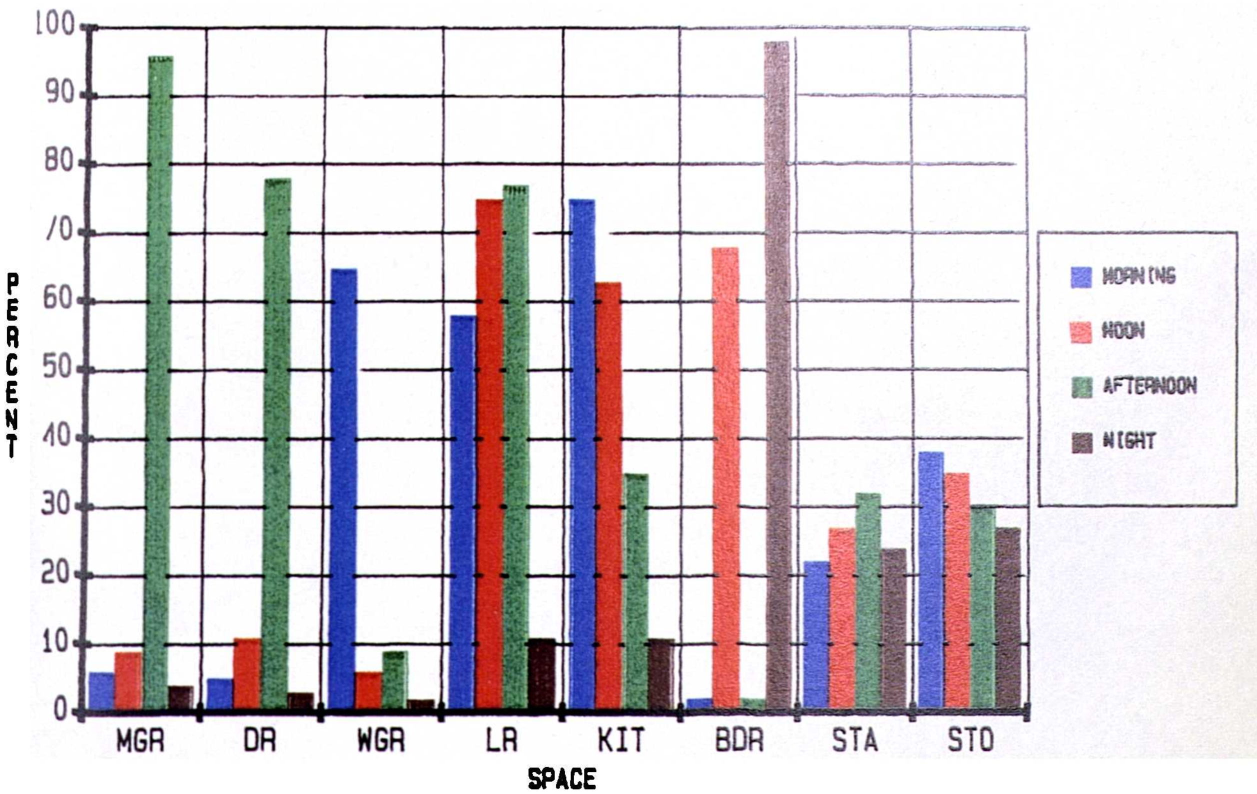
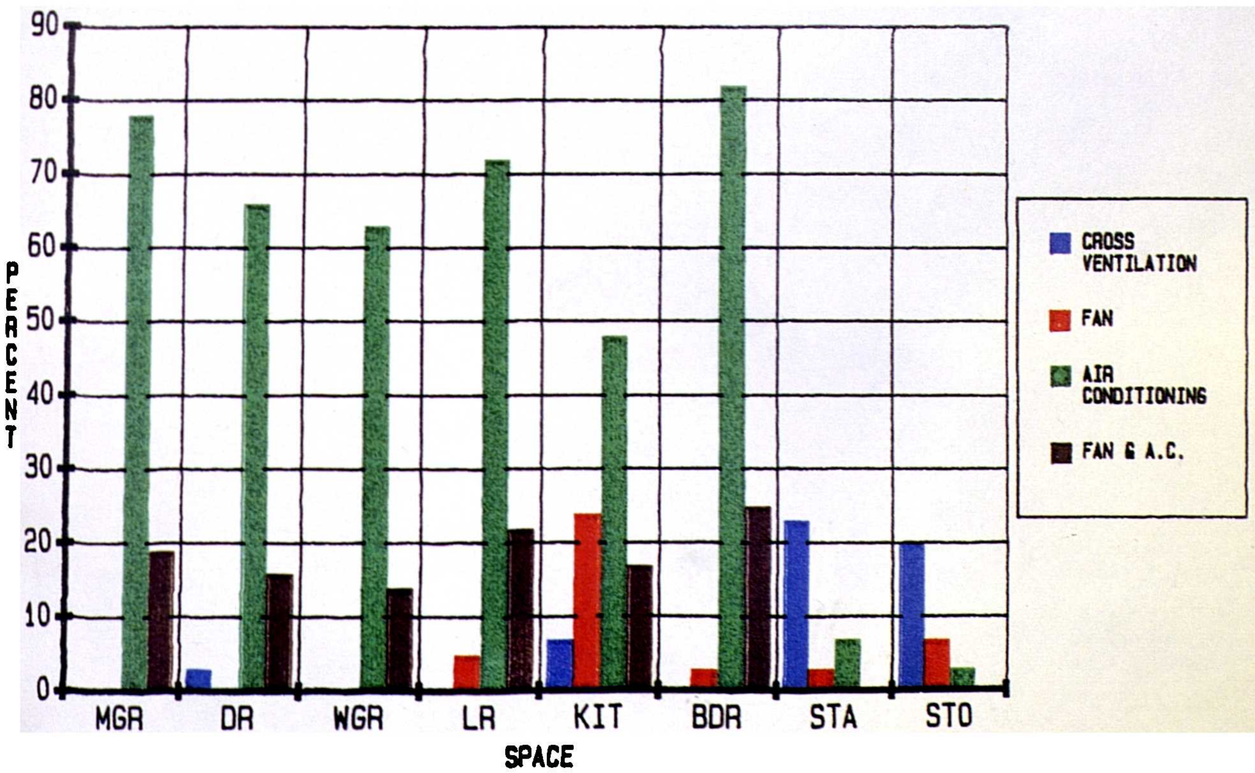


FIGURE 6.5: THE PERCENTAGE DISTRIBUTION OF THE DIFFERENT COOLING SYSTEMS USED IN VARIOUS ROOMS



Since there are several types of cooling systems which can be used in cooling the dwellings, and each cooling system has a different energy consumption, it is very important to identify specifically the different types of cooling systems used in the dwelling. The survey which has been conducted on various dwellings in Dammam region, showed that about 65 to 79% of the respondents were using only air conditioning units in cooling the different parts of their dwellings, except for the storage and staircase. The remaining 21 to 30% of the respondents were using a combination of air conditioning units and fans in cooling their dwellings (see figure 6.5).

Generally, all respondents were using air conditioning units, either alone or with the assistance of fans, to cool their dwelling and to condition the hot climate to their comfort. The intensive use of air conditioning units to ease the hot climate is a result of either the poor thermal performance of building materials, or a high rate of infiltration.

(b) <u>Efforts to save energy</u>

The survey, which was conducted on 500 sample dwellings, was very successful in illustrating the problems of wasting energy. It showed that the people in Dammam region did not use insulation to improve the thermal performance of the dwelling, and they did not allow cross ventilation to circulate the air and prevent the heat from accumulating inside the house (see figure 6.6). The efforts made by those people were very limited in using fewer rooms and reducing infiltration, which becomes ineffective effort due to the frequent movement of the children.

6.7.4 <u>People's attitudes</u>

The people's attitudes, in most cases, refer to the sum total of their inclinations, ideas, fears, and beliefs about specific topics. Usually the individual's attitudes are expressed in speech or behaviour when the object of the attitude is perceived. However, the attitude itself can be described by its content, its direction and its intensity. Generally, in this study the people in Dammam region were asked to express their attitudes towards certain phenomena related to their comfort and dwellings. These phenomena, which are, the perceived summer months, the comfort condition inside their dwellings, the efficiency of the means of solar control, and view, privacy and natural lighting, were discussed and presented as follows:

(a) Perceived summer months

In most parts of the world, the climatic seasonal variations are very clear, where all four seasons can easily be distinguished. But unfortunately, the seasonal variations in Dammam region are only limited to two seasons - spring, which is short, and summer which occur for most of the year. The survey revealed that almost 90 to 100 per cent of the respondents said that the perceived summer months were May, June, July, August, September and October. Also about 50 to 55 per cent of the respondents said that April and November were also included in the perceived summer months, where only about 33 per cent of the respondents perceived March as a summer month. Consequently, as a conclusion of the respondents' attitudes, it was obvious that the perceived summer period extends from April up to November, which increases the cooling season to be up to three quarters of the year, indicating the length of the summer season (see figure 6.7).

(b) Comfort condition and efficiency of the means of solar control means:

The temperature in Dammam region is always high, reaching up to 46^{o}C during the summer period which covers most of the year; the length of the overheated period makes it impossible for the people to adapt to the hot climate without the help of air conditioning units. The majority of the respondents (85 per cent) felt that their dwellings were uncomfortable even with the use of air conditioning units (see figure 6.8). The necessity of using air conditioning units to modify the dwelling's internal condition, indicated the poor thermal performance of the dwelling, which could be due to the poor building materials or the poor passive cooling design.

FIGURE 6.6: THE PERCENTAGE DISTRIBUTION OF THE DIFFERENT MEANS IMPLIED IN DWELLING TO MINIMISE THE ENERGY CONSUMPTION

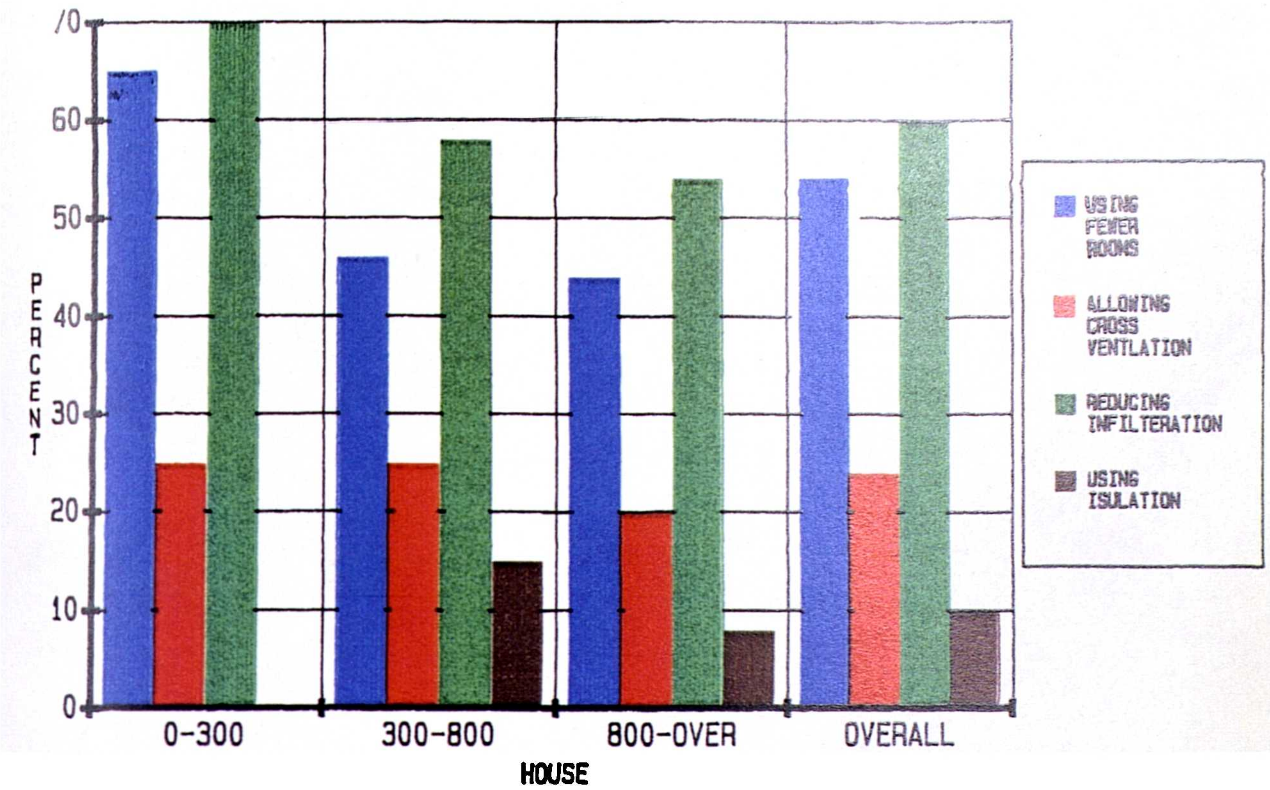


FIGURE 6.7: THE PERCENTAGE DISTRIBUTION OF THE DIFFERENT COOLING SYSTEMS USED IN VARIOUS ROOMS

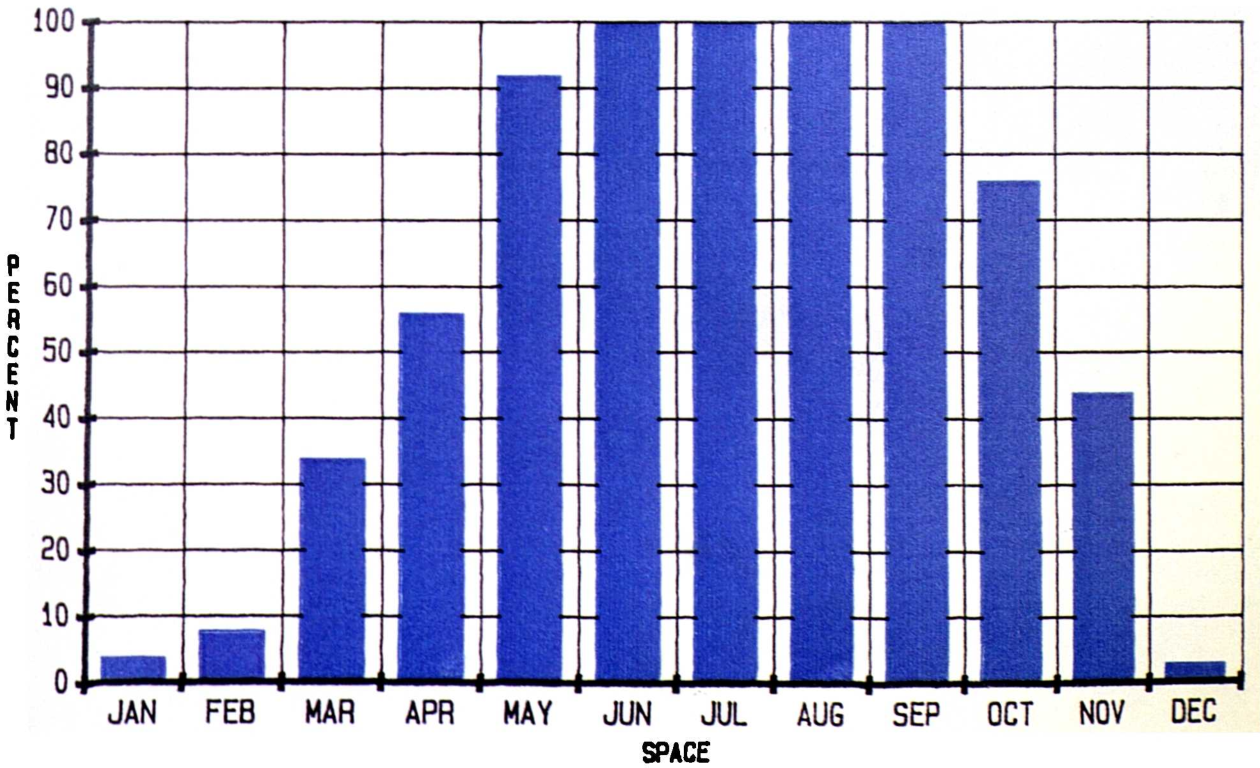


FIGURE 6.8: THE PEOPLE'S ATTITUDES TOWARD THE CONDITION OF THEIR DWELLING DURING THE SUMMER TIME WITHOUT THE USE OF A.C. SYSTEMS

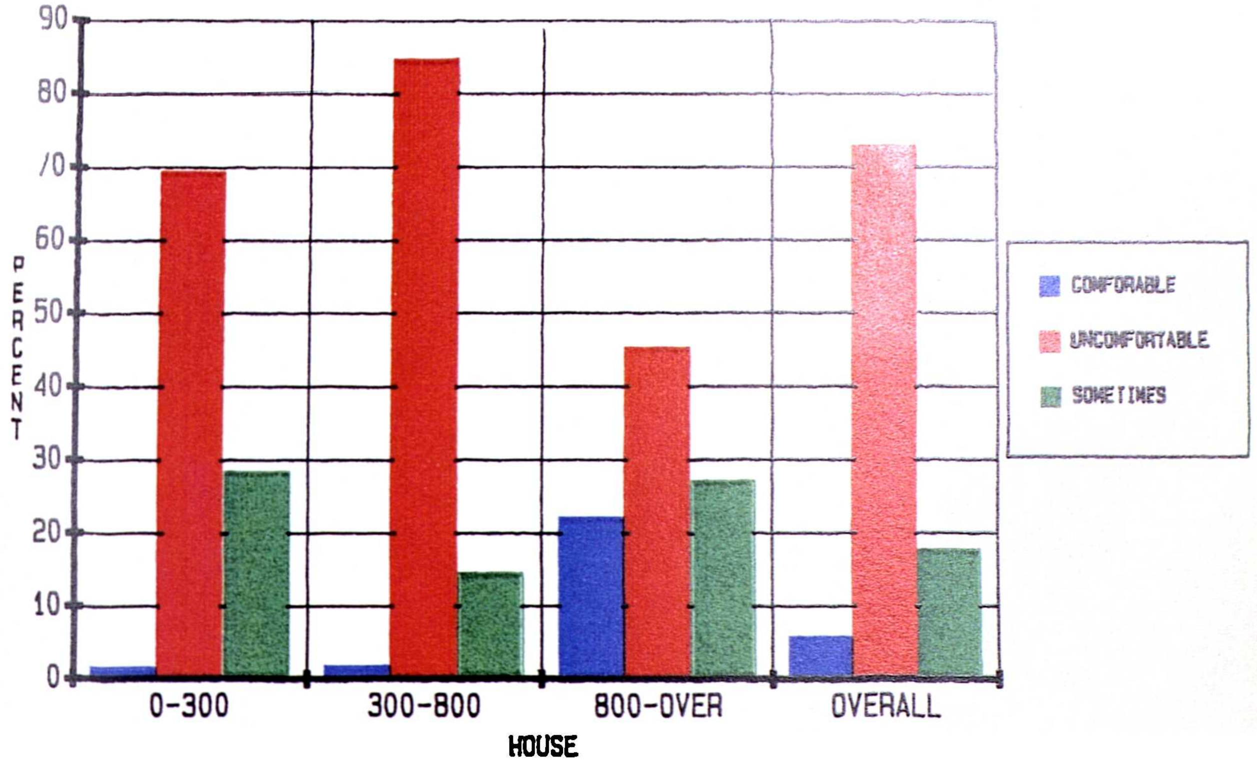
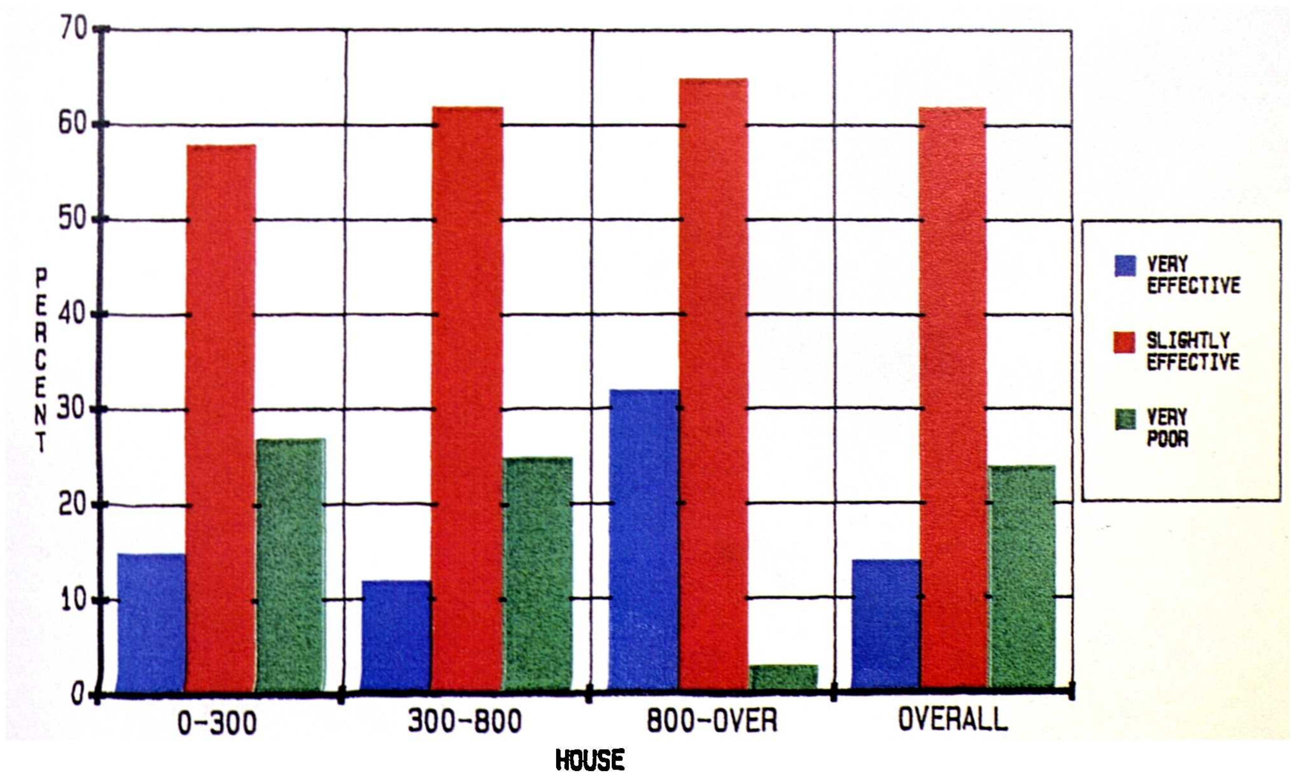


FIGURE 6.9: THE PEOPLE'S ATTITUDES TOWARD THE EFFECTIVENESS OF THE SOLAR CONTROL MEANS THEY HAVE USED IN THEIR DWELLINGS



The quality of saving energy and achieving comfortable conditions do not depend only upon using air conditioning units and some solar control means such as curtains, blinds, louvers, plants or reflective glass, but also depend upon the efficiency of these control means. Several climatic attribute variables related to the dwelling were presented to the respondents who were asked to evaluate them in terms of their efficiency. As shown in figure 6.9, the majority of the respondents said that the overall solar control means were slightly effective and some others were very poor; the lack of efficiency could be interpreted as either the people did *not know how to* use the solar control means properly or they did not choose the right materials for such a climate.

Generally, the problem seems to be related to the performance of the building envelope and the consciousness of the people in selecting adequate materials and using the available solar control means properly.

(c) <u>View, privacy and natural lighting</u>

As an important aspect in every society, privacy plays a major role in people's lifestyle, and is manifest in the way they arrange their dwellings in order to maintain a certain level of privacy. Usually, being able to see outside through a window is a very pleasant thing to do, especially if the view is worthwhile, but if the effect of the heat gain through the window is more than the enjoyment of the view, then this view is not worthy. Therefore, the people in Dammam region were asked to express their attitudes towards privacy, view, and natural lighting.

In reference to the view and privacy, the actual survey showed that the view to the outside is a preferable, but not an important aspect to the respondent's lifestyle, where the overall attitudes were almost split between 'slightly desirable' and 'it does not matter' (see figure 6.10a). At the same time and when the matter was associated with privacy all the respondents showed that they were highly in favour of achieving privacy at any cost (see figure 6.10b).

Apart from view and privacy, natural lighting, whether by preference or by necessity, is very beneficial for saving energy, as long as it is not associated with glare or intense heat. In a sunny region such as Dammam region with clear skies almost all the days of the year, indirect natural lighting is recommended. Unfortunately, the designers' ignorance of the cumulative heat gain through the window led them to design dwellings with large windows in all directions to get a good dwelling appearance with no respect to the motion of the sun. As a result, most of the respondents were suffering from the brightness of the incoming light, which increases the direct heat gain dramatically and reduces the thermal performance of the envelope due to the large glass opening (see figure 6.11).

Finally, view, privacy and natural lighting, all three are related to the necessity of the window and its limitation. As far as the amount of the external openings in the dwelling is concerned, and as a result of the *respondents' attitudes towards privacy and glare*, it is more desirable in hot climatic areas, under a sunny clear sky, to reduce the amount and size of the openings in the exterior exposed walls of the dwelling. Usually, the small openings protect the dwelling more against the dust and sand storms in the region, and minimise the heat gain during the daytime.

FIGURE 6.10a: THE PEOPLE'S ATTITUDES TOWARD THE NECESSITY OF BEING ABLE TO LOOK OUTSIDE

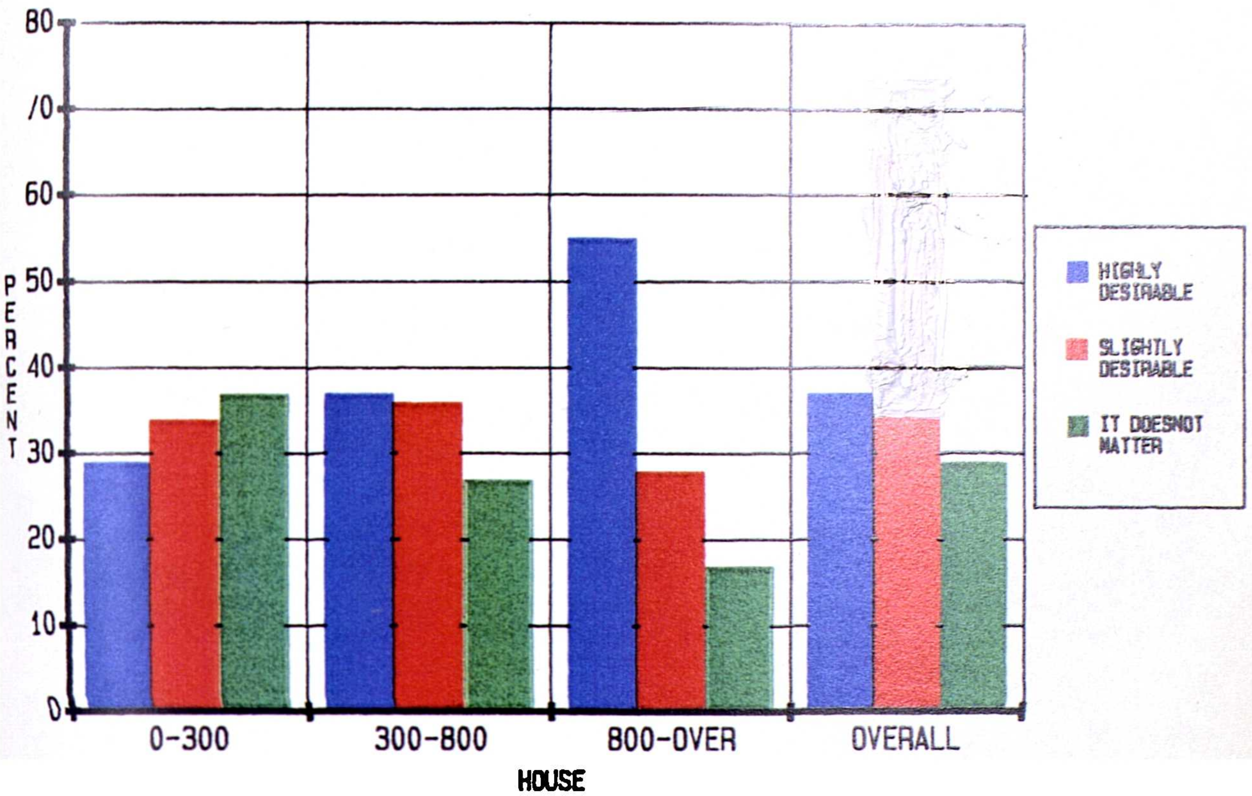


FIGURE 6.10b: THE PEOPLE'S ATTITUDES TOWARD PREVENTING OVER-LOOKING FROM OUTSIDE AND ACHIEVING PRIVACY

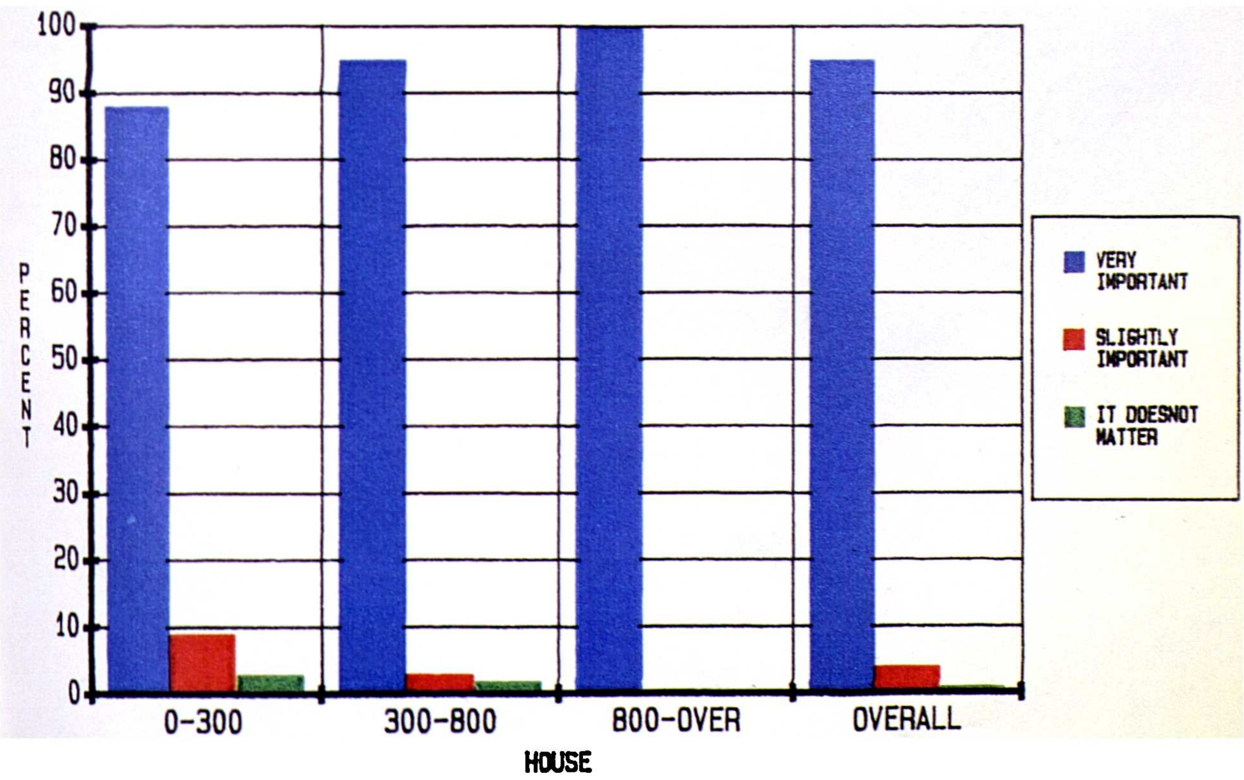
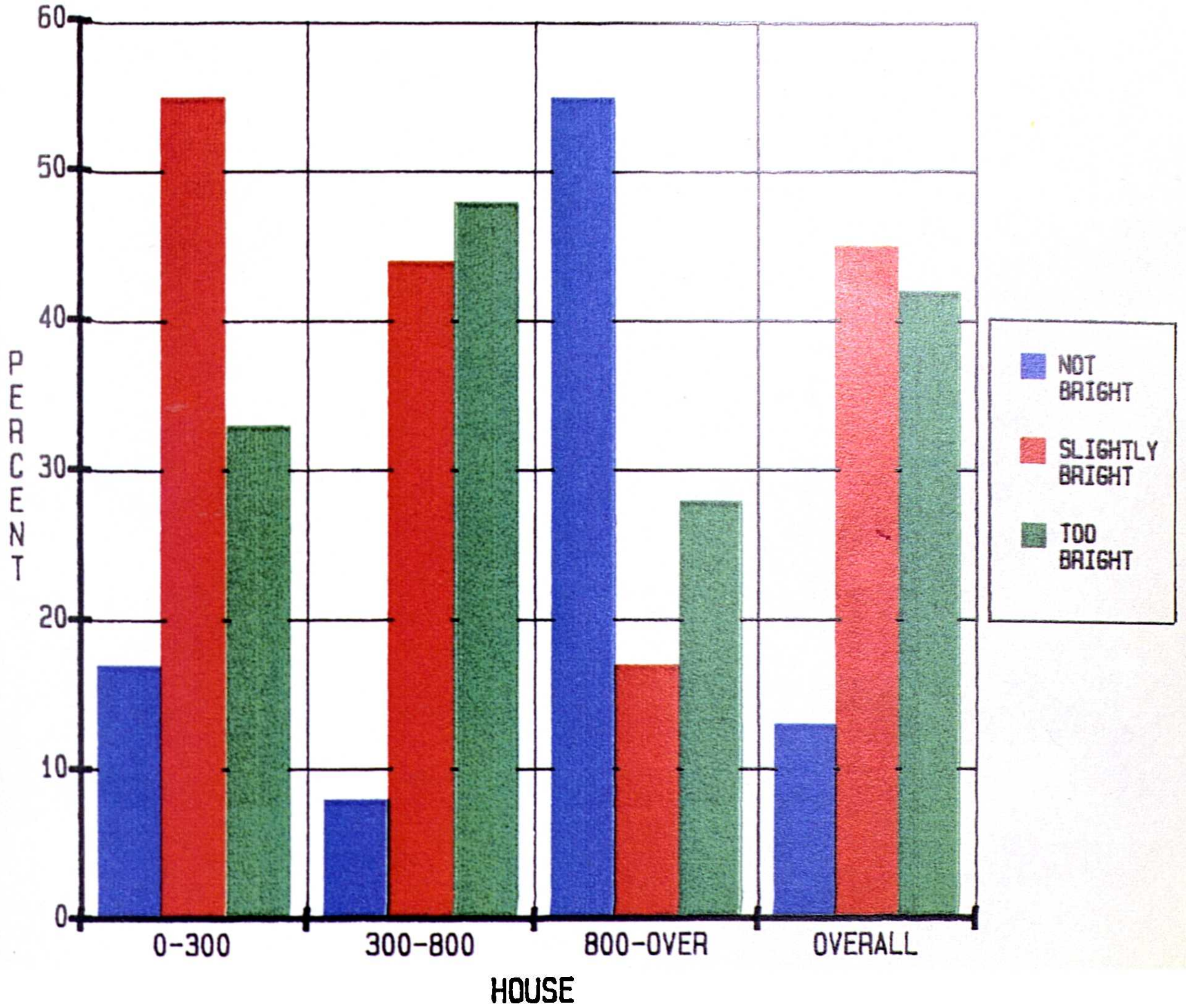


FIGURE 6.11: THE PERCENTAGE DISTRIBUTION OF THE PEOPLE'S ATTITUDES TOWARD THE INCOMING LIGHT AND ITS INTENSITY



6.7.5 <u>Analysis of uncomfortable warmth</u>

The information on being comfortable during the summer within the house is sought by Q14a which is:

Do you feel uncomfortably warm in summer within the house without the use of air conditioning?

Respondents were asked to answer to choose as follows:
Never, slightly uncomfortable, definitely uncomfortable.

The responses to the question indicate that 95 per cent of the respondents were uncomfortably warm during the summer (87 per cent definitely and 8 per cent slightly), while only 5 per cent were not. This high percentage of discomfort encouraged the investigator to test the annoyance with some other variables to see the possible relationship involved, which might give some clue to explain this phenomena.

The degree of discomfort was cross-tabulated against several variables which were orientation, area, energy consumption, total number of appliances, using fewer rooms than needed, allowing cross ventilation, reducing infiltration and using insulation materials, thought to be having some relationship to the high percentage of the discomfort. The result of the cross-tabulation, summarised in table 6.4, revealed that orientation, energy consumption, using fewer rooms than needed, and reducing infiltration were independent variables due to their poor level of significance in relation to their Chi-square. On the other hand, it revealed that area, total number of appliances, allowing cross ventilation and using insulation have some relation with levels of discomfort where it is directly dependent upon those variables. The authors' interpretation of the relationship between the discomfort and these variables is discussed as follows:

Table 6.4 : The level of significance of various variables which were cross-tabulated against uncomfortable warmth in Summer

VARIABLE	The effect of the discomfort		
	Chi-square	Degree of Freedom	Level of Significance
Orientation of the house	1.92508	2	0.3819
Area of the house	74.96276	4	0.0000
Energy consumption of the house	5.4477	4	0.2444
Total number of appliances in the house	41.76729	6	0.0000
Using fewer rooms than needed	3.27481	2	0.1945
Allowing cross-ventilation into the house	5.3796	2	0.0679
Using insulation materials in the envelope	5.95086	2	0.0510
Reducing infiltration in the house	3.7706	2	0.1518

(a) Area

The analysis of the responses on discomfort by the size of the area provided a reasonable argument which may reveal the existence of their relationship. The cross-tabulation of these two variables verified that as long as the area of the house increased, the number of uncomfortable people increased accordingly. This fact could be seen in table 6.5 where the proportion of the uncomfortable people to the comfortable ones was 5 to 1 in the large area houses, and 2 to 1 in the small area houses. Several interpretations were put forward to explain the relationship between these two variables. Firstly, the heat gain through the fabric could be higher in the large houses due to the large exposed envelope to the sun, which consequently produced more discomfort in the large house. Secondly, the size and number of spaces needing to be cooled in the large houses were more than the spaces in the small houses. Therefore, the occupants of the large houses do not run the cooling system at high efficiency due to the increase in energy consumption which leads them to suffer more discomfort. Thirdly, the large open spaces between the large houses reduced the chance of getting some shading from the neighbouring buildings, which again increases the heat gain. Finally, due to the lack of enough data on this particular issue, these interpretations will not be carried further in this survey analysis, but they might be considered later on during the cooling load's calculation procedures.

Table 6.5 : Cross-tabulation summary of uncomfortable warmth in summer against area.

UNCOMFORTABLE WARMTH IN SUMMER		AREA IN SQUARE METRES 300 or less	301 to 800	801 and over*
Never	Row Pct	16.7	33.3	50
	Col Pct	1.8	1.1	22.3
Slightly	Row Pct	34.8	58.2	6.5
	Col Pct	28.6	14.8	27.3
Definitely	Row Pct	19.7	77.8	2.5
	Col Pct	69.6	84.2	45.5

* The number of houses in this category is very small compared with the other categories.

(b) Total number of appliances

The number of appliances in each house and the level of discomfort the people tend to suffer were crosstabulated against each other to declare the type of relationship and to provide a logical explanation for the presumed relation. The analysis of the crosstabulation of these two variables showed that the increase in the number of appliances in the house was associated with an increase of the level of discomfort; for instance, the percentage of the people who tend to suffer more discomfort increased among the occupants of the houses which held more appliances, where the proportion of the very uncomfortable people to the slightly uncomfortable ranges from 11 to 1 and 5 to 1 in houses which held large numbers of appliances, and 5 to 1 and 2.5 to 1 in the houses which held small numbers of appliances (see table 6.6). This phenomena could be interpreted as follows:

1. Since the appliances radiate heat into the house, so the more numbers of appliances in the house the more heat is transmitted into the internal environment, which could increase the level of discomfort inside the house.

2. The level of discomfort in those houses may arise from the low efficiency of the cooling system, which results from the shortage in the electric current reaching the cooling system due to the high consumption of the electrical appliances in the house.

3. The overall high energy consumption of the house, due to the large number of appliances, discourages the people from running the cooling system at full output in order to cut down the energy consumption bills, and this may produce the discomfort in the house.

Table 6.6 : Cross-tabulation summary of uncomfortable warmth in summer against total number of appliances.

UNCOMFORTABLE WARMTH IN SUMMER		TOTAL NUMBER OF APPLIANCES PER HOUSE 1-15	16-20	21-25	26-47
Never	Row Pct	16.7	16.7	0	66.7
	Col Pct	1.1	1.3	0	1.6
Slightly	Row Pct	50.0	28.3	8.7	13.0
	Col Pct	26.4	16.8	8.2	16.2
Definitely	Row Pct	32.0	31.7	22.7	13.6
	Col Pct	72.4	81.9	91.8	73.0

(c) Allowing Cross-ventilation:

The survey showed that the majority of the respondents did not use cross-ventilation to cool their houses, or even to exhaust the accumulated heat during the day. In order to investigate the effect of cross-ventilation on the people, it was cross-tabulated against the discomfort of people. The cross-tabulation of these two variables showed that 80.5 per cent of the respondents who did not use cross-ventilation were suffering from discomfort, where only 55 per cent of those respondents were using cross-ventilation suffered discomfort (see table 6.7). Therefore, an increase in reduction of cross-ventilation in the house is associated with an increase in the level of discomfort among the people and this could be explained as follows:

1. The high percentage of uncomfortable people among those who did not use cross-ventilation in the house was due to the fact that the daily heat gain is trapped inside the house and accumulates which may produce uncomfortable internal conditions.

2. The lack of adequate cross-ventilation reduces the interchange of fresh air between the outside and the inside environment, which increased the discomfort level due to the concentration of the moisture content in the inside air.

Table 6.7 : Cross-tabulation summary of uncomfortable warmth in summer against allowing cross-ventilation.

UNCOMFORTABLE WARMTH IN SUMMER		ALLOWING CROSS-VENTILATION Yes	No
Never	Col Pct	19.8	1.6
Slightly	Col Pct	35.2	17.9
Definitely	Col Pct	55.0	80.5

(d) <u>Using insulation material</u>:

The discomfort of people inside the house is related to the availability of insulation materials in the envelope, due to their effect on improving the thermal performance of the building. The relation between using insulation material and the discomfort of people was defined by cross-tabulating one against the other. The analysis of this cross-tabulation revealed in table 6.8 that 77.8 per cent of the respondents who were not using insulation materials in their buildings experienced discomfort, where the remaining percentages were either slightly uncomfortable or reasonably comfortable. On the other hand only 36.7 per cent of the respondents who were using insulation materials in their buildings suffer discomfort and the remaining percentages were either slightly uncomfortable or reasonably comfortable. This result showed the strong relation between discomfort and the lack of use of insulation materials in the house. The obvious explanation of the high percentage of discomfort among the people who were not using insulation materials in their houses was as follows:

1. The high thermal conductivity of the building envelope due to the absence of insulation materials allows more heat gain into the house which results in people's discomfort.

2. Due to the poor thermal performance of the building envelope the internal temperatures responded quickly to the fluctuation of the external temperature which creates uncomfortable internal environments.

Table 6.8 : Cross-tabulation summary of uncomfortable warmth in summer against using insulation materials.

UNCOMFORTABLE WARMTH IN SUMMER		USING INSULATION MATERIALS Yes	No
Never	Col Pct	22.4	2.4
Slightly	Col Pct	31.9	19.9
Definitely	Col Pct	36.7	77.8

6.7.6 Respondents' general comments about their dwellings.

As a conclusion of the standardised questionnaire, an open ended question was forwarded to the respondents to explore their feelings and points of view towards their dwelling, neighbourhood and community and to add any other comments they may wish to say. Fortunately, a reasonable percentage of the surveyed people responded to the question as expected, and the direct translation of their comments is as follows:

1. One hundred and sixty respondents said that the house is always very hot, which makes them use the air conditioning units all day long.

2. Ninety-three respondents said that "the use of window type air conditioning units does not enable us to control the temperature in most of the spaces in the house, due to the absence of thermostat control, and this creates temperature differences between those spaces which, in turn, causes "flu and rheumatism".

3. Thirty-six respondents said that "the lack of plants on the street and the large pavement increase the heat around the house".

4. Nineteen respondents said that "the sunlight coming into the house is very bright and makes the place unsuitable for sitting during the daytime"; also they said that "this is a very common problem for the houses built off the street".

5. Two hundred and eleven respondents said that the absence of open green areas and public parks in the community creates problems for the children as well as their parents in avoiding the danger of sunstroke and traffic accidents.

6. Two hundred and twenty seven respondents said that the balcony has never been used except as a storage place because of the over looking problem which breaks the neighbours' privacy. Also they said it is a dangerous place where the children may jump out as well as being a place where sand and dust may gather.

7. One hundred and sixty-three respondents said that the house becomes hot immediately after the air conditioning units are turned

off, which urge them to use the air conditioning units all day.

8. One respondent said that "I am a tenant and the house is not worth commenting on".

9. One hundred and forty-one said that "there is no insulation in our houses because it is expensive and we know little about it". Similarly ninety-two respondents said that "apart from the fact that we have little experience in choosing insulating materials, we did not even bother insulating because we did not realise how hot the house was until we moved in".

10. Seventy-three respondents said that "the house yard is very hot and the surface of the passageway around the house is very hot too. Also the water is very hot and remains hot until midnight".

6.8 Summary

Survey and analysis are two complementary factors in any social sciences experimentation. Generally, the conducted survey specified the characteristics of the different dwelling types in Dammam region, and illustrated some of the observed problems related to the quality of the dwellings' thermal performance. In the light of the findings and the respondents' comments, it comes as no surprise that most of the respondents were suffering from discomfort as well as high energy consumption during the summer time. These two factors resulted from many problems taking place at the same time at the level of the dwelling as well as the community.

To have more grasp of the problem and to identify it more carefully, the housing stock in Dammam region was categorised into three dwelling categories, each of which was defined specifically by the number of rooms, the number of appliances and the size of the household. In accordance to the specification provided for each category of the housing stock in the region, the case studies were selected more carefully to represent the different categorical housings. These case studies will be studied in detail to identify the problems involved in the high energy consumption and to simulate them to see the possible potential in saving energy.

The occupants' behaviour participated, in one way or another, in the domestic energy crisis. Usually, the occupants' behaviour varies from one society to another, and from one person to another. In fact, the survey analysis indicated that the majority of the people in the region have some similarity regarding the cooling system used, as well as the usage time of the cooling system in the different spaces in the house. However, the analysis proved that most of the people did not make enough effort to reduce the heat gain inside the house, or even cool it passively. The lack of effort spent could be due to the people's insensitivity of using the different ways of saving energy, such as using insulation materials in the building envelope, using fewer rooms than needed, allowing cross-ventilation and reducing infiltration inside the house.

People's attitudes and preferences are useful indicator for reflecting the people's living reality and indicating the degree of the problem from which they are suffering. Actually, most of the people in Dammam region indicated that they could not stand the region's hot climate without using air conditioning units to adapt the house's internal condition, bearing in mind that the hot summer period is extended to over two thirds of the year (eight months). Also they showed their apprehensiveness towards the brightness of the incoming light into the house, which increases the heat gain due to the direct incidence of the solar radiation.

Discomfort of people was studied in detail to find out the associated factors in creating the uncomfortable conditions inside the house. The uncomfortable conditions cannot be circumscribed by only one factor, but actually are as a result of several factors affecting the house conditions. The cross-tabulation of these factors, which are the area of the house, the number of appliances, the cross-ventilation, and using insulation materials, against the people's discomfort, showed positive relationships on affecting the degree of discomfort among the people. It showed that the increase in area and in numbers of appliances is associated with an increase in the level of discomfort among the people; also it showed that the lack of allowing cross-ventilation and using insulation materials in the house resulted in a very poor thermal performance building, which allowed more discomfort to occur inside the house.

Finally, the awareness of the problem is the half-way solution; by reviewing the survey analysis, it could be concluded that the main problem which caused the annoyance of the people is on the increase of heat gain inside the house which consequently increases the energy consumption of the house. The actual increase of the heat gain inside the house is a consequence of several factors affecting the house's internal conditions. These factors, which were believed to have more effect on the heat gain, were the poor thermal performance of the building envelope and the people's insensitivity towards selecting adequate insulation materials and using the solar control means properly. The problems of the increase in heat gain will be discussed and investigated in more depth in the following chapter on the selected case studies.

FOOTNOTES

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3. Nachmias, C. and Nachmias, D. (1981)
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CHAPTER 7

CHAPTER 7

ANALYSIS OF SELECTED CASE STUDIES

7.11 Case Study III-B (H6)

- 7.11.1 House Conditions
- 7.11.2 Energy Used
- 7.11.3 Cooling System
- 7.11.4 Efforts Achieved in Saving Energy

7.12 House Details

7.13 Findings

7.14 Conclusion

ANALYSIS OF SELECTED CASE STUDIES

7.1 Introduction

The current interest in energy conservation in the home, due to the latest economic weakness of the country, has reinforced the need to be able to assess the effects on energy consumption and internal conditions of various energy saving measures. It is not sufficient, when examining the energy consumption of housing, to rely on the subjective and general survey alone, which can be obtained directly by asking the residents about their own perception and satisfaction with their residential environment. Rather, it is more important to identify the objective quantifiable features of the house. Moreover, it is important to base the study on more detailed analysis of a few houses which can represent the whole set of surveyed houses. Therefore, the model used in this study has mainly two stages. The first stage is when an individual evaluates his current house situation and his attitude towards the consumed energy by answering a questionnaire. The second stage is a detailed analysis of some chosen case studies to identify the different problems in saving energy.

In this chapter of the study, the three categories of the surveyed houses are represented by six case studies. The two cases in each category, which have been investigated in detail, will be analysed and evaluated to determine the different problems in consuming more energy. The analysis is based upon the major aspects which might effect the quality of saving energy; those major aspects are urban configuration, house conditions, the materials of the house envelope, the inhabitants' daily activities and the house details.

7.1.1 Urban Configuration

The urban configuration of the house within the community is of very great significance in saving energy. Its importance relies on the shade cast on the house by the neighbouring houses. Also, the house orientation and the height of the surrounding buildings affect the quality and quantity of the received wind and sun which are the most critical elements in passive cooling. Furthermore, the type of surfaces surrounding the house can increase or decrease the intensity of the reflected solar radiation into the house. Therefore, the urban configuration of the house is considered as one of the criteria according to which the case studies will be analysed.

Generally, the urban density of Dammam region is medium-sized, with one to two-storey concrete block buildings. These are mostly rectangular with flat roofs, balconies and high surrounding walls which create inner courts and areas, directing light inwards rather than outwards. Some of these courtyards (set back) are planted, but most are paved due to the narrow space between the buildings.

7.1.2 House Conditions

The phenomenal rapid development of housing in Saudi Arabia has given the people an experience of many types of housing, starting with the traditional housing, passing through the transitional and reaching contempory housing. Nowadays, the majority of the new houses occupied by an average Saudi family tends to be of villa-type houses which are individually designed and constructed. This individuality has produced different types of size, form and design of houses. Since the house conditions have a direct effect on the energy consumption of any house, it becomes very essential to investigate in detail the house conditions including the house size, the number of occupants, the level of education between the inhabitants, and the form and design of the house.

7.1.3 Inhabitants' Daily Activities

The human body always produces heat by its metabolic processes, but the amount of heat produced varies from male to female and from adults to children. Furthermore,the heat emission from the human bodies depends also upon the degree of activity. Moreover, since the temperature of the human body should be kept constant at about 37°C, any extra heat will be dissipated to the environment by conduction, convection,radiation and evaporation. Therefore, the type of activity and its duration are very important in predicting the heat input by the inhabitants and reflecting their different uses of spaces.

7.1.4 House Details

The house details are the most important part in calculating the energy consumption of any house for both cooling and heating. These details are the materials and dimension, ventilation rate, mean internal and external temperatures, appliances and internal gain.

The materials and dimensions should be very well investigated because the amount of heat gain depends mainly on the orientation of the facade and the proportion of glazing area in the facade. Also the amount of heat gain through the fabric is very much related to the composition of the fabric, so it is very important to specify the dimension of each facade and to illustrate the different material composition in each facade.

The ventilation rate can be measured in air changes per hour at mean wind speed. In general, ventilation occurs as a result of opening doors and windows and by infiltration of air through gaps such as around doors, windows and air conditioning frames. If the ventilation is used properly, it can reduce the heat inside the house and circulate the air very effectively, but if it is infiltrating the cold air to outside, this will increase the overall house cooling load.

The mean internal and external temperatures are the most critical parameters in the energy balance. The internal temperature is a result of the total sum of cooling systems and ventilation against the input heat by the occupants, appliances and heat gain through fabric and windows. The internal temperatures for the case study houses have been measured on a hourly basis for one week while the cooling air conditioner system was operating. As a result of the inhabitants' satisfaction, the mean internal temperature was considered as the thermal comfort level for the house occupants. On the other hand, the external temperature has a direct relation with the energy consumption which increases in the summer due to the overheated period and decreases in winter. The external temperature is the only factor which determines the length of the cooling season. Finally, it is important to know the difference between the indoor temperatures and the outdoor temperatures, which somehow reflects the envelope performance.

7.1.5 Incidental heat gain

The heat input to the house comprises of incidental gains for occupants, domestic appliances, hot water, and solar radiation. The incidental heat gain can make a significant increase in the cooling requirement.

The heat emission from occupants' bodies depends on the degree of activity; this is often taken as about 100W, but it varies between 70W in deep sleep, about 130W in sedentary work and over 1KW in heavy work[1]. Therefore the heat gain from the occupants must involve assumptions about the level and duration of occupancy.

The heat gain from the hot water occurs as a result of heat emission from the pipes and storage tank. This problem is very common in Dammam region where most houses use insulated steel pipes and tanks. Due to the high intensity of solar radiation, people tend to save more from the hot water and sometimes they consume more energy to cool the water in order to use it.

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1. Szokolay, S.V. (1987)
Thermal Design of Buildings, RAIA Education Division, Australia, February 1987, p.12.

Heat generated by the appliances depends on the size and type of the appliances. Most of the appliances, such as refrigerators, freezers, washing machines and cookers, are often used and this increases the cooling load of the house due to the heat they produce. The produced heat can be ventilated very effectively outside the house, especially if these appliances are properly placed.

Solar radiation gain depends on the orientation of the facade and the amount of glazing in the facade. The composition of the fabric also has an effect on the amount of solar gains. The solar radiation incident is supplemented by direct solar radiation, diffused sky radiation and reflected radiation from the ground. Usually, the hottest sun period occurs between 0900 and 1700 hours depending on the orientation.

7.2 Case Study I-A (H1)

This house has been selected to represent the first category of the surveyed houses, and it is located in Dammam City in a medium-density community where the majority of the houses around are two storey concrete block buildings. The case study house is surrounded by houses similar in plot size and building design, and their average height is about 8 metres. It is surrounded by two houses on the north and east and by a four metre wide alley and 20 metre wide street on the south and west. The average distances between the house building and the neighbouring buildings are about four metres from the north and east and twelve metres from the south. The house receives shade from the east and south sides due to the neighbouring buildings. The house has a large front yard open area which is mostly planted and used for afternoon outdoor sitting and children's play.

7.2.1 House conditions

In the recent residential development in Dammam Metropolitan Region, the classic villa-type house has become the standard house design. Case I-A house is one of the standard houses in the area and it is two storeys high, with large balconies and windows. It is four years old and in very good condition. It stands in its own grounds which act as an outdoor courtyard allowing heat to escape from the house. The main building of the house consists of two floors which are the ground floor and the first floor. The ground floor accommodates the living room, guest rooms, dining room and kitchen and therefore it is used for most of the day. The first floor accommodates only the bedrooms and that limits its use to sleeping purposes. The paved area around the house is very limited and the solar radiation intensity is very low (see figures 7.1 A, B and C).

The house accommodates fifteen persons, nine being adults and six children. Apart from the children, most of the inhabitants are very well educated (university level). Also the inhabitants of this house are all part of the same family. The plot gross area is 750 square metres and the net of the area is approximately 306 square metres. The average built area per person is approximately 20.4 square metres.

7.2.2 Energy used

The energy types most commonly used, both in this region and throughout the country, are electricity and gas. The occupants of this house use electricity for cooling systems and appliances and gas for cooking purposes. The average monthly energy consumption in the summer period for this house is 12984.18 Kwh, and the actual measured energy consumption for the month of September 1987 is 16842.14 Kwh.

Appliance	Number	Size
Fridge/freezer	1	18 ft^3
Freezer	1	18 ft^3
Gas oven	2	large
Kettle	1	2 litres
Washing Machine	1	44 litres
Drying Machine	1	5 kg
Television	4	26 inch
Video	1	-
Split unit AC	12	17000/5040 Btu/Watts
Boiler	2	80 litres
Lights	20	100 W

7.2.3 Cooling system

Most commonly the wealthier people tend to use the most sophisticated equipment in their houses, which is the case of the people in the Dammam region. The people in the Dammam region have left their traditional way of passive cooling and depend upon the active cooling system. The occupants of this house cool their house mechanically by using an active cooling system. They use 1.5 ton split unit cooling system in most of the rooms and fans and ventilation windows in the kitchen and storage areas. The ground floor is normally used during the day and the first floor is used at night for the sleeping purposes. Therefore they use either the upper floor or the ground floor cooling system at any one time.

7.2.4 Efforts achieved in saving energy

Usually people do not look for the cure before they suffer the problem. The occupants of this house realised the need for saving energy after they had started to feel the value of the money they paid every month. They started to struggle to make some contribution in saving energy by using cross ventilation at night to circulate the cool air inside. Also they improved the infiltration in the house to keep the cold air inside and prevent the hot air penetrating from outside. They also employed reflective glass and curtains at the windows very effectively.

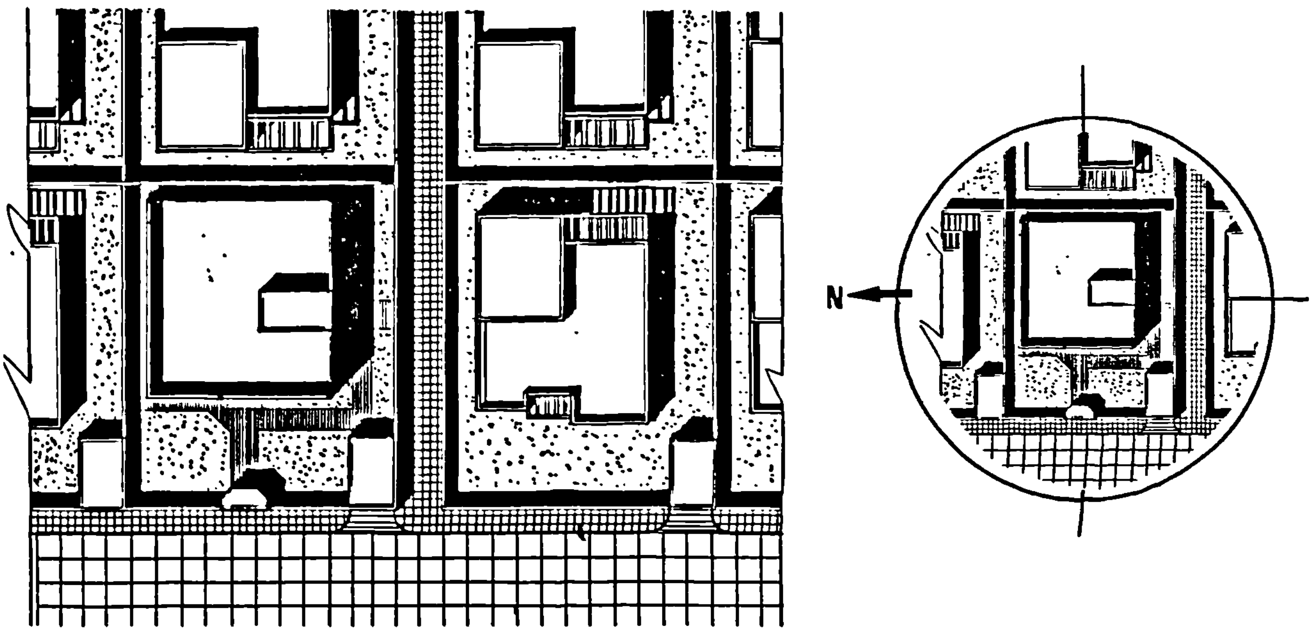
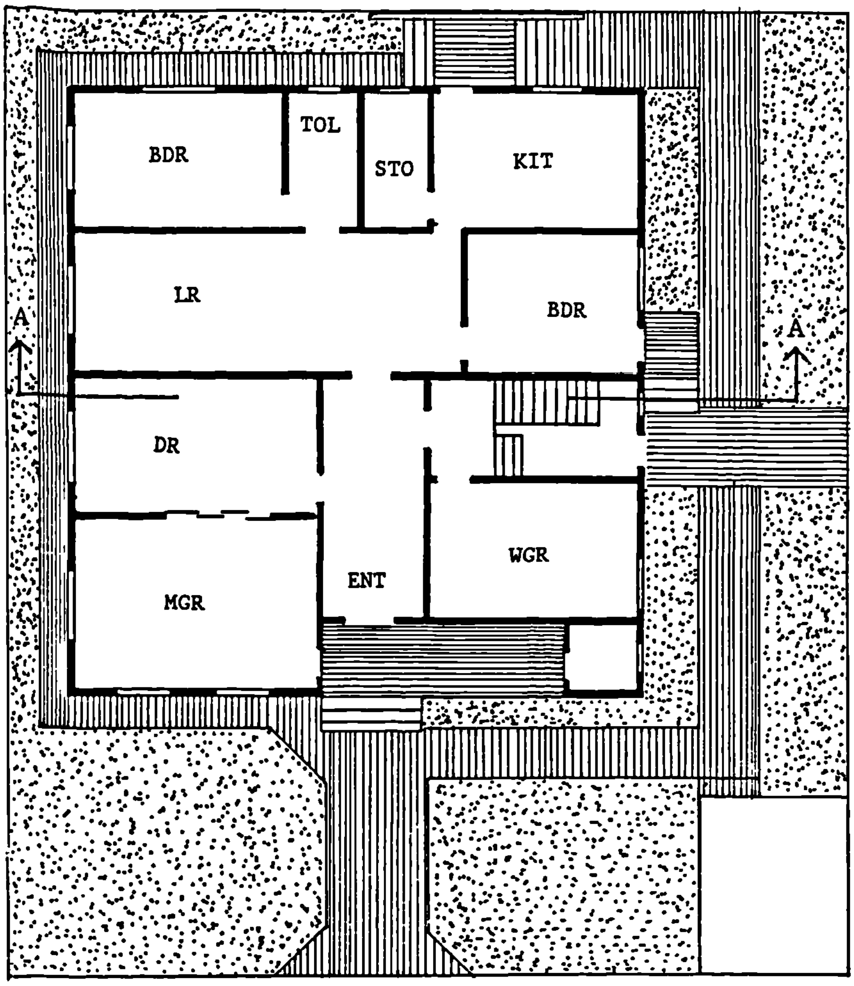
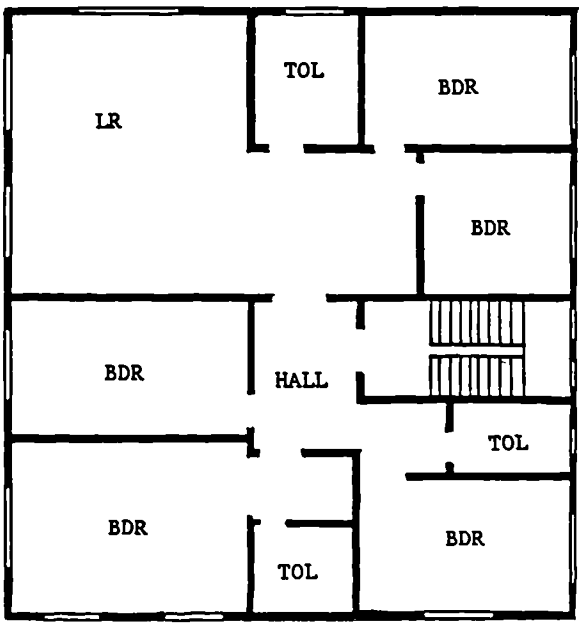


FIGURE 7.1 A: THE URBAN CONFIGURATION OF HOUSE 1, SHOWING THE HOUSE IN RELATION TO ITS NEIGHBOURS.



GROUND FLOOR PLAN



FIRST FLOOR PLAN

MGR : Men guest room
WGR : Women guest room
DR : Dining room
BDR : Bed room
LR : Living room
KIT : Kitchen
ENT : Entrance
TOL : Toilet
STO : Storage

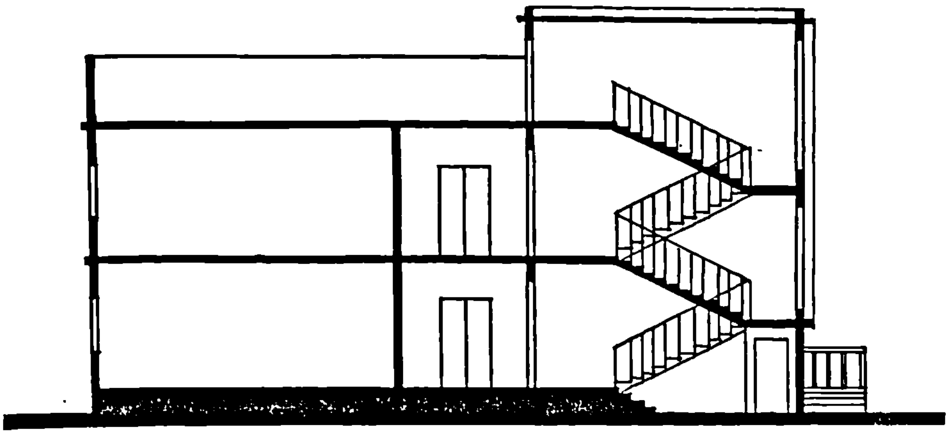
N

0 2 4 6 8 metre

FIGURE 7.1 B: DETAILED FLOOR PLANS OF HOUSE 1.

SOUTH ELEVATION

WEST ELEVATION



SECTION A-A

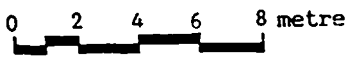


FIGURE 7.1 C: SOUTH AND EAST ELEVATIONS AND SECTION A-A OF HOUSE 1.

7.3 Case Study I-B (H2)

House 2 is the second selected house to represent the first category of the surveyed houses. The house is located in Alkohbar City in one of the suburbs which is called Athugbah. It is a two storey house with a total height of 8 metres. It is bounded from the north and west by two houses of the same height, and from the south and east by two paved streets, each of them being 20 metres wide. The house building and the neighbouring building are built onto each other's wall, which means that there is no space between the houses. The house does not have any open space for outdoor sitting or children's play.

7.3.1 House conditions

This house is built in a community which was planned in 1974 as a result of the formation of the Real Estate Development Fund (REDF) which offers free interest loans to the public. Most of the houses built in this community are built through the REDF loans. This house fronts directly onto the streets, with no open space grounds. Many houses in the community, as well as the whole region, have been built in the same fashion because of the absence of any clear building regulations. The house is designed and constructed individually and it consists of a ground floor and first floor. The ground floor is used only on occasions when they have special guests, while the first floor is used for all their activities and for the whole day (see figures 7.2 A, B and C).

The house accommodates fourteen persons: nine adults and five children. The inhabitants of the house are all part of one family, except the servants, and their level of education is quite good (high school level), even taking into account the servants who are not very well educated. The average built area per person is approximately 26.2 square metres and the net built area is about 368 square metres.

7.3.2 Energy used

The energy types used in this house are mainly electricity and gas. The residents of this house use electricity for cooling systems and appliances and they use gas for cooking only. The average monthly energy consumption in the summer period for this house is about 22197.23Kwh and the actual measured energy consumption for the month of September 1987 is 23430.45 Kwh The house accommodates the following appliances:

Appliances	Number	Size
Fridge/freezer	2	12 ft^3
Freezer	1	18 ft^3
Gas oven	2	Large
Washing machine	1	44 litre
Drying machine	1	5 Kg
Television	3	26 inch
Video	2	-----
Window type air-conditioning	11	14000/4100 Btu/Watts
Boiler	2	80 litre
Lights	20	100 W

7.3.3 Cooling system

The cooling system used in this house is a window type fridge cooling system. This system blows cold air from one side into the house and exhausts hot air from the other side. This exhausted heat goes back into the house by two means, either by infiltration around the unit itself or by conduction through the envelope. Moreover, this exhausted heat increases the solar intensity around the house, which creates a very hot environment around the house. The residents of this house use the first floor cooling system all day because they use mainly the first floor for all activity.

7.3.4 Efforts achieved in saving energy

The south and east building envelopes are totally exposed to the sun and need special treatments to avoid the heat gain through the glass and fabric. Unfortunately, the inhabitants of this house limited their effort to using fewer rooms than they required, and they use cloth curtains to stop the penetration of the direct sun. They reported that these means that they used to save energy were ineffective.

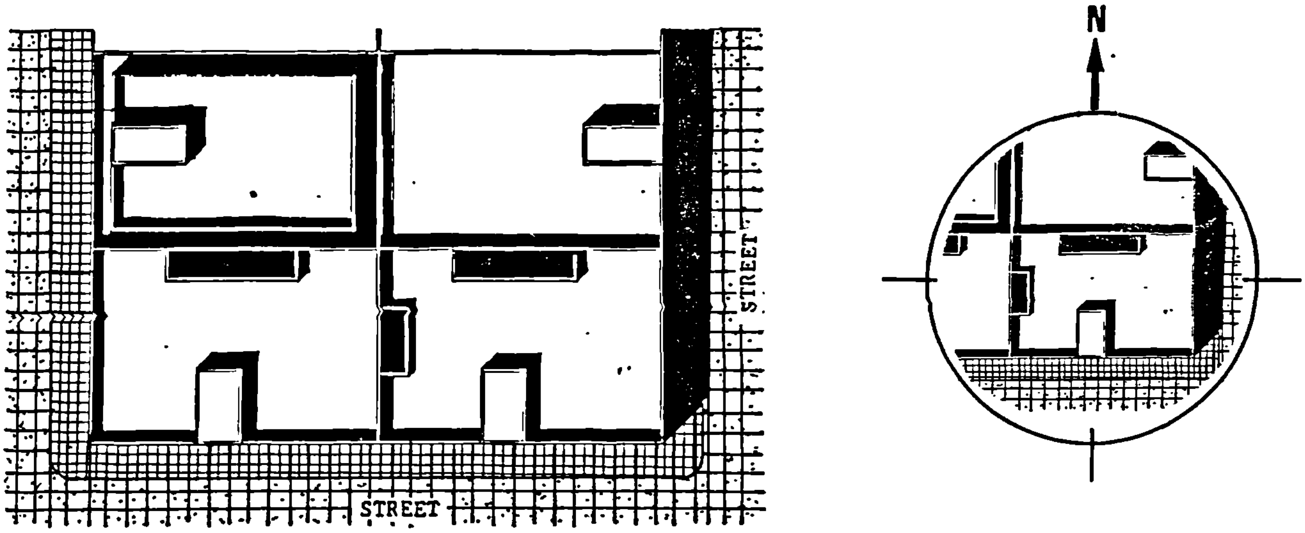
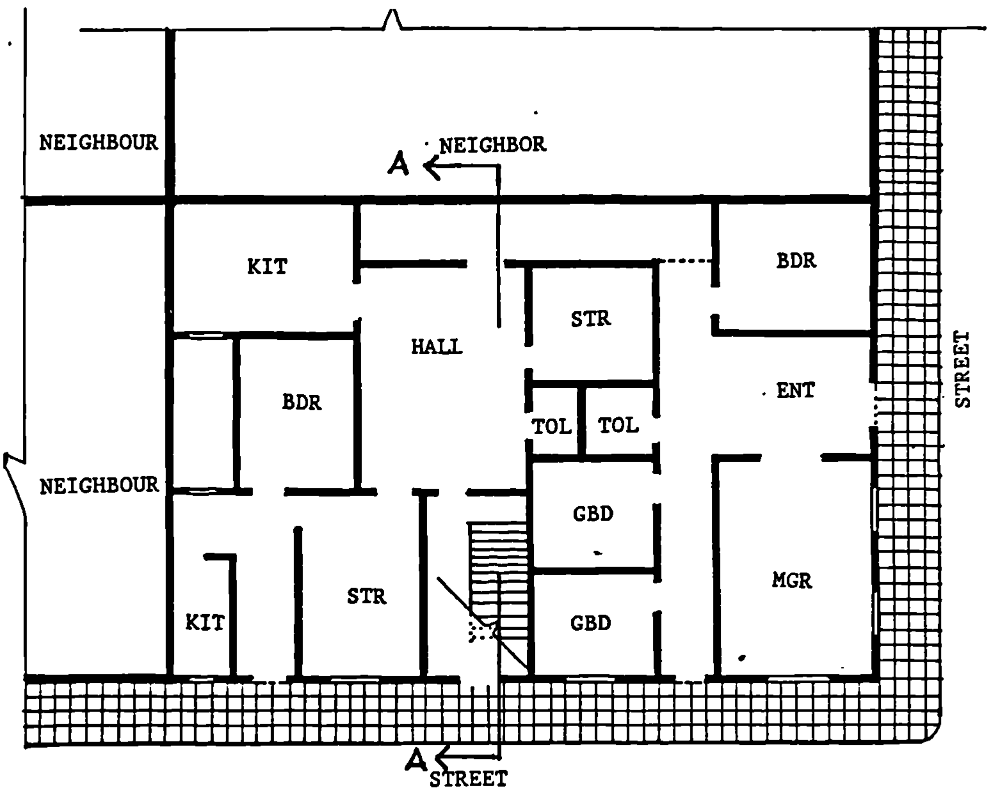
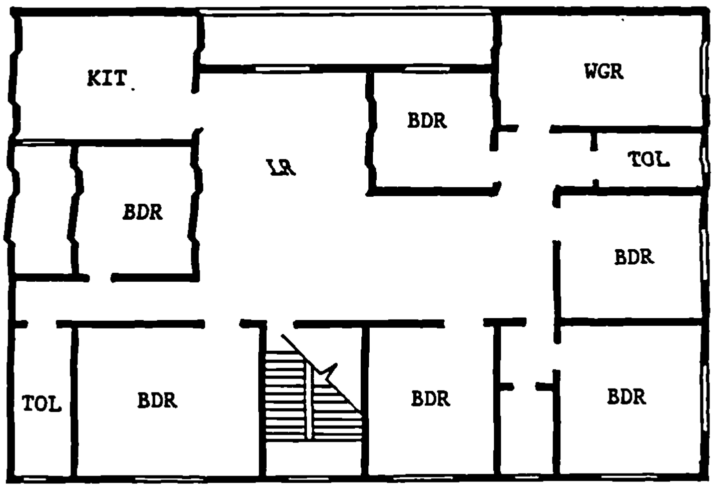


FIGURE 7.2 A: THE URBAN CONFIGURATION OF HOUSE 2, SHOWING THE HOUSE IN RELATION TO ITS NEIGHBOURS.



GROUND FLOOR PLAN



FIRST FLOOR PLAN

MGR : Men guest room
WGR : Women guest room
DR : Dining room
BDR : Bed room
GBD : Guest bed room
LR : Living room
STR : Sitting room
KIT : Kitchen
ENT : Entrance
TOL : Toilet

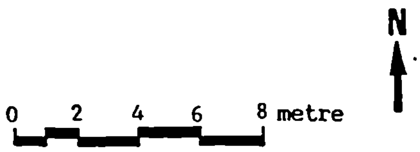
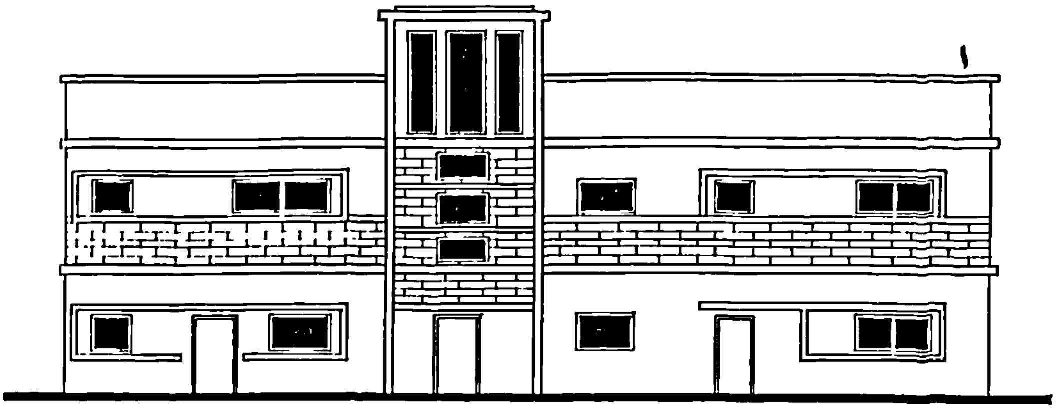
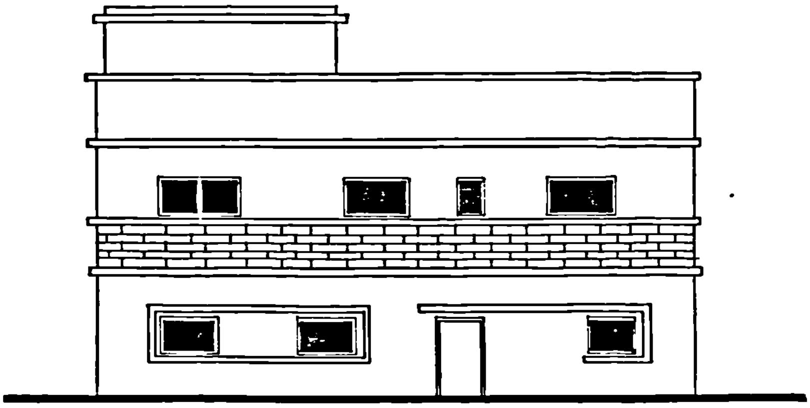


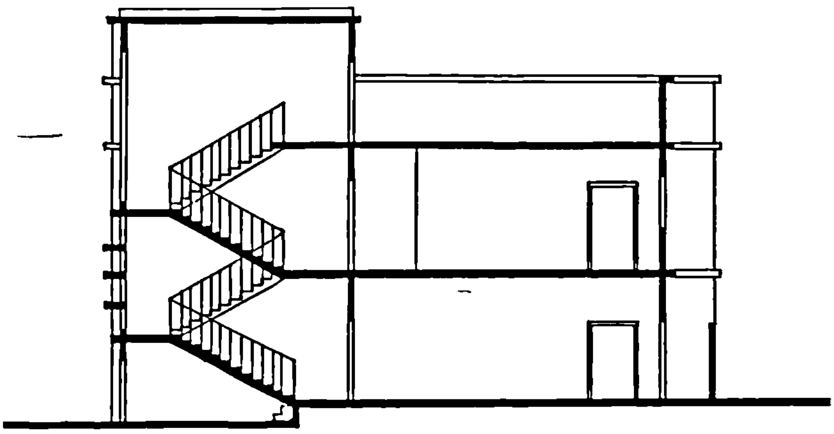
FIGURE 7.2 B: DETAILED FLOOR PLANS OF HOUSE 2.



SOUTH ELEVATION



EAST ELEVATION



SECTION A-A

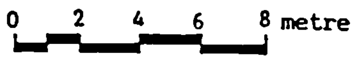


FIGURE 7.2 C: SOUTH AND EAST ELEVATIONS AND SECTION A-A OF HOUSE 2.

7.4 House Details

ITEMS	HOUSE 1	HOUSE 2
Dimensions		
Each house occupies a rectangular plot	30 m long by 25 m wide.	23 m long by 16 m wide.
The actual built area	18 x 17 x 2 = 612 sq m	23 x 16 x 2 = 736 sq m
2. **U-Value** (W/m^2k)		
Usually the house is built of a combination of several types of materials to produce an overall building envelope. The different U-values of the materials forming the envelope are vital in predicting the thermal performance of the building. The different U-values of this house envelope are as follows:		
External walls 210mm thick concrete block with 25mm plaster and granite paint finishing.	1.7	1.7
Glazing and curtains Reflective single glazed windows with heavy curtains and aluminium frame.	4.48	4.48
Roof Tiled reinforced concrete flat roof with plastered ceiling.	3.35	3.35
Floor Reinforced concrete floor in contact with the earth, tiled and mostly carpeted.	1.13	1.13
3. **Ventilation Rate**		
The average volume of fresh air allowed to enter the house every hour. The ventilation rate measured in air changes per hour at mean wind speed.	1.0 (ach)	1.0 (ach)

	HOUSE 1	HOUSE 2
4. Mean internal temperature		
The measurement of the mean internal temperature was taken while the air conditioning was running. It is an average of hourly readings for the one week period between 24th and 30th August 1987.	24°C	25°C
5. Mean external temperature		
This mean external temperature is an average temperature calculated from an hourly reading for the month of August 1987. The reading was taken before, during and after the experimental work.	36.2°C	36.2°C
6. Areas		
The building envelopes of these houses have been investigated in detail to identify the different types and areas of the material used. These envelopes are a combination of opaque and glass walls and the areas of these walls in each facade of each house are:		
opaque wall facing north	95.75 sq m	134.5q m
opaque wall facing east	94.75 sq m	84.0 sq m
opaque wall facing south	92.25 sq m	120.0 sq m
opaque wall facing west	93.75 sq m	96.0 sq m
glazing facing north	12.25 sq m	3.5 sq m
glazing facing east	7.25 sq m	12.0 sq m
glazing facing south	15.75 sq m	18.0 sq m
glazing facing west	8.25 sq m	0.0 sq m
Roof Flat reinforced concrete tiled with plastered ceiling.	306.0 sq m	368.0 sq m
Floor Solid concrete floor with contact with the earth, tiled and carpeted.	306.0 sq m	368.0 sq m

7.5 Findings

Sometimes survey and observation can do what simulation and calculation cannot do. These two case studies, which have been selected to represent the best and worst houses (House 1 and House 2) of the first category of the surveyed houses, are investigated and surveyed in detail. The survey and observation of these two houses highlight some of the problems which make House 2 consume more energy than House1.

1. Usually the absence of building regulations lead to environmental deterioration and unhealthy buildings. House 2 is one of many houses which are built onto the street ignoring the harmful intensive solar radiation which can be reflected by the streets and sidewalks into the house. Actually House 2 is bounded by very reflective surfaces which are streets and sidewalks. In contrast, House 1 has soft surfaces around the house which absorb the heat and minimise the solar intensity around the house.

2. The location of the appliances and the availability of proper ventilation are very essential in saving energy, especially in the cooling period. The kitchen in House 2 is very poorly ventilated and it opens directly to the family living room which exhausts the heat into the living room. Moreover, the appliances are badly positioned and they generate a great deal of heat which cannot escape due to the poor design. In the same matter, the kitchen in House 1 is very well located in relation with the other house functions and it is also very well ventilated. Furthermore, the appliances are grouped in one place and ventilated separately (see figure 7.3).

3. The use of cross ventilation in House 1 improves the house performance by allowing air to change and circulate very efficiently. Also the use of curtains reduces the solar gain by preventing the sun from penetrating into the house. On the other hand, House 2 uses a deep light well to get daylight into the

house, but unfortunately this deep light well acts as a heat trap for the exhausted heat from the air conditioners.

4. Usually the flat roof receives sun radiation from all directions which makes the heat gain through the roof very high. As a result of the House 2 inhabitants' use of the first floor for all their activities, the cooling load was very high due to the massive heat gain through the roof. On balance, the inhabitants of House 1 use the ground floor for the daytime activities and use the first floor, after it has been ventilated from the heat, for sleeping purposes only. This way of shifting allows the heat to escape from the first floor and reduces the cooling load (see figure 7.4).

5. The internal heat gain in House 2 is higher than House 1 because in House 2 the children play inside due to the lack of open space in the house, while in House 1 the children play outside in the house garden. Also the infiltration rate in House 2 is higher than that of House 1 due to the children's movement and play inside House 2.

6. The efficiency of the cooling systems is a very important factor to consider in conserving energy. The cooling system used in House 1 is the split unit cooling system which controls the temperature very easily and does not exhaust heat in the same place of cooling. In House 2 the cooling system used is the window type air conditioning which blows cold air to the inside and exhausts heat from the other side. Unfortunately, the exhausted heat infiltrates into the house owing to the use of a very thin frame around the window type air conditioning unit.

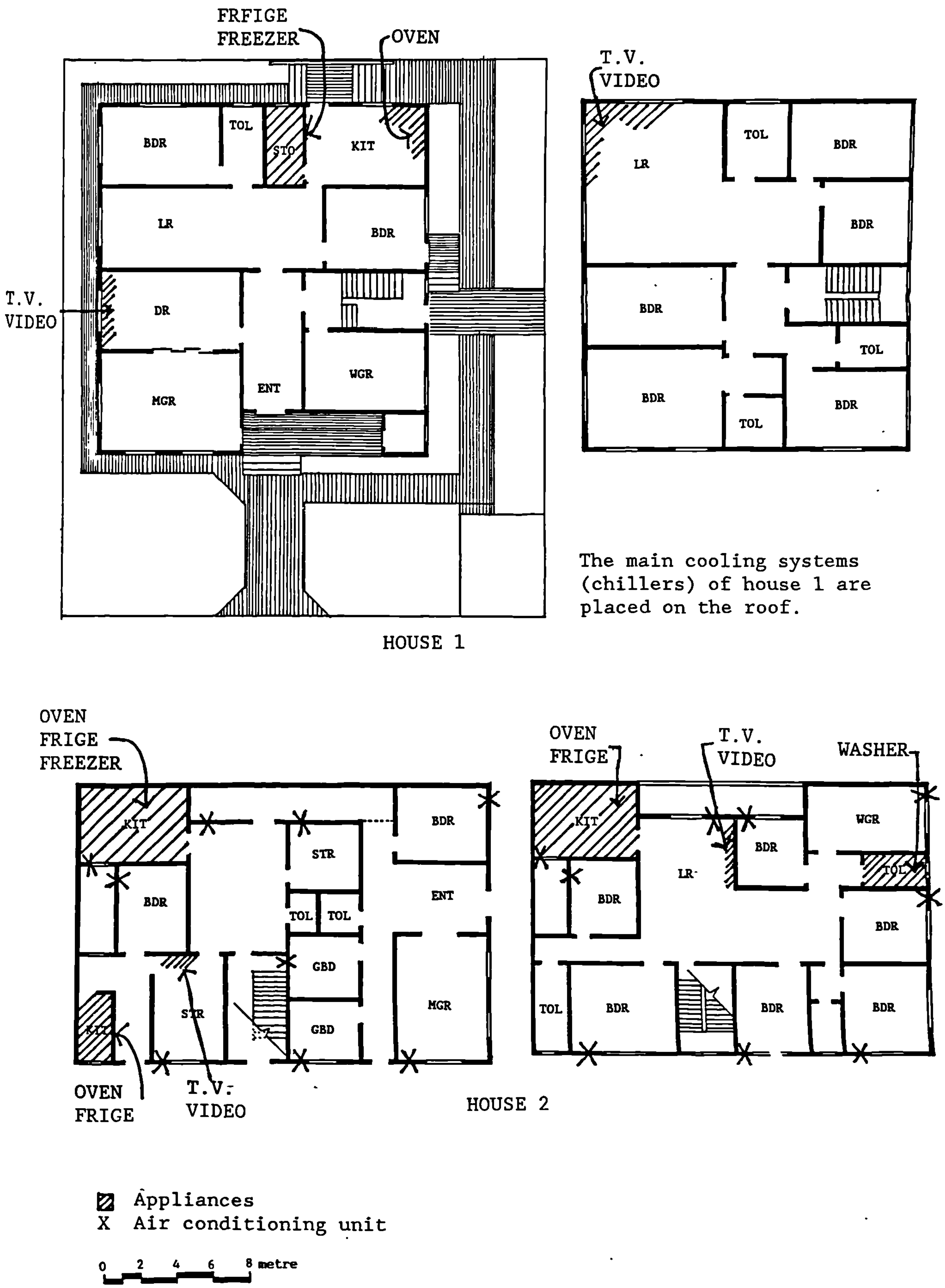
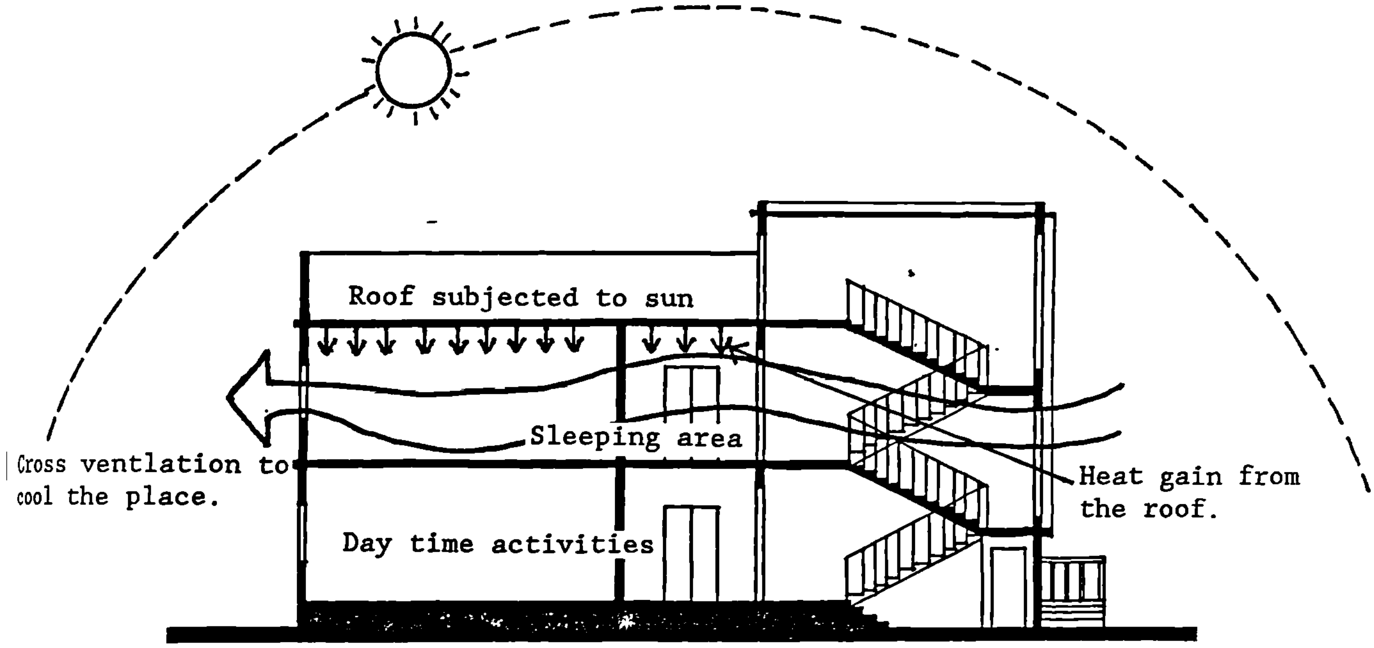
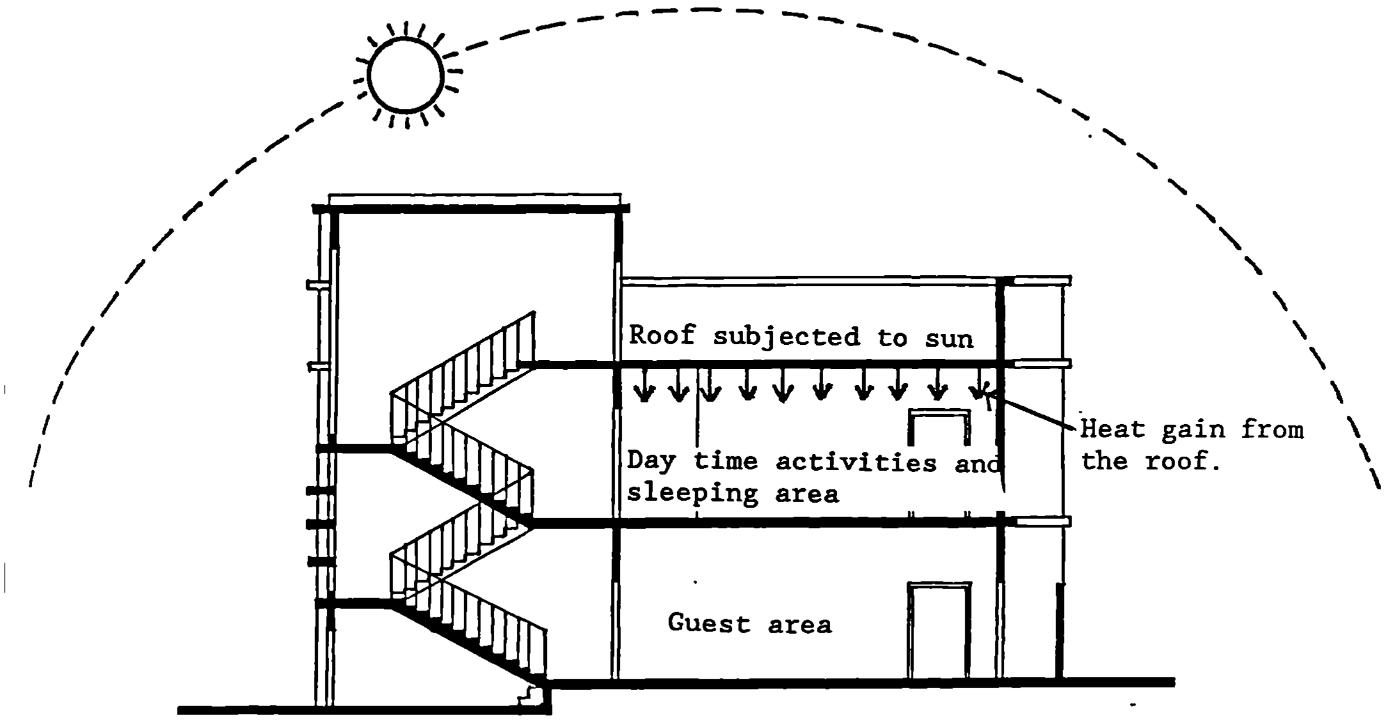


FIGURE 7.3: THE VARIOUS LOCATIONS OF APPLIANCES IN HOUSES 1 AND 2.



HOUSE 1



HOUSE 2

FIGURE 7.4: THE RELATION BETWEEN THE HEAT GAIN FROM THE ROOF AND THE INHABITANCE DAILY ACTIVITIES OF HOUSES 1 AND 2.

7.6 Case Study II - A (H3)

This case study is one of two houses which represent the second category of our surveyed houses. It is located in Alkhobar City, and orientated east-west like most houses in the city. The house is a two-storey house, eight metres in height. It is surrounded by five houses on all directions, except for the west, where it is bounded by a two metre tiled sidewalk and twenty metres wide paved street. The five buildings surrounding the house are equal in height, which is eight metres high, and the total average distance between these buildings and the actual house is four metres. The house has a ten metre by twenty-two metre front yard, which is mostly paved, to accommodate the garage and the children's playground.

7.6.1 House Condition

The house, located in a newly planned community in Alkhobar City, is a villa type house, which is individually designed and constructed. The house is set in the middle of an individual plot which permits an outdoor circulation as well as allowing more ventilation to the house. It consists of a ground floor and first floor, which are mostly laid out on a grid iron sub-division due to the simple structure of the building. The ground floor is mostly used for the daily activities such as receiving guests, sitting, cooking and family gathering, and the first floor is usually used at night for sleeping, as well as for family gathering. Unfortunately, the building is surrounded by paved passage ways, which increase the solar radiation intensity around the house (see figures 7.5 A, B and C).

The house accommodates a family of six, four being adults and two children, on a plot of 565.76 square metres. Most of the inhabitants of the house are very well educated and they are all part of one family. The net built area is approximately 226.617 square metres and the average room size is around 5 x 6 metres by 2.85 metres high.

7.6.2 Energy Used

The energy used in this house is not so different from the common energy used throughout the whole country. The energy used in this house is electricity only and it is used for all purposes such as cooling systems, appliances and cooking. The average monthly energy consumption in a summer period for this house is about 14514.40 Kwh and the actual measured energy consumption for September 1987 is 16420.78 Kwh. Finally, the appliances found in this house are as follows:

Appliances	Number	Size
Fridge/Freezer	2	12 ft^3
Electric oven	1	7500 W
Washing machine	1	44 litre
Drying machine	1	5 Kg
Television	2	22 inch
Video	1	medium
Microwave	1	1500 W
Split unit Air conditioners	12	17000/5040 Btu/Watts
Boiler	1	80 litre
Lights	10	100 W

7.6.3 Cooling System

The cooling systems used in Saudi Arabia, and particularly in the Dammam region, are mostly mechanical systems. The rapid development that the Dammam region has experienced over the last two decades did not allow people to adapt to some of the traditional passive cooling systems in the new houses. Also, the availability of the active cooling systems at affordable prices discourage people from trying to use the passive cooling means within their houses. This house is one of those houses which did not use the passive cooling system, the inhabitants using instead split unit air conditioners in all rooms of the house, even the kitchen. The ground floor cooling system is used mainly during the daytime and the upper floor system is used at night.

7.6.4 Efforts Achieved in Saving Energy

The high energy consumption sometimes encourages people to put some effort into saving energy as well as money. Unfortunately, the people in Dammam region did not make any effort in the cause of saving energy because, in the short term, they can afford to pay for it. Similarly, the occupants of this house did not make a noticeable effort. They restricted their effort to using fewer rooms than they needed and reducing infiltration in the house. Moreover, they use reflective glass and curtains, which could increase the heat gain inside the house.

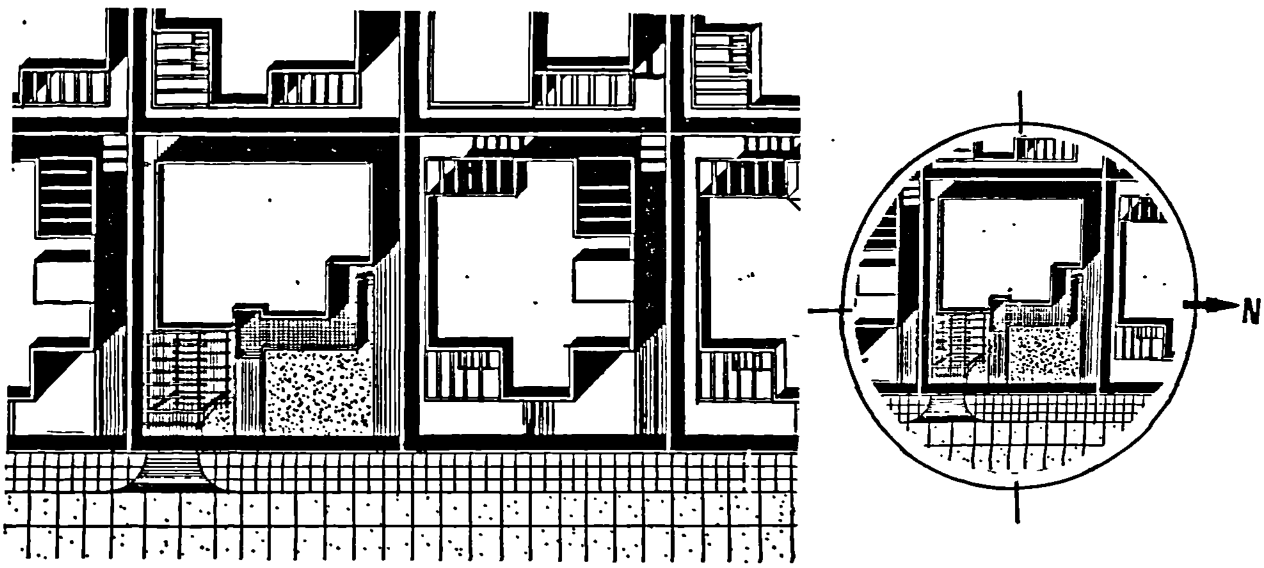
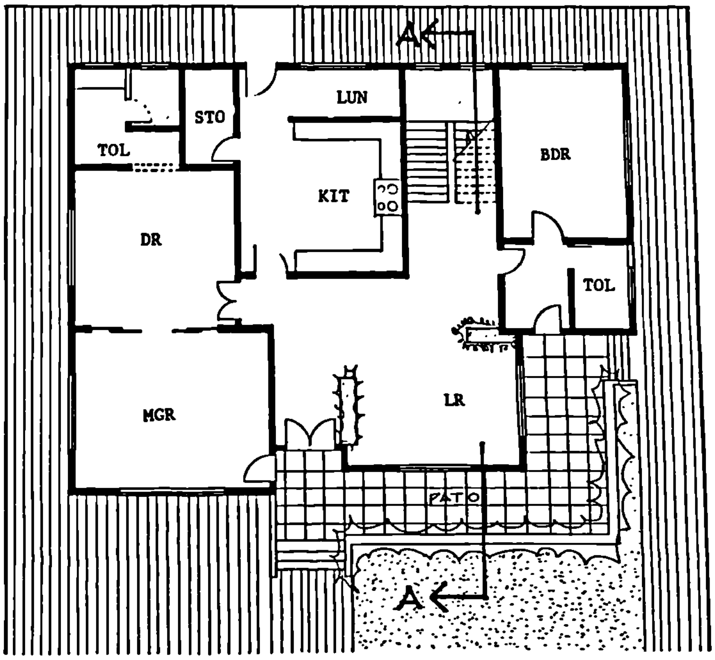
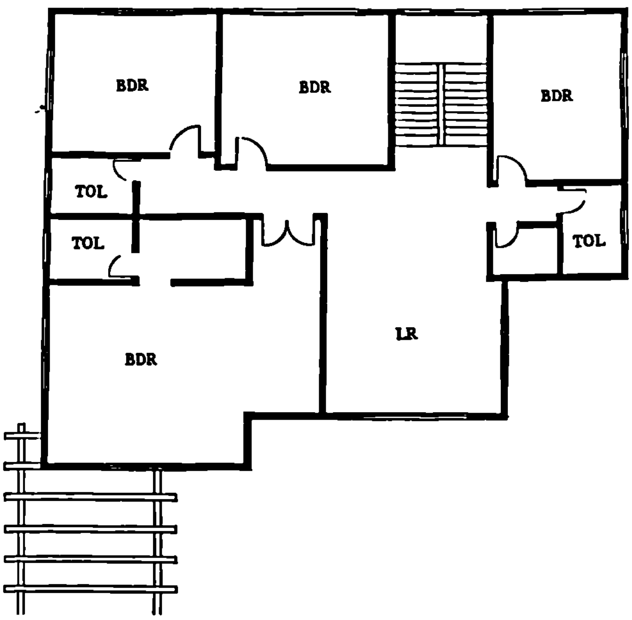


FIGURE 7.5 A: THE URBAN CONFIGURATION OF HOUSE 3, SHOWING THE HOUSE IN RELATION TO ITS NEIGHBOURS.



GROUND FLOOR PLAN



FIRST FLOOR PLAN

MGR : Men guest room
DR : Dining room
BDR : Bed room
LR : Living room
KIT : Kitchen
LUN : Laundry
TOL : Toilet
STO : Storage

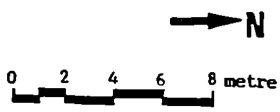
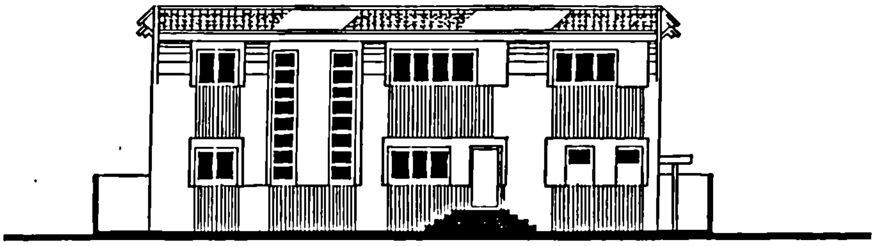
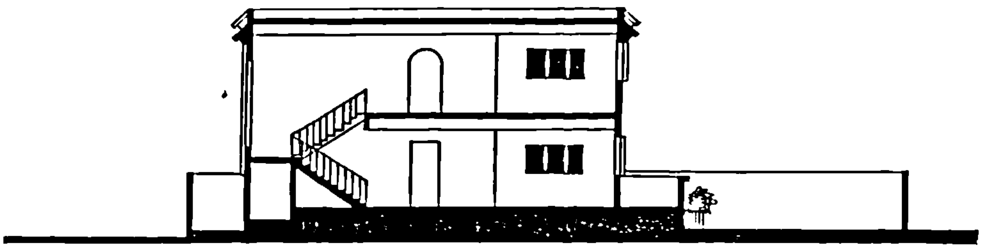


FIGURE 7.5 B: DETAILED FLOOR PLANS OF HOUSE 3.



WEST ELEVATION

EAST ELEVATION



SECTION A-A

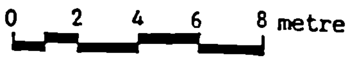


FIGURE 7.5 C: WEST AND EAST ELEVATIONS AND SECTION A-A OF HOUSE 3.

7.7 Case Study II - B (H4)

This house is the second case study house which represents the second category of the surveyed houses. It is located in Dammam city and orientated north-south. The house is a two storey building with a total height of eight metres. It is built between a group of houses with the same height of eight metres. The neighbouring houses surround the case study house from east, south and west. The distance that separates them from the case study house is four metres from the east and south and about six metres from the west. The house is eight metres set back from the street which is in the north side, and this front 'set back' is used for the garage and children's playground. Finally, the house has very little paved area around it, which minimises the solar radiation intensity.

7.7.1 House Condition

The house, which is located in Dammam city, is one of those standard modern villa-type houses which is built in the middle of the plot. It is a two storey building, sub-divided on a variation of a grid iron plan for simple building form and structure. Also, it is designed and built individually without any professional supervision which could improve the quality of the house. The house has two floors: the ground floor, which accommodates all the daily activities such as family sitting room, eating, cooking, reading and watching television, and the first floor, which is only for sleeping. The surface around the house is grass, which helps in reducing the solar radiation intensity (see figure 7.6 A, B and C).

The house accommodates six people, four adults and two children. The level of education is quite high among the inhabitants of this house (university level), in comparison with the average Saudi person. The plot gross area is approximately 399.75 square metres, and the net built area is 166.75 square metres; the average room size is approximately 4.5 x 5.5 m.

7.7.2 Energy Used

The most common energy used in the region is gas for cooking and electricity for the other purposes such as cooling and appliances. The residents of this house use electricity for cooling systems, lighting and appliances and use gas for cooking purposes. The monthly energy consumption in the summer time is 10832.925 Kwh and the actual measured energy consumption in September is 11222.71 Kwh.

Appliance	Number	Size
Fridge/Freezer	1	18 ft^3
Freezer	1	18 ft^3
Gas oven	1	large
Washing machine	1	36 litre
Drying machine	1	3 Kg
Dish washer	1	medium
Television	2	20 inch
Video	1	medium
Split unit Air conditioning	12	17000/5040 Btu/Watts
Boiler	2	80 litre
Lights	10	100 W

7.2.3 Cooling Systems

The cooling system used in this house is one of the newest machines in Saudi Arabia, which is the split unit cooling system. This system is very efficient in reducing infiltration and reducing the exhausted heat from the system. The occupants of the house use the split unit to cool all the rooms, except the kitchen, where they use a fan and ventilation window. The ground level cooling system is mostly used during the day time and the first floor cooling system is mostly used at night time.

7.7.4 Effort achieved in Saving Energy

The inhabitants of this house are aware of the high energy cost and they are trying very hard to save energy. They use, to some extent, cross ventilation to circulate the air and reduce the infiltration in the house to keep the cool air inside and prevent the hot air penetrating inside. They also use curtains in all directions at all times, which are costly and beneficial.

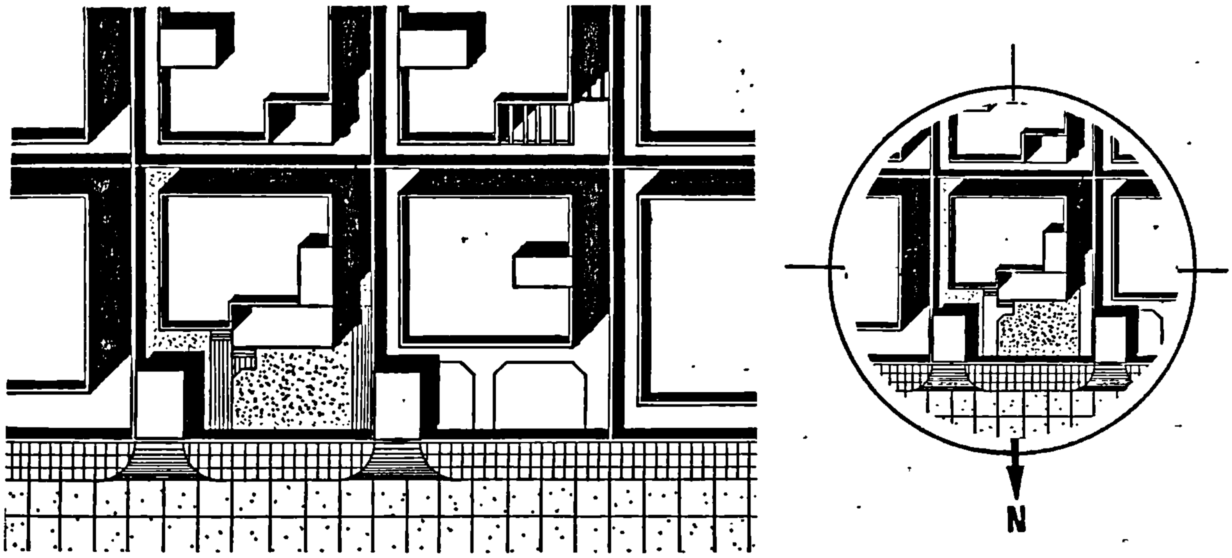
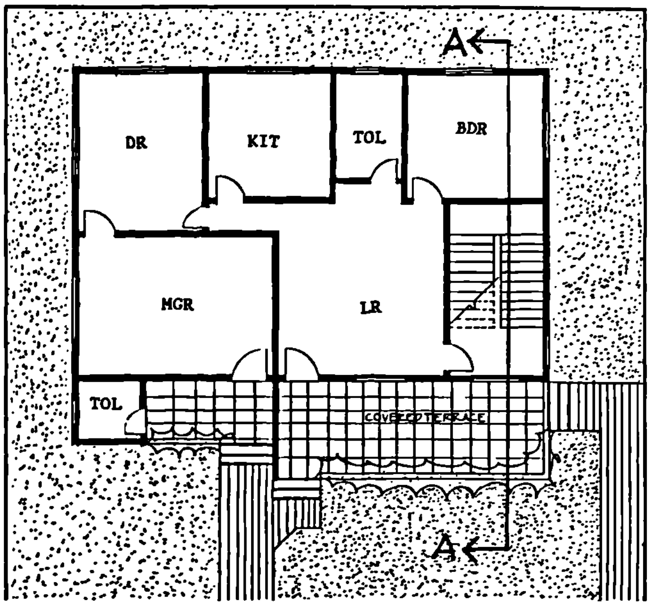
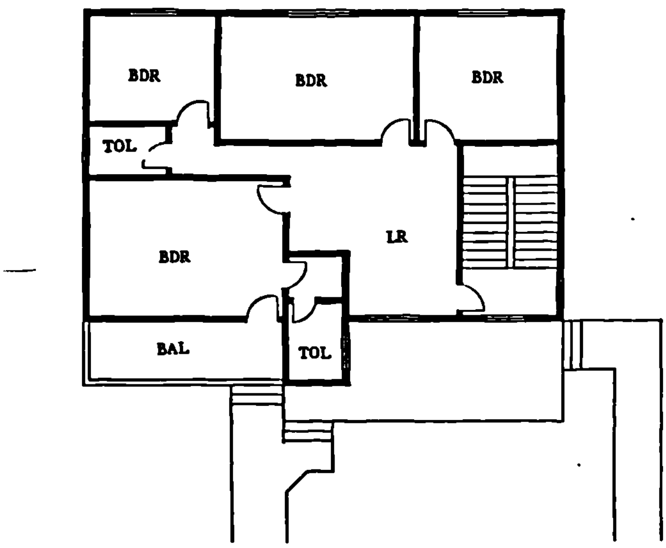


FIGURE 7.6 A: THE URBAN CONFIGURATION OF HOUSE 4, SHOWING THE HOUSE IN RELATION TO ITS NEIGHBOURS.



GROUND FLOOR PLAN



FIRST FLOOR PLAN

MGR : Men guest room
DR : Dining room
BDR : Bed room
LR : Living room
BAL : Balcony
KIT : Kitchen
TOL : Toilet

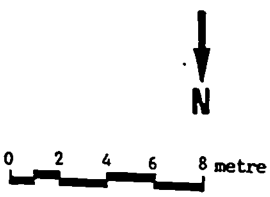
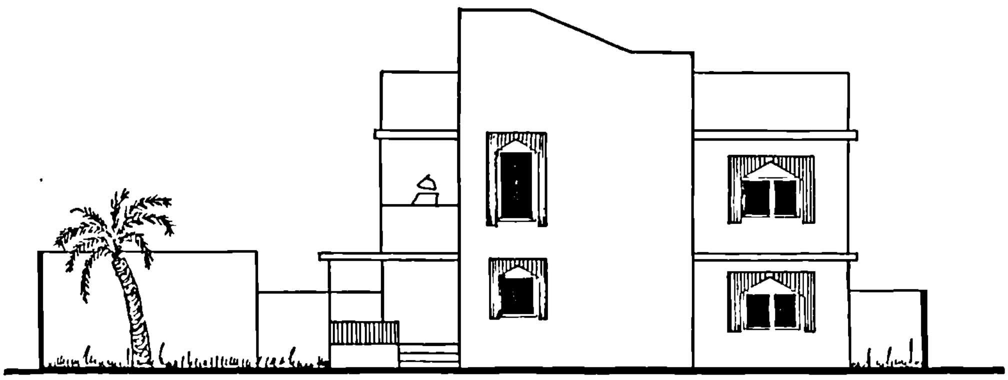
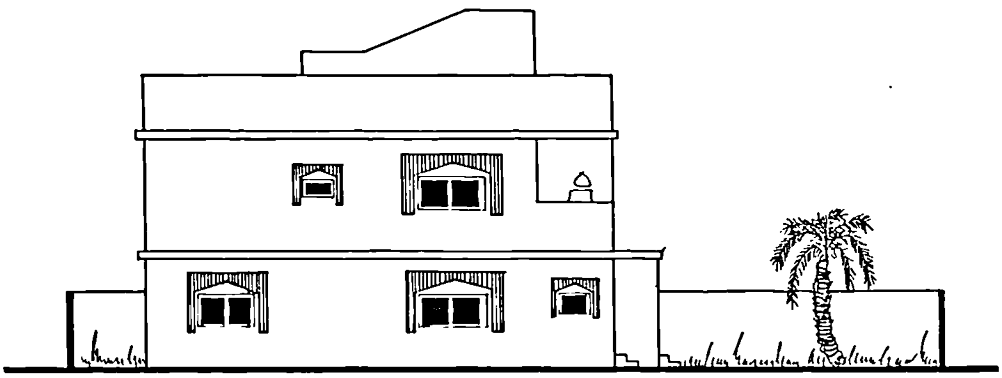


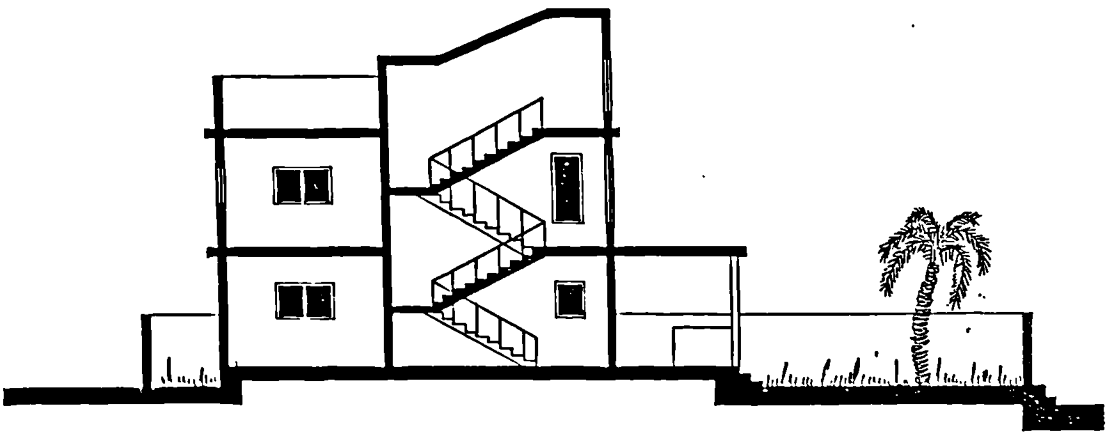
FIGURE 7.6 B: DETAILED FLOOR PLANS OF HOUSE 4.



WEST ELEVATION



EAST ELEVATION



SECTION A-A

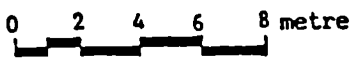


FIGURE 7.6 C: WEST AND EAST ELEVATIONS AND SECTION A-A OF HOUSE 4.

7.8 House Details

ITEMS	HOUSE 3	HOUSE 4
1. Dimensions:		
Generally these houses are rectangular and the plot sizes are: actual built areas are:	26.0 m long by 21.75 m wide 17.76x12.76x2 = 453.23 sq m	23.5 m long by 21.5 m wide The 16.5x12.5x2 = 412.5 sq m
2. U-Values: (W/m^2K)		
The building envelopes are groups of different materials put together to form an overall skin. The U-values of the different envelope materials are as follows:		
External walls 210 mm thick hollow concrete block with 25 mm plaster finishing.	1.70	1.70
Glazing and curtains reflective single glazed windows with light curtains and metal frames.	4.48	4.48
Roof 200 mm reinforced concrete with 30 mm sand cement mortar and 20 mm tiles and plaster ceiling.	3.35	3.35
Floor Solid floor in contact with the earth, tiled and carpeted.	1.13	1.13
3. Ventilation rate:(ach) The average volume of fresh air introduced each hour into the house. It is measured in air changes per hour. Since the ventilation rate is not measured properly it will be assumed to be:	1.0	1.0

4. Mean internal temperature: This mean internal temperature is an average of an hourly reading for a period of one week with the use of air conditioning. The measurement was in the first week of September 1987.	$25^{o}C$	$25.7^{o}C$
5. Mean external temperature: This mean external temperature is an average hourly reading for one month. The reading was taken during the experimental work. The measurement was in September 1987.	$35.8^{o}C$	$35.8^{o}C$
6. Areas: A survey conducted on the different envelope materials in each direction of the house to determine the type of material and its area. There are two materials used in these houses which are concrete blocks as an opaque wall and glass and metal frame as a glazing wall. The different areas of each direction are as follows:		
opaque wall facing north	95.89 sq m	80.5 sq m
opaque wall facing east	62.37 sq m	62.65 sq m
opaque wall facing south	86.13 sq m	78.15 sq m
opaque wall facing west	71.46 sq m	64.0 sq m
glazing facing north	10.71 sq m	6.5 sq m
glazing facing east	20.43 sq m	6.35 sq m
glazing facing south	20.43 sq m	8.85 sq m
glazing facing west	11.34 sq m	5.0 sq m
Roof Flat solid reinforced concrete with plastered ceiling.	226.61 sq m	206.25 sq m
Floor A flat solid reinforced concrete.	226.61 sq m	206.25 sq m

7.9 Findings

Survey and observation are very effective tools in measuring the social life and the house conditions, but they are not good enough for measuring the thermal performance of the building. The previous two case studies, which represent the best house (Case 4) and the worst house (Case 3), in energy consumption in the second category, were surveyed and observed to find a reasonable answer for the different consumptions. The survey and observations of these two houses show some explanations for this difference, which are as follows:

1. One of the most obvious differences between these two houses is the proportion of solid and void in the building envelope. In House 3, the building envelope has very large portions of glass windows, especially in the east and west elevations, which increase the direct heat gain from the low sun. In contrast, the building envelope of House 4 has a very small percentage of glass, which helps in protecting the house from the hot sun and minimising the heat gain through conduction, due to the better U-value of the wall than the glass (see figure 7.5 A, B and C).

2. In House 3, the design of the living room in relation to the staircase makes it difficult to control the infiltration of the cold air to and from the upper floor. Not only that, but it also increases the heat gain from the roof due to the open airflow from one level to another. On the other hand, House 4 has a closed staircase which helps in minimising the infiltration from one level to another and is good for the individual space cooling (see figure 7.7).

3. The design of the kitchen in both houses is similar in shape and location and it inputs more heat into the living room. But House 3's kitchen has more heating problems because it is isolated by the laundry room from having direct ventilation and direct access to the courtyard. This isolation accumulates the heat gain and releases it to the house, which increases the cooling load (see figure 7.5B and 7.6B).

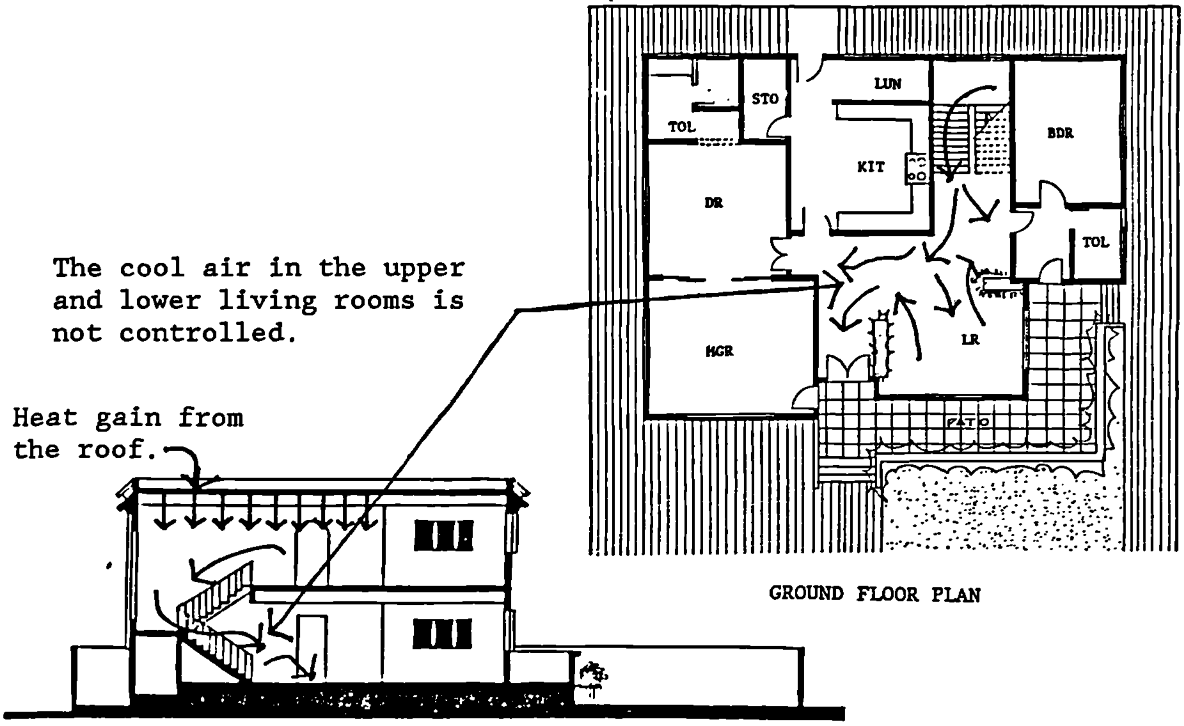
4. Sometimes, the direct solar radiation can be stopped by simple means such as plants and shading devices, but the indirect solar radiation, which is the diffused and reflected radiation, needs a great deal of thought if it is to be eliminated, taking into account such factors as the type of ground surface and the surface characteristics of the surrounding objects. Unfortunately, House 3 is surrounded by paved passage ways which increase the solar intensity around the house and reflect more solar radiation into the house. Additionally, the uncovered terrace in front of the living room reflects the solar radiation into the living room through the large single glazed window. In comparison, House 4 is surrounded by soft surfaces such as grass, which makes the solar intensity around the house very low due to the minimum paved area around the house.

5. The cooling systems in both houses are the same and they are 1.5 tons split unit air conditioners. Also they are about the same age and by the same manufacturing company, so the cooling systems' efficiency and consumption will be theoretically the same in both houses.

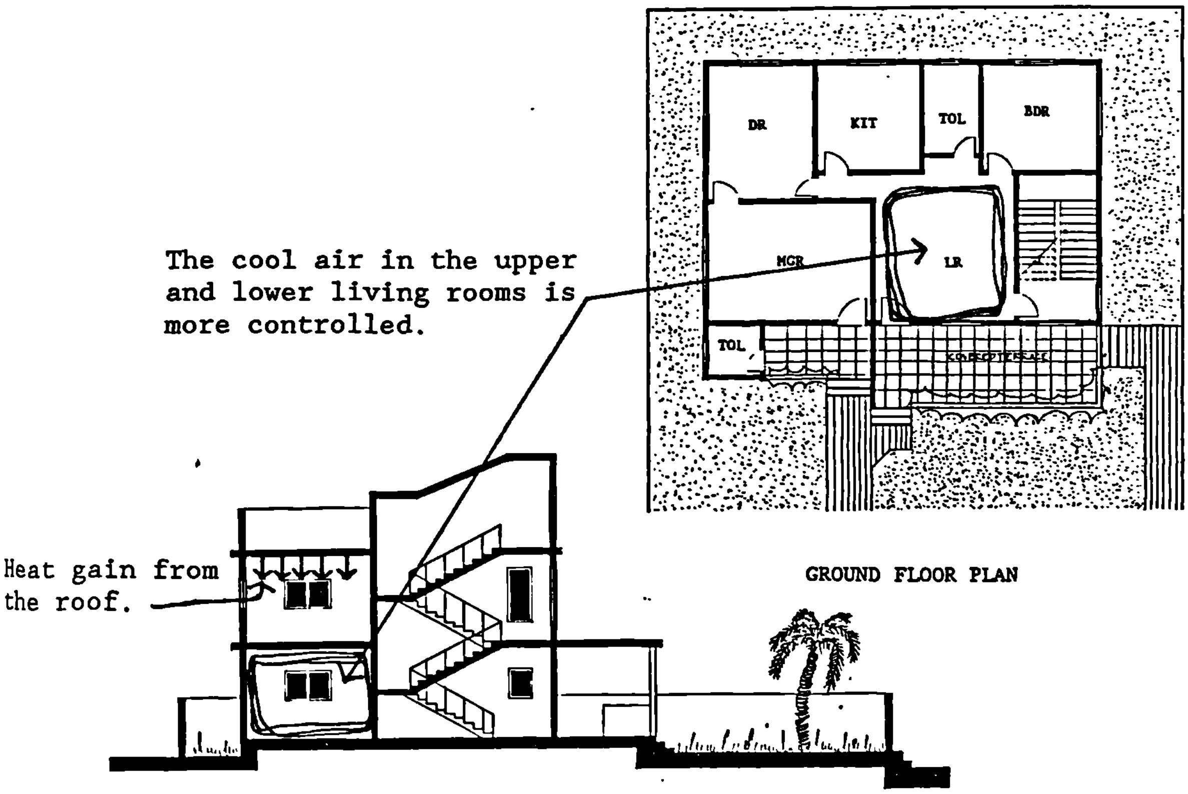
6. Usually, the use of outdoor space reduces the indoor cooling load which consequently reduces the energy consumption. The survey showed that the inhabitants of House 4 use the outdoors more often for a sitting area on the afternoon. More specifically, they use the covered terrace which is shaded and planted for outdoor activities and, at the same time, they watch their children playing in the garden. In contrast, the inhabitants of House 3 do not use the outdoor space because it is mostly paved and not shaded and it stores heat. Also the orientation and the location of the terrace is not adequate for afternoon sitting because it does not get any shade from the building, which makes it very hard to to use.

7. The life styles of the inhabitants of House 3 and House 4 are not similar but not so different. The inhabitants of House A use the living room, which is on the first floor, for sleeping purposes,

especially for the afternoon siesta. Also they use both levels at the same time, which increases the cooling load in the house. The inhabitants of House 4 use the ground floor for all of their daily activities, due to the privacy of their bedrooms in the upper floor which is used only for sleeping. By using one floor at a time, they reduce the cooling load by about half, which reduces the energy consumption by about the same rate.



HOUSE 3



HOUSE 4

FIGURE 7.7: THE INFILTERATION OF COOL AIR IN HOUSE 3 (POORLY SEALED) AND IN HOUSE 4 (WELL SEALED).

7.10 Case Study III-A (H5)

House 5 is one of two houses which represent the third category of the surveyed houses. This house is located in Alkhobar city in a low-density community where the houses vary from one to two storeys. The house is surrounded by two storey houses on the north and south sides, and by vacant land on the east and a 15 metre wide street on the west. The average distance between the house and the neighbouring houses is four metres from the south and two metres from the north. The house receives shade from the south side and slightly from the north, due to the neighbouring buildings. The house is surrounded by a two metres' wide alley which is partly paved and partly planted, the plants being especially in front of the house.

7.10.1 House conditions

The house is a villa type house which is individually designed and constructed. It is located in Alkhobar city in a low density, newly-planned community. The built area is situated in the middle of the plot to permit an outer ring of alleys for circulation purposes and heat exhausts from the air conditioning. The actual building consists of one floor which accommodates all the occupants' activities.

The house accommodates ten persons, six of them being adults and the remaining four are children. The inhabitants of this house are all part of the same family and they are partly educated; the house head has been educated to university level and the rest to middle school level. The gross area of the house is 290 square metres and the net of the built area is approximately 213 square metres, which results in 21.3 square metres per person (see figures 7.8 A and B).

7.10.2 Energy used

The inhabitants of this house use two types of energy; electricity for all appliances, cooling systems and lighting and gas for cooking purposes only. The average monthly energy consumption in summer time is 7909.98 Kwh, but for September 1987 the energy consumption was 7142.71 Kwh. The survey conducted on this house shows the availability of the following appliances:

Appliance	Number	Size
Fridge/Freezer	2	12 ft^3
Freezer	1	12 ft^3
Gas oven	1	medium
Washing machine	1	36 litre
Drying machine	1	3 Kg
Television	3	22 inch
Video	1	-------
Air conditioners	7	14000/4100 Btu/Watts
Boiler	1	80 litre
Lights	8	100 W

7.10.3 Cooling system

Usually the use of different cooling systems in the region reflects the availability of many varieties of cooling equipment in this region, whereas this is not the case in Dammam region. In Dammam region there are three types of cooling systems including the central air conditioner, the split unit air conditioner and the window type air conditioner. The occupants of this house use the window type air conditioner to cool their house. They cool most rooms in the house, except the kitchen and the storage, where they use fans and ventilation windows. Since they have only one floor, they use it for all day and night activities.

7.10.4 Efforts achieved in saving energy

Despite the medium level of education between the occupants of this house, they contribute very effectively to saving energy. They limit their use to a few rooms to minimise the size of the cooling area. Also they minimise the infiltration inside the house and they make it very tidy. Moreover, they do not cool the house all the time and they use some shading devices to reduce the penetration of direct solar radiation. Finally, they have mentioned that they do not use any type of insulation material due to their lack of knowledge on this matter.

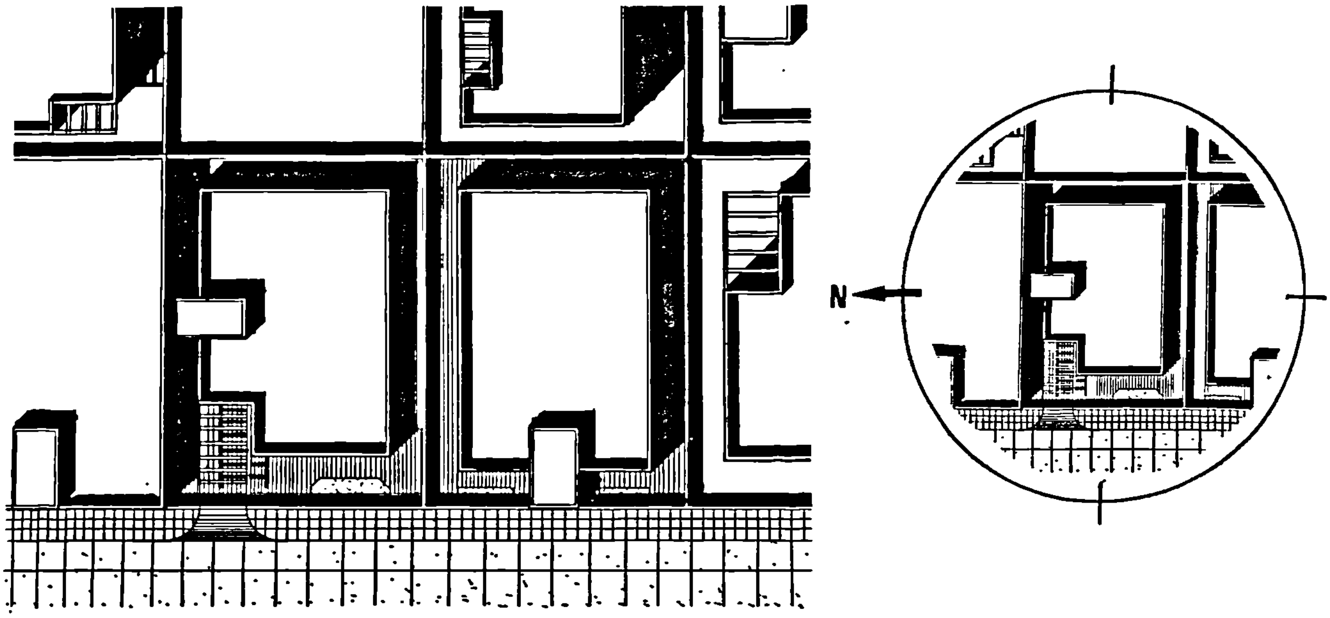
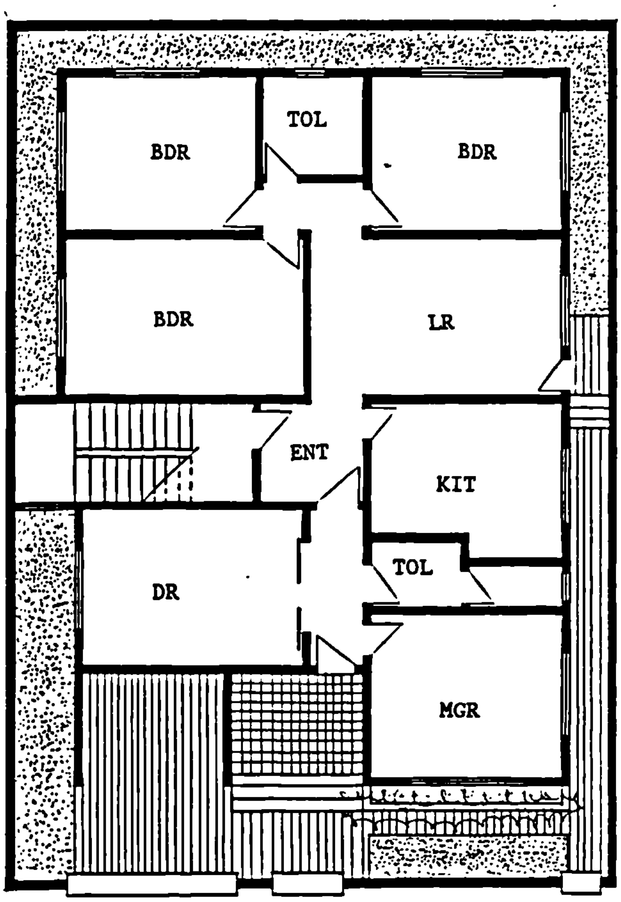
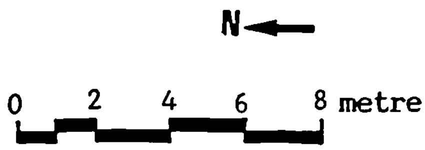


FIGURE 7.8 A: THE URBAN CONFIGURATION OF HOUSE 5, SHOWING THE HOUSE IN RELATION TO ITS NEIGHBOURS.

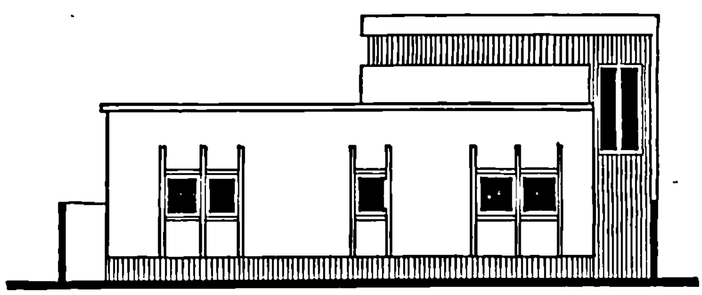


GROUND FLOOR PLAN

MGR : Men guest room
DR : Dining room
BDR : Bed room
LR : Living room
KIT : Kitchen
ENT : Entrance
TOL : Toilet



WEST ELEVATION



EAST ELEVATION

FIGURE 7.8 B: FLOOR PLAN AND WEST AND EAST ELEVATIONS OF HOUSE 5.

7.11 Case Study III-B (H6)

This house is the second house to represent the third category of the surveyed houses. It is located in Dammam city in a low density residential community with one to two-storey houses. The house is situated along a very major street which connects King Abdulaziz harbour with the rest of the region and carries a very large traffic volume. Most of the passing cars are heavy loading vehicles which increase the heat environment around the house and pollute the atmosphere. The other three sides of the house, which face north, south and west, are surrounded by one-storey houses similar in height and form. The average distances between the actual building and the neighbouring buildings are 3.5 metres from the north and south and 4 metres from the west.

7.11.1 House conditions

The house is a one-storey high building and is located in Dammam city next to the Saudi railway employees' compound. The house is designed to accommodate two separate families with private access for each family for financial reasons but, due to the expansion of the family, they use the whole house for only one family, and this is very clear in the layout of the house design. The actual building of the house is situated in the middle of the plot to form a villa type house, which provides outside circulation for the occupants to move very easily around the building. The surrounding outside area is totally paved and that increases the solar intensity around the building due to the reflectivity properties of the paved surface. Since the house is one storey high, all the house activities take place on the ground floor level. The house consists of six bedrooms, one men's guest room and one women's guest room, one living room, one kitchen, one storage and four toilets (see figure 7.9 A and B).

The house accommodates nine persons, seven of them are adults and the remaining two are children. All the occupants of this house are very well educated to university level and they are all part of one family.

The plot gross area is about 345.32 square metres and the net of the built area is 227.92 square metres. The average built area per person is approximately 25.32 square metres.

7.11.2 Energy used

The energy types used in this house are similar to the energy used throughout the country. These energy types are electricity and gas. The occupants of this house use electricity for cooling systems, appliances and lighting and they use gas for cooking purposes.

The master of the house showed his annoyance at the high energy consumption of the house. Actually the average monthly energy consumption in the summer months is about 11444.61 Kwh and the actual measured energy consumption for the month of September 1987 is 11437.71 Kwh. The different appliances available in the house are as follows:

Appliance	Number	Size
Fridge/freezer	1	18 ft^3
Gas oven	1	large
Washing machine	1	36 litre
Drying machine	1	3 Kg
Dish washer	1	medium
Television	2	26 inch
Video	2	-------
Window type air conditioners	8	14000/4100 Btu/Watts
Boiler	2	80 litre
Lights	8	100 W

7.11.3 Cooling system

The house is cooled totally mechanically through an air conditioner cooling system. The system used in cooling the house is the window type cooling system, which is very widely used in the region, despite the system exhausted heat and its short life efficiency due to the accumulative heat on the unit. The occupants of the house use the window type air conditioners to cool all the different rooms in the house except the kitchen, where they use a fan.

7.11.4 Effort achieved in saving energy

Despite the occupants' high level of education and their awareness of the high energy consumption problem, their contribution towards saving energy was very limited. They limited their contribution to using fewer rooms than their needs, and reduced the infiltration in the house; this is the least people can do. Also they did not use shading devices to stop the penetration of the sun, and they did not shade the air conditioner units to improve their efficiency.

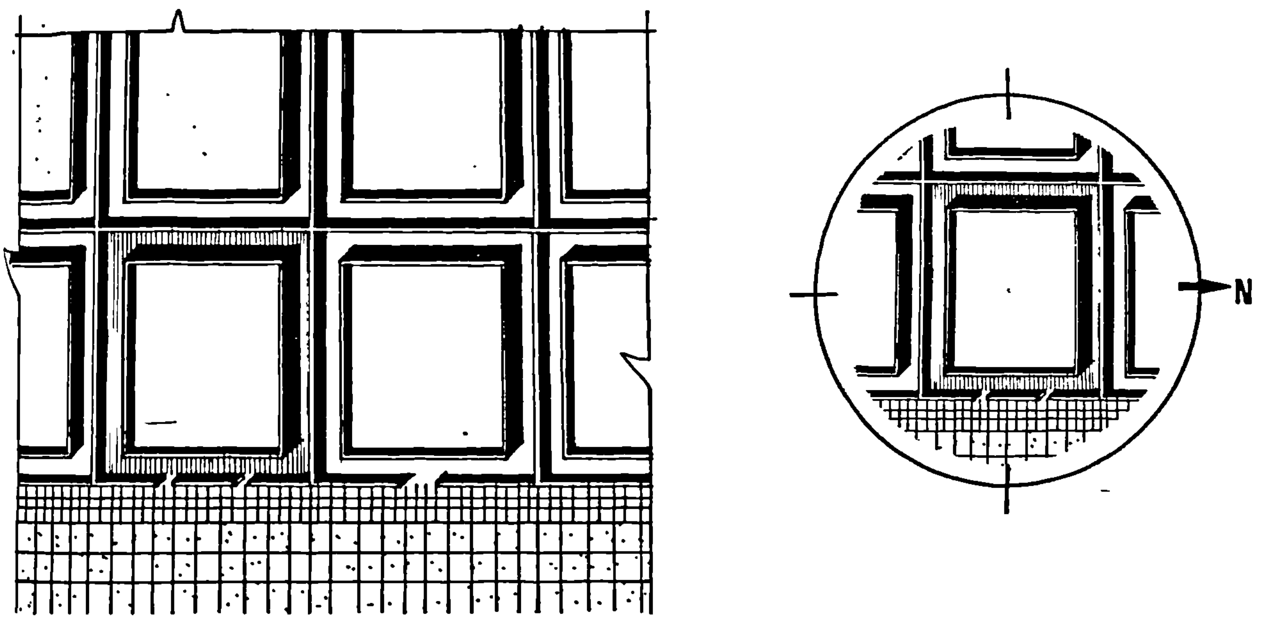
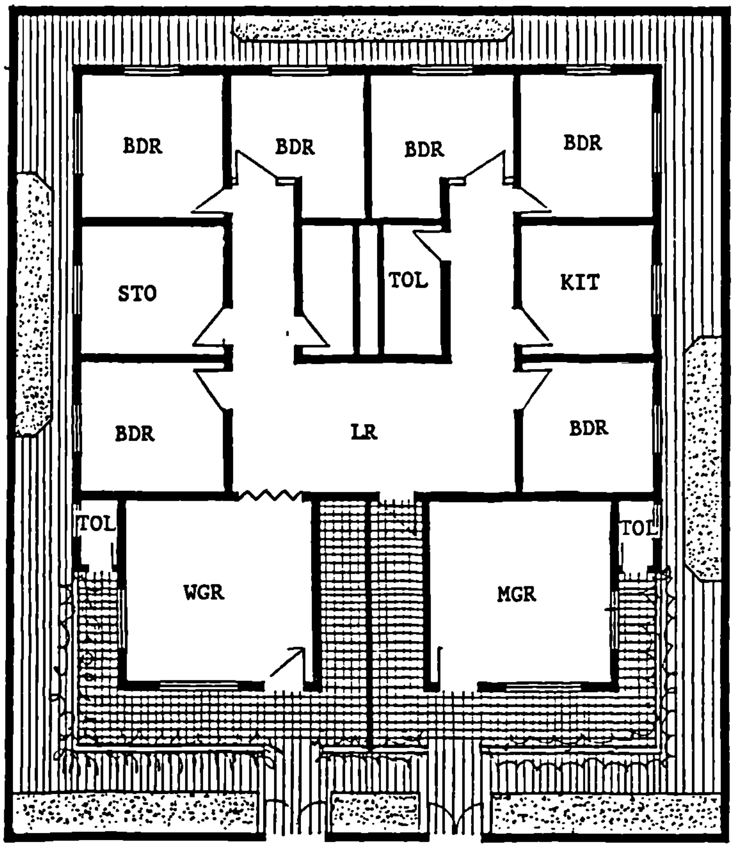
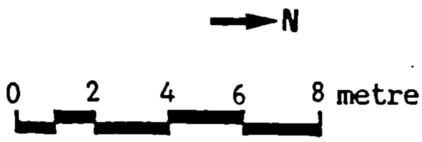


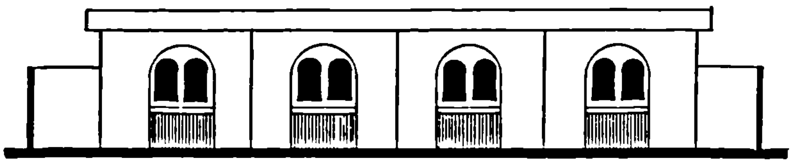
FIGURE 7.9 A: THE URBAN CONFIGURATION OF HOUSE 6, SHOWING THE HOUSE IN RELATION TO ITS NEIGHBOURS.



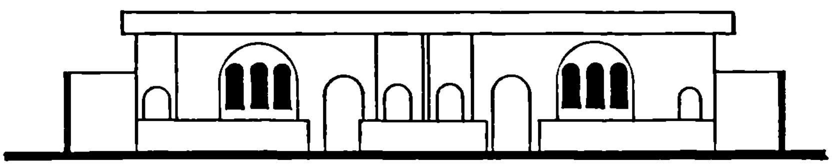
GROUND FLOOR PLAN

MGR : Men guest room
WGR : Women guest room
DR : Dining room
BDR : Bed room
LR : Living room
KIT : Kitchen
TOL : Toilet
STO : Storage





EAST ELEVATION



WEST ELEVATION

FIGURE 7.9 B: FLOOR PLAN AND WEST AND EAST ELEVATIONS OF HOUSE 6.

7.12 House Details

ITEMS	HOUSE 5	HOUSE 6
1. Dimensions -These two houses are rectangular in shape and their plots are:	20 m long by 14.5 m wide	19.70 m long by 17.80 m wide
The actual built area is:	16.6 x 12.85 x 1= 213.31 sq m	15.4 x 14.8 x 1 = 227.92 sq m
2. U Values in W/m_2k		
Since the external walls of these two houses consist of more than one material, it is important in simulating and calculating the performance of the house to specify the U value of each component of the envelope.		
External walls 210 mm thick hollow concrete block wall with 10 mm plaster and paint as a finishing texture.	1.7	1.7
Glazing and curtains single glazed windows with heavy cloth curtains and aluminium frame.	4.48	4.48
Roof 200 mm reinforced concrete flat roof with tiled surface and plastered ceiling.	3.35	3.35
Floor Solid concrete floor in contact with the earth, tiled and carpeted.	1.13	1.13
Ventilation rate The ventilation rate, which is the average interchange of air per hour between the inside and the outside atmosphere, is very hard to measure and there is not any information about the ventilation rate in the region. Therefore it is assumed for all houses equal to one.	1.00	1.00

	HOUSE 5	HOUSE 6
Mean internal temperature These mean internal temperatures are the average temperatures inside the house with the use of air conditioners. These are measured hourly for a period of one week (1-7 Sept 1987).	23	22
Mean external temperature The mean external temperature has been measured by King Fahad University of Petroleum and Minerals for the whole month on a daily basis.	33.48	33.48
Areas The survey which is conducted on the different envelope materials shows that these two houses are mostly constructed with two major materials which are concrete as an opaque wall and glass as a glazing wall. The areas of each material in each direction are as follows:		
opaque wall facing north	45.3 sq m	43.2 sq m
opaque wall facing east	34.55 sq m	37.9 sq m
opaque wall facing south	43.8 sq m	43.2 sq m
opaque wall facing west	35.55 sq m	37.9 sq m
glazing facing north	4.5 sq m	3.0 sq m
glazing facing east	4.0 sq m	6.5 sq m
glazing facing south	6.0 sq m	3.0 sq m
glazing facing west	3.0 sq m	6.5 sq m
Roof Flat solid reinforced concrete	213.31 sq m	227.92 sq m
Floor Concrete floor with contact with the earth	213.31 sq m	227.92 sq m

Profile Summary of the Case Study Houses

	House1	House2	House3	House4	House5	House6
1.Area in m^2	612	736	453.2	412.5	213.3	227.9
a.Wall						
North wall	95.75	134.5	95.89	80.5	45.3	43.2
East wall	94.75	84.0	62.37	62.65	34.55	37.9
South wall	92.25	120.0	86.13	78.15	43.8	43.2
West wall	93.75	96.0	71.46	64.0	35.55	37.9
b.Glazing						
North glazing	12.25	3.5	10.71	6.5	4.5	3.0
East glazing	7.25	12.0	20.43	6.35	4.0	6.5
South glazing	15.75	18.0	20.43	8.85	6.0	3.0
West glazing	8.25	0.0	11.34	5.0	3.0	6.5
c.Roof	306	368	226.6	206.2	213.3	227.9
d.Floor	306	368	226.6	206.2	213.3	227.9
2.No. of Storeys	2	2	2	2	1	1
3.No. in Household	15	14	6	6	6	6
4.Cooling system	S.U.	W.U.	S.U.	S.U.	W.U.	W.U.
5.Consumed energy Kwh	16842	23480	16420	11222	7142	11437
a.Cooling energy Kwh	16869	23357	16347	11161	7101	11385
b.Base load Kwh	73.05	72.8	73.61	61.13	41.34	52.59
6.Internal temp.°C	24	25	25	25.7	23	22

S.U. Split unit cooling system
W.U. Window type unit cooling system

Note: All houses built with similar building materials.

7.13 Findings

Survey and observation are very necessary in recording the user behaviour and measuring the different spaces of the house. Also they require special skills for conducting a precise measurement and obtaining information. The previous two survey case studies represent the best house,5,and the worst house,6,in energy consumption in the third category of the surveyed houses. The survey and observation of these two houses give some explanation for the difference in energy consumption between these two houses. These explanations are as follows:

1. The clear distinguishing feature between these two houses is the proportion of glazing in the building envelope. In House 5 the building envelope consists of a very small percentage of glass, which improves the thermal performance of the building. On the other hand, in House 6 the building envelope has a very large proportion of glass, especially in the east and west elevations, which increases the solar gain through the building envelope.

2. The type of the surface around the house has a great deal of effect on the solar intensity as well as the solar temperature around the house. In the survey conducted on these two houses, it was observed that House 5 is mostly surrounded by plants with a very limited pavement area, whilst House 6 is mostly surrounded by paved alleys which increase the solar intensity around the house and also increase the heat gain into the house. The increase in heat gain requires more energy to exhaust it, which is the case in House 6 (see figure 7.8B and 7.9B).

3. House 6 was designed in two parts to accommodate two separate families, but due to the extension of the family, the occupants joined the two parts together to form one house. The new formation of the house creates some problems, such as dead spaces which cannot be cooled directly and also cannot be ventilated. Unfortunately some of these dead spaces are used as the family

living room, which is the most frequently used area in the house due to its central location. In contrast, House 5 was originally designed to accommodate one family. Therefore there are no problems of dead spaces or of ventilation in this house (see figures 7.8B and 7.9B).

4. The proper circulation link between the different spaces is essential in minimising the infiltration in the house and preventing direct heat gain. In House 6 the circulation link between the men's guest room and the rest of the house is through an open corridor. The frequent movement of the inhabitants from the living room to the rest of the house increases the infiltration of hot air into the house and cold air out of the house. This process increases the cooling load of the house, which increases the energy consumption. In House 5, the internal circulation links are acceptable and there is no danger of wasting energy through these links.

5. The surrounding environment forms a micro-climate which can increase or decrease the heat gain in the building. In House 6, the surrounding environment consists of houses on three sides and a street on the other side. The houses which are on the north, south and west sides are useless as regards House 6 because they do not provide any shading for the house. Also the street on the east side is very wide and carries very heavy volumes of traffic which increase the heat around the house. House 5 is surrounded by two storey houses on the north and south which cast shade onto the house, and also the street is very narrow and the volume of traffic is very light.

7.14 Conclusion

Looking at the different problems illustrated by the survey and observation in each category, it is clear that the energy consumption (E) is a complex function of life style (LS), cooling system efficiency (CE) and building design (BD).

$$E = LS + CE + BD$$

The life style very much influences the energy consumption in any house. Usually different occupants do various activities at different times. Not only that, but their responses to the thermal environment vary from one person to another. Unfortunately, very little is known about the responses, which may be dependent on personal, social, cultural and economic variables. These variables are very hard to ascertain or to observe in a Saudi society, due to the secrecy of their personal lives. On the other hand, people are not willing to respond to any advice which may restrict their freedom in their houses, no matter what the reason may be. Therefore, due to the difficulty in dealing with the occupants directly, the study will not emphasise the life style, but this could be a very challenging subject for further research.

The cooling system efficiency depends on the type and condition of the cooling unit. Nowadays there are many types of cooling systems on the market and the dealers are competing with each other to provide costless systems with high efficiency. All the various types of cooling systems available on the market have been surveyed and these could be categorised according to their efficiency and cost.

The building design, which is the fabric and the building form, is a critical element which can contribute very efficiently towards saving energy. It is very much under the control of the architect and the local authority, which makes it possible for the design to be changed. Usually the architect is a channel between the private sector and the local authority for building matters. Since there is a greater potential for improving the performance of the building envelope through proper coordination between the local authorities and the architect, this study will try to investigate the potential for saving energy and will illustrate some recommendations, for the authority, the architect and the client to follow up the improvement of the building envelopes.

Finally, due to the secrecy of the occupants' life style and the possibilities of recommending a specific cooling system based upon the direct analysis of cost and efficiency, this study will concentrate on improving the energy consumption by proposing adequate building materials for that specific climate.

CHAPTER 8

CHAPTER 8

THE ENERGY CONSUMPTION PREDICTION MODEL

THE ENERGY CONSUMPTION PREDICTION MODEL

8.1 Introduction

A few years ago, basic data describing patterns of heat gain and loss in buildings in Saudi Arabia were unavailable. It is true that there were some well designed buildings, but these were considered to be innovative designs, and therefore not representative of the bulk of new buildings. Also there were some traditional buildings, which were performing very efficiently due to the type of materials used in their construction and the thickness of their walls. Nowadays, the situation is changing rapidly, and scientists are providing various means to tackle the different problems involved in heat gain and loss in buildings.

The basic principles being applied in controlling the building heat gain or loss are fairly straightforward; control is achieved by using different materials to slow down the rate at which internal conditions react to the variations in the external conditions, and by admitting direct radiation and sunlight during the heating season to reduce the load on the heating plant, and in some circumstances to eliminate it entirely. Most of the heat gain comes through the walls, roofs and windows, due to the temperature difference between the inside and outside, and to solar gain through the windows.

This chapter discusses the method of estimating the cooling load in order to improve the energy consumption in housing. The discussion consists of three major sections. The first section deals with establishing and developing a model for calculating the cooling load as well as the energy consumption for the house. The second section tests the developed model against the six measured houses. Finally, the results are discussed and evaluated in detail to investigate the possibility of applying the model to reduce energy consumption in any house in Dammam region.

8.1.1 The Scope of the Problem

Most of the contemporary buildings in Dammam region are built with medium weight cement block and dense concrete in compacted form as primary building materials. The dominant contemporary building materials are the cement hollow block and mortar as infill walls, and reinforced concrete as the structural element. The entire resulting building structure functions as a light skin envelope, which does not provide enough thermal protection for the inside environment. As a result of the wide use of contemporary materials in housing in the region, energy consumption has increased due to the increase of the cooling load in the house, especially in the summer period.

On 14th of June 1988, the managing director of the Saudi Consolidated Electric Company (SCECO) in the eastern province, reported in Alyaum newspaper, issue number 5478, that, due to the high domestic energy consumption on 13th of June 1988, the company reached its maximum production, which is 4340 MW; this increase in production prompted the company to ask for more supplies from the Saline Water Conversion Corporation Plants of Alkhobar and Jubaill. This report by the managing director shows the deep concern of the local authority for the high energy consumption of housing in Dammam region. The problem of high energy consumption has become the major concern of the local authorities, as well as the people in the region, who have been frightened by the increase of energy demand and shortage of supplies, a sign of future increases in the energy prices.

8.1.2 The Heat Gain and Loss Parameter

At any particular time, the rate of heat gain or loss by the interior of a building is the result of several phenomena occurring simultaneously. These individual gains or losses may include heat transmission through the envelope, internal heat gain, solar gain through windows and ventilation heat gain or loss.

The most important factors affecting heat gain or loss by heat transmission through the envelope are the outside and inside temperatures, radiation affecting the outside surfaces and the properties of the building envelope. The internal heat gain is a result of the heat input by the occupants, appliances, electronic equipment and lighting in the house.

Ventilation has a great effect on the internal conditions. Whenever the inside air escapes from a building, it is immediately replaced by an equal volume of the outside air. In this case, if the outside air is at a higher temperature than the inside air, then this is considered to be a heat gain by the interior. On the other hand, if the inside air is warmer than the outside air, then this is considered to be a heat loss.

Solar gain through the windows is a result of the sun shining through the windows into the interior. This results in heat gain, which is quantified by the intensity of solar radiation, the orientation, the angle of the falling radiation and the properties of the fenestration.

The sum of these rates of gains or losses gives the rate at which heat must be removed from or supplied to the interior of the building to maintain a constant internal air temperature. The model which will be developed is a mathematical interpretation of the sum of these rates of gains or losses which affect the internal conditions of the building. Due to the great potential in saving energy by improving the thermal performance of the building envelope, a method has been developed to calculate the energy consumption of the house, based upon the CIBS Guide recommended energy balance equation in calculating the heat loss in the building.

8.2 The Parameters of the Energy Balance Equation

The energy balance equation has several parameters which may vary from one climate to another, due to the fact that there are some parameters which may be considered in one part of the world and ignored in others. For example, in the climate of Dammam region, latent heat and moisture input are considered important factors in the heat gain which is required to be extracted from the building, whereas in the climate of the United Kingdom for example these parameters are unimportant since cooling is not a problem. Therefore, the amount of heat required to be supplied to or extracted from the house in order to keep the internal temperature constant depends on several parameters, which are reasonably related to the climate of the region.

The parameters affecting the energy balance model are the heat gain through the fabric by conduction, the incidental heat gain which is comprised of solar gain and internal gain, ventilation heat gain, and moisture and latent heat gain.

$$Q_T = Q_C + Q_I + Q_V + Q_M \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 8.1$$

where : Q_T = Total heat needing to be extracted from the building

Q_C = Fabric heat gain by conduction

Q_I = Incidental heat gain which is

$= Q_{\text{solar heat gain}} + Q_{\text{internal heat gain}}$

Q_V = Ventilation heat gain

Q_M = Moisture and latent heat gain

8.2.1 Conduction heat gain or loss: (Q_C)

The conduction heat gain or loss through the fabric is a result of heat transmission processes between the fabric and its surrounding environment. This heat gain or loss by conduction can be calculated from the products of the envelope area, temperature differences, and the different thermal transmittance (U-value) of each component of the building envelope $(\Sigma AU)^2$. Since the external temperature is mostly higher than the internal temperature, and the purpose of the calculation is to cool the space, so the conducted heat gain (Q_C) is calculated as follows:

$$Q_C = 24\ (\Sigma AU)\ (T_o - T_i) \quad \text{.................} \quad 8.2$$

where : Q_C = fabric heat gain by conduction .... wh/day.

A = area of the envelope .... M^2

U = envelope transmittance value .... w/M^2K

T_o = outside mean daily temperature .... ^oC

T_i = internal mean daily temperature .... ^oC

24 = number of hours in a day

In reality, solar radiation effects the rate of conducted heat flow through the envelope; in determining the rate of heat flow due to solar radiation falling on the envelope of a building, it is convenient to base the calculations on a temperature difference. It is clear that when the surfaces of a building are subjected to solar radiation, a rise in the internal temperature is produced similar to that which would occur if the outside temperature were increased. Thus the absorbed radiation has the same effect as a rise in the outside temperature. Therefore, for building design purposes and energy calculation, it is useful to combine the heating effect of radiation incident on a building with the effect of warm air. This can be facilitated by the concept of sol-air temperature T_{sa} which is discussed further in this chapter. The conducted heat gain through the envelope is calculated as follows:

$$Q_C = 24\ (\Sigma AU)\ (T_{sa} - T_i) \quad \text{.........................} \quad 8.3$$

where : T_{sa} = sol-air mean daily temperature

8.2.1.1 The concept of the sol-air temperature :

The sol-air temperature concept was introduced in 1944 by Mackey and Wright to include the solar radiation incident on the wall. In 1946, further researches have been done on sol-air temperature by Mackey and Wright, which led them to the following mathematical equation for estimating the sol-air temperature[3]:

$$T_{sa} = t_{ao} + \frac{Ia}{h_o} \quad \ldots\ldots\ldots\ldots,\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 8.4$$

where : T_{sa} = sol-air temperature ^oC

t_{oa} = external air temperature ^oC

I = intensity of solar radiation incident on the outside surface of the wall ....w/m^2

a = absorptivity of the outside wall surface for solar radiation

h_o = heat transfer coefficient for outdoor air film..$m^{2o}C/W$

8.2.1.2 Modifications of the sol-air temperature concept :

As time has passed many ideas and researches have been brought to life in developing and in enriching the concept of sol-air temperature. Many researchers have worked on the sol-air temperature concept, believing that various factors have been neglected by the first concept or suggesting further improvement in the degree of accuracy; among these researchers are Roux (1950), Loudon (1963) and Hoglund, Mitalas and Stephenson (1967). In 1967 Hoglund and his colleague did a comparative study on three sol-air concepts, the original (Mackey and Wright, 1944) and two modified versions, and a thermal response factor method to assess the thermal performance of a flat roof[4]. They found that the original concept gives, on clear nights, a higher surface temperature than the measured temperature; this indicates that the sol-air temperature is higher than it ought to be at night. They explained that the first concept of sol-air is based on the assumption that the sky radiates as a black body at outside temperature. They confirmed the findings of Roux in 1950 when he noticed the neglect of the long wave radiation exchange between the surfaces and the environment. Therefore, he suggested the following modifying equation:

$$T_{sa} = t_{oa} + \frac{I - I_L}{H_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 8.5$$

where : T_{sa} = sol-air temperature .... ^oC

t_{oa} = outside dry-bulb temperature .... ^oC

I = solar radiation incident on the surface .... W/m^2

I_L = long wave radiation incident on the surface .W/m^2

H_c = convection heat transfer coefficient .... $M^{2o}C/W$

In 1963, London introduced a similar modified concept of sol-air temperature. This modified concept defines the heat flow on the external surface as the difference between the heat gain by solar radiation and the heat loss by long wave radiation. In 1970 the IHVE Guide adopted this conceptual equation, and in 1979 the CIBS Guide adopted it also and defined the sol-air temperature concept as "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 air temperature and incident solar radiation"[5]. The final adapted equation is given as:

$$T_{sa} = t_{so} + R_{so}\,(aI - EI_L) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 8.6$$

where : T_{sa} = sol-air temperature .... ^oC

t_{so} = outside air temperature .... ^oC

R_{so} = external surface resistance .... M^2K/W

a = surface absorption

I = solar radiation incident on the surface ...... W/m^2

E = emissivity of the surface

I_L = Long wave radiation incident on the surface .. W/m^2

The long wave radiation gain from the ground to the vertical surface is balanced by the long wave radiation loss from the wall to the sky, which produces zero radiation exchange. Actually the IHVE Guide gives a value of 100 wm^{-2} for the long wave radiation from horizontal roofs to a clear sky, also the Guide stated that EI_L can be taken as zero in the case of vertical surfaces, due to the approximately balanced emitted and received radiation by the walls[6].

Therefore the above equation can be written for the wall sol-air temperature as:

$$T_{sa} = T_o + R_{so} * a * I_v \text{.............................} \quad 8.7$$

where : I_V = solar radiation incident on vertical surfaces . W/m^2

8.2.1.3 Solar radiation on a vertical surface :

Usually meteorological records of global, direct, diffuse and ground reflected irradiation on vertical or tilted surfaces are more scarce than those for horizontal surfaces. However, for most building design purposes, like the necessity of estimating the cooling loads arising from radiation incident on walls or transmitted through windows, or even for predicting the efficiency of the solar collectors, the information of the solar radiation incident on vertical or tilted surfaces is very essential.

Therefore, solar radiation on vertical surfaces has to be calculated from the data on horizontal irradiation. The method used to calculate the solar radiation on sloping surface is that suggested by Markus and Morris which is :[7]

$$I_v = (I - I_d) * R + I_d \, (1 + Cos_S)/2 + rI \, (1 - Cos_s)/2 \; \ldots \; 8.8$$

where : I_v = solar radiation on tilted surface .... W/m^2

I = mean global solar radiation on horizontal surface. W/m^2

I_d = mean diffused radiation on horizontal surface .... W/m^2

R = function of latitude and orientation

r = ground reflective factor

S = slope angle of surface from horizontal

For vertical surfaces :

$$S = 90^o$$

Therefore $\cos_s = 0$

By substitution in equation for the value of $\mathrm{Cos}_s\ 90$

$$I_v = (I - I_d) * R + I_d\ (1 + \mathrm{Cos}_s\ 90)/2 + rI\ (1 - \mathrm{Cos}_s\ 90)/2$$

$$I_v = (I - I_d) * R + I_d\ (1 + 0)/2 + rI\ (1 - 0)/2$$

Therefore

$$I_v = (I - I_d) * R + I_d/2 + rI/2 \qquad \text{8.9}$$

8.2.2 Incidental heat gain: (Q_I)

The incidental heat gain comprisestwo major gains, internal heat gain and solar heat gain. The internal heat gains are produced from the occupants, domestic appliances, electronic equipment and lighting, and these are known as casual gains. The solar gain is a result of the sun shining on the windows of the house.

$$Q_I = Q_{In} + Q_S \qquad \text{8.10}$$

where : Q_I = incidental heat gain
Q_{In} = internal heat gain
Q_S = solar heat gain

The internal heat gain (Q_{In}) is calculated from the total heat input from people, cooking, appliances and lighting. This heat cannot be calculated precisely, but there are several ways of estimating it. Firstly, it could be estimated from the tables by knowing all the different heat sources in the house. Secondly, it could be measured by subtracting the cooling load (if known) from the total energy consumed.

Q_{In}(internal gain)= base load + heat gain from occupants----(2a)···8.11

The solar heat gain (Q solar gain) can be calculated from the following equation:

$$Q_S \text{ (solar gain)} = IV * T * M * a * A \quad \ldots\ldots\ldots\ldots\ldots 8.12$$

where

IV = solar radiation on tilted surface ....Wh/m^2

T = transmission factor for glazing which is 0.87 for single clear glazing[8]

M = Maintenance factors for vertical glazing which is 0.9 for clear glazing[9]

a = Shadow factor

A = the area of the glazing surface .... M^2

hence:

$$Q_I\text{(incidental)} = Q_{In}\text{(internal gains) (equation 8.11)} + Q_S\text{(solar gain) (equation 8.12)}$$

$$= Q_{In}\text{(internal gains)} + I_V * 0.783 * a * A\text{----(2)} \ldots\ 8.13$$

Therefore, after the sum of equation 8.3 and 8.13, the energy balance equation has become as follows :

$$Q_T\text{(total heat)} = Q_C\text{(fabric heat gains} + Q_I\text{(incidental heat gains)}$$

$$Q_T = 24\ (\Sigma AU)(T_{sa} - T_i) + Q_{In} + I_v * 0.783 * a * A \ldots\ldots \quad 8.14$$

8.2.3 Ventilation heat gain or loss :

Ventilation usually occurs by opening the doors and windows and also by infiltration through air gaps. The ventilation heat gain or loss can be expressed as :

$$Q_V = Cpv\ (T_i - T_o) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 8.15$$

where : Q_V = heat gain through ventilation W

C = specific heat capacity of air J/kg °C

p = density of air kg/m^3
v = ventilation rate m^3/s
T_i = internal mean daily temperature ^oC
T_o = outside mean daily temperature ^oC

Evaluation of this expression for the normal range of air temperature, specific heat capacity and density produces:

$$Q_V = 1200\ v(T_o - T_i) \quad .... \text{ where } V = \frac{N * V}{3600}$$

This equation can be expressed in terms of the air change rate as follows:

$$Q_V = 0.33\ NV(t_o - t_i) \text{ ------------(3)........... } 8.16$$

where : N = rate of air interchange per hour
V = room volume

The mean daily heat gain due to ventilation is then

$$Q_V = 24 * 0.33\ N_V\ (t_o - t_i) \text{ .... } 8.17$$

8.2.4 Moisture and latent heat: (Q_M)

In an air conditioned house the refrigeration system controls the relative humidity by extracting moisture from the air. This process requires the use of energy. In order to maintain constant conditions the moisture extracted must be equal to the gains of moisture from the various sources. Moisture gains occur from the following:

(i) = moisture emitted by people (MP)
(ii) = moisture emitted by bathing (Mb)
(iii) = moisture by clothes' washing (MW)
(iv) = moisture by preparation of food and cooking (MC)
(v) = moisture from ventilation air (MV)

The moisure that has to be extracted per day ME is given by:

$$M1 = MP + Mb + MW + MC$$

$$MV = M\ (go - gi)$$

$$ME = M1 + 24\ MV$$

where : ME = moisture extracted by refrigeration system

M1 = moisture input by people bathing, cooking and clothes washing

M = ventilation rate kg/s

g_o = outside moisture content Kg/s

g_i = inside moisture content Kg/s

$$Q_M(\text{Energy used}) = ME \times \text{Latent heat } L$$

$$Q_M = \left(M1 + \frac{\text{ach x vol}}{\text{sp. vol}} \times 24\ (g_o - g_i)\right) \times L \quad \text{------- .... } 8.18$$

The developed model for calculating the total heat needing to be extracted is as follows:

$$Q_T(\text{Total heat extracted}) = \text{equation}(8.3) + \text{equation}(8.13) + \text{equation}(8.16) + \text{equation}(8.18)$$

which is :

$$Q_T = Q_C + Q_I + Q_V + Q_M$$

$$Q_T = (24 * A_{wall} * U_{wall}\ (T_{sa} - T_i) + 24 * A_R * U_R\ (T_{sa} - T_i) + 24 * A_F * U_F\ (T_o - T_i) + 24 * A_{win} * U_{win}\ (T_o - T_i) + I_v * 0.783 * A_{win} * a + Q_{In} \text{ internal heat gain} + 24 * 0.33 * NV\ (T_o - T_i) + Q_M\ ) * \text{days in the month} \quad \text{.................. } 8.19$$

The above expression only applies when cooling is taking place. When used in computer program a test is applied while acts value of Q_M to zero when the sum of Q_C, Q_I and Q_V is zero or negative.

To obtain the energy required to run the cooling system, the heat extracted has to be divided by the coefficient by performance of the system.

$$\text{Energy} = \frac{Q_T}{COp} \text{ kwh} \qquad 8.20$$

8.3 The Breakdown of the Model

The model is broken down into several parts for detailed calculations:

1 - Fabric gains: (Q_C)

a. Wall gains for each facade:
$Q_w = U_{wall} * A_{wall} (T_{sa} - T_i)$ "for each facade"

b. Roof gain:
1 - daytime $= U_R * A_R (T_{sa} - T_i)$
2 - night-time $= U_R * A_R (T_{sa} - T_i)$

c. Floor gain:
$Q_F = U_F * A_F (T_o - T_i)$

d. Window gains for each facade:
$Q_{win} = U_{win} * A_{win} (T_o - T_i)$

2 - Incidental gain: (Q_I)

a. Solar gain:
$Q_s = I_V * 0.783 *$ a "shadow factor" $* A_{win}$

b. Internal gain:
Q_{In} = base load + heat input by occupants

3 - Ventilation gain: (Q_V)

$$Q_v = 0.33 * N * V (T_o - T_i)$$

4 - Moisture and latent heat gain: (Q_M)

$$Q_M = (M1 + \frac{\text{ach x vol}}{\text{sp. vol}} * 24 (g_o - g_i)) * L$$

Note : The sol-air temperature (Tsa) used for the wall calculation is different than the one used for the roof calculation. This is due to the fact that the sol-air temperature used for the wall is based upon the solar radiation falling on vertical plane, where the other one is based upon solar radiation falling on horizontal plane.

8.4 The Model Validation

Building up a mathematical model, a number of simplifying assumptions are needed in order to produce a tractable solution. However, most of the parameters required by the mathematical model are subjected to estimation errors. Additionally, it has to be recognised that the mathematical model as a whole is an approximation of the reality. Therefore, if the predicted variables of the model are compared with the corresponding measured variables from the real measurements, the perfect agreement between both the measured and the predicted values is rarely reached. To improve the quality of the model results with respect to the real measurements, a validation is then needed before the model can be used to represent the reality for any practical purpose. The validation is responsible for providing confidence in the results predicted by the model and the corresponding variables in the real measurements match within a reasonable degree of accuracy.

8.4.1 Validation

Validation is concerned with testing the validity of a model's theoretical basis and its ability to reproduce observed performance. However, several validation techniques such as the analytical verification, the inter model comparisons, and the empirical validation are available to the researcher to calibrate his model and to bring it within a reasonable prediction range. Actually, the most widely used technique is the empirical validation method while it has the greatest potential for assessing whether the approximation and operations in the model are adequate to predict the measured building response. In principle, the empirical validation can provide a truthful model and it is not limited in validating the models of simple buildings[10]. In general, the empirical validation is a comparison of the predictions of the model with physical measured building and the main advantage of this method is that it involves experimentation with all its attendant problems. However, the process of the empirical validation are subjected to some errors; therefore, it is necessary to examine the sources of error in the validation process and give some indication of their relative magnitude.

The sources of error involved in the empirical validation can be categorised into two main errors; internal errors and external errors. The internal errors occur due to inaccuracies in the equations used and in the modelling and numerical solution techniques adopted by the model and due to the coding errors. On the other hand, the external errors usually occur in gathering the data, in feeding this data to the model, in measuring the building response and in comparing measured and predicted values. However, the possible external error sources may occur in the model validation are as follows.

1. Climatic data errors due to some data taken at a remote site, frequency of measurement insufficient to define variable, or/and finite accuracy of measurements.

2. Site data errors due to unmeasured shading objects around the building or inadequate information about the ground reflected radiation or undefined reflectivity.

3. Building data errors due to inadequate description of building geometry and construction, uncertain workmanship and/or infiltration and conduction rates are not measured.

4. Occupying data errors due to uncertain wild gains from appliances, uncertain of heat input by the people and uncertainty in modelling furnishings.

5. User interface errors due to interpretation of poorly documented input data and/or assuming values to replace the missing data just to satisfy the model requirements.

Eventually in designing the experiments for the use of empirical validation the main challenge is to limit, control and specify the many thermal mechanisms which operate in the building, so the causes of divergence between the measured values and those predicted by the model can be identified easily. However, it is understandable that it is virtually impossible to identify and fully quantify all the different interacting mechanisms occurring in the buildings. Therefore, the validation is likely restricted to comparisons between the model predictions and the measured values which reflect the performance of the building. Finally, it is important that the precise data needed in the prediction model is satisfied by the collected data which should contain an adequate physical description of the building, details of the building operation and control schedules, comprehensive climatic records conducted in the site, measurements of some of the building responses, and users behaviour in the building.

8.4.2 The Scope of the Validation

The aim of this test is to investigate the validity of the calculation model, which has been developed previously, in order that it be used in further calculations for building improvement. The obvious way in which the model is tested is by comparing the actual energy consumptions in the sample of occupied houses with the consumptions predicted by the model. The collection of data on monthly energy consumption was maintained by computer output records for each house for twelve months. Similarly, predictions of energy consumption were based on a physical survey of the house, internal temperature measurement and a short questionnaire which established details of the house and its occupancy.

The developed models for calculating the cooling load in the house were tested against actual measured energy used in occupied houses for a period of twelve months. The group of houses comprised six houses, four two-storey houses and two single-storey houses. Three of them were cooled by electrical window type air conditioning units; the other three houses were cooled with an electrical split air conditioning unit. It was inevitable that certain limitations arose from the crude nature of some of the data collected and the small number of houses considered, due to the limitation of time available and the nature of the occupants' privacy and the lack of instruments. For example, physical measurements of the sizes of the windows in the house were, in some cases, taken from the house working drawings to minimise disturbance to the occupants. Finally, the purpose of this test was to check the validity of the model by comparing the predicted cooling load with the actual measured cooling load.

8.4.2 Data Collection

A. Actual energy consumption:

The amount of actual energy consumed by every one of the six houses was provided by the Saudi Consolidated Electric Company in the eastern province, for a period of one year. The monthly statements of the energy used which were provided represent the energy used for cooling as well as the energy used for other purposes in the house such as cooking, washing, drying, lighting etc. Therefore, the actual energy used by the cooling systems is determined by subtracting the base load, which is the energy used in the house other than the cooling system, from the actual energy consumed. This can be presented as:

energy consumed by cooling load = total energy consumed - base load

B. Measurements and questionnaire:

The measurements were selected in a way as to get maximum information with the minimum number of instruments. The physical measurements taken during the survey were as follows:

(1) The external width, depth and height of the house including any extensions.

(2) The total glass and window (glass plus frame) areas on each facade, note being made of the orientations.

(3) The internal temperature and humidity of each house was measured with a thermo hydrograph, while the air conditioning was working, to determine the comfort level of each house and humidity.

(4) Daily as well as monthly outside air temperature data were derived from the records provided by the Meteorology Station at the Research Institute at King Fahad University of Petroleum and Minerals.

(5) Daily as well as monthly global, direct and diffuse solar radiations were provided by the Meteorological Station at the Research Institute of King Fahad University of Petroleum and Minerals.

These details were used to calculate the following quantities:

(1) The total areas of all external elements of the house, required to evaluate the sum of (area * U-value).

(2) The volume of the house, required in the estimation of ventilation heat gain.

(3) The areas of glass and opaque fabric on each external facade of the house, to permit the estimation of the solar gain in the house.

(4) The quantity of solar radiation on the horizontal as well as vertical surfaces in order to calculate the sol-air temperature.

(5) The energy used by the lighting appliances and electronic equipment.

The remaining data was obtained by interviewing the householder and by personal observation. The subjects covered were as follows:

<u>House construction</u>:

(1) External wall types and presence of insulation.

(2) Roof type and details of slope and insulation.

(3) Window shading devices.

Cooling:

(1) Type of cooling system used and proportion of house cooling.

(2) The different types of energy used for cooling.

(3) Time of cooling and different time usage of spaces.

(4) Supplementary cooling such as fan or cross ventilation.

Incidental gains and energy used for non-cooling purposes:

(1) The different appliances, lighting and equipment using electricity.

(2) The energy used for cooking.

(3) The number of occupants and the time the house is occupied.

8.4.4 Calculation Procedures

The energy consumption for cooling the house can be predicted by applying the model to the data obtained for each house. In the houses the actual energy consumed was the total energy used by the cooling system and by other miscellaneous purposes in the house. In order to apply the model most effectively there are a few calculations needing to be done on the obtained data. Those calculations concern the energy used for miscellaneous purposes in each house, the actual energy used for cooling and the internal heat gain.

8.4.4.1 The energy used for miscellaneous purposes.

The energy used for miscellaneous pruposes is determined by surveying all the different appliances and equipment in each house of the case study houses. Fortunately, the electricity company provides information on the average consumption of a range of domestic appliances[11]. These figures were combined with the survey data to produce the tables below.

House Profile : House 1
=======================

Appliances (from survey)	Quantity (from survey)	Size (from survey)	Working hour/day	Consumption kwh/d
Fridge/freezer	1	$18ft^3$	15h/day	18.75
Freezer	1	$18ft^3$	6h/day	7.5
Kettle	1	2 litre	2h/day	4.00
Washing Machine	1	44 litre	1h/day	4.00
Drying Machine	1	5 kg	1h/day	2.00
Television	4	26 inch	8h/day	3.84
Video	1	--	8h/day	.96
Boiler	2	80 litre	4h/day	12
Lights	20	100 W	10h/day	20
Estimated Base Load				73.05

House Profile : House 2
=======================

Appliances (from survey)	Quantity (from survey)	Size (from survey)	Working hour/day	Consumption kwh/d
Fridge/freezer	2	$12ft^3$	15h/d	22.5
Freezer	1	$18ft^3$	6h/d	7.5
Washing machine	1	44 litre	1h/d	4
Drying machine	1	5 kg	1h/d	2
Television	3	26 inch	8h/d	2.88
Video	2	--	8h/d	1.92
Boiler	2	80 litre	4h/d	12
Lights	20	100 W	10h/d	20
Estimated Base Load				72.8

House Profile : House 3

Appliances (from survey)	Quantity (from survey)	Size (from survey)	Working hour/day	Consumption kwh/d
Fridge/freezer	2	$12ft^3$	15h/d	22.5
Electric oven	1	7500 W	3h/d	22.5
Washing machine	1	44 litre	1h/d	4
Drying machine	1	5 kg	1h/d	2
Television	2	22 inch	8h/d	2.4
Video	1	--	8h/d	.96
Microwave	1		1h/d	3.25
Boiler	1	80 litre	4h/d	6
Lights	10	100W	10h/d	10
Estimated Base Load				73.61

House Profile : House 4

Appliances (from survey)	Quantity (from survey)	Size (from survey)	Working hour/day	Consumption kwh/d
Fridge/freezer	1	$18ft^3$	15h/day	18.75
Freezer	1	$18ft^3$	6h/day	7.5
Gas oven	1	Large	--	-
Washing machine	1	36 litre	1h/day	4
Drying machine	1	5 kg	1h/day	2
Dishwasher	1	Medium	1h/day	4
Television	2	20 inch	8h/day	2.4
Video	1	--	4h/day	0.48
Boiler	2	80 litre	4h/day	12
Lights	10	100 W	10h/day	10
Estimated Base Load				61.13

House Profile : House 5
======================

Appliances (from survey)	Quantity (from survey)	Size (from survey)	Working hour/day	Consumption kwh/d
Fridge/freezer	2	$12ft^3$	15h/d	22.5
Freezer	1	$12ft^3$	6h/d	5
Washing machine	1	36 litre	1h/d	4
Drying machine	1	3 kg	1h/d	2
Television	3	22 inch	8h/d	2.88
Video	1	--	8h/d	.96
Boiler	1	80 litre	4h/d	6
Lights	8	100 W	10h/d	8
Estimated Base Load				41.34

House Profile : House 6
======================

Appliances	Quantity	Size	Working hour/day	Consumption kwh/d
Fridge/freezer	1	$18ft^3$	15h/d	18.75
Washing machine	1	36 litre	1h/d	4
Drying machine	1	3 kg	1h/d	2
Dishwasher	1	Medium	1h/d	4
Television	2	26 inch	8h/d	1.92
Video	2		8h/d	1.92
Boiler	2	80 litre	4h/d	12
Lights	8	100 W	10h/d	8
Estimated Base Load				52/59

8.4.4.2 Actual energy used for cooling.

Measuring precisely the actual energy consumed by the cooling systems is a very hard task to achieve in a society with a high concern for privacy. The available data on the consumed energy is the total energy consumed by each house, and this energy includes the cooling consumption and the appliances' and equipment consumption, so the possible way of calculating the actual energy used in cooling is by deducting the base load, which is the energy used by appliances, equipment and lighting, from the total energy consumption.

Therefore:

$$E_c = E_t - E_b \qquad 8.21$$

E_c = The energy consumed by the cooling systems
E_t = The total energy consumed by the house
E_b = The base load of the house, which is calculated previously as miscellaneous consumption.

8.4.4.3 Internal heat gain

The internal heat gain is comprised of input heat from occupants, appliances, equipment and lighting. The heat input by the appliances, equipment and lighting is considered equal to the house base load; therefore, the total internal heat gain is the sum of the base load and the heat input by the occupants.

8.4.5 Results and Analysis of the Test

Bearing in mind that the purpose of this calculation at this stage is to test the accuracy of the model, the various energy consumptions for cooling the houses were predicted by applying the model, described earlier in this chapter, to the data obtained for each house. In fact, apart from the original trials done during the process of establishing the actual model, two other trials were also undertaken by the author in order to test the accuracy of the model in estimating the cooling loads of the house; six houses were considered in total.

As a result, an over-estimation of the cooling load was given by the model in the first trial when the actual measured energy consumption of the house was compared with the estimated one (see figure 8.1). It should be mentioned that the model was applied for the whole house as a cooling zone.

In the second trial the same six houses were tested again. A reasonable estimation of the cooling load was derived by the model. This time two additional factors were taken into account. These two factors, which were determined by a survey conducted by the author, are as follows:

(1) The model was applied in the cold zone of the house.
(2) The time of cooling of the different spaces in the house.

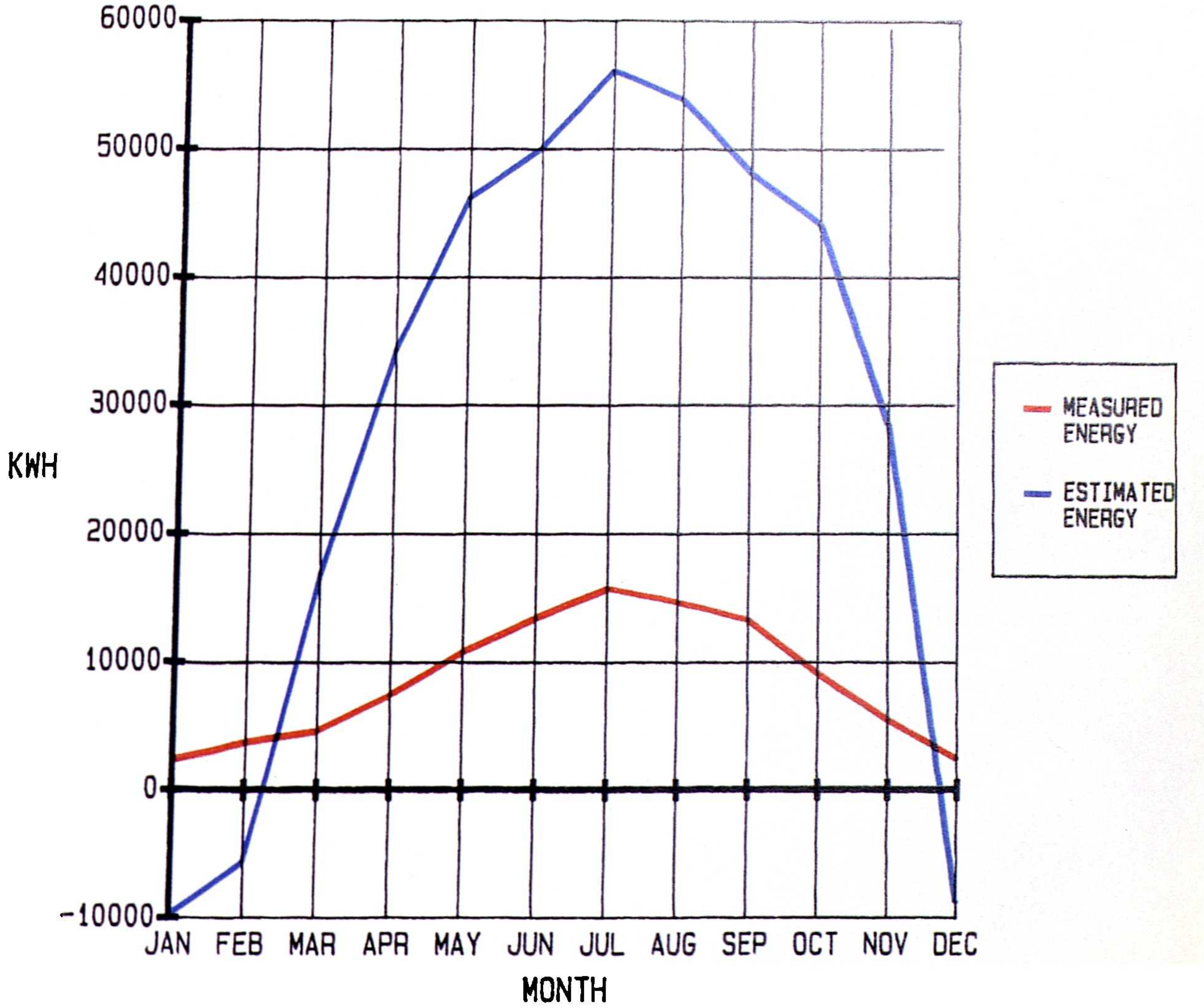
8.4.5.1 The Results

A better understanding of the concept of the model can be established from the following figures.

The predicted cooling load for each house was plotted on a monthly basis together with the measured energy use for cooling in figures 8.2 to 8.7.

It can be seen from the figures that the model predicts a negative cooling load during the months of January, February and December (Section AB & DE for figures 8.2 to 8.7). This means that heating is required to maintain the internal conditions. In order to investigate further whether this is a reasonable result, figures of outside air temperature were plotted for the appropriate months. It can be seen from those figures that for the months of January, February, and December, external temperatures are in general lower than would be required for comfort (see figures 8.8 (1, 2) and 8.10 (4). This provides some confirmation that heating may be needed during those months. Even though those two sections, AB & DE, form a quarter of the figures as can be seen clearly which revealed that the amount of heating that

FIGURE 8.1: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY CONSUMED BY HOUSE 1



may be needed is very small and does not constitute a problem for the occupants of the houses. This is further backed up by the survey results (Chapter 6).

The weather data for March was plotted in figure 8.8(3); it indicates that for some of the time heating may be required and for other times cooling may be necessary. Section BC for all figures (8.2 to 8.7) shows indications of cooling and heating loads at the same time. As it is not known for how long a heating requirement may exist, it was decided to omit March from the analysis and only concentrate on those months where a definite cooling requirement exists.

Section CD for all figures (8.2 to 8.7) indicates the cooling load for the rest of the year, which is the period between April and November. In these eight months the cooling is definite due to the high temperature which is clearly above the comfort level of the people (see figures 8.8, 8.9 and 8.10). In this section there is a good agreement between the measured energy consumption and the estimated ones which can be seen in figures 8.2 to 8.7.

Three categories of conditioning the house have resulted by studying plots of the daily maximum, minimum and average temperatures for each month against the comfort level; these categories are as follows:

(1) Heating during the months of January, February and December, which can be verified from the figures (8.8 (1.2) and 8.10 (4)). The daily maximum, minimum and average temperatures of those months fall below the comfort level, which indicates that heating is accumulated by the house.

(2) Cooling and heating during March only, which can be verified from figure 8.8 (3). The daily maximum, minimum and average temperatures in March fluctuate above and below the comfort level. This fluctuation indicates that there is alternating heating and cooling in the house during some periods of the month, though not necessarily the same ones.

FIGURE 8.2: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY CONSUMED BY HOUSE 1

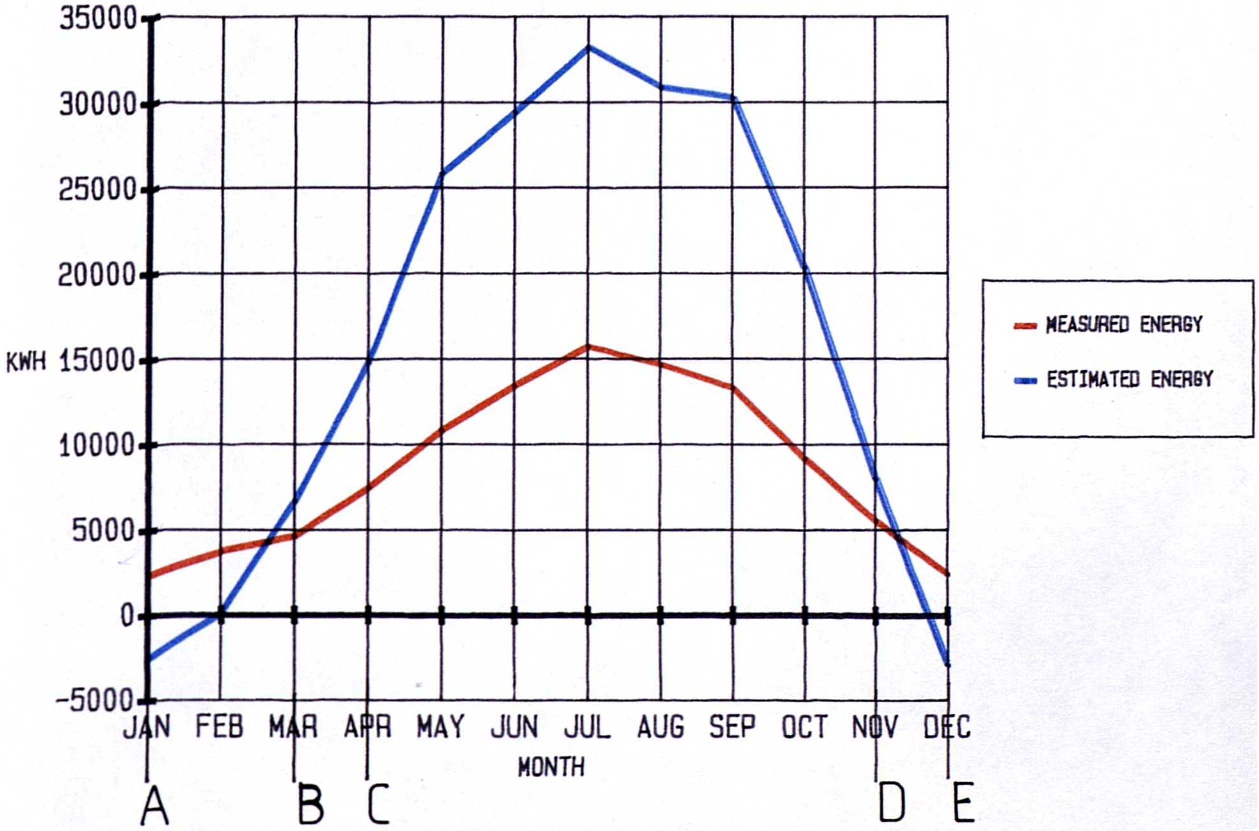


FIGURE 8.3: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY CONSUMED BY HOUSE 2

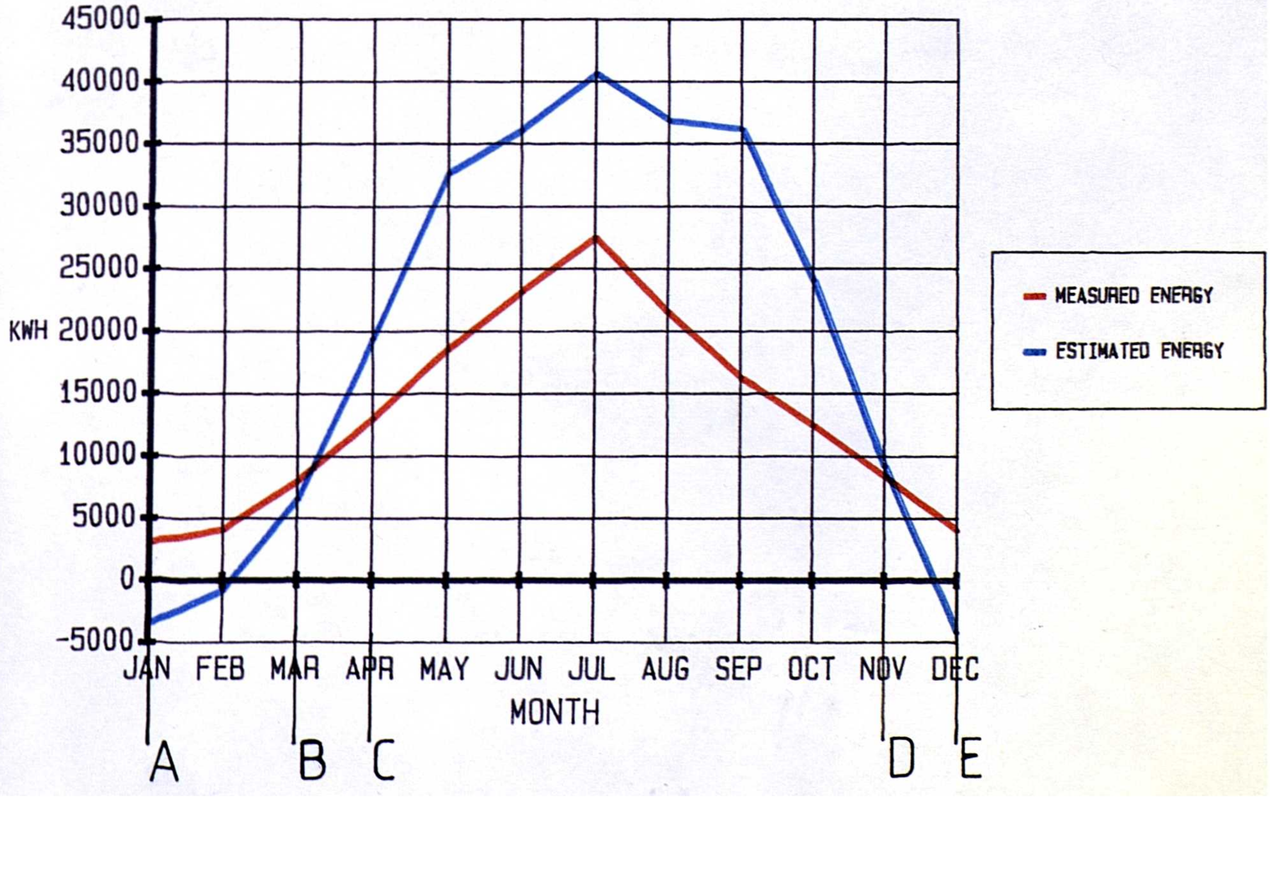


FIGURE 8.4: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY CONSUMED BY HOUSE 3

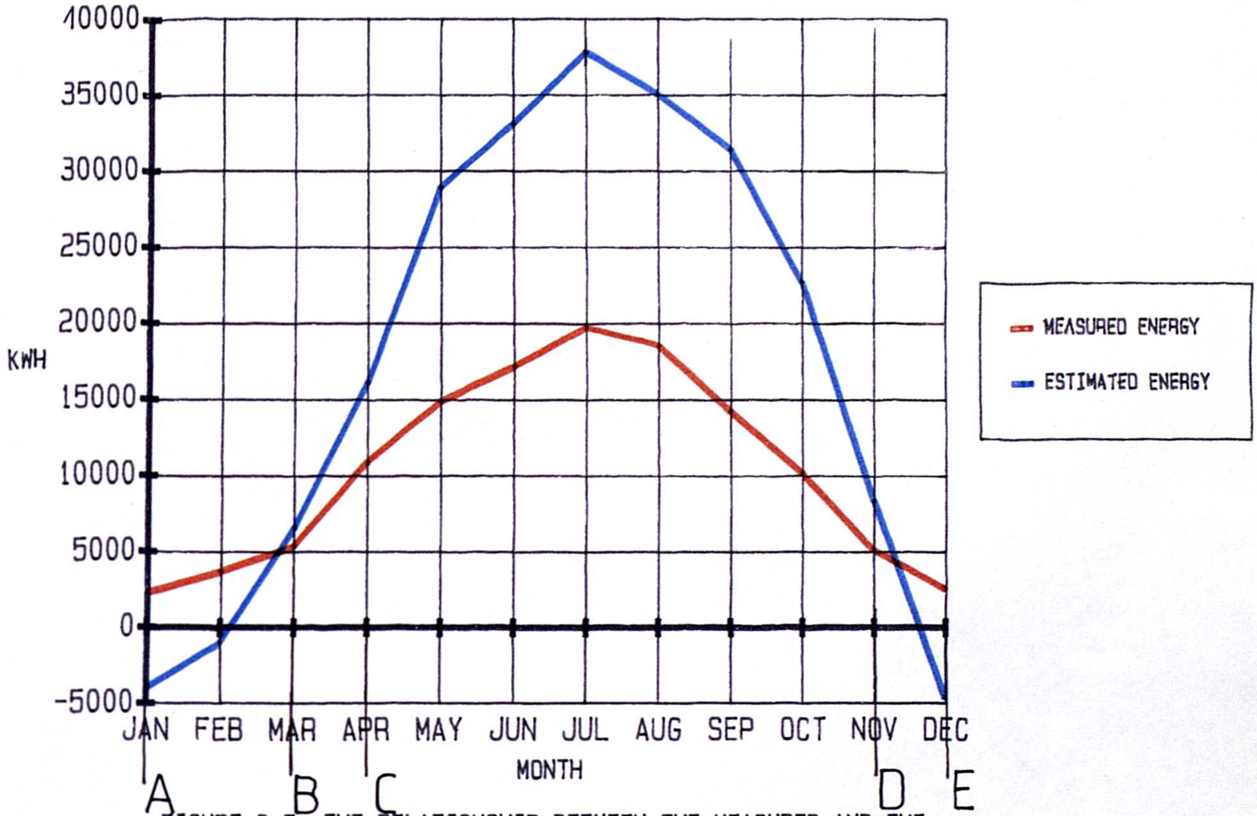


FIGURE 8.5: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY CONSUMED BY HOUSE 4

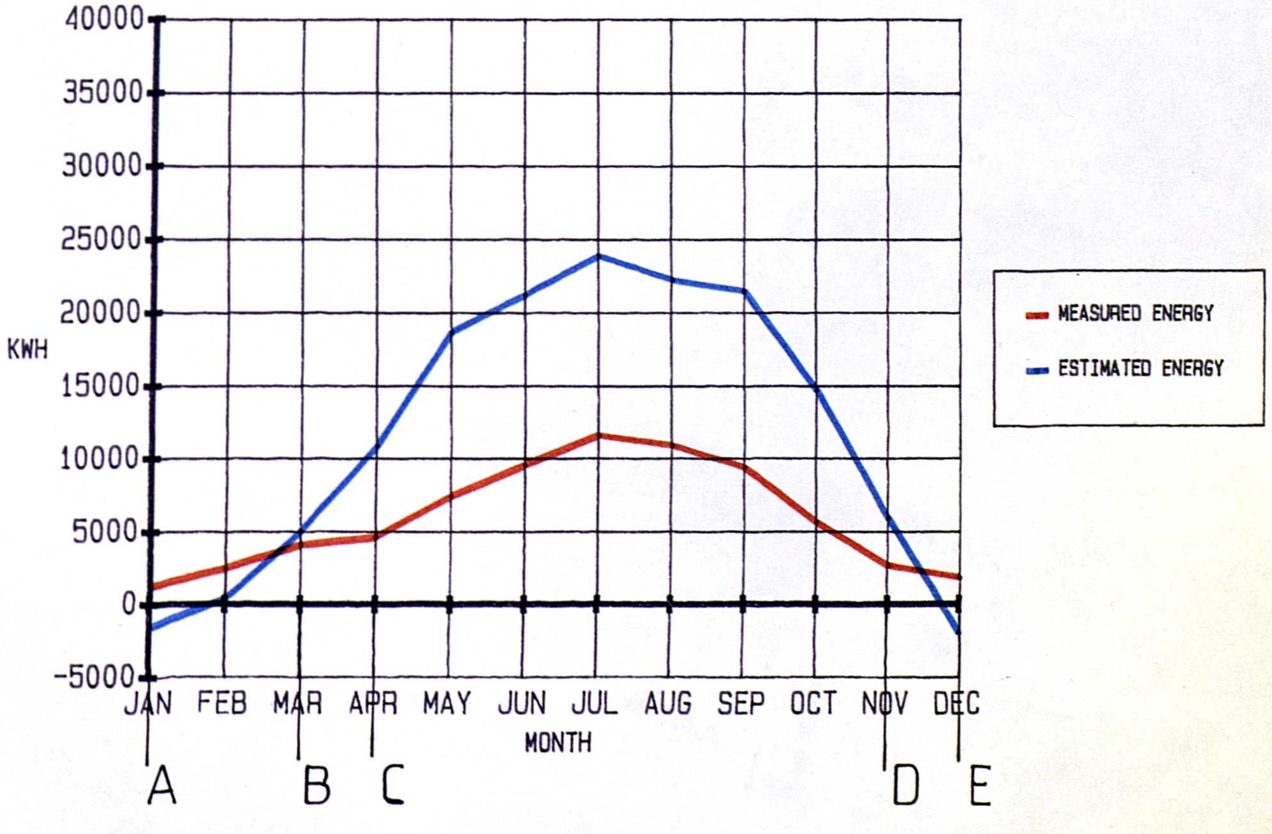


FIGURE 8.6: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY CONSUMED BY HOUSE 5

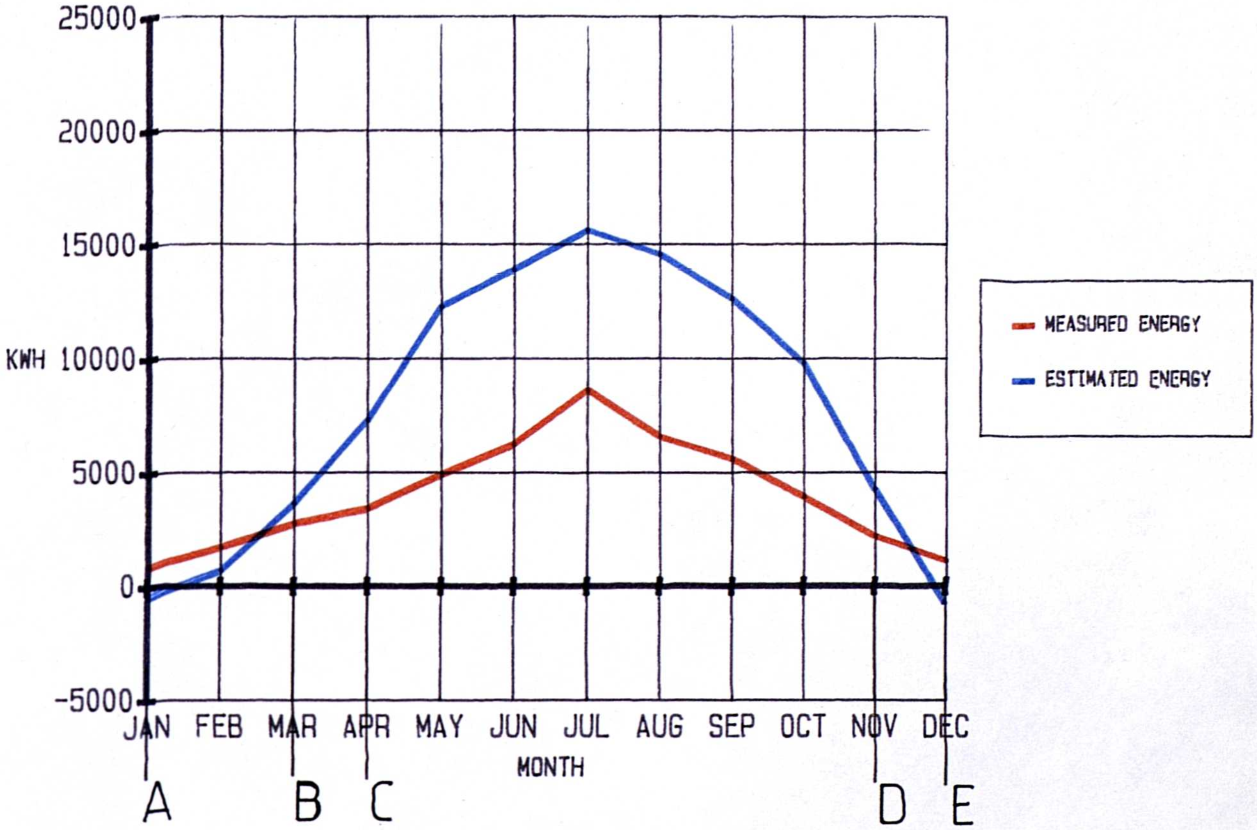


FIGURE 8.7: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY CONSUMED BY HOUSE 6

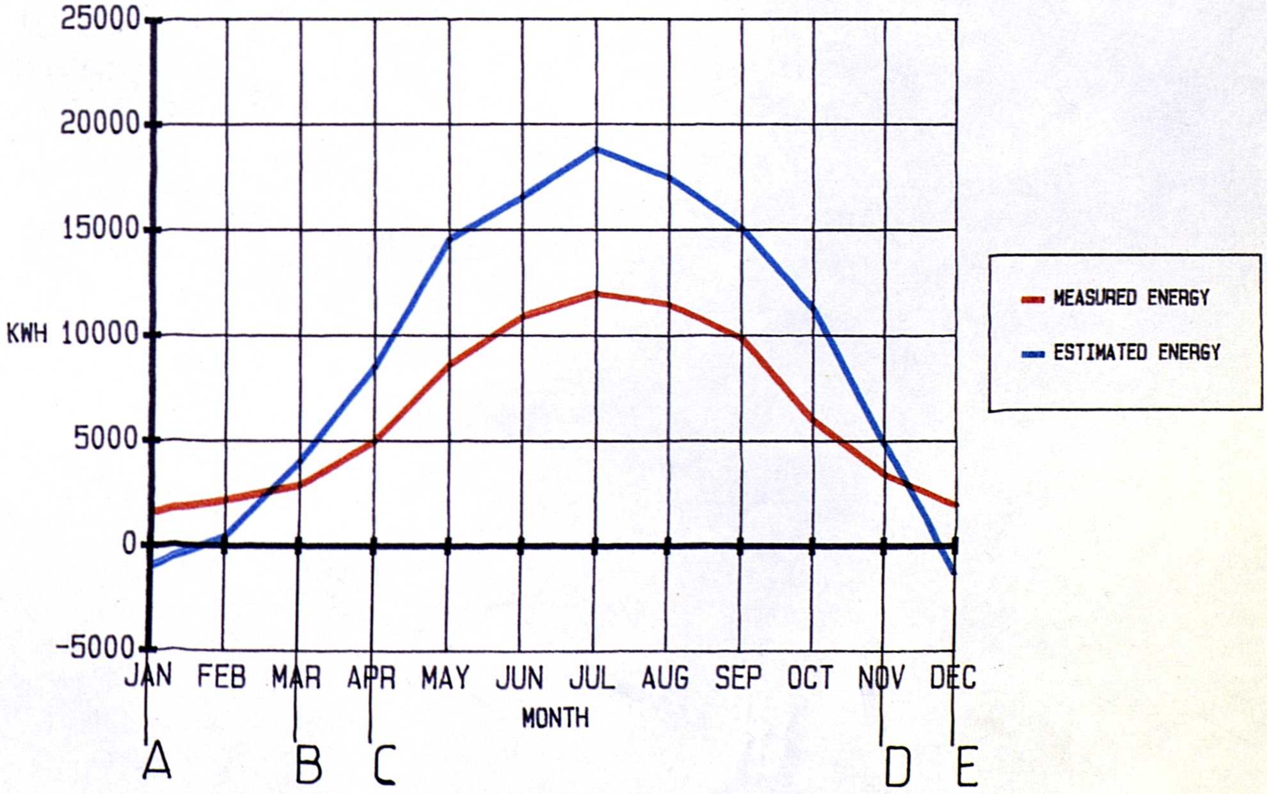


FIGURE 8.8: THE DAILY AVERAGE MAXIMUM, MINIMUM, AND MEAN TEMPERATURES FOR JANUARY, FEBRUARY, MARCH AND APRIL

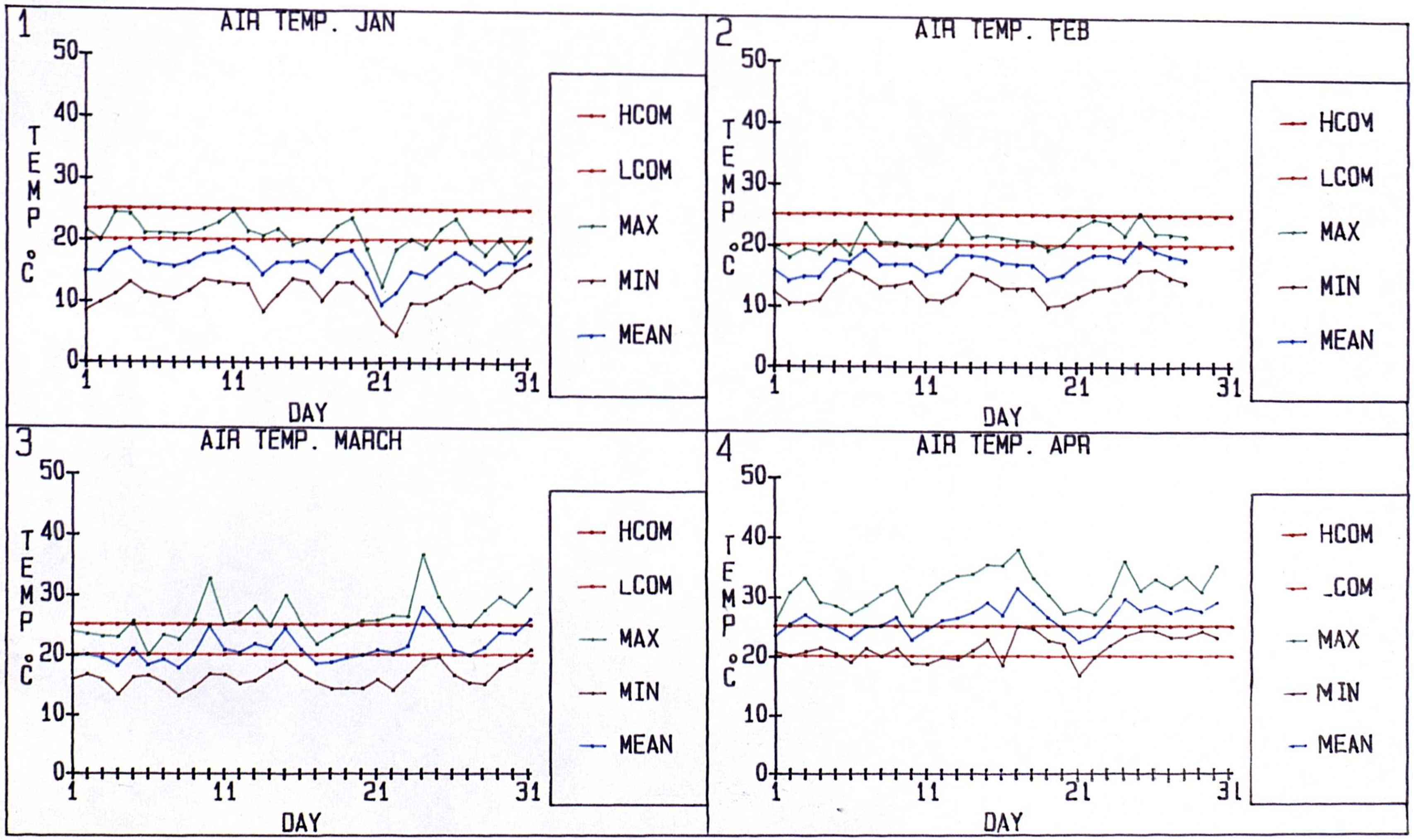


FIGURE 8.9: THE DAILY AVERAGE MAXIMUM, MINIMUM, AND MEAN TEMPERATURES FOR MAY, JUNE, JULY AND AUGUST

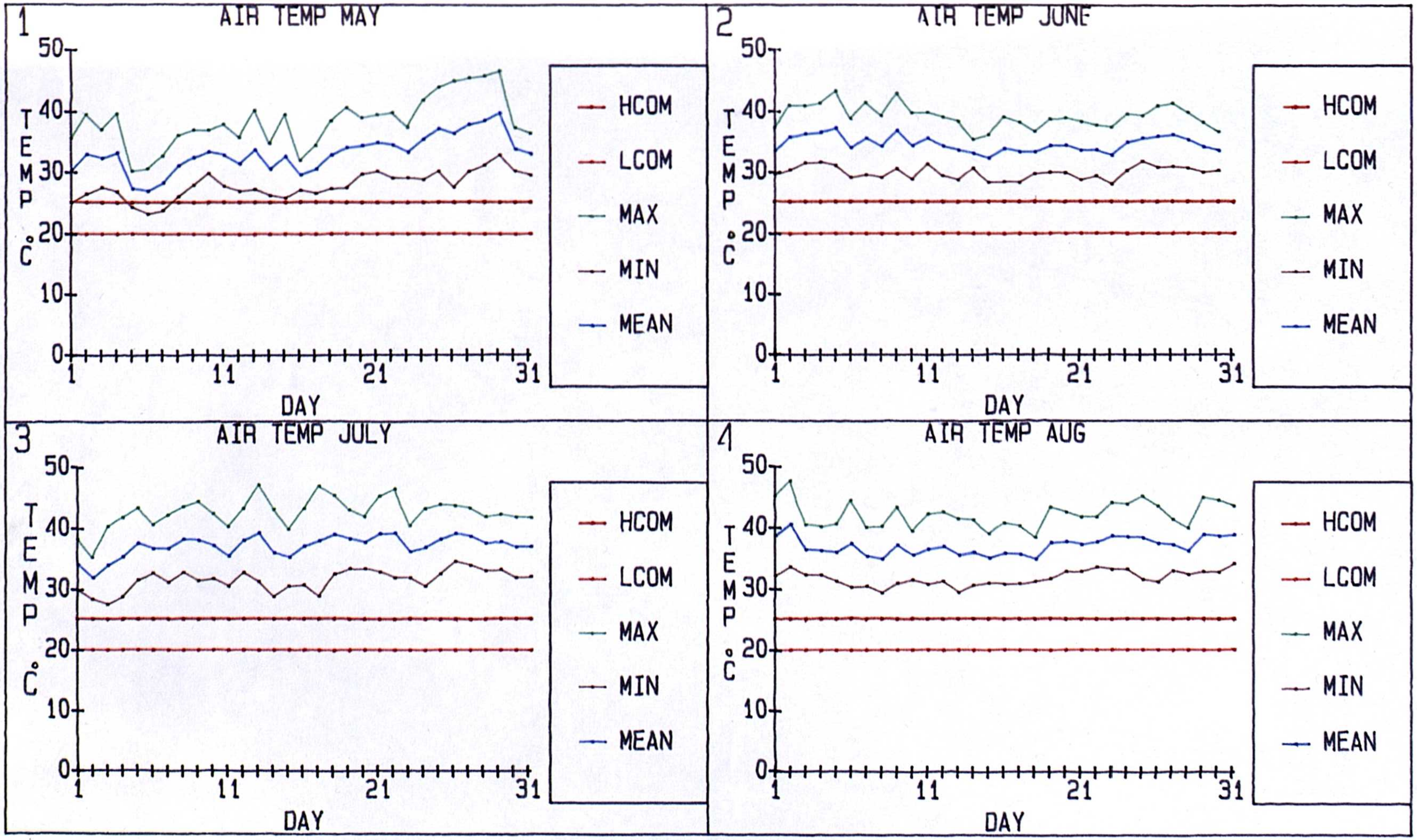
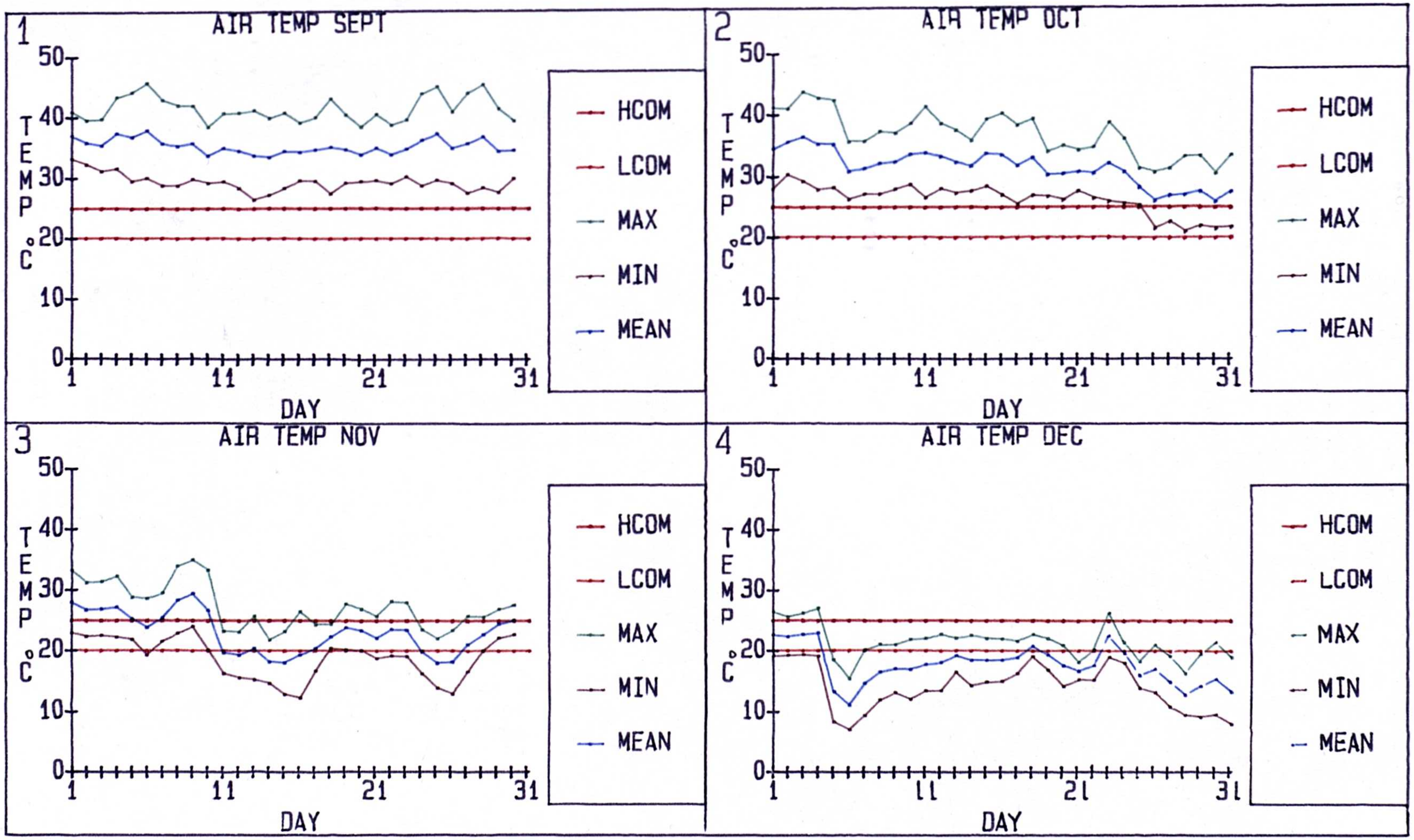


FIGURE 8.10: THE DAILY AVERAGE MAXIMUM, MINIMUM, AND MEAN TEMPERATURES FOR SEPTEMBER, OCTOBER, NOVEMBER AND DECEMBER



(3) Cooling during the rest of the year, which can be verified from the figures (8.8 (4), 8.9 (all), and 8.10 (1,2,3)). The daily maximum, minimum and average temperatures of those months are well above the comfort level. It indicates that cooling is supplied to the house during those months.

For further validation, the model was tested against the energy consumed during the certain cooling months which are specified previously as April, May, June, July, August, September, October and November; that period is indicated by section CD in figures 8.2 to 8.7. In order to compare predicted energy consumption with the measured values it is necessary to determine values of the coefficient of performance of the system. Therefore for each month the predicted cooling load was divided by the cooling energy derived from the measurements to give a cop. For cooling months, the model produces a range of different coefficients of performance of the differing cooling systems used in the case study houses as shown in table 8.1. It shows that the coefficient of performance of the split unit cooling system ranges between 2.26 to 1.89 with an overall average of 2.05 which indicates a high efficient system. At the same time the model also shows that the coefficient of performance of the window type unit ranges between 1.31 to 1.64 with an overall average of 1.43 with low efficient system in respect to the split unit system. However, by comparing the predicted coefficient of performance (COP) of each system against those from the manufacturer, it appears that the relation between the predicted COP of the split unit cooling which is 2.05 and the manufactured COP which is 2.455* is a very good relation. Also the comparison indicates a good relationship between predicted coefficient of performance of the window type units which is 1.42 and the manufactured one which is 1.8*. It is to be expected that actual cop s would be less than the manufacturer figures due to the seasonal variation in load. (see table 8.2).

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* These figures have been calculated from the manufacturer Catalogue, Sanyo Electric Tracking Company Limited, Osaka, Japan; and Al-Zamil Refrigeration Industries, Dammam, Saudi Arabia, footnote 12, 13. relation between the measured values and the predicted values is as follows:

Consequently by applying the different coefficients of performance of the systems on the predicated load for conditioning the house, the followings have resulted.

1. By averaging the monthly COP of the system in the house for the cooling period only, the model gives an accuracy of about 78.4 per cent, as shown in figure 8.11.

2. By averaging the COP of the system on a month-by-month basis for all houses, the model gives an accuracy of about 84.6 per cent as shown in figure 8.12.

3. By averaging the month-by-month COP of the split unit systems as well as the window type unit systems separately for the different three houses in which they were used, the model shows its consistency by giving a close estimate of the actual measured energy used in these houses as shown in figures 8.13 and 8.14.

Finally, in the validation process of the model during the cooling period which is represented by section CD in figures 8.2 to 8.7, the sets of measured values of the energy consumption compare very favourably with the estimated ones. The result of this comparison produces a reasonable degree of accuracy which encourages the author to apply this model to case study houses for further improvement.

Table 8.1

The Different Coefficients of Performance for the Different Case Studies Predicted by the Model from the Collected Survey and Detailed Measurements Data

HOUSES SYSTEMS MONTHS	1 S.UNIT	2 W.UNIT	3 S.UNIT	4 S.UNIT	5 W.UNIT	6 W.UNIT	S.UNIT COP	W.UNIT COP	ALL COP
APR	1.98	1.04	1.47	2.3	1.47	1.29	1.91	1.26	1.58
MAY	2.3	1.3	1.94	2.5	1.89	1.42	2.20	1.53	1.85
JUN	2.1	1.24	1.92	2.25	1.78	1.32	2.09	1.44	1.76
JUL	2.11	1.31	1.91	2.06	1.53	1.38	2.02	1.41	1.72
AUG	2.1	1.41	1.89	2.04	1.79	1.33	2.01	1.51	1.76
SEP	2.08	1.55	2.2	2.12	1.8	1.34	2.1	1.56	1.83
OCT	2.22	1.54	2.23	2.6	1.78	1.49	2.3	1.6	1.95
NOV	1.44	1.54	1.63	2.21	1.12	0.9	1.96	1.1	1.43
AVERAGE COP	2.02	1.36	1.89	2.26	1.64	1.31	2.05	1.43	1.74

Table 8.2

Comparison between the manufactured coefficient of performance and the predicted ones, with reference to the model accuracy

TYPE OF SYSTEM	MANUFACTURED COP	MANUFACTURED COP SU:WT	PREDICTED COP	PREDICTED COP SU:WT	% OF MODEL ACCURACY
SPLIT UNIT	2.455	2.455 : 1.8 = 1 : 073	2.02) 1.89)2.05 2.26)	2.05:1.43 = 1 : 070	83.5%
WINDOW TYPE UNIT	1.8		1.31) 1.64)1.43 1.36)		79.4%

FIGURE 8.11: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY USING AN OVERALL AVERAGE COP FOR ALL SYSTEMS

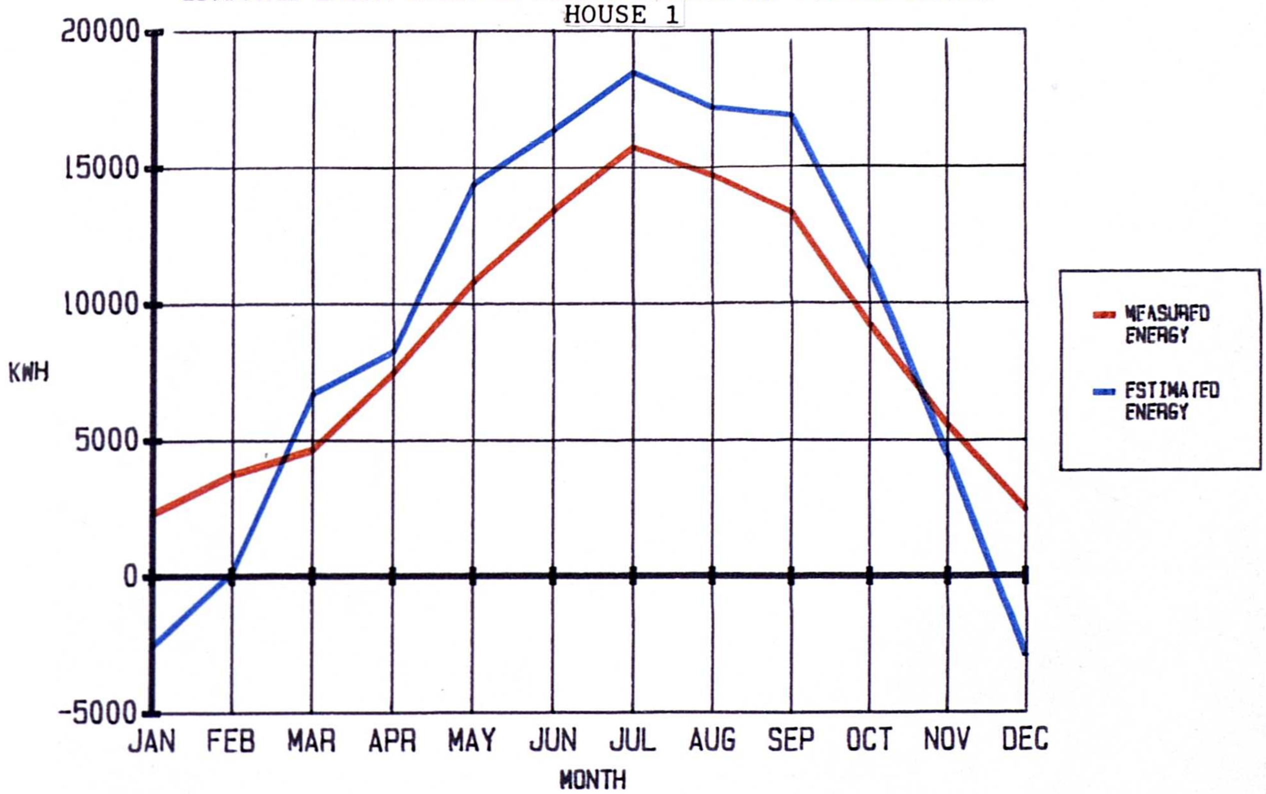


FIGURE 8.12: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESIMATED ENERGY USING A MONTH-BY-MONTH AVERAGE COP FOR ALL SYSTEMS

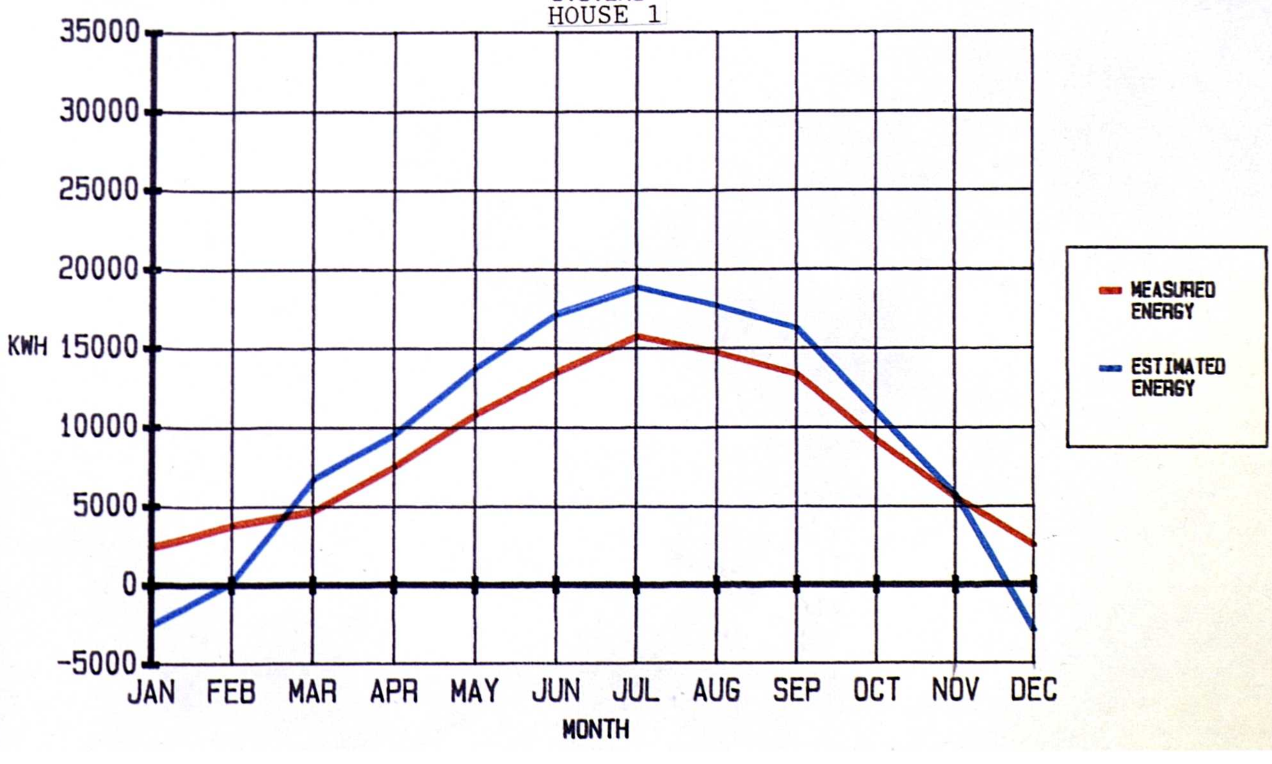


FIGURE 8.13: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY USING A MONTHLY AVERAGE COP FOR SPLIT UNIT SYSTEMS

HOUSE 1

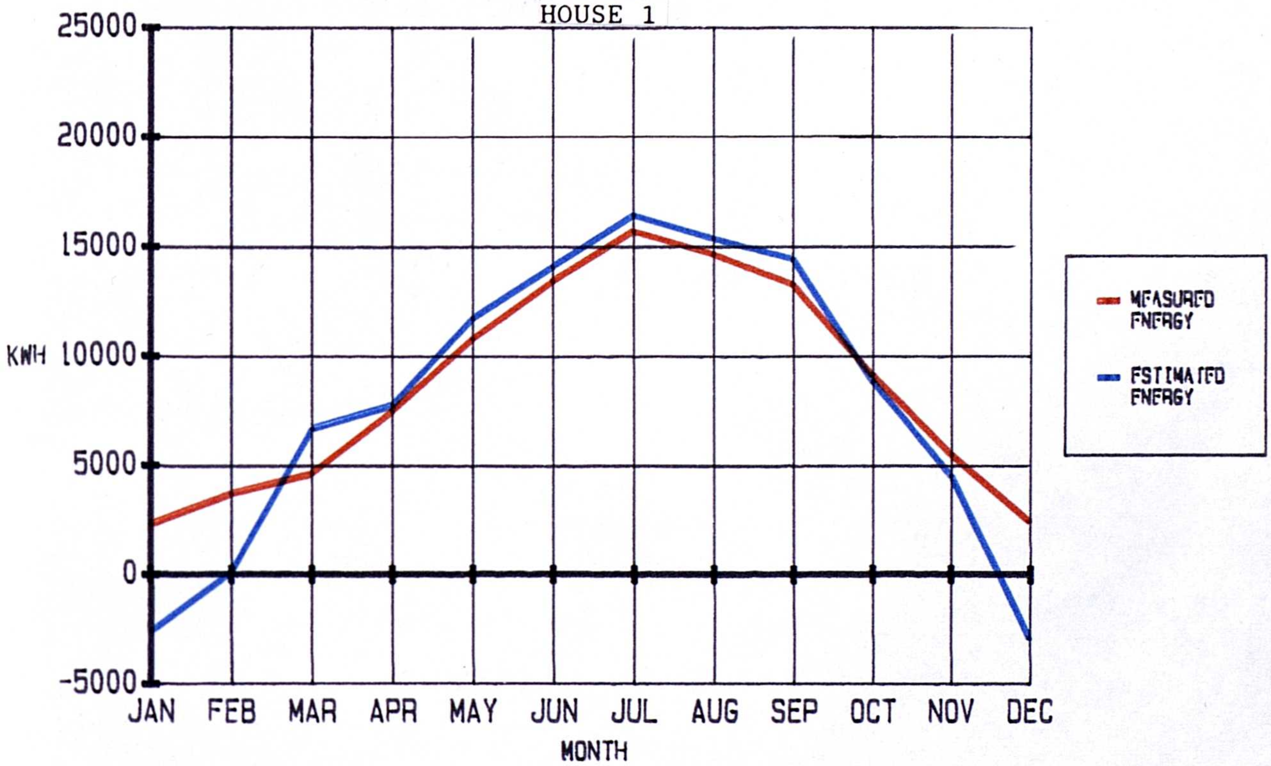
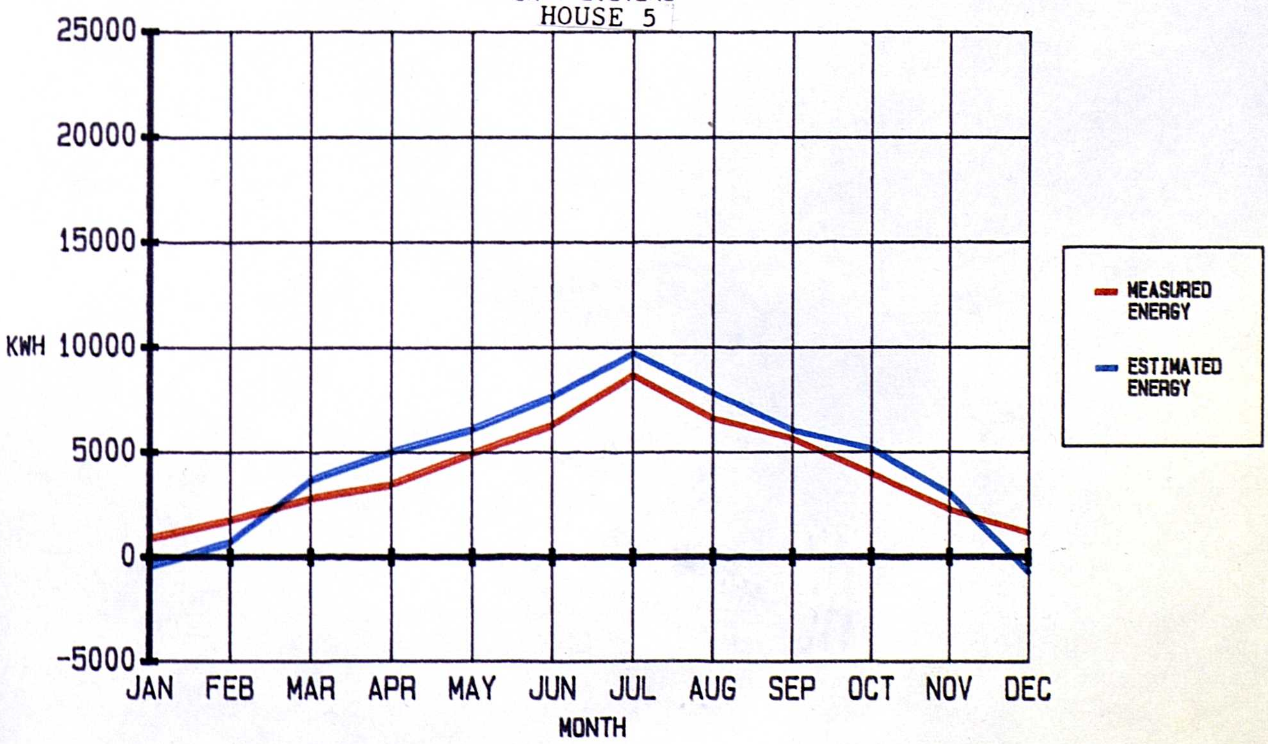


FIGURE 8.14: THE RELATIONSHIP BETWEEN THE MEASURED AND THE ESTIMATED ENERGY USING A MONTHLY AVERAGE COP FOR WINDOW TYPE UNIT SYSTEMS

HOUSE 5



8.5 Summary

The results of the test aimed at investigating the validity of a simple method of calculating the estimated cooling load of a house in the Dammam region during a year have been reported.

The general conclusion obtained from studying this particular group of six houses is that although the method is deemed to be reasonably accurate for eight months, namely the period between April and November. For the other four months either heating only is required or a very small period of cooling. The results for this period are uncertain since either heating or cooling could be taken place. Such as heating and cooling loads taking place at the same time. Also it is of considerable importance that the energy consumption is low during these months of the year, namely January, February and December, and not in the peoples' concern. This fact is backed up by the (SCECO) actual energy consumption bills and by the result of the survey carried out by the author. Therefore, these months have been omitted from the analysis.

Finally, the developed model can also be applied to the study houses to improve their thermal performance by modelling certain parameters such as wall and roof materials and glazing etc. The model has been developed using information from a small sample of houses. The results are encouraging and suggest that the model can be used to assume the effect of energy saving measures. If the model is to be generally applied for predicting energy use, more extensive validation is required.

FOOTNOTES

1. Al-Yaum (1988)
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2. CIBS Guide (1986)
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10. Bowman, N.T. and Lomas, K.J. (1985)
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11. SCECO (1987)
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13. Alzamil Company (1986)
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CHAPTER 9

CHAPTER 9

A STUDY OF POTENTIAL SAVINGS BY MODIFICATION OF BUILDING ELEMENTS

A STUDY OF POTENTIAL SAVINGS BY MODIFICATION OF BUILDING ELEMENTS

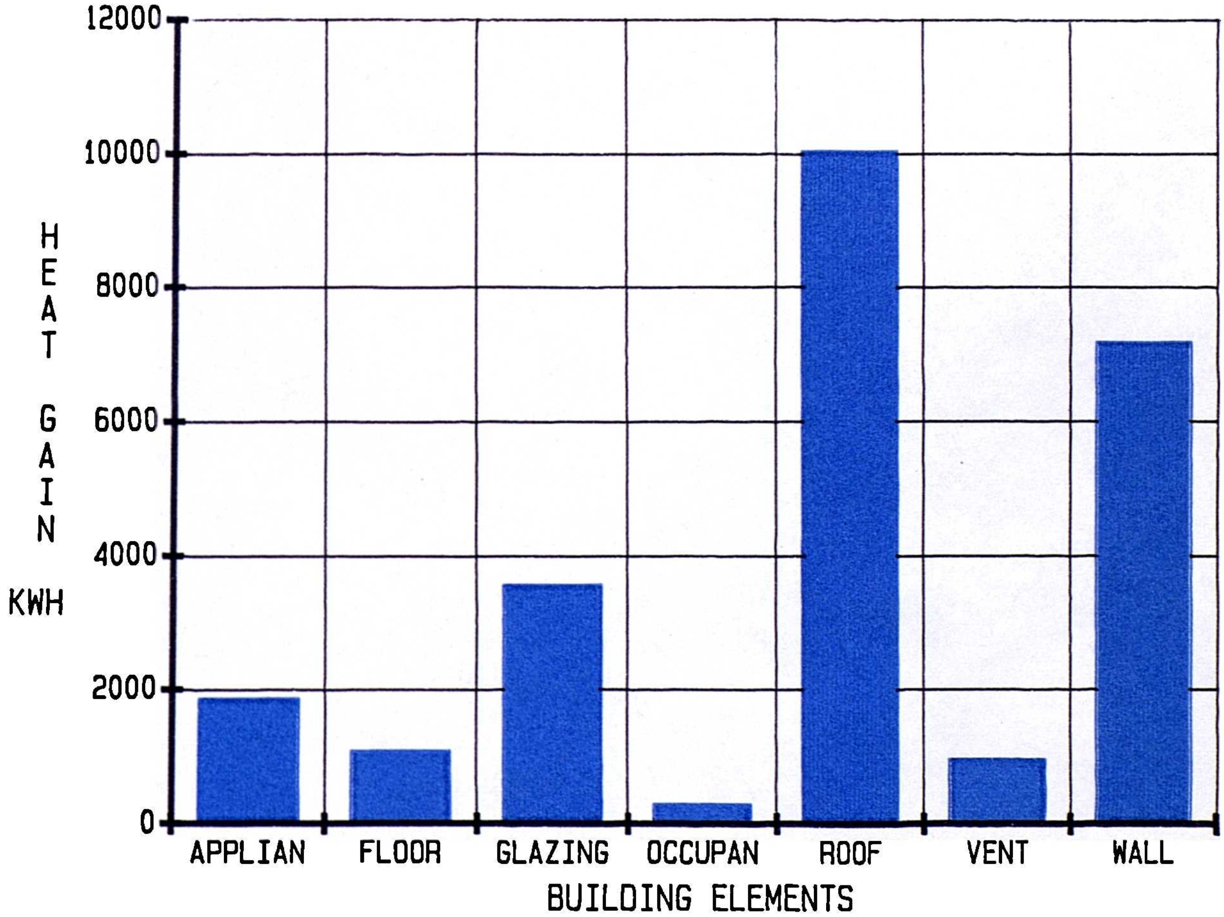
9.1 Introduction

For the case study houses discussed in the previous two chapters, energy consumption is indeed excessive. The consumption of these houses reflects the energy consumption of most of the houses in Dammam region. The average peak electrical load for cooling is 17515 kwh during the month of July and the overall monthly average for the summer period is 12748.33 kwh. However, the model developed and discussed in Chapter 8 is applied to one of the case study houses to illustrate the potential for saving energy. In this section, attention is devoted to the impact of the energy consumption during the period of summer months, specified previously in the survey section as April, May, June, July, August, September, October and November.

The energy consumption is very closely related to the amount of heat gain through the different components of the building. However, the initial application of the prediction model revealed that the amount of heat gain through the building envelope and the other internal heat sources varies considerably, which may lead to different measures of energy consumption. Use of the prediction model indicates that most of the energy consumed by the building is due to the huge heat gain through the roofs, walls and windows (see figure 9.1). There is some other heat gain into the building from the occupants, appliances, and infiltration, but this heat gain has relatively little impact on the energy consumption. The study in this section will concentrate on the improvement of the building envelope, namely roofs, walls and windows (glazing), for several reasons.

The first reason is that the heat gain through the building envelope is very great and its impact on the energy consumption is very high. Also the quality of the building envelope can easily be controlled and monitored by the government by issuing building regulations towards energy conscious design.

FIGURE 9.1: THE MONTHLY AVERAGE HEAT GAIN BY THE VARIOUS BUILDING ELEMENTS



Furthermore, the other sources of heat gain, ie. occupants, appliances and infiltration, are very difficult to deal with or control because the people do not accept the fact that they have to adapt to a new way of life in order to save energy; not only that, but also they may feel it is part of their personal life style and that no-one has the right to interfere with it. Even then if these obstacles have been removed, it becomes impossible to educate the occupants to the level of applying the proposed way of behaviour and to ensure its application. Therefore, this section will concentrate on the improvement of the components of the building envelope which are mainly under the architects' control.

In this section the measures for energy conservation involve the use of different building materials for walls and roofs and also the use of different types of glazing. Various combinations of multiple modified walls, roofs and glazing were tested in this study to determine the combinations that would give the best energy saving. Finally, the cost effectiveness of the different combinations of the building parameters was analysed in order to determine the practicable savings which could be achieved.

9.2 The use of insulation materials in the Case Study House

The materials used in constructing the case study houses have the property of conducting heat or cold into or out from the rooms. These materials have some insulation value, which is not, however, effective to the extent desired for a comfortable internal environment. There is an inflow of heat through the outside walls, floors, windows and roofs in the hot weather which consequently affects the comfort of the occupants. Therefore, the use of insulation materials in these buildings is an important factor for providing a comfortable environment inside the building. Also the insulation materials reduce the operating costs of air-conditioning in hot climates by maintaining cool conditions inside the building for a longer duration.

The building materials' market supplies the world with many types of insulation materials, which have different insulating properties. The availability of many varieties of insulation materials puts the builder and the client in an uncertain situation when choosing the proper insulation materials for adequate energy saving. The improper selection of insulation materials may drive the user of the building to use more energy. Therefore, in order to identify the possible savings that can be achieved by using insulation materials, various types and thicknesses were applied to the walls and roofs which seem to allow more heat flow into the building.

9.2.1 The Saving Potential of Modifying the Materials of the Walls

The exterior walls of the building are mostly exposed to the sun, being heated during the day and losing some of their heat at night. The rate of heat gain through the walls depends mainly on their thermophysical properties, where they absorb and reflect some of the heat and the remainder passes to the interior. Usually, the thermal performance of the wall depends on the density, thickness and specific heat of its components. The 'U' value of a construction can be reduced either by increasing its thickness or by the use of lightweight insulating materials. However, the increase in the density is accompanied by an increase in the thermal conductivity which consequently reduces the thermal resistance of the wall. Therefore, the replacement of heavy weight with lighter materials of higher thermal resistance will improve the thermal conditions in the summer.

In this section various types of wall construction are simulated by the model developed in Chapter 8. The simulation of the various wall components is aimed to stand on the different energy savings that can be provided by the use of the different wall components. However, the different wall types used in this simulation are mainly of different combinations of various building materials available on the Saudi Arabian market, as reported in more detail in Chapter 2.

The composition of the different wall types are described more specifically in table 9.1, where six different wall types are defined.

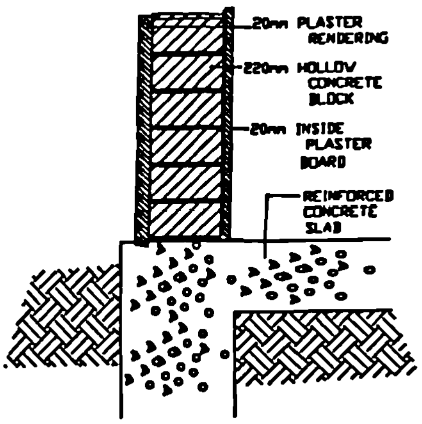
The Chapter starts by describing the most common wall type used in Dammam region which is the 220mm hollow concrete block with 20mm outside rendering surface and 20mm plaster internal surface (w1); followed by the second most common type which is the 220mm calcium silicate block with 20mm plaster board as an internal surface (w2); bearing in mind that the second type (W2) is rarely used in residential buildings due to the skill required in its construction. The third, fourth and fifth wall types (w3, w4, w5) are constructed of the typical wall type used all over the region but adding various thickness of insulation materials of 25mm, 50mm and 75mm extruded polystyrene respectively, these walls are not in use despite the availability of the materials in the region. The last wall type (w6); is a cavity wall consisting of 105mm brick as the external leaf, a fully filled cavity with 50mm extruded polystyrene, hollow concrete block as the internal leaf, and mortar plaster as the internal surface finish (see figure 9.2).

The saving in cooling load by using walls with different u-values is shown in figure 9.3. This figure shows a positive relationship between the cooling load and the different wall u-values, where the decrease in the wall u-values is associated with a decrease in the cooling load. The result revealed that by modifying the typical wall type by Calcium silicate blocks a possible energy saving of about 6 per cent can be achieved. Also, it revealed that by applying insulation materials such as extruded polystyrene of various thicknesses, 25mm, 50mm, and 75mm, as external surfaces of the typical walls, a possible energy saving of about 17 per cent, 21 per cent and 25 per cent respectively can be obtained (see table 9.2). It appeared that by using a cavity wall of 105mm brick externally, backed by 50mm extruded polystyrene and with 220mm hollow concrete block work internally savings could be made of about 23 per cent, and that despite the thickness of the wall. Thus, figure 9.2 reveals that there is a good potential for saving energy, indicating a possible reduction of about 25 per cent of the cooling load simply by insulating the external wall.

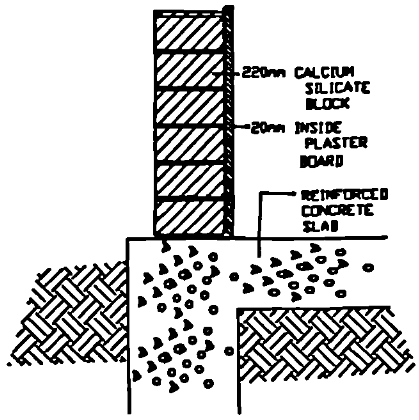
Table 9.1: Description of the various composition of the simulated walls and the corresponding thermal conductivity, resistance, and transmittance values.

Wall types	Materials description	Thickness (M)	Conductivity (W/M K)	Resistance (M^2 K/W)
Wall-1 (typical wall)	Hollow concrete block (mw)	0.22	0.510	0.431
	Outside rendering	0.02	0.260	0.076
	Inside mortar plaster	0.02	0.663	0.030
	Total Resistance ---------- = 0.537 M^2 K/W			
	U-Value = 1/R --- = 1/0.537 = 1.86 W/M^2 K			
Wall-2	Calcium silicate block	0.22	0.40	0.550
	Inside plaster board	0.02	0.160	0.125
	Total Resistance ---------- = 0.675 M^2 K/W			
	U-Value = 1/R --- = 1/0.675 = 1.48 W/M^2 K			
Wall-3	Cement plaster or stone	0.02	0.260	0.076
	Extruded polystyrene	0.025	0.032	0.781
	Hollow concrete block (mw)	0.22	0.510	0.431
	Inside plaster board	0.02	0.160	0.125
	Total Resistance ---------- = 1.413 M^2 K/W			
	U-Value = 1/R --- = 1/1.413 = 0.707 W/M^2 K			
Wall-4	Cement plaster or stone	0.02	0.260	0.076
	Extruded polystyrene	0.050	0.032	1.560
	Hollow concrete block (mw)	0.22	0.510	0.431
	Inside plaster board	0.02	0.160	0.125
	Total Resistance ---------- = 2.194 M^2 K/W			
	U-Value = 1/R --- = 1/2.194 = 0.455 W/M^2 K			
Wall-5	Cement plaster or stone	0.02	0.260	0.076
	Extruded polystyrene	0.075	0.032	2.340
	Hollow concrete block (mw)	0.22	0.510	0.431
	Inside plaster board	0.02	0.160	0.125
	Total Resistance ---------- = 3.611 M^2 K/W			
	U-Value = 1/R --- = 1/3.611 = 0.276 W/M^2 K			
Wall-6	External brick wall	0.105	0.40	0.262
	Extruded polystyrene	0.050	0.032	1.560
	Hollow concrete block (mw)	0.22	0.510	0.431
	Inside plaster	0.02	0.698	0.0286
	Total Resistance ---------- = 3.141 M^2 K/W			
	U-Value = 1/R --- = 1/3.141 = 0.304 W/M^2 K			

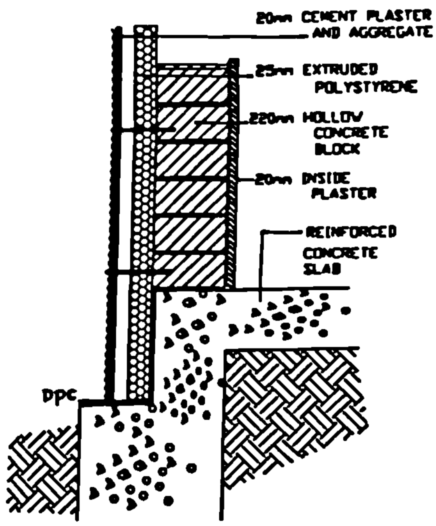
FIGURE 9.2: DETAILED DRAWINGS OF THE VARIOUS COMPOSITIONS OF THE SIMULATED WALLS



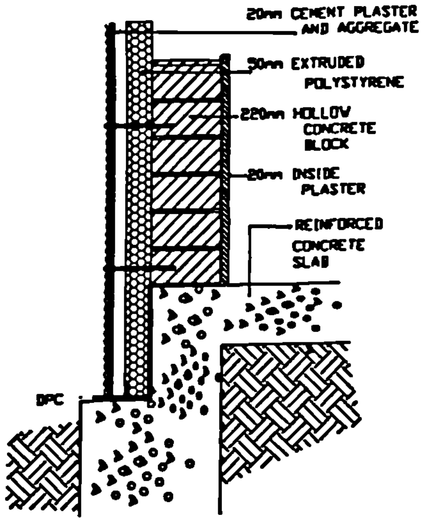
WALL 1



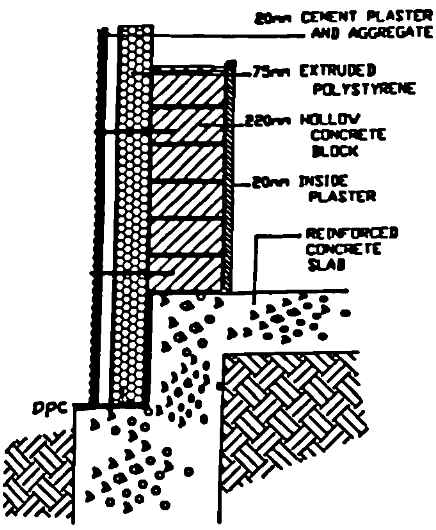
WALL 2



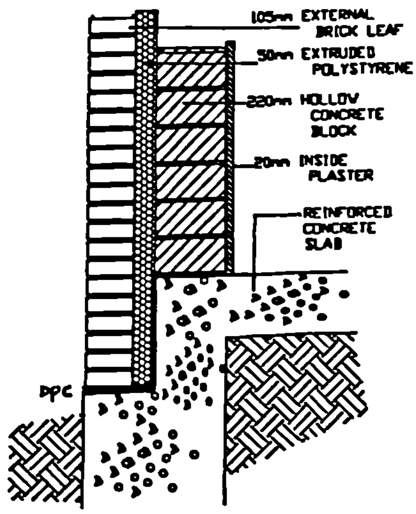
WALL 3



WALL 4



WALL 5



WALL 6

Table 9.2

The different savings achieved by using various wall u-values

Wall Type	U-values w-m2k	Yearly Savings kwh	Saving Percentage
W1	1.86	0	0%
W2	1.48	6991.88	6%
W3	0.707	31558.726	17%
W4	0.455	39567.592	21%
W5	0.276	45256.48	25%
W6	0.304	44366.56	23%

9.2.2 The Saving Potential of Modifying the Materials of the Roofs

The roof is the building element most exposed to the effects of the climate. It is subjected to direct and diffused solar radiation all day long due to the sun striking it from all directions. The intensity of solar radiation received by a flat roof is a great deal higher than that received by the walls, because the solar radiation falling on the horizontal plane is always higher than that falling on the vertical plane in lower latitude. Actually, the roof is the element that responds the most to the temperature fluctuations of the external climate; it gains heat during the daytime and loses most of it by long wave radiation during the night. Therefore, the impact of solar radiation and heat gain and loss affects the roof more than any other part of the building. However, the heat absorbed by the external surface of the roof is transferred mainly by conduction to the internal environment, unless there is an airspace in the composition of the roof materials. Thus, the thermal conductivity of the different components of the roof is essential in determining the amount of heat gain and loss through the roof.

Most of the residences built in Dammam region use single skin reinforced concrete roofs. These types of roof do not incorporate any type of insulation material except those which are added only for construction purposes, such as sand, tiles and mortar. As a result, the amount of heat gain through the roof is very large, as noted during the calculation procedures of the model. Therefore, different roof types are simulated using the developed model to calculate the possible savings that can be achieved by applying various roof u-values. However, these types of roof are a combination of different roof materials available on the local market. The various roof types are described in detail in table 9.3, defining six types of roof by specifying the thickness of their materials, their thermal conductivity, thermal resistance and overall thermal transmittance. The different roof types described in table 9.3 start with the most common roof type (R1) used in the region which is the 200mm reinforced concrete roof, and is followed by the second roof type (R2) which is the combination of lightweight foam concrete as an insulation material on top of the reinforced concrete slab. The roof types (R3, R4, R5) are similar to R1 with some additional insulation materials of 25mm, 50mm and 75mm of extruded polystyrene* respectively. The sixth roof type (R6) is similar to R5 but with different insulation finish (see figure 9.4).

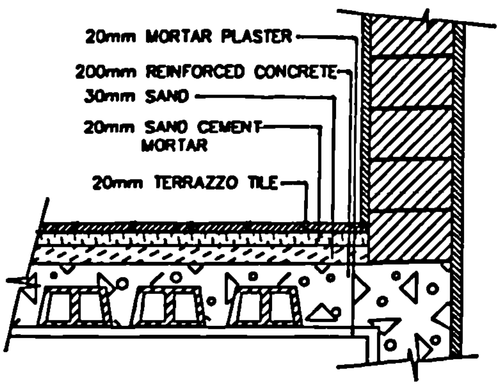
The effects of modifying the roof type of the case study house with various proposed roof u-values are presented graphically in figure 9.5. The figure shpws that there is a positive relationship between roof u-value and the estimated cooling load. Eventually, the result of the roof simulation represented in figure 9.5 revealed that by using lightweight foam concrete as an insulation material one can save about 25 per cent of the consumed energy. Also it revealed that in the case of applying extruded polystyrene insulation materials of various thicknesses of 25mm, 50mm, 75mm on top of the typical roof type, one can save about 26 per cent, 30 per cent, and 35 per cent of the consumed energy respectively (see table 9.4). This result shows a very good potential for saving energy by modifying the typical roof which can be easily achieved by adding insulation materials to produce lower U-values.

* The use of polystyrene in the hot climate regions requires especial attention and treatment; this is due to the fact that certain types of polystyrene insulation material lose their durability and may be dissolved in extremely high temperatures.

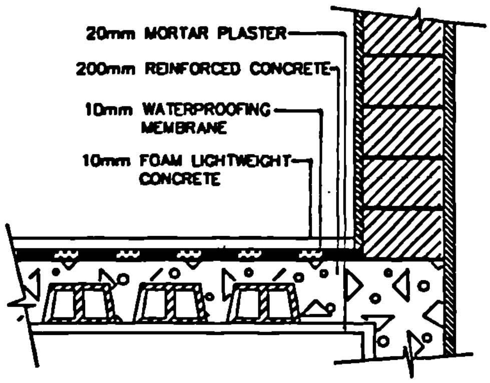
Table 9.3: Description of the various composition of the simulated roofs and the corresponding thermal conductivity, resistance, and transmittance values.

Roof types	Materials description	Thickness (M)	Conductivity (W/M K)	Resistance (M^2 K/W)
Roof-1 (typical roof)	Terrazzo tile	0.02	0.840	0.023
	Sand cement mortar	0.02	0.530	0.037
	Sand	0.03	1.745	0.0172
	Reinforced concrete	0.20	0.930	0.215
	Mortar plaster	0.02	0.663	0.030
	Total Resistance ---------- = 0.322 M^2 K/W			
	U-Value = 1/R --- = 1/0.322 = 3.110 W/M^2 K			
Roof-2	Foam lightweight concrete	0.10	0.128	0.781
	Waterproofing membrane	0.01	0.50	0.020
	Reinforced concrete	0.20	0.930	0.215
	Mortar plaster	0.02	0.663	0.030
	Total Resistance ---------- = 1.046 M^2 K/W			
	U-Value = 1/R --- = 1/1.046 = 0.960 W/M^2 K			
Roof-3	Paving slab (sand & mortar)	0.04	0.530	0.075
	Extruded polystyrene	0.025	0.032	0.781
	Waterproofing membrane	0.01	0.50	0.020
	Reinforced concrete	0.20	0.930	0.215
	Mortar plaster	0.02	0.663	0.030
	Total Resistance ---------- = 1.121 M^2 K/W			
	U-Value = 1/R --- = 1/1.121 = 0.892 W/M^2 K			
Roof-4	Paving slab (sand & mortar)	0.04	0.530	0.075
	Extruded polystyrene	0.050	0.032	1.560
	Waterproofing membrane	0.01	0.50	0.020
	Reinforced concrete	0.20	0.930	0.215
	Mortar plaster	0.02	0.663	0.030
	Total Resistance ---------- = 1.900 M^2 K/W			
	U-Value = 1/R --- = 1/1.900 = 0.520 W/M^2 K			
Roof-5	Paving slab (sand & mortar)	0.04	0.530	0.075
	Extruded polystyrene	0.075	0.032	2.340
	Waterproofing membrane	0.01	0.50	0.020
	Reinforced concrete	0.20	0.930	0.215
	Mortar plaster	0.02	0.663	0.030
	Total Resistance ---------- = 2.680 M^2 K/W			
	U-Value = 1/R --- = 1/2.680 = 0.373 W/M^2 K			
Roof-6	Paving slab (sand & mortar)	0.04	0.530	0.075
	Extruded polystyrene	0.075	0.032	2.340
	Waterproofing membrane	0.01	0.50	0.020
	Reinforced concrete	0.20	0.930	0.215
	Plaster board	0.02	0.160	0.125
	Total Resistance ---------- = 2.775 M^2 K/W			
	U-Value = 1/R --- = 1/2.775 = 0.360 W/M^2 K			

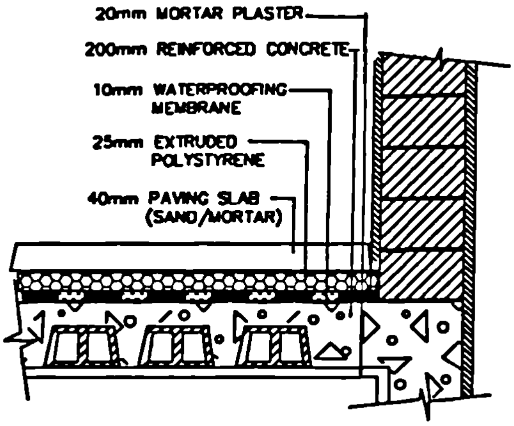
FIGURE 9.4: DETAILED DRAWINGS OF THE VARIOUS COMPOSITIONS OF THE SIMULATED ROOFS.



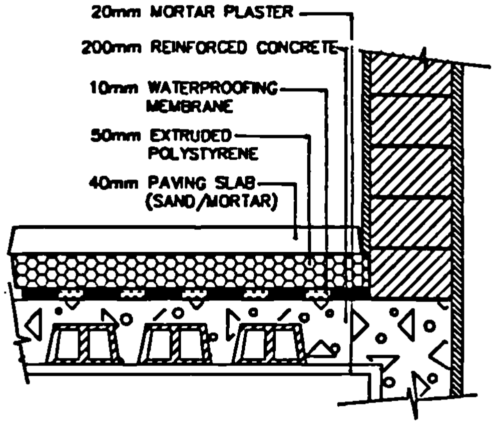
ROOF 1



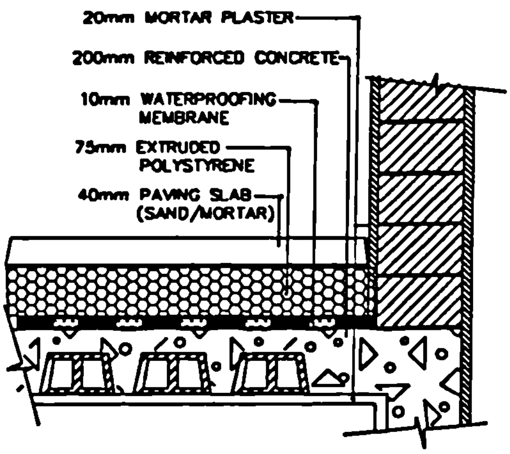
ROOF 2



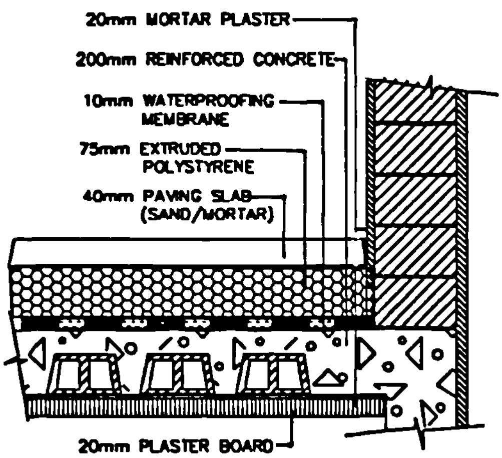
ROOF 3



ROOF 4



ROOF 5



ROOF 6

FIGURE 9.3: THE POTENTIAL FOR SAVING ENERGY BY USING WALLS WITH DIFFERENT U-VALUES

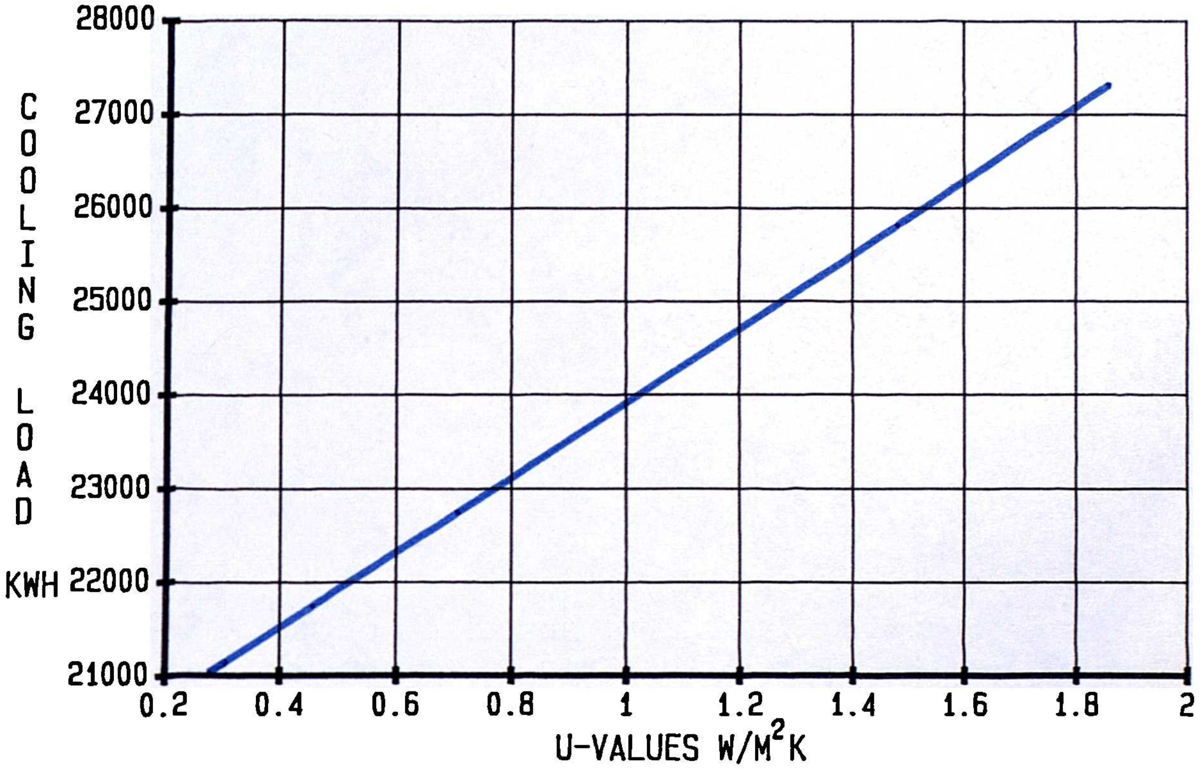


FIGURE 9.5: THE POTENTIAL FOR SAVING ENERGY BY USING ROOFS WITH DIFFERENT U-VALUES

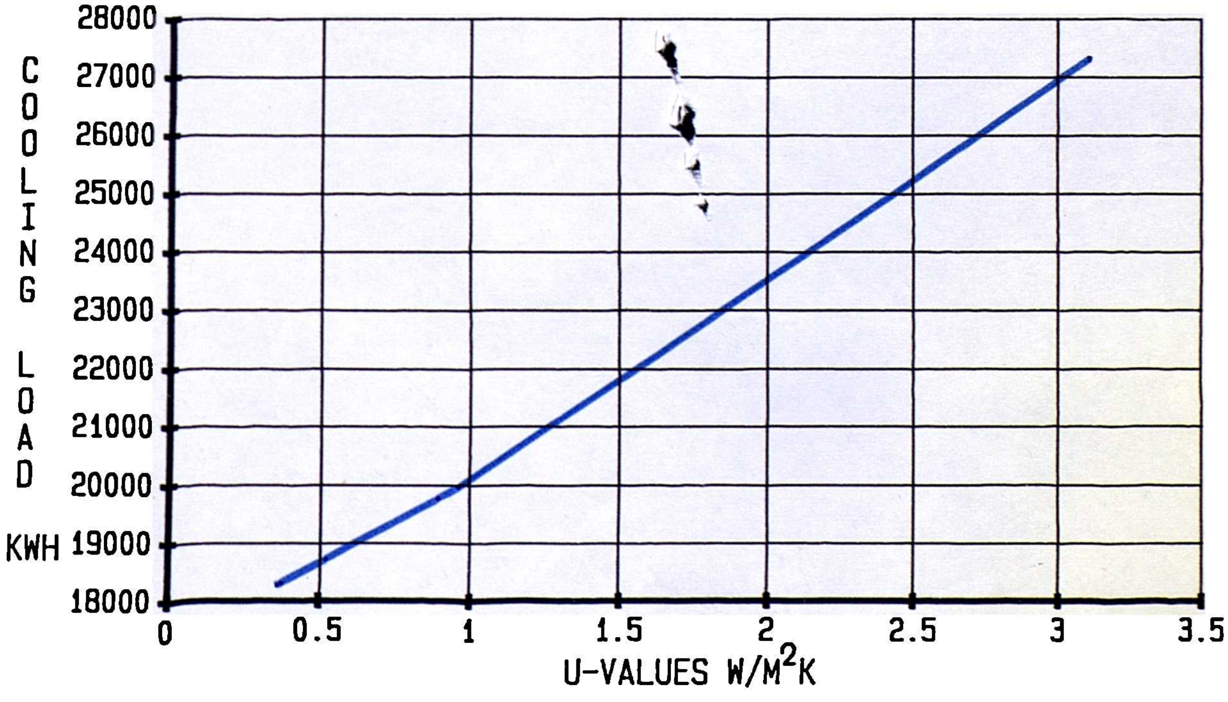


Table 9.4

The different savings achieved by using various roof u-values

Wall Type	U-values w-m2k	Yearly Savings kwh	Saving Percentage
R1	3.11	0	0%
R2	0.960	53849.672	25%
R3	0.892	55381.792	26%
R4	0.520	63763.416	30%
R5	0.373	67075.512	35%
R6	0.360	67368.416	35.15%

9.3 Window Glazing and Sizes

The main functions of the window in a building are to admit adequate daylight, permit air ventilation into the building and provide a pleasant view. However, the results of the survey discussed in Chapter 6 revealed that the people of Dammam region suffer from the problems of glare and lack of privacy, and they are not particularly concerned of having outside views. All these facts indicate that the treatment of the window size and the use of various glazing types are flexible and can vary the amount of energy saving that can be achieved within limits.

The thermal effect of the windows is dependent on the glazing properties, the size and orientation of the window and the type of the shading devices used. Although glass is a relatively poor conductor, it is used in buildings in such thin membranes that, compared with other building materials, it has a high rate of heat transfer by conduction. Also it is largely transparent to radiation in the visible and near infra-red wavelengths and, therefore, directly transmits a portion of incident solar radiation into the building, reflecting and absorbing the other portion before it is re-radiated and convected. In the case of double glazed windows, the heat is transferred by conduction and convection due to the presence of the air space between the two glass layers. The insulation value of the glazing can be improved by making use of multiple layers of glass, the improvement depending on the number of air spaces and their widths. Different types of glazing and various sizes of windows are simulated in the study to examine the various potential for energy saving that can be achieved.

Many types of window glazing are available, from single glazing up to triple glazing window. However, the double glazed window is the most popular type used in most developed countries such as the United States of America and the United Kingdom. In the developing countries, such as Saudi Arabia, the single glazed window is still the most common type used; thus the people and local authorities do not know the advantages of using double glazing, and do not exert enough effort to investigate or study its advantages. On the other hand, the most developed countries such as the USA and the UK have invested a lot of money in studying the effect of the different types of double glazed window and have formulated recommendations that suit their climatic conditions. They classified the double glazed window into two types: the hermetically sealed glass unit and the secondary window. The hermetically sealed unit is made by the factory specifically to suit the customer's needs. It is basically two sheets of glass with static air space in between them of 3mm to 12mm in width. The secondary window is particularly designed to provide good sound insulation, but the large air space in between the glasses gives the property of good thermal performance also.

The various types of glazing that have been simulated by the model to improve the energy consumption in the house are described in table 9.5, whereas the actual impact of the conservation measures calculated by applying the model on these different glazing types is illustrated in figure 9.6. The figure reveals that the modification of the typical window glazing type with the various types of double glazing gives a respectable energy saving. Specifically, the result of the simulation revealed that modifying the typical single glazed window with double glazed windows of 3mm, 6mm, 9mm and 12mm air space in between will give energy savings of about 4.98 per cent, 5.8 per cent, 6.9 per cent and 7.4 per cent respectively. Also, it revealed that the use of a double glazed window with a reflecting outer pane will give an energy saving of about 12.03 per cent (see table 9.6) The predicted savings from the use of various double glazed windows are very small compared to the other building elements.. Additionally figure 9.7 shows the impact of the conservation measures that resulted from the reduction of the window sizes and the use of double glazed window. The figure positively shows a very good potential as far as the energy saving is concerned. Therefore, a significant improvement on energy savings can be achieved by using sealed double glazed windows with a narrow air space in between and with a smaller size of window.

Table 9.5: Description of the various simulated glazings and their thermal transmittance and the air space in between.

Glazing type	Description	U-Values
G-1 (Typical window)	. Ordinary glass single glazed .	4.48
G-2	. Double glazed window with 3mm air-space in between. .	3.60
G-3	. Double glazed window with 6mm air-space in between. .	3.20
G-4	. Double glazed window with 9mm air-space in between. .	2.9
G-5	. Double glazed window with 12mm air-space in between. .	2.8
G-6	. Double glazed window with 6mm air-space in between and reflective glass outer pane. .	1.9

Table 9.6

The different savings achieved by using various roof u-values

Wall Type	U-values w-m2k	Yearly Savings kwh	Saving Percentage
G1	4.48	0	0%
G2	3.60	1264.723	4.98%
G3	3.20	1474.978	5.8%
G4	2.9	1874.352	6.9%
G5	2.8	2014.891	7.4%
G6	1.9	3012.687	12.03%

FIGURE 9.6: THE POTENTIAL FOR SAVING ENERGY BY USING GLAZING WITH DIFFERENT U-VALUES

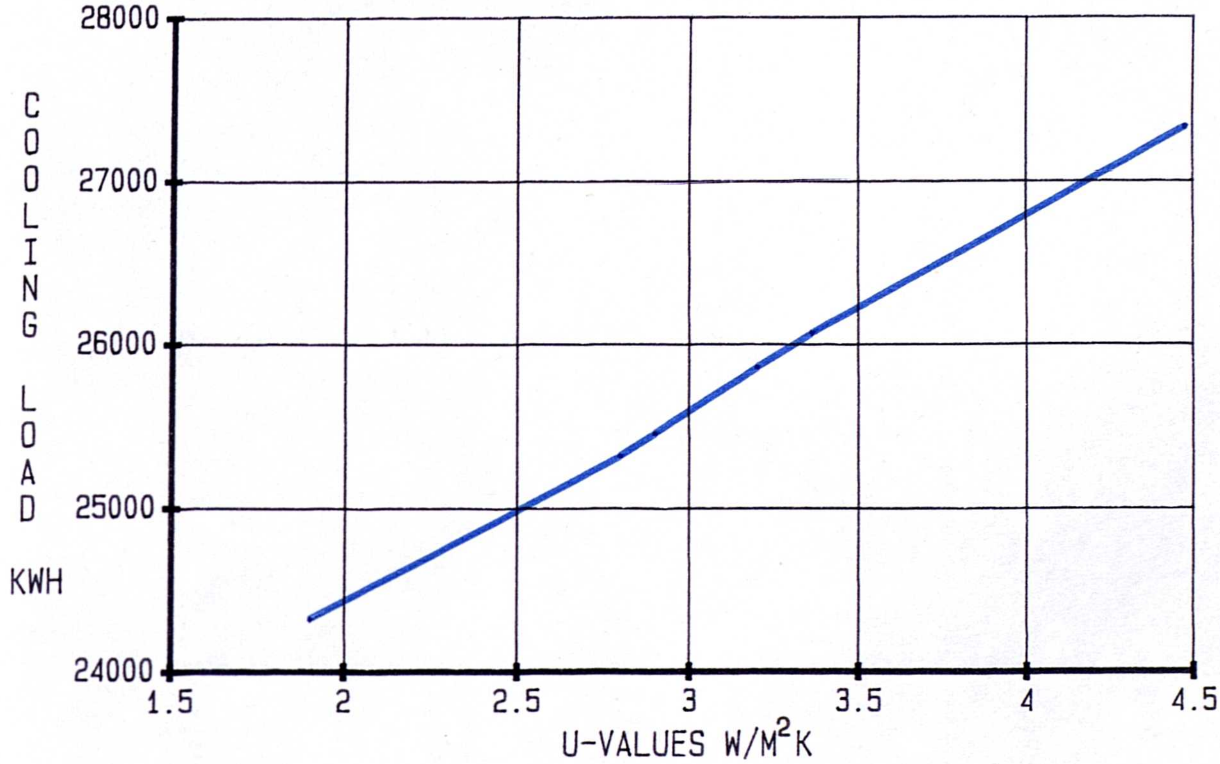
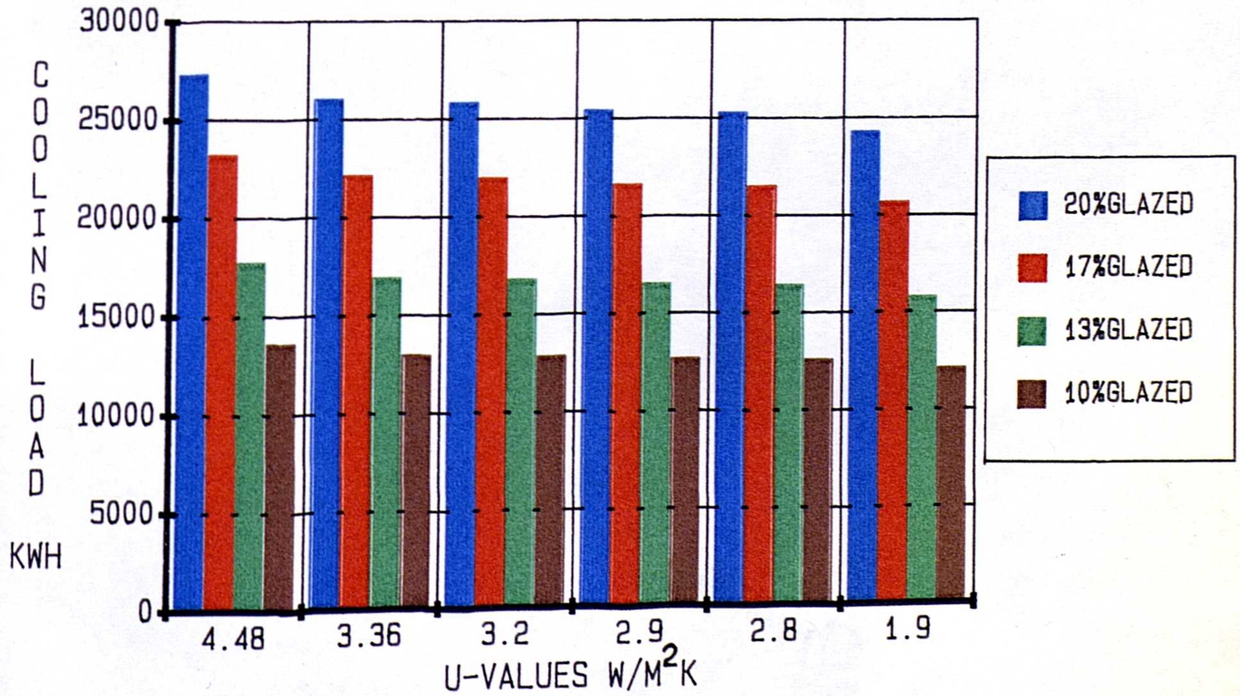


FIGURE 9.7: THE POTENTIAL FOR SAVING ENERGY BY USING DIFFERENT GLAZING SIZES IN RESPECT OF VARIOUS GLAZING U-VALUES



9.4 Combination of Improved Walls, Roofs and Glazings

Due to modifying walls, roofs and glazing the amount of energy saving by each building element separately shows an encouraging potential for saving energy. However, this amount of saving does not reflect the optimum saving that can be achieved by the improvement of the building elements at the same time a considerable amount of energy savings. However, figures 9.8 and 9.9 show the greater potential of saving energy that can be accomplished by using different combinations of modified walls' and roofs' u-values. These two figures point out a superior energy saving that varies from 17 per cent up to 54 per cent. Also table 9.7 summarises the various percentages of energy savings that are concluded from the simulation procedures. The result of the simulation revealed that roofs 5 and 6 which are constructed of 40mm paving slab, 75mm extruded polystyrene, 10mm water proofing membrane, 200mm reinforced concrete and 20mm mortar plaster or plaster board as a finishing surface, give the maximum energy savings in respect of the various wall u-values. The simulation indicated specifically that using roof 5 or 6 with respect to W1, W2, W3, W4, W5 and W6 will give savings of about 30.67 per cent, 47.44 per cent, 51.11 per cent, 53.7 per cent and 53.15 per cent respectively.

Similarly, by simulating the different combinations of the u-values for walls and window types, a significant energy saving is accomplished. As figure 9.10 indicates, the energy savings that can be provided by using a combination of low wall u-values and double glazing vary from about 4.98 per cent up to 32.50 per cent. This saving shows a quite encouraging potential of possible energy savings, as presented in table 9.8. Also by simulating the different roof u-values with the various window types, a good indication of profitable savings is given. However, the impact of the energy conservation measures by using the combination of different roofs and window types is shown in figure 9.11. The figure reveals that the energy savings from different window types range from 4.98 per cent up to 40.12 per cent. The detailed percentage savings from different roof and window combinations are summarised in table 9.9.

The different combinations of building elements indicate a great potential of energy savings, but it does not specify or indicate the optimum combination that would provide maximum overall saving. This is due to the fact that there are some other factors to be considered and these factors are discussed in the following sections.

Table 9.7

The predicted percentage of energy saving that can be accomplished by combining the various roofs U-values within the different walls U-values

Roof Type \ Wall Type	W1	W2	W3	W4	W5	W6
R1	0%	5.52%	16.76%	20.42%	24.02%	22.61%
R2	24.63%	30.1%	41.39%	45.05%	47.65%	47.24%
R3	25.33%	30.8%	42.09%	45.75%	48.35%	47.95%
R4	29.16%	34.68%	45.92%	49.58%	52.19%	51.78%
R5	30.67%	36.20%	47.44%	51.11%	53.7%	53.15%
R6	30.813	36.337	47.574	51.237	53.839	53.433

Table 9.8

The predicted percentage of energy saving that can be achieved by combining various wall u-values with the different window types

Glazing Type \ Wall Type	W1	W2	W3	W4	W5	W6
G1	0%	5.52%	16.76%	20.42%	24.02%	22.61%
G2	4.98%	10.13%	21.32%	24.87%	27.39%	26.99%
G3	5.77%	10.68%	21.89%	25.06%	27.58%	27.21%
G4	6.858%	12.25%	22.45%	25.76%	27.91%	27.52%
G5	7.373%	12.96%	23.44%	26.61%	28.45%	27.63%
G6	12.024%	18.08%	27.38%	30.18%	32.69%	32.30%

Table 9.9

The predicted percentage of energy saving that can be achieved by combining various roof u-values with the different window types

Glazing Type \ Roof Type	Percentage of Saving					
	R1	R2	R3	R4	R5	R6
G1	0%	24.64%	25.33%	20.16%	30.67%	30.813%
G2	4.98%	31.07%	31.8%	35.43%	36.88%	37.014%
G3	5.771%	31.61%	32.29%	35.90%	37.72%	37.83%
G4	6.858%	32.05%	32.63%	36.67%	38.5%	38.72%
G5	7.373%	32.43%	32.75%	36.79%	38.61%	39.11%
G6	12.024%	33.44%	34.12%	37.44%	39.62%	40.12%

FIGURE 9.8: THE POTENTIAL FOR SAVING ENERGY BY USING DIFFERENT ROOF U-VALUES WITH VARIOUS WALL TYPES

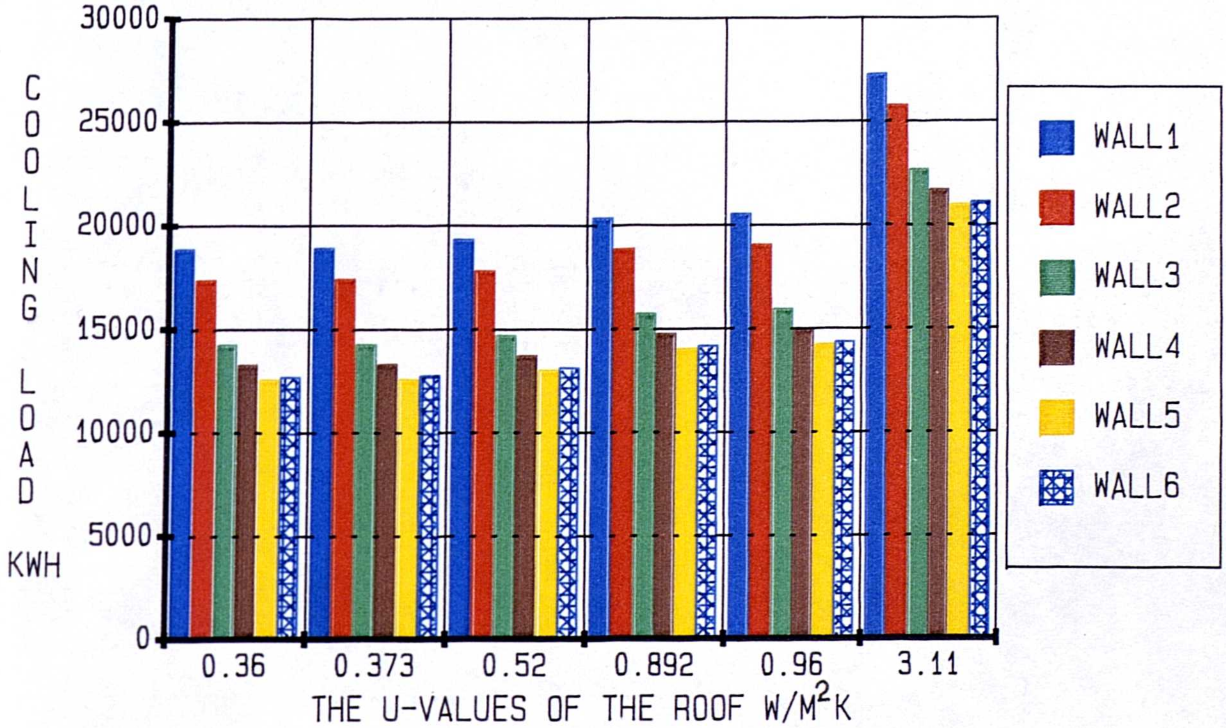


FIGURE 9.9: THE POTENTIAL FOR SAVING ENERGY BY USING DIFFERENT WALL U-VALUES WITH VARIOUS ROOF TYPES

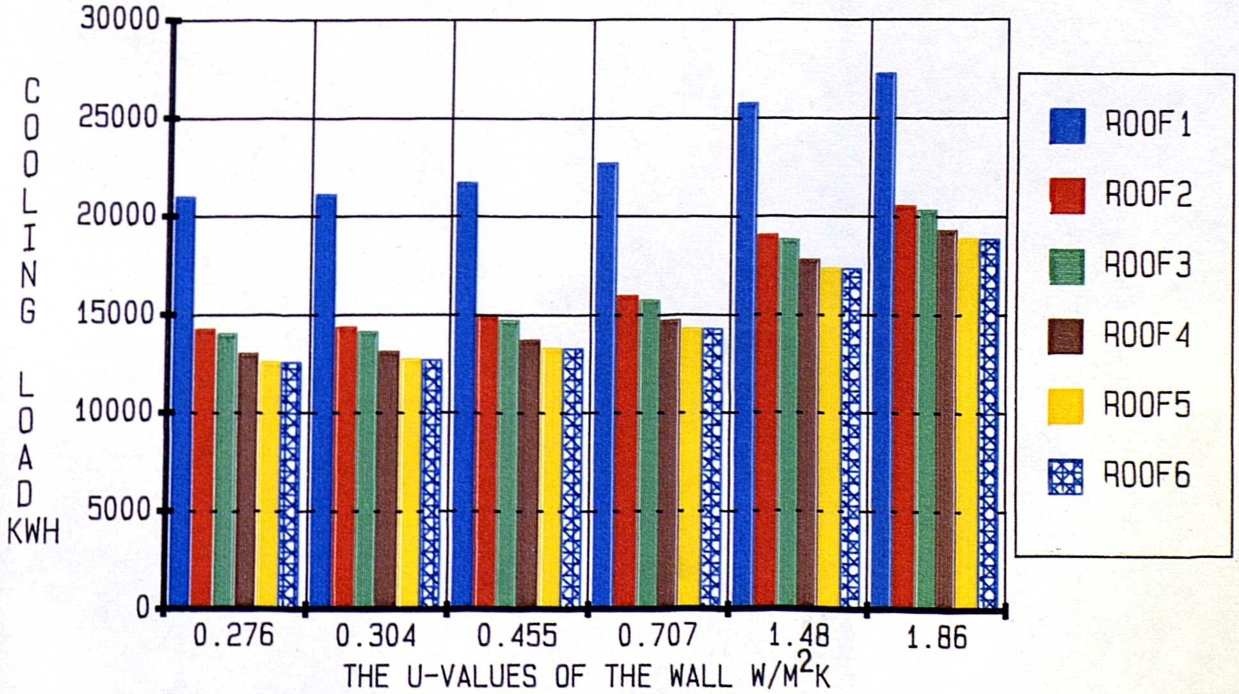


FIGURE 9.10: THE POTENTIAL FOR SAVING ENERGY BY USING DIFFERENT WALL U-VALUES WITH VARIOUS GLAZING TYPES

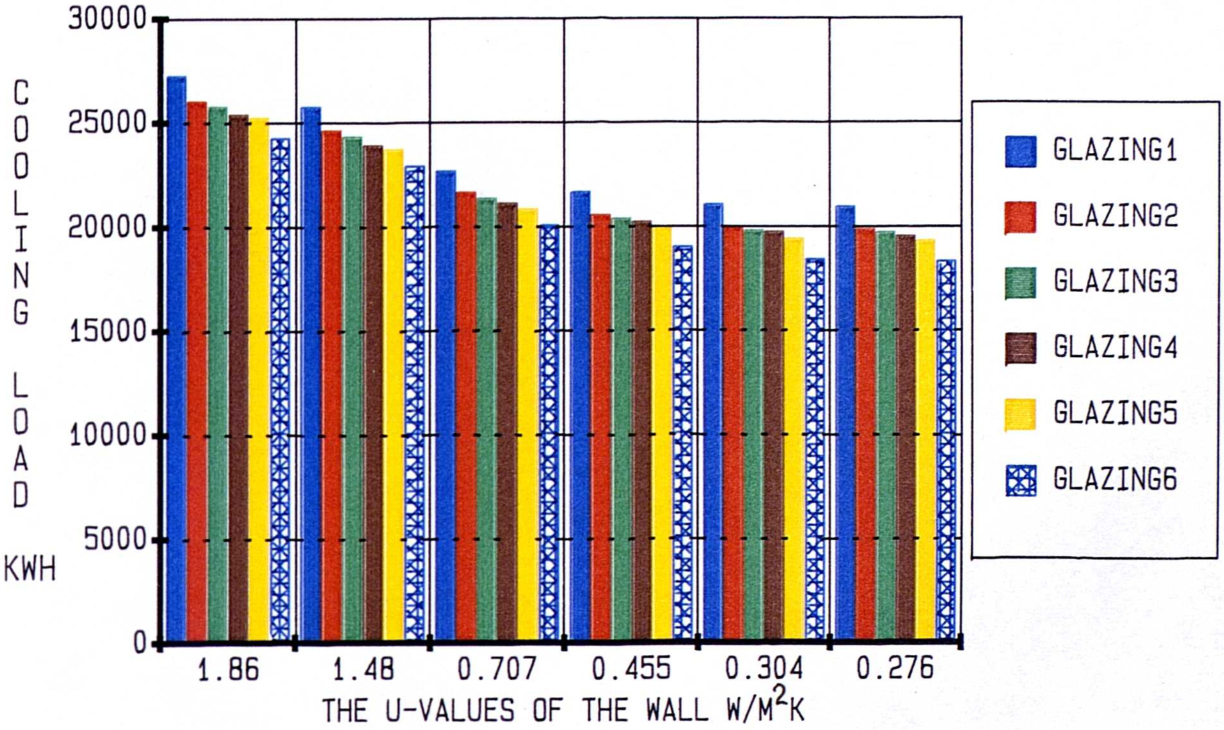
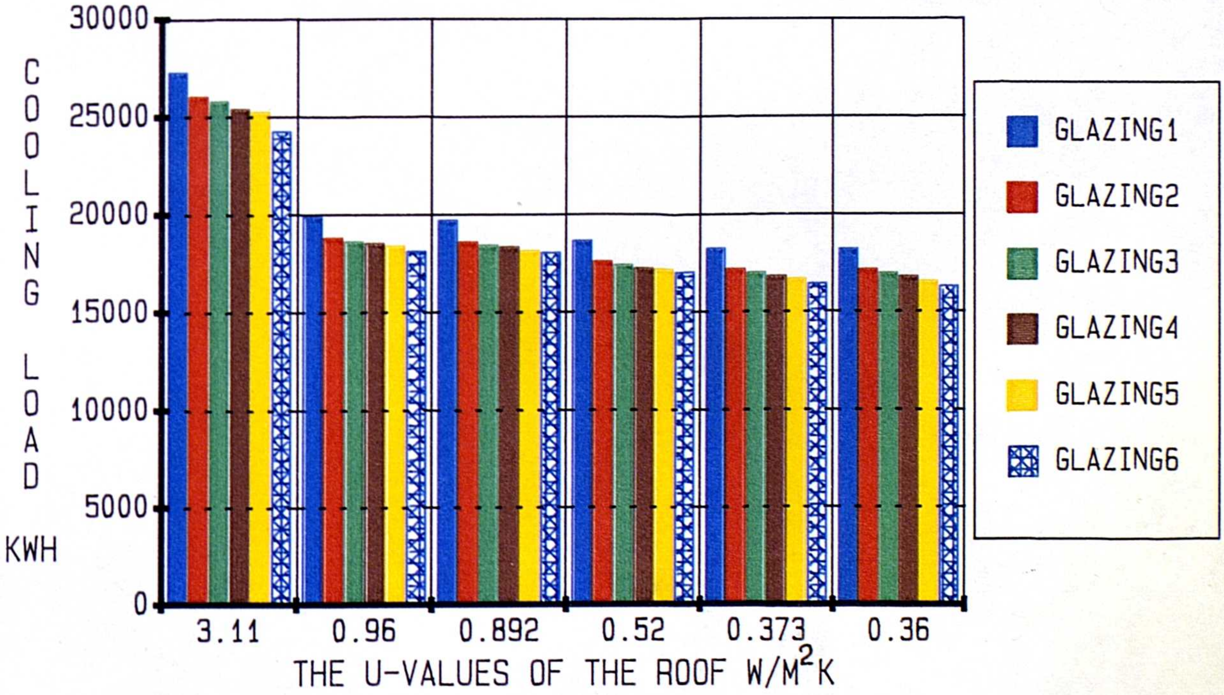


FIGURE 9.11: THE POTENTIAL FOR SAVING ENERGY BY USING DIFFERENT ROOF U-VALUES WITH VARIOUS GLAZING TYPES



9.5 Optimization

The main objective of the client is to save energy and consequently to reduce his expenditures; in other words he need to find the optimum solution. Usually, the client wants to have options for reducing expenditure on energy presented to him in such a manner that they can be easily evaluated. Therefore, by listing the alternative options in order according to their cost-effectiveness, the client can obtain a strategic framework of implementation that can produce a good system of energy management. For each proposed solution it is necessary to know:

(1) what the proposed measure is;
(2) what its initial cost would be;
(3) how cost-effective it is; and
(4) any other advantages and disadvantages it has.

Some of the energy conservation measures are very highly cost effective due to their low purchasing and installation costs in contrast with their savings, while others may be expensive to purchase and install with little achievable savings. Therefore, it is essential to demonstrate the cost-effectiveness of the proposed solutions. The simple way of calculating the cost-effectiveness of the proposed solutions is the pay-back calculation. This is the initial capital cost divided by the annual energy cost saving, and it measures the number of years it takes for a project to pay for itself.

However to demonstrate a proper cost effectiveness analysis of any suggested solution, it is important to have a reasonable knowlege or an idea about the various prices of the building materials, the labour and the building construction in Saudi Arabia. This is due to the fact that the pay back period and the annual savings are all depending upon the customer net investment. Therefore, a brief and quick estimate of the construction costs, building materials prices, and labour prices is discussed below.

Contractors for the construction of residential buildings in Saudi Arabia are generally managed in two different ways. The first way is the turn key contract where the contractor constructs the building from the foundation up complete with services installation and finishes, and hands the key to the owner. This type of contract generally costs around 1200 SR per square metre for normal construction, 1500 SR per square metre for a better quality construction, and 1800 SR per square metre for deluxe construction. The second way is the skeleton contract where the contractor constructs only the main structural elements of the building including walls. This type of construction costs 650 SR per square metre. The services installation and finishing trades are completed by individual labour employed by the owner.

Regarding the individual manpower prices there are daily prices and unit prices; the daily prices are 30 SR for unskilled labour and 50 SR for skilled labour. The unit prices vary considerably depending upon the unit type, such as kitchen unit, bathroom unit, or plumbing unit, and on the agreement between the manpower and the owner.

Finally, the prices of the main building materials are summarised as follows:

- Conventional building materials:

Hollow concrete block	1 SR/block
Cement	10SR/bag
Coarse aggregate	17SR/M^3
Fine aggregate	7SR/M^2
Plastering	12SR/M^2
Paint	8SR/M^2
Tiles	30SR/M^2
Tiles installation	12SR/M^2
Electrical accessories and installation	20-25SR/point

- New building materials:

Calcium Silicate block	1.20SR/block
Calcium Silicate brick	0.60SR/brick
Single glazed window in aluminium frame	8SR/M^2
3mm double glazed window in aluminium frame	100SR/M^2
6mm double glazed window in aluminium frame	145SR/M^2
9mm double glazed window in aluminium frame	199SR/M^2
12mm double glazed window in aluminium frame	310SR/M^2
12mm double glazed window in aluminium frame with external reflected pane	380SR/M^2

- Insulation materials including installation:

25mm extruded polystyrene	$27SR/M^2$
75mm extruded polystyrene	$27SR/M^2$
Lightweight concrete foam	$250SR/M^3$

The above mentioned prices are based on personal interviews with various building contractors, owners, and architectural offices in the Dammam region. These prices are quoted for the year 1987.

9.5.1 Cost Effectiveness Analysis

The situation in Saudi Arabia is that energy is heavily subsidised by the government. Thus, although the overall cost of producing domestic energy (electricity) is very high (0.45 Saudi Riyals per kwh) the selling cost to the consumers is very low, varying from 0.07 to 0.15 Saudi Riyals per kwh. It is the government policy in Saudi Arabia to subsidise electricity costs as part of the services that the government provides for its people. Nowadays the national economy is facing difficulties in funding the different projects in the country and a call for energy saving has been issued by the government to all the various sectors. Hence, if the expected savings are not achieved voluntarily the government does not achieve the prospective energy savings; the government may reduce its subsidisation of the cost of electricity in order to force people to expend more effort in saving energy. However, if the consumer is to be forced to apply some energy conservation measures, then the government will have to introduce building regulations in which the energy saving in the building is controlled. In this case the government should consider the pay back period, in which the proposed materials could pay for themselves in a reasonable period. The basis for selecting the most cost effective energy consumption measures is the pay back period derived as follows:

$$SQ = TQ - PQ$$
$$ES = SQ/Cop$$
$$ES_1 = ES/A$$
$$MS = ES_1C$$
$$pb = dc/Ms \qquad (9.1)$$

where

SQ = Reduction in heat gain
TQ = predicted heat gain using typical building elements
PQ = predicted heat gain using proposed building elements
ES = energy saved for all the house
ES_1 = energy saved per square metre
A = area of the modified elements
Cop = coefficient of performance
Ms = money saved
C = cost of the electricity per kwh
pb = pay back period
dc = the square metre cost differences between the typical and the proposed elements

Savings per square meter and payback periods were calculated for each wall type. Values of C and dC are calculated from tables supplied by the electricity company and the statistical year book of 1987 respectively.

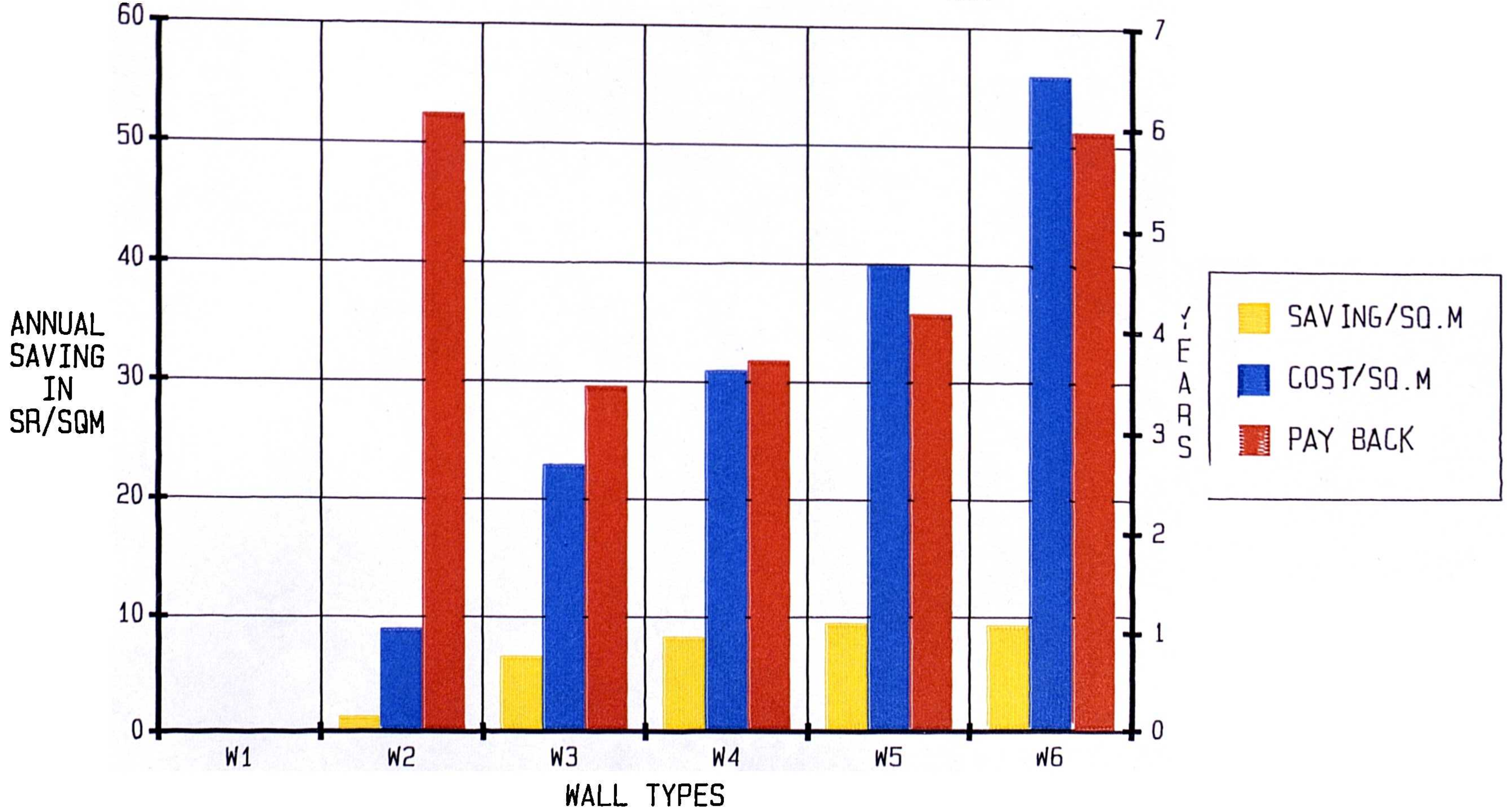
The elements are shown in figure 9.12 which shows the cost of the wall per square metre, the savings per square metre, and the overall pay back period. The figure does not specify or even indicate the optimum wall type to be used. This is due to the fact that the overall savings are very much dependent on the life of the building, the length of time that the occupant will stay in the house, and the minimum requirement of the building regulations. Nevertheless, the figure does show short periods of pay back for all the simulated wall types; this is an indication that they are very cost effective, bearing in mind that one may be more effective than another, depending on the initial cost, the annual savings, and the overall use of the proposed element.

Similarly, figure 9.13 shows the comparative cost effectiveness of the different simulated roof types. Basically, it shows the relationship between cost of the roof per square metre, the savings per square metre and the overall pay back period for the different roof types. It can be seen that the different simulated roof types are very highly cost effective, due to the fact that the predicted pay back periods are very small indeed. Nevertheless, any one of these roof types could be the optimum roof to use in a given situation due to their low cost, in contrast with their savings. However, the actual optimum roof type again relies on the life of the building and the length of its occupation, as mentioned previously . It can be seen from the figure that the saving increment decreases with each successive increase in thickness of insulation indicating that at certain u-values the saving will be constant and therefore any increase in insulation useless.

Figure 9.14 indicates the cost effectiveness of the different simulated type of glazing by specifying the costs per square metre, the saving per square metre, and the overall pay back periods of the different glazing types. The cost effectiveness of the different glazing types are not highly significant due to their high purchase costs compared to their savings. These high purchase costs are a result of the high price of imported materials and the limitation of the glass industry in the country. However, the overall cost effectiveness of the simulated glazings are reasonably effective, especially when the building is occupied for a long time. The difference between the cost effectiveness of the various simulated glazings is very noticeable, reflecting the difference in savings that they may provide.

The cost effectiveness of the various wall types, roof types, and glazing types present a very encouraging picture. While some of the modifications are more cost effective than others, overall they indicate the possibility of considerable future savings. Generally, the client or the builder wants to make optimum savings by using the most economical building materials. However, the optimum building elements vary from one client or builder to another depending upon the net saving they may provide. Therefore, an optimum saving study of various cost effectiveness of the building elements, is essential to define the optimum building elements.

FIGURE 9.12: THE COST EFFECTIVENESS OF THE SIMULATED BUILDING MATERIALS AND THE PREDICTED PAY BACK PERIOD



9.5.2 Optimum Savings Analysis

It is appropriate within the context of this study one can recognise or calculate the optimum savings that may vary from one occupant to another. In the optimum savings analysis the variation in the pay back periods and the possible net savings that may result from the use of the new conservation measures, with respect to the variations in the period of building occupancy are briefly studied. However, by studying the cost effectiveness of the building elements more sensitively in respect to the period of occupancy more than one optimum building element may result. This is due to the fact that the optimum building element for one occupant is not necessarily the same as that for the others, especially if the basis for selecting the set of measures for the greatest energy conservation is maximization of the total benefit. The explanation for this phenomenon is that circumstances vary from one occupant to another where one occupant may live in the building up to its life, while others may live there for a short period of time. Also, the optimum element for government savings may be different from those for the occupants. Therefore, there are three categories of savings in which the decision of optimum solution or optimum element is different.

These categories are:

1. Permanent occupant (life time)
2. Temporary occupant
3. Government authority

Since there are various categories on which the optimum solution is based, it is clear that the shortest pay back period does not necessarily have to be the optimum solution. Therefore for the sake of calculating the different optimum values for each category, a simple formula has been developed by the author. This formula calculates the total benefit of the various building elements and also specifies the optimum building elements for each category by calculating the maximum total benefit in respect of the expected usage period. Furthermore, the simplified formula indicates the best combination of the various building elements for each category. The developed formula can be expressed as follows:

FIGURE 9.13: THE COST EFFECTIVENESS OF THE SIMULATED BUILDING MATERIALS AND THE PREDICTED PAY BACK PERIOD

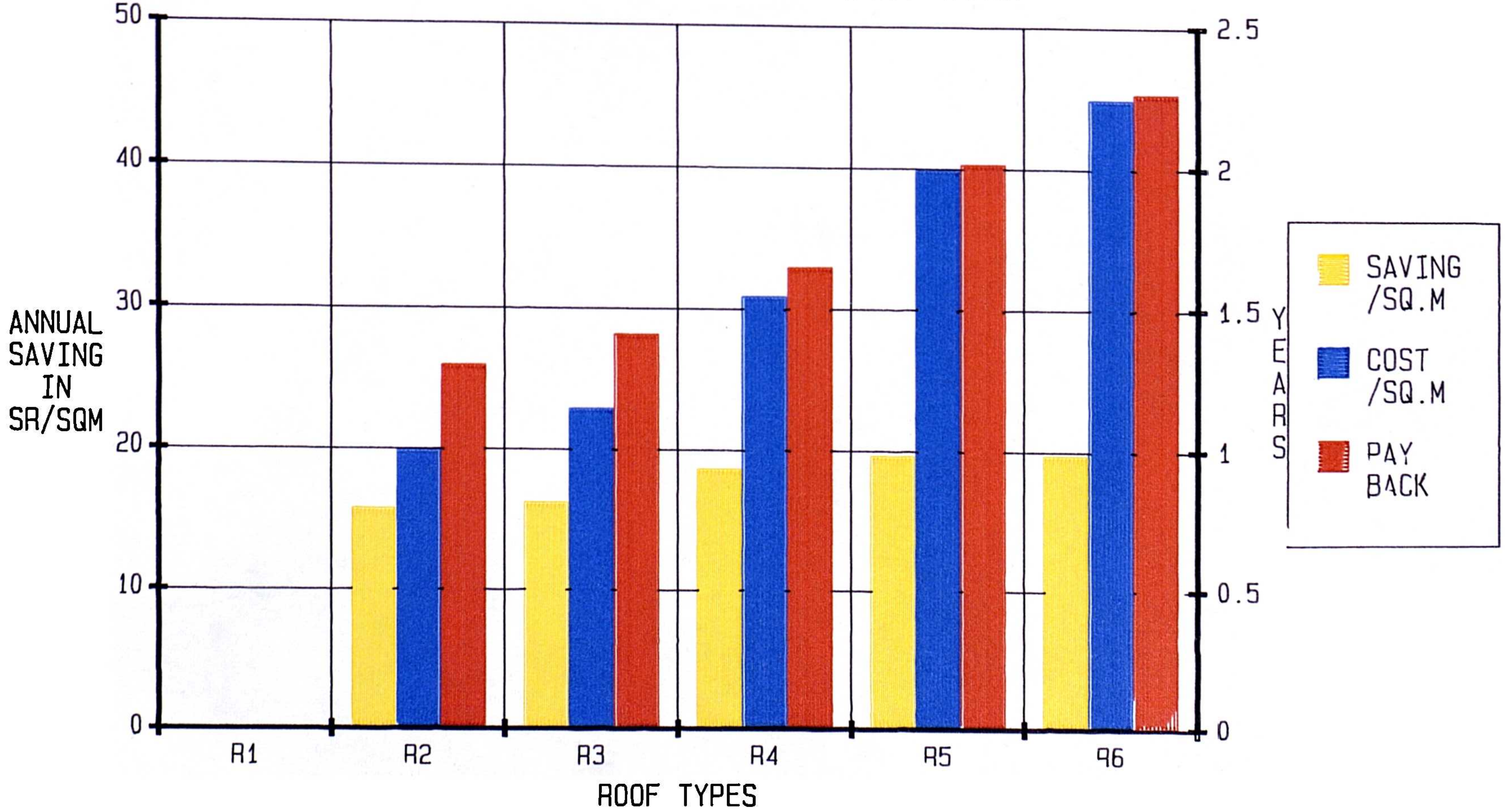
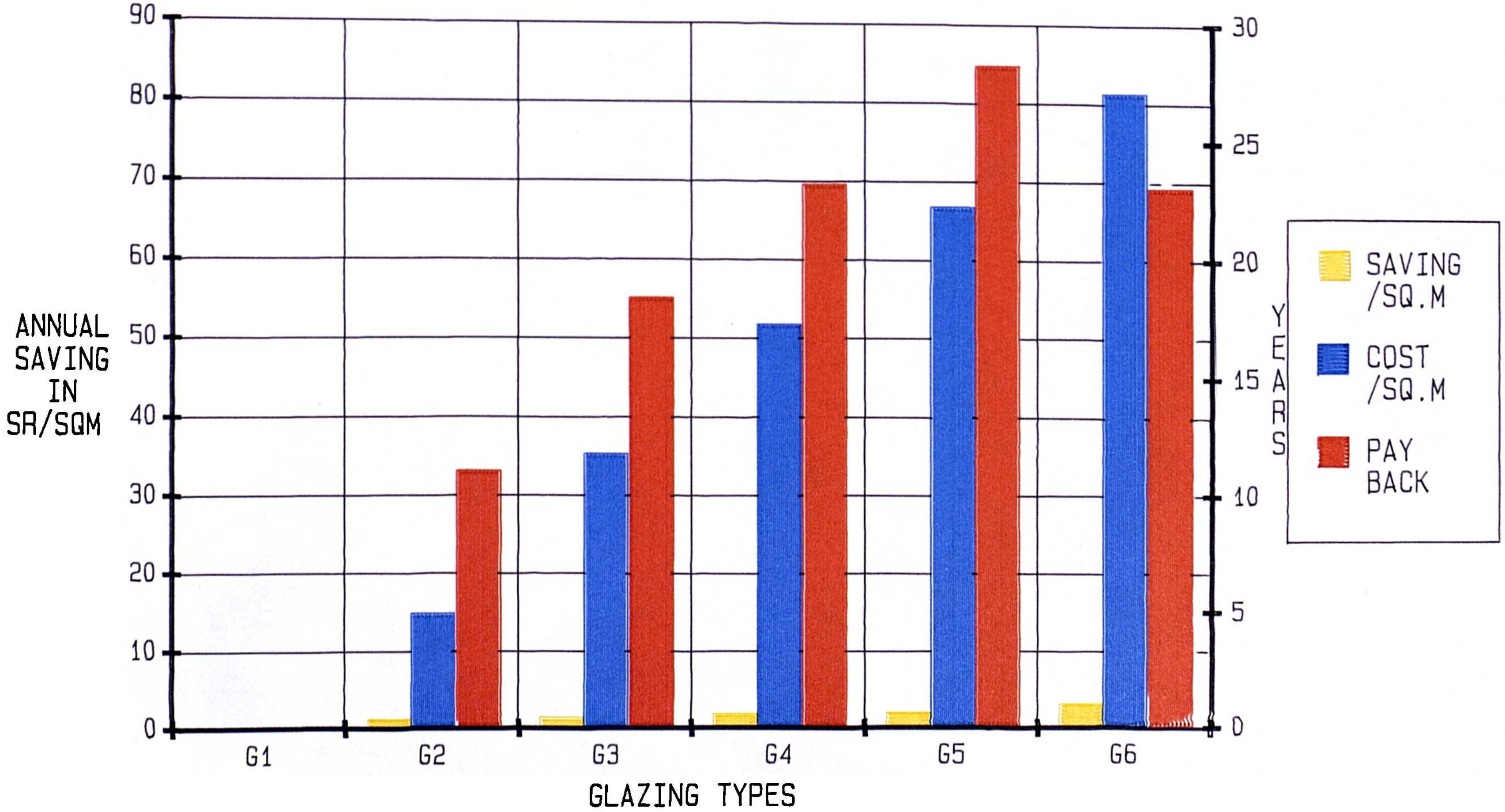


FIGURE 9.14: THE COST EFFECTIVENESS OF THE SIMULATED BUILDING MATERIALS AND THE THE PREDICTED PAY BACK PERIOD



$$NB = (LB - PB) * S$$
$$NB = LB*S - PB*S \text{ where } PB = C/S$$
$$NB = LB*S-C \qquad (9.2)$$

where

NB = Net benefit
LB = period of living in the building (years)
PB = calculated pay back period (years) (SR/M^2 year)
S = the saving of the new building parameter (SR/M^2)
C = the cost of the new building element

9.5.2.1 Permanent Occupant Optimum Building Paremeters

The optimum building element for the permanent occupant is surely different from that of the short period occupant, due to the criteria on which the different selections are based. In fact some building elements may have a very short pay back period, but concerning long term savings they are not the best elements to give the maximum total benefit. Generally the permanent occupant is not interested in the short pay back period as much as the total benefit. The main objective of the permanent occupant is the maximization of the total benefit. However, the period during which the permanent occupant will inhabit the building is not certain, but for practical use the period is limited by the age of the building, which again is limited to a minimum of 30 years.

By applying the simplified formula (NB) on various building elements with respect to the occupancy period (30 years for a permanent occupant), a clear picture of saving has resulted (see table 9.10). Usually, at the maximum savings one obtains the optimum set of conservation measures. Therefore, for a permanent occupant of 30 years the following conclusions of the best building elements can be drawn.

1. The best wall type is wall number 5, the cement plaster or stone construction with 75mm of extruded polystyrene as insulation material, 220mm hollow concrete block, and inside plaster, which gives a pay back of 4.18 years and a total savings of 246.56 SR/SQM for a period of 30 years.

2. The best roof type is roof number 5, the paved slab of sand and mortar construction, with 75mm of extruded polystyrene as insulation material, 10mm waterproofing membrane, 200mm reinforced concrete, and mortar plaster, which gives a pay back of 2.02 years and a total savings of 551.99 SR/SQM for a period of 30 years.

3. The best type of glazing is glazing number 2 which is a double glazing window with 3mm air space in between. This gives a pay back period of 11.11 years and a total savings of 25.5 SR/SQM for a period of 30 years.

4. The combination of those best elements would give substantial energy savings of about 799 SR/SQM for the period of 30 years (see table 9.10).

Table 9.10
The various net total benefit in Saudi Riyals per square metre of the different combinations of the building elements, walls, roof and glazing, that the permanent occupant might gain over a period of 30 years

	R1	R2	R3	R4	R5	R6
W1	0.0	455.260	465.760	531.740	551.990	549.570
W2	33.000	488.260	498.760	564.740	584.990	582.570
W3	176.800	632.060	642.560	708.540	728.790	726.370
W4	219.500	674.760	685.260	751.240	771.490	769.070
W5	246.560	701.820	712.320	778.300	798.550	796.130
W6	224.920	680.180	690.680	756.660	776.910	774.490
G1	0.0	455.260	465.760	531.740	551.990	549.570
G2	25.500	480.760	491.260	557.240	577.490	575.070
G3	17.800	473.060	483.560	549.540	569.790	567.370
G4	10.400	465.660	476.160	542.140	562.390	559.970
G5	2.200	457.460	467.960	533.940	554.190	551.770
G6	20.600	475.860	486.360	552.340	572.590	570.170

9.5.2.2 Temporary Occupant Optimum Building Elements

Generally the temporary occupant lives in his house for a short period of time because he is either a tenant or planning to move to a larger house as soon as the size of the family increases. Therefore, in these circumstances this occupant is not keen to apply any energy conservation measures that would achieve their optimum savings after he had moved from the house. Logically he is in favour of achieving the best saving in the shortest possible period, indirectly stressing the building elements that have the shortest pay back period with maximum savings. However, the length of time which the temporary occupant may inhabit the house is not known for certain, varying from one occupant to another. For the purpose of this calculation, the minimum living period will be assumed as 7 years, which is considered reasonably adequate for the people living in Dammam region.

The simplified formula for determining the optimum building elements (NB) was used on the various building elements to identify the optimum solution. Consequently, the formula produced a wide range of savings that may result from the use of the proposed building elements (see table 9.11). However, since the purpose of this process is to determine the best elements that would achieve the maximum savings in a 7 year period, the following conclusions are drawn.

1. The optimum type of wall is wall number 4, which gives a pay back period of 3.71 years and a total saving of 27.45 SR/SQM for a period of 7 years.

2. The optimum roof type is roof number 4, the paved slab of sand and mortar construction, with 50mm of extruded polystyrene as insulation material, 10mm waterproofing membrane, 200mm reinforced concrete, and mortar plaster, which gives a pay back of 1.652 years and a total saving of 100.31 SR/SQM for a period of 7 years.

3. The optimum type of glazing is the typical glazing used in the region as the pay back period for the other types of glazing is above 7 years.

4. The optimum combination of elements is the combination of wall 4, roof 4 and glazing 1. The combination of these elements would give a significant saving of about 127.756 SR/SQM for a period of 7 years (see table 9.11).

Table 9.11
The various net total benefit in Saudi Riyals per square metre of the different combinations of the building elements, walls, roof and glazing, that the temporary occupant might gain over a period of 7 years

	R1	R2	R3	R4	R5	R6
W1	0.0	90.894	91.044	100.306	98.131	93.733
W2	0.800	91.694	91.844	101.106	98.931	94.533
W3	23.620	114.514	114.664	123.926	121.751	117.353
W4	27.450	118.344	118.494	127.756	125.581	121.183
W5	26.864	117.758	117.908	127.170	124.995	120.579
W6	9.548	100.442	100.592	109.854	107.679	103.291
G1	0.0	90.894	91.044	100.306	98.131	93.733
G2	- 5.550	85.344	85.494	94.756	92.581	88.183
G3	-18.080	72.814	72.964	82.226	80.051	75.653
G4	-35.140	55,754	55.904	65.166	62.991	58.593
G5	-47.020	43.874	44.024	53.286	51.111	46.713
G6	-53.460	37.434	37.584	46.846	44.671	40.273

9.5.2.3 Government Optimum Building Elements

The main objective of the government is to capitalise the energy saving in some way. The possible methods of achieving this objective may differ according to the degree of savings required. However, the decision of the optimum building elements generally depends upon the answers of the following questions. These questions are:

(1) Does the government want to save energy in order to reduce the demand on the electricity power plant and at the same time encourage people to save money?

(2) Does the government want to save energy for the purpose of cutting down the subsidy?

(3) Is it profitable for the government to install insulation free of charge for the houses rather than subsidising their electricity bills?

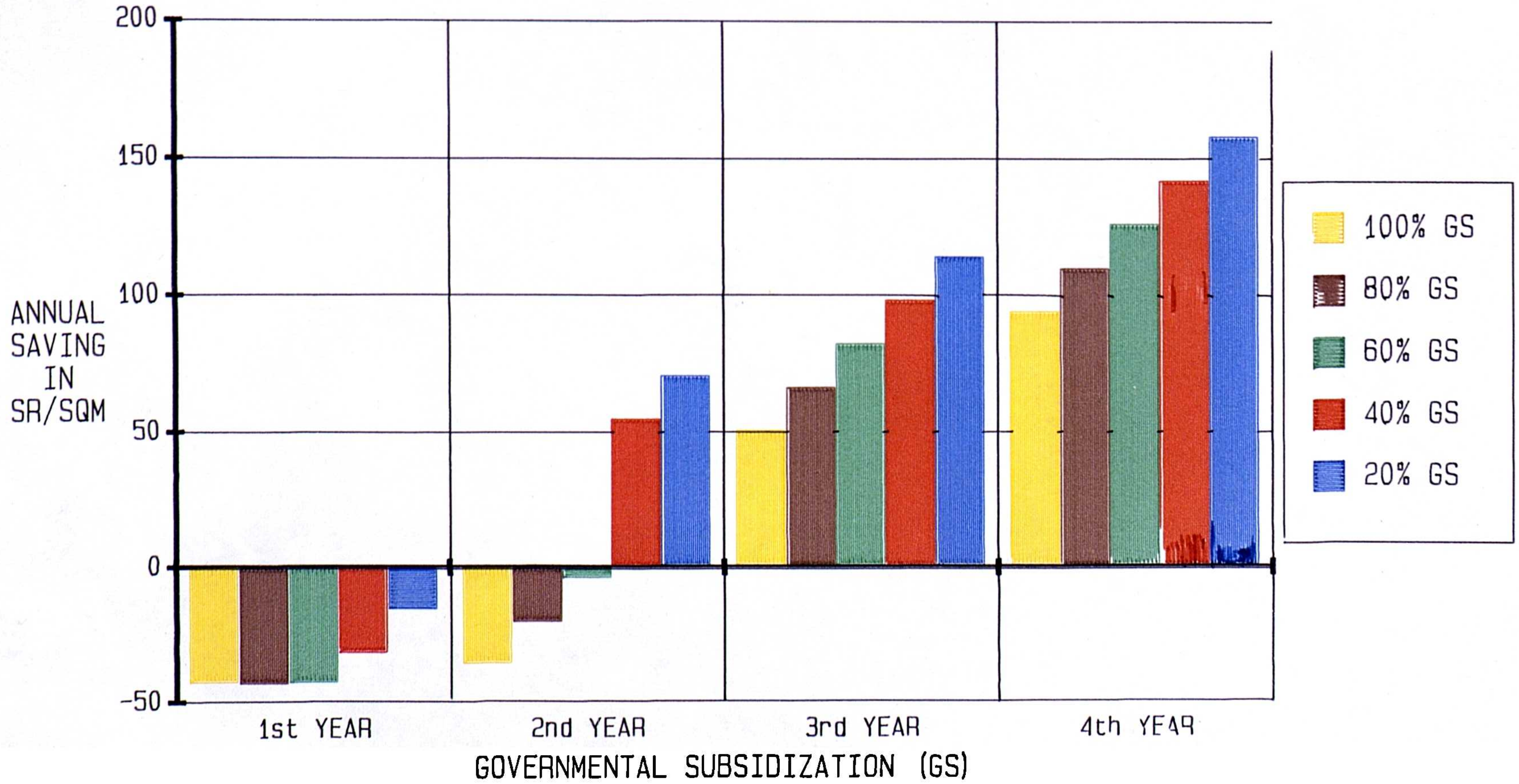
All of these questions will be answered and analysed in this section in order to define the possible various optimum building elements.

Assuming that the government would like to save energy for the sake of reducing energy demand at the power plant and encouraging the people to save money, it has two alternatives. The first is to ask the people to apply the optimum building elements that would give the best saving in the long term; the second is to ask the people to apply the optimum building elements that would give the best saving in the short term. The saving potential of both these options has been discussed previously in Sections 9.5.2.1 and 9.5.2.2. Forcing the people to apply the long term saving recommendations is not a practical decision for the government to make. This is due to the fact that some occupants cannot afford to install insulation which has a high initial cost, and others may not wish to pay for high cost recommendations if they are temporary residents. Therefore, the logical decision for the government to take is to make the optimum building elements that would give the best savings in a short period a compulsory requirement for constructing new buildings, and leave the long term optimum building elements as an alternative requirement. This suggestion faces the disadvantage that it takes four to five years for new building regulations to be approved by the local authority. Also it cannot be applied to existing buildings. Nevertheless, it is worth the government's seriously considering this suggestion for its great potential in saving energy both on the local and national scale.

Considering the presumption that the government would like to save energy for the purpose of reducing the subsidies on the energy bills, two approaches may be investigated. The first approach is that the government could encourage people to install insulation by paying some percentage of its installation costs; the second is that the government could install insulation free for different buildings. These two approaches are discussed and analysed in more detail in order to find out whether it is profitable or not for them to be followed.

By discussing the feasibility study of the first approach, where the government will subsidise some percentage of the installation costs, a useful saving of energy has resulted. Figure 9.15. indicates that if the government were to subsidise the instalment costs by paying 20%, 40%,

FIGURE 9.15: THE POTENTIAL FOR SAVING ENERGY THAT THE GOVERNMENT WOULD ACHIEVE BY THE VARIOUS PERCENTAGE OF SUBSIDIZATION



60% and 80% of these costs, then this outlay will be covered within one year, two years and nine years, depending on the terms of the subsidy. This will also make a saving of about 158, 143, 126 and 110 Saudi Riyals respectively in the first four years. This approach provides the government with two advantages, one being the saving of at least 43 SR/SQM per annum, and the other being the reduction of the electricity load on the power plant, which might lead to indirect money saving by cutting down the number of generators.

Furthermore, by studying the possibility of the government installing insulation free, ie. fully subsidising the cost of insulation, a positive answer has resulted. It is demonstrated in figure 9.15 above that if the government pays all the expenses of the insulation as well as the instalment costs, it will still reduce its subsidisation of energy by 43 SR/SQM every year (after the pay back period). Not only that, but also the overall energy saving of the region will become enormous and definitely would lead to a surplus in some of the power plants.

Therefore, it is better for the government to install insulation free in all buildings, rather than waiting for the new building regulation for compulsory insulation, which might take up to four to five years to be approved.

The above argument for government intervention in the interest of saving energy has been based upon the implications of the theoretical formulae developed and validated by the author. This argument requires more detailed investigations taking into account building costs, building maintenance costs, cost of electricity installation, and the consequences of inflation. This detailed analysis is in fact beyond the scope of this study; it requires a specialised research from a building economist.

With the above qualification, it would appear from the analysis of the potential for energy saving, that the government can save a great deal of money by installing insulation in houses. This is due to the fact that if the ordinary consumer, who pays 0.1 SR/kwh, can save a considerable amount of money by installing insulation, then it will mean more saving for the government who subsidises the consumed energy by 0.3 SR/kwh. However, the problem now is not whether installing insulation free is profitable or not. The problem now rests on how the energy saved can be secured. This is due to the fact that some people will use the energy saved to improve the conditions of comfort inside their houses, while others may use the energy carelessly because they are paying less than they used to. These phenomena may lead the government into expenditure due to the subsidy of insulation with less savings. However, to overcome this problem the author suggests that the government should specify a reasonable maximum limit for consuming energy, introducing a new tariff to reward those who are within the limit and penalise those who exceed it. This is just one method of overcoming this problem; there are many other ways of controlling energy consumption which are beyond the scope of this study.

CHAPTER 10

CHAPTER 10

SUMMARY AND RECOMMENDATIONS

Summary

Recommendations

SUMMARY AND RECOMMENDATIONS

Summary

Every day numbers of new dwellings are added to the housing stock of Dammam region. This is a result of the rapid growth of population, a rapid increase in oil production and the interest free loans furnished by the REDF programme. These new dwellings have abandoned traditional building techniques and regional architectural values in favour of modern amenities and contemporary western styles. Their standard of construction and finish also is generally poor, because of the lack of adequate supervision and failure of building regulation implementation. The result is that more poor quality buildings are being added to the poor existing buildings. The consequences of the increase of these poor quality buildings is a huge increase in demand for energy, and this has led the government to unnecessary expenditure in subsidising energy costs.

The intention of this thesis is to study the potential for energy conservation in the buildings in Dammam region, a region with a hot maritime climate. The analysis has been conducted by applying two techniques, field measurements and a social survey, and by modelling a real building using a computer thermal model developed by the author. This chapter aims to summarise the main findings of the study, and to recommend some design improvement for energy conservation for a hot maritime climate.

Traditional cooling systems have successfully provided comfortable conditions inside traditional buildings. The compact planning reduces the percentage of the envelope exposed to the sun, the wind catchers draw the cool breeze into the house, the courtyard regulates the temperature inside the house by exhausting the hot air and drawing in cool air, and the Mushrabiyah provides a cool place with adequate privacy. Some of these elements, such as courtyards and Mushrabiyah, have been adapted in contemporary buildings with some modifications made to suit the building techniques; this is discussed in more detail in Chapter 3. The internal courtyard was replaced by a set back, or an extroverted courtyard, which allows passageways around the house, daylight from four sides, and separation from neighbouring houses. It has successfully achieved these purposes, but it fails to cool the house when necessary, and it creates problems of lack of privacy and overheated areas around the house. The Mushrabiyah was also adapted by the contemporary buildings as a cooling element but because of the use of improper materials and the greenhouse effect these create, it tends to heat the house more than it cools it. It also creates the problem of overlooking into the neighbouring houses. It is suggested, then, that the government should revise the set back regulation and also discourage the use of glass in balconies in the first place or abandon the use of balconies if the above becomes unachievable.

In relating the climatic data of Dammam region to thermal design strategies, it has been found that passive cooling has some potential for improving the internal environment of the residences in a hot maritime climate. In fact, passive cooling has the ability to provide comfortable conditions inside the house for a few months of the year and reduce the discomfort level during the rest of the year. It shows some promising potential for saving energy through proper orientation, adequate ventilation and sufficient shading which lead to an overall heat gain reduction. However, the mechanical cooling system is still needed during most of the year to provide an acceptable level of comfort inside the house.

A survey was carried out of the housing stock of Dammam region, mainly Dammam and Al Khobar cities, between the 15th August and the 20th October 1987. The primary method used in collecting the information was personal observation and a questionnaire delivered to a sample of 500 houses from both cities. The sample was drawn by systematic selection from a list of about 14,000 houses supplied by the Electricity Company.

The findings of the survey are reported in detail in Chapter 6, along with the interpretation of the results and the residents' comments, but the summary of these findings is as follows:

1. Houses in Dammam region are classified by size into three classes, large, medium and small. The medium size house occupied most of the surveyed houses (58.6%) which may represent the percentage among the whole housing stock of Dammam region (figure 6.1).

2. The daily activities of most of the respondents of all sizes of housing are similar and the houses accommodate more or less the same uses of space with some variations in their numbers and sizes.

3. The numbers and sizes of electrical appliances have a direct influence on the energy consumption of the house by either their direct consumption or by their heat input which requires energy to extract it.

4. Almost all the houses in Dammam region are cooled by refrigerating air-conditioning units. Also the cooling period of the different spaces is generally similar in most houses.

5. The people of Dammam region restrict the use of the rooms to certain times of the day and infiltration to the house was reduced as ways of saving energy and thereby reducing the cost, but they do not apply any insulation materials to the buiding envelope.

6. The view to the outside from the house is important to the people of Dammam region, but the matter of privacy is paramount. The respondents were in favour of achieving privacy at any cost, even at the expense of natural lighting.

7. The various factors that affected the thermal comfort of residents inside the dwelling were cross tabulated against the residents' perceived discomfort. This result revealed that the dwelling area,

the number of appliances, the amount of cross-ventilation and the use of insulation materials in the envelope of the dwelling, have a very strong correlation with the perceived level of discomfort among the people.

Generally, the survey reflected the major concern of the people about the high consumption of energy due to the need for cooling during the greater part of the year (April to November). The analysis of the survey demonstrated the necessity of studying some houses in greater detail, and this led the author to select a few houses representation of all the houses surveyed.

Six houses were studied in detail. Each of the three categories of the houses in the survey was represented by two houses, those with the highest and lowest energy consumption in that category. All these houses were funded by the REDF programme and they were newly built (7 year old). The measured internal air temperatures of these houses varied from 22^{o}C up to 25.7^{o}C while the air conditioning unit is on which may reflect the actual comfort level of the people living within. The conclusion that can be drawn from the detailed study other than the detailed measurements used in the calculation procedures, is that all the case study houses used the same building materials, mainly a single skin envelope, which generally has a very poor thermal performance. In general, all the studied houses consumed too much energy, though some of them consumed less energy than the others.

It was discovered that the variation of levels of energy consumption in the houses studied is caused by the different behaviour of the occupants within the house, the efficiency of the cooling systems used, the design of the open spaces and the availability of green areas around the house, and the thermal performance of the building envelope. The analysis of these findings suggested that the study should concentrate on investigating the potential of saving energy by improving the thermal performance of the building materials.

The combination of poor thermal design and rising electricity prices has resulted in high annual fuel bills for running the air conditioning systems. There exists, therefore, an urgent need to investigate how this situation may be improved. As a result, a simple computer model was developed to be used to predict the annual amount of energy used in air conditioned houses. A steady state energy balance prediction method based on sol-air temperature was carried out, using mean monthly solar radiation and other weather data, together with typical incidental heat gain data based on family size and power ratings of appliances. Fabric gains were predicted using the appropriate house element areas and 'U' values. The effect of orientation was also taken into account when considering the solar gains through glazing.

Computed cooling loads were converted to energy consumptions using average coefficients of performance of air conditioning systems derived from measured energy consumption and manufacturers' data.

An empirical validation of the model was carried out, using six houses about which the energy consumption was known. The comparisons of predicted energy and measured energy were favourable and show that predictions can be made with a fair degree of confidence. The fully developed model will be of considerable help in assessing the effect of applying energy conserving measures to air conditioned houses.

With regard to the potential of the building material in reducing energy consumption, it has been found that the use of appropriate building materials can help to minimise heat gain during the summer period. This suggests that the indoor environment will consequently improve and produce some saving in the cooling load of the house.

Modelling the real buildings demonstrated some interesting results that cannot be observed by actual measurements only. It revealed that the roof is the crucial building elements in its effect on the internal environment. Also, it revealed that insulating the roof and the walls would contribute largely to reducing the conducted heat and eventually lower the indoor air temperature. The simulation of various combinations of wall u-values, roof u-values and window glazings indicated a significant potential for energy savings.

The simulated building elements were evaluated in the light of their initial costs and their cost effectiveness. The cost effectiveness analysis was based on the net benefit and the pay back period. The cost effectiveness analysis concluded that modifying the existing roofs and walls would save a great deal of money and have a short pay back period. The optimum savings analysis of the cost effectiveness concluded that there are three categories of house occupancy, each with its optimum solution. These are houses with a permanent occupant, those with a temporary occupant and those owned by a government authority. The methodology outlined in Chapter 9 shows how to arrive at the optimum levels of energy conservation for each category. In the optimisation process there are major differences between the government, permanent occupants, and temporary occupants in the benefits they accrue, which can be very considerable even if the government installs insulation materials free.

Recommendations

The recommendations of this study fall into three parts. These are the general design concept concerning the micro-climate, the building fabric, and areas requiring further research. Although the principal aim of the study is concerned with the thermal performance of existing buildings and with the means by which these can be modified to provide maximum energy conservation, included in these recommendations are certain principles of good climatic design which should be applied in the design of new buildings.

1. General Design Concept

The general design concepts are derived from the analysis of the cooling strategy described in Chapter 4, and from the analysis of the survey and case study houses in Chapters 6 and 7. These concepts mainly concern the improvement of the micro-climate around the house and the possible method of getting cool air into the building. These concepts are mostly under the control of the architect; they are briefly summarised as follows:

(a) Orientation should be optimised with regard to solar radiation and wind direction in order to minimise the surface area exposed to solar radiation and to maximise the utilisation of the wind. However, a specific orientation cannot be recommended here due to the absence of a detailed study of sun motion and wind speeds and directions.

(b) The set back spaces and the open areas around the house should be landscaped to modify the micro-climate. A careful planting of green areas would reduce the reflected solar radiation and provide some shade for walls, windows and roofs. Also trees and plants cool the incoming air and reduce the glare and dust in the air.

(c) The courtyard and balcony should be designed properly to provide adequate protection from the high solar intensity during the day and allow night cooling. The privacy of the occupants and the neighbouring houses should be considered very highly in designing these elements.

(d) External walls should be painted with light colours especially in a hot climatic region, due to their low absorbance of solar radiation.

(e) The designer should draw the attention of the occupants to the best way of controlling the internal conditions of their houses and encourage them to use cross-ventilation during the summer nights.

2. Building Fabric

The building fabric is a crucial element in protecting the internal environment from the effect of the external conditions. Considering the simulation results in Chapter 9, the improvement of the building fabric demonstrated a very good potential for energy conservation. The deployment of energy conservation on a large scale could save the country a large amount of power generating capacity and corresponding amounts of air-conditioning units. The main factors are the use of insulation materials on the building fabric, good glazing and efficient air-conditioning units. The recommendations drawn from the analysis of the simulation, regarding the optimum building materials and their implementation, are summarised as follows:

(a) The government should encourage the house builder, through the building regulations, to build new houses to specifications that would ensure maximum energy conservation. Such specifications would include wall number 5 (the cement plaster or stone construction with 75mm of extruded polystyrene as insulation material, 220mm hollow concrete block and the inside plaster), roof number 5(the paved slab of sand and mortar construction, with 75mm extruded polystyrene as insulation material, 10mm waterproofing membrane, 200mm reinforced concrete and mortar plaster), and double glazed windows with 3mm air space in between. But as a consequence the government should consider two things;

(i) If the net benefit and the pay back period is reasonable for the consumer (not more than 5 years) then the government does not have to subsidise the installation costs;

(ii) If the net benefit is little and the pay back period is more than 5 years then the government should partially subsidise the installation costs.

(b) The government should specify a maximum limit for the peak electrical load of a building, in kwh, for space cooling purposes. Then it should introduce a lower tariff to reward those who are within the limit and high tariff to penalise those who exceed it.

(c) High standard specifications related to the climate of the region should be introduced to govern the quality of the manufactured and the imported cooling systems and a minimum coefficient of performance should be specified.

(d) It is recommended that the architect who designs the building should supervise the construction process up to the finishing touches. This procedure improves the quality of the building and secures the use of insulation materials.

It is suggested that similar approaches could be adopted for all the residential buildings in similar climatic regions in Saudi Arabia or the Gulf countries. However, energy savings will then depend on local weather patterns, user behaviour, building practices, and energy prices in each country.

3. <u>Areas Requiring Further Research</u>

From the analysis of the various findings of this study it is evident that the contemporary situation of the housing stock in Dammam region and the whole of Saudi Arabia requires more research into areas of thermal behaviour which are at present not fully understood. Such research would assist this study if it were available; some areas to consider are:

(a) **The adaptation of traditional cooling systems.**
A comprehensive thermal study and evaluation of the adaptation of traditional cooling systems, compact planning, windcatchers courtyards and Mushrabiyah is necessary. The study should investigate the best way of adapting these cooling systems to contemporary buildings and the possible energy conservation measures that could be achieved by using these systems.

(b) **Air movement and ventilation rate**
A detailed study to measure the ventilation rate and its effect on the internal environment of the house is urgently needed. It is of

same importance that the ventilation rate of the contemporary housing in Dammam region should received especial attention due to the little research done in this field.

(c) **Tariff strategy**
A careful study is required to investigate the possible tariff strategy that the government could apply to balance the cost of installing insulation against the subsidisation of the electricity bills. The study should also consider consumer satisfaction.

(d) **Model validation**
Only limited validation of the model has been undertaken by this study. For it to be used with more confidence a validation exercise needs to be undertaken, using the Science Engineering Research Council (SERC) validation studies as an example.

(e) **Infiltration measurement**
A study of programme pressure testing is required to test the typical contemporary dwellings to determine their air tightness and to estimate the infiltration rates for the various dwellings.

(f) **Practicality of the proposed recommendations**
Lastly, and most importantly, a more detailed study is required into the practicality of applying the recommended changes to the existing building fabric, considering the people's attitude towards the cost and adaptability of the new materials and the consequences of the new changes in the building envelope

Finally, since this study was concerned with the potential for energy conservation of residential buildings and was limited to one region, the findings and recommendations must be considered as suggestive rather than conclusive. However, this study should be seen as one of a series of studies in Dammam region and Saudi Arabia. It provides some useful tools and techniques for evaluating and improving the thermal performance of the buildings in general.

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APPENDICES

A P P E N D I X   A

QUESTIONNAIRES, CODING PROCEDURES AND EXAMPLES OF MEASUREMENTS SHEETS

A-1 The Arabic version questionnaire for the main houses survey in Dammam region

A-2 The English version questionnaire for the main houses survey in Dammam region

A-3 Samples of the coding system used to manipulate the survey raw data

A-4 Samples of the hourly temperature and humidity measurements inside the case study houses.

A-1 The Arabic version of the questionnaire Survey in Dammam Region

١ ـ ماهو عنوان المنزل ؟

أ ـ رقم المنزل ________

ب ـ اسم الشارع ________

ج ـ رقم تقاطع الشارع ________

د ـ اسم الحي والمدينة ________

هـ ـ اتجاه المنزل ________

☐ او ☐ ش

٢ ـ هل انت صاحب المنزل او مستاجر ؟

صاحبه ☐ مستاجر ☐

٣ ـ كم لك ساكن في هذا المنزل ؟

شهر ________ سنة ________

٤ ـ كم شخص ساكن في المنزل ؟

بالغين ________ اطفال ________

٥ ـ كم طابق هذا المنزل ؟

واحد ☐ اثنان ☐ ثلاثة ☐ اربعة ☐

٦ ـ ماهي مساحة منزلك ؟

صفر ـ ٣٠٠م٢ ☐ ٣٠٠ ـ ٨٠٠م٢ ☐ ٨٠٠ واعلى ☐

٧ـ هل من الممكن ان تضع علامة (✓) على الاماكن المختلفة فى المنزل وعددها ؟

الاماكن	العلامة	العدد
مجلس الضيوف (رجال)		
غرفة طعام الضيوف		
مجلس الضيوف (نساء)		
صالة معيشة		
مطبخ		
غرفة نوم		
حمام		
درج وصالة الدرج		
مخزن		
كراج		
اخـــرى		

٨ـ هل من الممكن ان تضع علامة (✓) على الاشهر التى تستخدم فيها المكيف ؟

يناير	يوليو
فبراير	اغسطس
مارس	سبتمبر
ابريل	اكتوبر
مايو	نوفمبر
يونيو	ديسمبر

٩ ـ هل كان المنزل بارد كفاية خلال فترة الصيف بدون استخدام المكيفات ؟

نعم ☐ لا ☐ بعض الاحيان ☐

١٠ ـ ماهى اعلى فاتورة كهربه دفعتها خلال فترة الصيف ؟

صفر ـ ١٠٠ ☐ ١٠٠ ـ ٢٠٠ ☐ ٣٠٠ ـ ٥٠٠ ☐ ٥٠٠ واعلى ☐

١١ ـ ماهى انواع الطاقة المستخدمة فى المنزل ؟

	التكييف	الاجهزة	المطبخ
كهرباء			
غـــاز			
فحـــم			

١٢ ـ من فضلك ضع علامة (✓) على الاجهزة المستخدمة فى المنزل وعددها ومقاسها ؟

الاجهـــزة	العلامة	العدد	المقاس
ثلاجة مع فريزر			
فريزر فقط			
فرن مع طباخ غاز			
فرن مع طباخ كهربائى			
ابريق شاى كهربائى			
غسالة ملابس			
نشافة ملابس			
غسالة اوانى			
تلفزيون			
فيديو			
مكيف			
اخـــرى			

١٣ ـ من قائمة ادوات التبريد ضع نوع المبرد المستخدم فى كل غرفة من غرف المنزل مع وضـــع التوقيت ؟

ت تهوية عن طريق فتح نافذتين على الاقل

م مروحة كهربائية

هـ مكيف هواء كهربائى

الغـــرف	نوع المبرد	التوقيت
مجلس الضيوف (رجال)		
غرفة طعام الضيوف		
مجلس الضيوف (نساء)		
صالة معيشة		
مطبخ		
غرفة نوم (١)		
غرفة نوم (٢)		
غرفة نوم (٣)		
غرفة نوم (٤)		
غرفة نوم (٥)		
غرفة نوم (٦)		
صالة الدرج مع الدرج		
المخزن		
الكراج		
اخـــرى		

١٤ ـ هذا السؤال من فضلك ضع علامة (✓) فى المكان المناسب ؟

	الفصل	(لا) اطلاقا	قليلا غير مرتاح		كليتا غير مرتاح		ماعندى فكره
			بعض الاحيان	غالبا	بعض الاحيان	غالبا	
هل تشعر بعدم ارتياح لارتفاع درجة الحرارة	الصيف						
	الشتاء						
هل تشعر بعدم ارتياح لانخفاض درجة الحرارة	الصيف						
	الشتاء						
هل تشعر بعدم ارتياح لان الهواء جاف	الصيف						
	الشتاء						
هل تشعر بعدم ارتيح لان الهواء رطب	الصيف						
	الشتاء						
هل تشعر بجفاف	فى الجو الحار						
	فى الجو البارد						
هل تشعر برطوبة	فى الجو الحار						
	فى الجو البارد						

١٥ ـ هل عملت اى شىء لتوفير استهلاك الكهرباء فى التبريد المنزل ؟

أ ـ استخدام غرف اقل من العدد اللازم

ب ـ استخدام التهوية واستخدام الهواء الطلق

ج ـ تقليل تسرب الهواء البارد الى خارج الغرفة

د ـ عمل عوازل حرارية للمبنى وتظليل النوافذ

هـ ـ اخـــرى

١٦ ـ كم هو مهم لك ان تستطيع الرؤيا خلال النوافذ ؟

مهم جدا ١ ٢ ٣ ٤ ٥ ٦ ٧ غير مهم

١٧ ـ كم هو مهم لك ان تمنع الناس الرؤيا من الخارج خلال النوافذ ؟

مهم جدا ١ ٢ ٣ ٤ ٥ ٦ ٧ غير مهم

١٨ ـ كم هو مضياء نور الشمس القادم من خلال النوافذ ؟

غير مضيا كفاية ١ ٢ ٣ ٤ ٥ ٦ ٧ مضىء جدا

١٩ ـ هل استخدمت اى معانى لتقليل ضوء الشمس الساطع من الاشعاع داخل المنزل ؟

نعم ☐ لا ☐ اذهب الى السؤال رقم ٢٠

المعانى	الشمال	الجنوب	الشرق	الغرب
ستائر				
بلبند				
لوفرز خارجية				
لوفرز داخلية				
مظلة				
زراعة «اشجار توقف الشمس»				
زجاج عاكس				
اخـــرى				

اذا كان يوجد لديك بعض المعانى لتقليل الضوء

أ ـ مامدى استخدامها ؟

فى الشتاء غالبا ١ ٢ ٣ ٤ ٥ ٦ ٧ اطلاقا

فى الصيف غالبا ١ ٢ ٣ ٤ ٥ ٦ ٧ اطلاقا

ب ـ كم فعالية هذه المعانى ؟

جيده جدا ١ ٢ ٣ ٤ ٥ ٦ ٧ رديئه جدا

٢٠ ـ هل تستخدم النوافذ للتهوية ؟

غالبا ١ ٢ ٣ ٤ ٥ ٦ ٧ اطلاقا

٢١ ـ مامدى فتحك لاكثر من نافذه فى اليوم ؟

غالبا ١ ٢ ٣ ٤ ٥ ٦ ٧ اطلاقا

اذا كان نعم فمتى ؟

النهار ☐ العصر ☐ الليل . ☐

٢٢ ـ اى تعليقات اخرى عن منزلك .

A-2 The English version of the questionnaire Survey in Dammam Region

1. What is the house address:

   a. House Number: ____________________
   b. Street Name: ____________________
   c. Street Intersection: ______________
   d. Zone End City Name : ______________
   e. House Orientation : ______________

2. Are you the owner of the house or a tenant?

   Owner ☐ Tenant ☐

3. How long have you been living in this house?

   Months ___ Years ___

4. How many persons are living in this house?

   Children ___ Adults ___

5. How many storeys is the house?

   One ☐ Two ☐ Three ☐ Four ☐

6. What is the size of your house?

   0-300 sq.m. ☐ 300-800 sq.m. ☐ 800-Upward sq.m. ☐

7. Would you please check the different spaces of the house and write down the number?

Spaces	Number
Men's Guest Room	
Guest Dining Room	
Women's Guest Room	
Family Living Room	
Kitchen	
Bedroom(s)	
Bathroom	
Staircase/Hall	
Storage Room	
Garage	
Others	

8. Would you please check the different summer months?

Jan ☐ July ☐

Feb ☐ Aug ☐

March ☐ Sept ☐

April ☐ Oct ☐

May ☐ Nov ☐

June ☐ Dec ☐

9. Have you been comfortable enough during the summer period without using the air conditioning?

No ☐ Yes ☐ Sometimes ☐

10. What is your maximum monthly energy bills during the summer time?

0-100 SR ☐ 100-200 SR ☐ 200-500 SR ☐ 500-Over ☐

11. What types of energy are you using in your house?

Energy/ For	Cooling	Lighting	Appliances	Cooking
Electricity Gas Coal Other				

12. Please check the different appliances in the house and their numbers and sizes?

Appliances	Number	Size
Fridge & Freezer Freezer Gas Cooker Electric Cooker Kettle Washing Machine Dryer Machine Dishwasher Television Video Special Lighting Air Conditioning Other		

14. For the questions below please put a tick in the appropriate column beside each item. Bearing in mind it is without the use of A.C. units.

	Never	Slightly Uncomfortable		Definitely Uncomfortable		No Experience
		Occasionally	Often	Occasionally	Often	
Do you ever feel uncomfortably warm.. (a) In summer?						
(b) In winter?						
Do you ever feel uncomfortably cold.. (a) In summer?						
(b) In winter?						
Does the air ever feel uncomfortably dry.. (a) In summer?						
(b) In winter?						
Does it ever feel uncomfortably humid.. (a) In summer?						
(b) In winter?						
Does it feel draughty.. (a) In warm weather?						
(b) In cold weather?						
Does it feel stuffy.. (a) In warm weather?						
(b) In cold weather?						

13. From this list of forms of cooling, can you tell which you use in each room in the house and at what times of the day they are used?

Cross Ventilation	C
Fan	F
Air Conditioning	A

ROOM	TYPE	TIME USED
Men's Guest Room		
Guest Dining Room		
Women's Guest Room		
Family Living Room		
Kitchen		
Bedroom 1		
Bedroom 2		
Bedroom 3		
Bedroom 4		
Bedroom 5		
Bedroom 6		
Bathroom		
Staircase/Hall		
Storage Room		
Garage		
Others		

15. Have you done anything to save the cost of cooling your house?

i) Using fewer rooms than you would like to;
ii) Allowing cross ventilation;
iii) Reducing the infiltration from outside air;
iv) Insulating the building; shading the window;
v) Others

16. How important is it to you to be able to see outside through the windows?

HIGHLY DESIRABLE 1 2 3 4 5 6 7 IT DOES NOT MATTER

17. How important is it to you to prevent people from outside seeing in through the window?

HIGHLY DESIRABLE 1 2 3 4 5 6 7 IT DOES NOT MATTER

18. How bright is the light coming from the window?

NOT BRIGHT ENOUGH 1 2 3 4 5 6 7 TOO BRIGHT

19. Is there any means provided to cut down glare from the sky or direct sunlight shining into the room?

YES ☐ NO ☐ ------> GO TO 20

MEANS	NORTH	SOUTH	EAST	WEST
Curtains				
Blinds				
Outside louvres				
Inside louvres				
Cantilever overhang				
Planting				
Reflective glass				
Other				

If you do have some means of control, then:

(a) How often are they used?

(i) In winter? OFTEN 1 2 3 4 5 6 7 NEVER
(ii) In summer? OFTEN 1 2 3 4 5 6 7 NEVER

(b) How effective are they?

VERY GOOD 1 2 3 4 5 6 7 VERY POOR

20. Do you use the windows for cross ventilation?

OFTEN 1 2 3 4 5 6 7 NEVER

21. How often do you open the window, more than one?

OFTEN 1 2 3 4 5 6 7 NEVER

If so, when

Daytime ☐ Evening ☐ Nighttime ☐

22. Any other comments about your house?

THIS QUESTION IS TO BE ASKED TO THE PEOPLE WHO LIVE IN THE CASE STUDY HOUSES ONLY.

Please tick any of the activities below which you are normally involved in?

ACTIVITIES	TIME	PLACE
Reading and writing		
Watching T.V.		
Talking		
Playing and moving		
Sewing		
Cooking		
Eating		
Sleeping		
Other (please specify)		
Washing and bathing		
Laundry		

A-3 : Examples of the code book of the questionnaire survey in Dammam Region

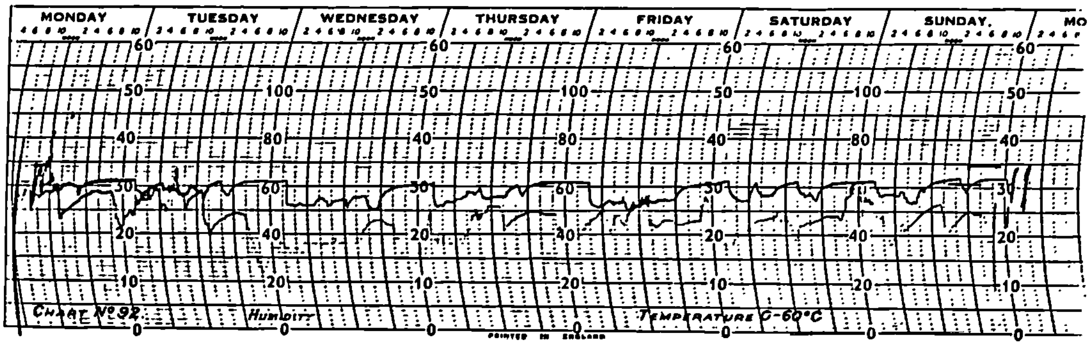
Columns	Variable Name	Variable Description	Codes & Meanings
1-3	I.D.	Case identification	001 to 500
4	LN	Lne number	1
5	Orient	House orientation	1 = North, 2 = South, 3 = East 4 = West, 5 = North East 6 = North West, 7 = South East 8 = South West
6	Tenure	House Tenure	1 = owned, 2 = rental
7	TLH	Time living in the house	1 = less than one year 2 = more than one year
8-9	Adults	Number of adults living in the house	Actual Number
10	Children	Number of children living in the house	Actual Number
11-12	House	Total number of people living in the house	Actual Number
13	Height	The number of storeys of the house	Actual Number
1A	Area	The range of the house area	1 = 300 or less 2 = 301 to 800 3 = 801 and over

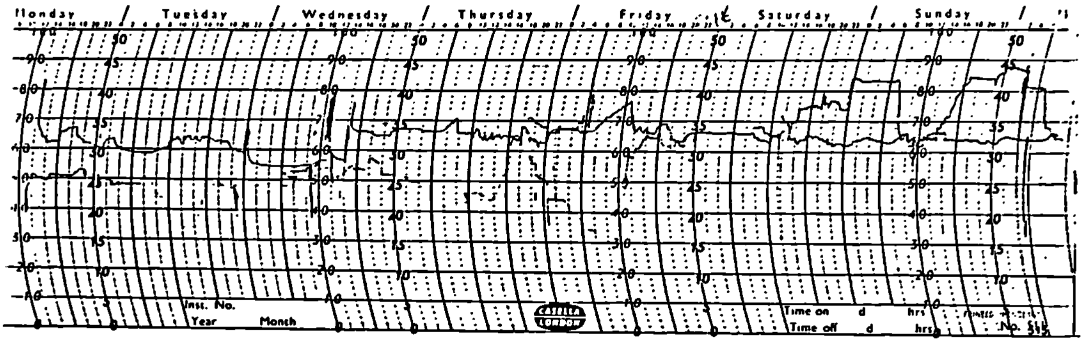
15-26	Summer	Percentage summer months for the people in Dammam area	1 = Jan, 2 = Feb, 3 = March 4 = April, 5 = May, 6 = June 7 = July, 8 = August, 9 = September 10 = October, 11 = November 12 = December
27	MGR Rm 1	Number of mens guest rooms	Actual Number
28	WGR	Number of womens guest rooms	Actual Number
29	DR	Number of dining rooms	Actual Number
30	LR	Number of living rooms	Actual Number
31	Bed Rm	Number of bedrooms	Actual Number
32	Kitchen	Number of kitchens	Actual Number
33	Toilet	Number of toilets	Actual Number
34	STA	Number of staircase and hall	Actual Number
35	STO	Number of storages in the house	Actual Number
36	Garages	Number of garges in the house	Actual Number
37-38	NTLR	Total number of rooms in the house excluding toilets, kitchens, garages, storages, staircase hall.	Actual Number
39	Comfort	Is the house condition during the summer time cold enough without using the air conditioning	1 = Yes 2 = No 3 = Sometimes
40	ELECON	The maximum monthly energy bills during the summer time.	1 = less than 100 2 = 101 to 200 3 = 201 to 500 4 = 500 and over
41	Ac ENE	Type of energy used in cooling the houses	1 = Electricity 2 = Gas, 3 = Coal
42	Appl. ENE	Type of energy used in appliances	1 = Electricity 2 = Gas, 3 = Coal

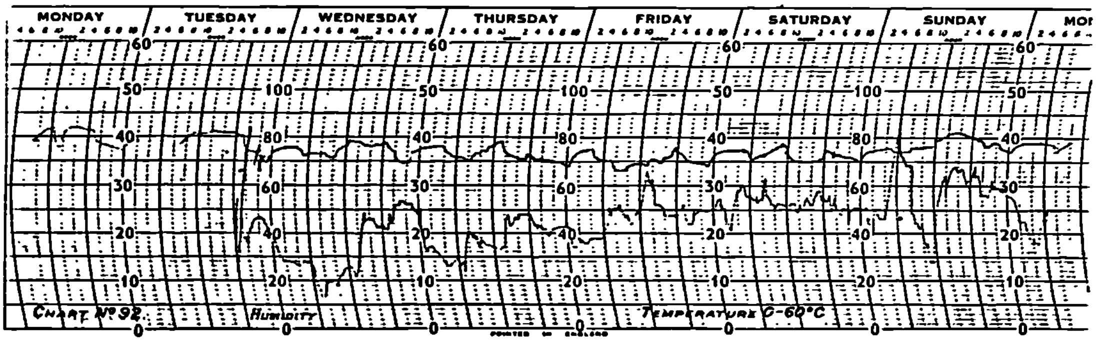
43	Cook ENE	Type of energy used in the kitchen	1 = Electricity 2 = Gas, 3 = Coal 4 = Electricity and Gas
6	FRIG 7 FRIZ	Number of fridges and freezers in the house and their sizes	Actual number, 1 = small, 2 = medium, 3 = large
7-8	FRIZ	Number of freezers ??? in the house and its size	Actual number 1 = small, 2 = medium, 3 = large
9-10	GASOVS	Number of gas ovens in the house and its size	Actual number 1 = small, 2 = medium, 3 = large
11-12	ELEC oven	Number of electric ovens within house and their sizes	Actual number 1 = small, 2 = medium, 3 = large
13-14	Kettle	Number of kettles in the house and their sizes	Actual number 1 = small, 2 = medium, 3 = large
15-16	Washer	Number of washing machines and their sizes	Actual number 1 = small, 2 = medium, 3 = large
17-18	Dryer	Number of drying machines and their sizes	Actual number 1 = small, 2 = medium, 3 = large
19-20	Dish	Number of dishwashers and their sizes	Actual number 1 = small, 2 = medium, 3 = large
21-22	T.V.	Number of televisions in the house	Actual number 1 = small, 2 = medium, 3 = large
23-24	VIDEO	Number of video machines in the house and its size	Actual number 1 = small, 2 = medium, 3 = large

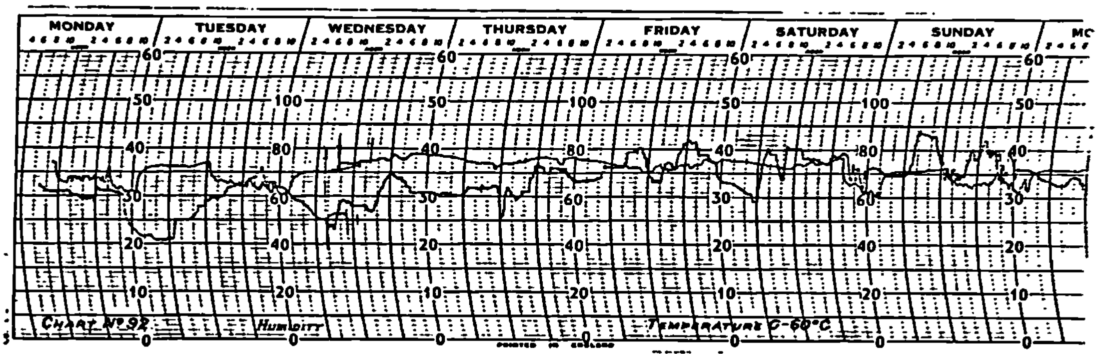
25-27	A.C.	Number of air conditioning units and their sizes	Actual number 1 = small, 2 = medium, 3 = large
28-29	Total	Total number of appliances in the house	Total number

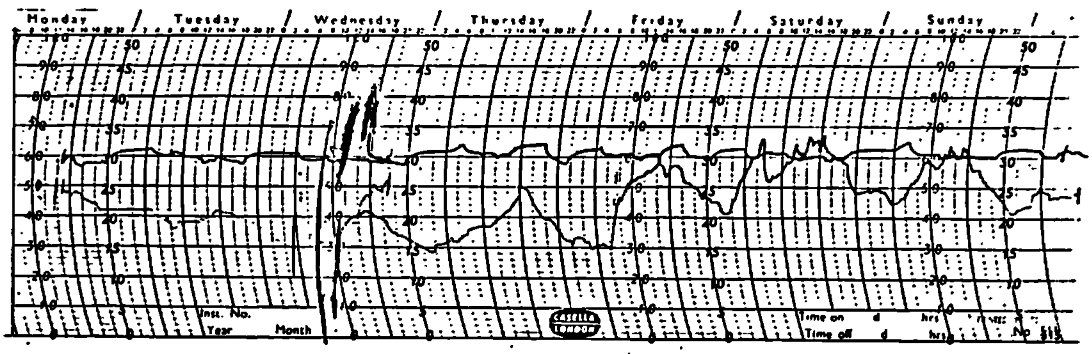
A-4 : A Few Samples of the air temperature and humidity measurements inside the dwelling.











APPENDIX B

EXAMPLES OF MODEL CALCULATIONS AND THE VARIOUS TABLES USED

B-1 Calculation Examples

B-2 Various tables used in the calculation procedures

B.1.1.1

SAMPLE OF HOUSE 2 Calculation Procedures

	1	2	3	4	5	6	7
1	ti	to	ach	rhi	rho	gi	go
2	25	34	1	44.2	63.5	0.00887	0.0242
3	gl h rad	6323	n factor	0.336	ew factor	0.408	s factor V
4	gl diff	1359	g reflect	0.2	solabs	0.8	0.41
5	v n rad	124.15433	v s rad		v ew rad		
6	u-values	walls	windows	roof	floor	solair-rf	fn
7		1.7	4.48	3.35	1.13		10
8	areas n	135.5	3.5	solair-n		asgf-n	0.2
9	areas e	84	12	solair-e		asgf-e	0.2
10	areas s	120	18	solair-s		asgf-s	0.2
11	areas w	96	0	solair-w		asgf-w	0.2
12	occupants	man out	man in	women out	women in	child out	child in
13		4	0	4	1	4	1
14	pleasure o ut	>	8				
15	misc gainsgas cook		3.26	elec cook	0	appl/light	3.5
16	latent heat gain		>0.678275	cold area	196.25	cold vol	588.75
17	heat extra cted..		33006.64	eng used	21246.45	coeff perf	1.5535132
18	volume	588.75	aroof	196.25	absroof	0.5	139.04633
19	spec vol	0.8563					
20	formulas	below			0.01533		139.46
21	fl-n	124.15433	139.46	139.04633	radiation on vert su rfaces		
22	solair	43.932347	45.123707	45.1568	solair n e & w s		
23	solairf	47.172917	info > area roof		196.25	area floor	196.25
24	ventilatio42.34761		wall gain	351.14178	roof gain	349.85537	
25	qwlgain	104665.59	147788.5	98687.693	351.14178		
26	qrfgain	349.85537	qflgain	47.9007			
27	qglgain	32.41728					
28	glsol	6.2711009	9.4346364	1.6331758	0	17.338913	
29	inthtgain	12.5					totalapplV
30	appliances	4	cook gas	3.26	cook elec	0	72.8
31	moistgain	10.08	clothwash	1	2		total mois
32			cookprep		7		21.88
33			washbath		2.8		
34	e equation186.41968						
35							
36	totals	743.34476	186.41968	80.31798	17.338913	72.8	33006.64
37							
38							
39							
40							
41							
42							
43							
44	energy	summary	of house 2				
45	heat gain	ventltn	42.35				
46		walls	351.14				
47		roof	349.86				
48		floor	47.90				
49		window	32.42				
50		sol glaze	17.34				
51							
52	internal	heat gain					
53		a:people	12.50				
54		b:cooking	3.26				
55		c:appl/lts	4.00				
56	total int	heat gain	72.80				
57							
58	moisture	input					
59		a:people	10.08				
60		b:wash/bth	2.80				
61		c:clth/wsh	2.00				
62		d:cooking	7.00				
63	total mst	heat gain	21.88				
64							
65	total heat	extracted	33006.64				
66	act energy	consumed	21246.45				
67							
68	coeff of	performnce	1.5535				

B.1.1.2

SAMPLE OF HOUSE 2 Formula Procedures 43/144

	1	2	3	4
1	"ti"	"to"	"ach"	"rhi"
2	25	34	1	44.2
3	"gl h rad "	6323	"n factor "	0.336
4	"gl diff "	1359	"g reflect"	0.2
5	"v n rad "	vnr	"v s rad "	
6	"u-values"	"walls"	"windows"	"roof"
7		1.7	4.48	3.35
8	"areas n"	135.5	3.5	"solair-n"
9	"areas e"	84	12	"solair-e"
10	"areas s"	120	18	"solair-s"
11	"areas w"	96	0	"solair-w"
12	"occupants"	"man out"	"man in"	"women out"
13		4	0	4
14	"pleasure out"	"ut >"	8	
15	"misc gains"	"gas cook "	3.26	"elec cook"
16	"latent heat"	"t gain >"	0.678275	"cold area"
17	"heat extracted"	"cted.."	R(+19)C(+4)	"eng used"
18	"volume"	R(-2)C(+5)	"aroof"	R(-2)C(+1)
19	"spec vol"	0.8563		
20	" formulas bel"	"below"		
21	"fl-n"	((h-hd)*nr+hd/2+gr*h/2)/24	((h-hd)*sr+hd/2+gr*h/2)/24	((h-hd)*ewr+hd/2+gr*h/2)/24
22	"solair"	to+vnr*a/fn	to+vewr*a/fn	to+vsr*a/fn
23	"solairf"	to+(h*abrf/fn)/24	"info >"	"area roof"
24	"ventilation"	24*0.333*v*(to-ti)*0.001	"wall gain"	24*uw*((an*(soln-ti)+((ae+aw)*(solew-ti))+as*(sols-ti)))*0.001
25	"qwlgain"	24*uw*((an*(soln-ti)))	24*uw*(((ae+aw)*(solew-ti)))	24*uw*((as*(sols-ti)))
26	"qrfgain"	24*ur*arf*(solrf-ti)*0.001	"qflgain"	24*uf*af*(to-ti)*0.001
27	"qglgain"	24*ug*(wn+we+ws+ww)*(to-ti)*0.001		
28	"glsol"	24*vewr*gfe*we*0.783*0.001	24*vsr*gfs*ws*0.783*0.001	24*vnr*gfn*wn*0.783*0.001
29	"inthtgain"	omo*1+omi*1.9+owo*0.8+owi*1.5+oco*0.6+oci*1.4		
30	"appliances"	4	"cook gas"	mgc
31	"moistgain"	omo*0.72+omi*1.12+owo*0.72+owi*1.12+oco*0.72+oci*1.12-pol*0.1	"clothwash"	1
32			"cookprep"	
33			"washbath"	
34	"e equation"	(totalmoist+ach*v*24*(go-gi)/spv)*lhg		
35				
36	"totals"	R(-12)C+R(-12)C(+2)+R(-12)C(+4)	R(-2)C(-1)	R(-10)C+R(-9)C(-2)
<Blank Lines>				
44	"energy "	"summary"	"of house 2"	
45	"heat gain"	"ventltn "	R(-21)C(-1)	
46		"walls "	R(-21)C(+2)	
47		"roof "	R(-21)C(-1)	
48		"floor "	R(-22)C(+1)	
49		"window "	R(-22)C(-1)	
50		"sol glaze"	R(-22)C(+3)	
51				
52	"internal"	"heat gain"		
53		"a:people "	R(-24)C(-1)	
54		"b:cooking"	R(-24)C(+1)+R(-24)C(+3)	
55		"c:appl/lts"	R(-25)C(-1)	
56	"total int"	"heat gain"	R(-26)C(+4)	
57				
58	"moisture"	"input "		
59		"a:people "	R(-28)C(-1)	
60		"b:wash/bth "	R(-27)C(+2)	
61		"c:clth/wsh "	R(-30)C(+2)	
62		"d:cooking "	R(-30)C(+2)	
63	"total mst"	"heat gain"	R(-31)C(+4)	
64				
65	"total heat"	" extracted"	R(-29)C(+4)	
66	"act energy"	"consumed"	R(-49)C(+2)	
67				
68	"coeff of"	"performnce"	R(-51)C(+4)	

B.1.1.3

SAMPLE OF HOUSE 3 Calculation Procedures 56/144

	1	2	3	4	5	6	7
1	ti	to	ach	rhi	rho	gi	go
2	25	32.5	1	21.8	43.8	0.004032	0.01331
3	gl h rad	7160	n factor	0.336	ew factor	0.408	s factor V
4	gl diff	2162	g reflect	0.2	solabs	0.8	0.41
5	v n rad	144.847	v s rad		v ew rad		
6	u-values	walls	windows	roof	floor	solair-rf	fn
7		1.7	4.48	3.35	1.13		10
8	areas n	95.89	10.71	solair-n		asgf-n	0.2
9	areas e	62.37	20.43	solair-e		asgf-e	0.2
10	areas s	71.46	20.43	solair-s		asgf-s	0.2
11	areas w	86.13	11.34	solair-w		asgf-w	0.2
12	occupants	man out	man in	women out	women in	child out	child in
13		2	0	1	1	2	0
14	pleasure o ut >		2				
15	misc gainsgas cook		0	elec cook	2.6	appl/light .	4
16	latent heat gain >	0.678275	cold area	198.3	cold vol	594.9	
17	heat extra cted..	28919.676	eng used	14845.98	coeff perf	1.9479803	
18	volume	594.9	aroof	198.3	absroof	0.5	159.841
19	spec vol	0.8563					
20	formulas	below			0.009278		160.2575
21	fl-n	144.847	160.2575	159.841	radiation on vert su		rfaces
22	solair	44.08776	45.28728	45.3206	solair n e & w s		
23	solairf	47.416667	info > area roof		198.3	area floor	198.3
24	ventilatio	35.658306	wall gain	256.83994	roof gain	357.39609	
25	qwlgain	74677.273	122916.57	59246.091	256.83994		
26	qrfgain	357.39609	qflgain	40.33422			
27	qglgain	50.730624					
28	glsol	12.273249	12.30523	5.8304487	6.8124643	37.221392	
29	inthtgain	5.5					totalapplV
30	appliances	4	cook gas	0	cook elec	2.6	73.61
31	moistgain	4.52	clothwash	1	2		total mois
32			cookprep		3		10.72
33			washbath		1.2		
34	e equation	112.19864					
35							
36	totals	649.89433	112.19864	91.064844	37.221392	73.61	28919.676
37							
38							
39							
40							
41							
42							
43							
44	energy	summary	of house 3				
45	heat gain	ventltn	35.66				
46		walls	256.84				
47		roof	357.40				
48		floor	40.33				
49		window	50.73				
50		sol glaze	37.22				
51							
52	internal heat gain						
53		a:people	5.50				
54		b:cooking	2.60				
55		c:appl/lts	4.00				
56	total int heat gain		73.61				
57							
58	moisture input						
59		a:people	4.52				
60		b:wash/bth	1.20				
61		c:clth/wsh	2.00				
62		d:cooking	3.00				
63	total mst heat gain		10.72				
64							
65	total heat extracted		28919.68				
66	act energy consumed		14845.98				
67							
68	coeff of performnce		1.9480				

B.1.1.4

SAMPLE OF HOUSE 3 Formula Procedures 67/144

	1	2	3	4
1	"ti"	"to"	"ach"	"rhi"
2	25	32.5	1	21.8
3	"gl h rad "	7160	"n factor "	0.336
4	"gl diff "	2162	"g reflect"	0.2
5	"v n rad "	vnr	"v s rad "	
6	"u-values"	"walls"	"windows"	"roof"
7		1.7	4.48	3.35
8	"areas n"	95.89	10.71	"solair-n"
9	"areas e"	62.37	20.43	"solair-e"
10	"areas s"	71.46	20.43	"solair-s"
11	"areas w"	86.13	11.34	"solair-w"
12	"occupants"	"man out"	"man in"	"women out"
13		2	0	1
14	"pleasure out"	"ut >"	2	
15	"misc gains"	"gas cook "	0	"elec cook"
16	"latent heat"	"t gain >"	0.678275	"cold area"
17	"heat extracted"	"cted.."	R(+19)C(+4)	"eng used"
18	"volume"	R(-2)C(+5)	"aroof"	R(-2)C(+1)
19	"spec vol"	0.8563		
20	" formulas bel"	"below"		
21	"fl-n"	((h-hd)*nr+hd/2+gr*h/2)/24	((h-hd)*sr+hd/2+gr*h/2)/24	((h-hd)*ewr+hd/2+gr*h/2)/24
22	"solair"	to+vnr*a/fn	to+vewr*a/fn	to+vsr*a/fn
23	"solairf"	to+(h*abrf/fn)/24	"info >"	"area roof"
24	"ventilation"	24*0.333*v*(to-ti)*0.001	"wall gain"	24*uw*((an*(soln-ti)+((ae+aw)*(solew-ti))+as*(sols-ti)))*0.001
25	"qwlgain"	24*uw*((an*(soln-ti)))	24*uw*(((ae+aw)*(solew-ti)))	24*uw*((as*(sols-ti)))
26	"qrfgain"	24*ur*arf*(solrf-ti)*0.001	"qflgain"	24*uf*af*(to-ti)*0.001
27	"qglgain"	24*ug*(wn+we+ws+ww)*(to-ti)*0.001		
28	"glsol"	24*vewr*gfe*we*0.783*0.001	24*vsr*gfs*ws*0.783*0.001	24*vnr*gfn*wn*0.783*0.001
29	"inthtgain"	omo*1+omi*1.9+owo*0.8+owi*1.5+oco*0.6+oci*1.4		
30	"appliances"	4	"cook gas"	mgc
31	"moistgain"	omo*0.72+omi*1.12+owo*0.72+owi*1.12+oco*0.72+oci*1.12-pol*0.1	"clothwash"	1
32			"cookprep"	
33			"washbath"	
34	"e equation"	(totalmoist+ach*v*24*(go-gi)/spv)*lhg		
35				
36	"totals"	R(-12)C+R(-12)C(+2)+R(-12)C(+4)	R(-2)C(-1)	R(-10)C+R(-9)C(-2)
<Blank Lines>				
44	"energy "	"summary"	"of house 3"	
45	"heat gain"	"ventltn "	R(-21)C(-1)	
46		"walls "	R(-21)C(+2)	
47		"roof "	R(-21)C(-1)	
48		"floor "	R(-22)C(+1)	
49		"window "	R(-22)C(-1)	
50		"sol glaze"	R(-22)C(+3)	
51				
52	"internal"	"heat gain"		
53		"a:people "	R(-24)C(-1)	
54		"b:cooking"	R(-24)C(+1)+R(-24)C(+3)	
55		"c:appl/lts"	R(-25)C(-1)	
56	"total int"	"heat gain"	R(-26)C(+4)	
57				
58	"moisture"	"input "		
59		"a:people "	R(-28)C(-1)	
60		"b:wash/bth "	R(-27)C(+2)	
61		"c:clth/wsh "	R(-30)C(+2)	
62		"d:cooking "	R(-30)C(+2)	
63	"total mst"	"heat gain"	R(-31)C(+4)	
64				
65	"total heat"	" extracted"	R(-29)C(+4)	
66	"act energy"	"consumed"	R(-49)C(+2)	
67				
68	"coeff of"	"performnce"	R(-51)C(+4)	

B.1.1.5

SAMPLE OF HOUSE 4 Calculation Procedures

		1	2	3	4	5	6	7
1	ti	to	ach	rhi	rho	gi	go	
2	25	34.4	1	18.2	41.2	0.003225	0.01427	
3	gl h rad	7744	n factor	0.336	ew factor	0.408	s factor V	
4	gl diff	1893	g reflect	0.2	solabs	0.8	0.41	
5	v n rad	153.61817	v s rad		v ew rad			
6	u-values	walls	windows	roof	floor	solair-rf	fn	
7		1.7	4.48	3.35	1.13		10	
8	areas n	80.5	6.5	solair-n		asgf-n	0.2	
9	areas e	62.65	6.35	solair-e		asgf-e	0.2	
10	areas s	78.15	8.85	solair-s		asgf-s	0.2	
11	areas w	64	5	solair-w		asgf-w	0.2	
12	occupants	man out	man in	women out	women in	child out	child in	
13		2	0	1	1	1	1	
14	pleasure o ut	>	3					
15	misc gains	gas cook	3.26	elec cook	0	appl/light	3.5	
16	latent heat gain >	0.678275	cold area	104.5	cold vol	313.5		
17	heat extra cted..	21216.773	eng used	9388.81	coeff perf	2.2597937		
18	volume	313.5	aroof	104.5	absroof	0.5	171.17117	
19	spec vol	0.8563						
20	formulas	below			0.011045		171.65875	
21	fl-n	153.61817	171.65875	171.17117	radiation on vert su	rfaces		
22	solair	46.689453	48.093693	48.1327	solair n e	& w s		
23	solairf	50.533333	info > area roof		104.5	area floor	104.5	
24	ventilatio	23.551625	wall gain	264.32842	roof gain	214.52596		
25	qwlgain	71236.841	119332.5	73759.077	264.32842			
26	qrfgain	214.52596	qflgain	26.639976				
27	qglgain	26.98537						
28	glsol	4.0851437	5.7096859	3.7528304	3.2166486	16.764308		
29	inthtgain	6.3					totalapplV	
30	appliances	4	cook gas	3.26	cook elec	0	61.13	
31	moistgain	4.82	clothwash	1	2		total mois	
32			cookprep		3		11.02	
33			washbath		1.2			
34	e equation	73.300122						
35								
36	totals	502.40601	73.300122	53.625346	16.764308	61.13	21216.773	
37								
38								
39								
40								
41								
42								
43								
44	energy	summary	of house4					
45	heat gain	ventltn	23.55					
46		walls	264.33					
47		roof	214.53					
48		floor	26.64					
49		window	26.99					
50		sol glaze	16.76					
51								
52	internal	heat gain						
53		a:people	6.30					
54		b:cooking	3.26					
55		c:appl/lts	4.00					
56	total int	heat gain	61.13					
57								
58	moisture	input						
59		a:people	4.82					
60		b:wash/bth	1.20					
61		c:clth/wsh	2.00					
62		d:cooking	3.00					
63	total mst	heat gain	11.02					
64								
65	total heat	extracted	21216.77					
66	act energy	consumed	9388.81					
67								
68	coeff of	performnce	2.2598					

B.1.1.6

SAMPLE OF HOUSE 4 Formula Procedures 98/144

	1	2	3	4
1	"ti"	"to"	"ach"	"rhi"
2	25	34.4	1	18.2
3	"gl h rad "	7744	"n factor "	0.336
4	"gl diff "	1893	"g reflect"	0.2
5	"v n rad "	vnr	"v s rad "	
6	"u-values"	"walls"	"windows"	"roof"
7		1.7	4.48	3.35
8	"areas n"	80.5	6.5	"solair-n"
9	"areas e"	62.65	6.35	"solair-e"
10	"areas s"	78.15	8.85	"solair-s"
11	"areas w"	64	5	"solair-w"
12	"occupants"	"man out"	"man in"	"women out"
13		2	0	1
14	"pleasure out"	"ut >"	3	
15	"misc gains"	"gas cook "	3.26	"elec cook"
16	"latent heat"	"t gain >"	0.678275	"cold area"
17	"heat extracted"	"cted.."	R(+19)C(+4)	"eng used"
18	"volume"	R(-2)C(+5)	"aroof"	R(-2)C(+1)
19	"spec vol"	0.8563		
20	" formulas bel"	"below"		
21	"fl-n"	((h-hd)*nr+hd/2+gr*h/2)/24	((h-hd)*sr+hd/2+gr*h/2)/24	((h-hd)*ewr+hd/2+gr*h/2)/24
22	"solair"	to+vnr*a/fn	to+vewr*a/fn	to+vsr*a/fn
23	"solairf"	to+(h*abrf/fn)/24	"info >"	"area roof"
24	"ventilation"	24*0.333*v*(to-ti)*0.001	"wall gain"	24*uw*((an*(soln-ti)+((ae+aw)*(solew-ti))+as*(sols-ti)))*0.001
25	"qwlgain"	24*uw*((an*(soln-ti)))	24*uw*(((ae+aw)*(solew-ti)))	24*uw*((as*(sols-ti)))
26	"qrfgain"	24*ur*arf*(solrf-ti)*0.001	"qflgain"	24*uf*af*(to-ti)*0.001
27	"qglgain"	24*ug*(wn+we+ws+ww)*(to-ti)*0.001		
28	"glsol"	24*vewr*gfe*we*0.783*0.001	24*vsr*gfs*ws*0.783*0.001	24*vnr*gfn*wn*0.783*0.001
29	"inthtgain"	omo*1+omi*1.9+owo*0.8+owi*1.5+oco*0.6+oci*1.4		
30	"appliances"	4	"cook gas"	mgc
31	"moistgain"	omo*0.72+omi*1.12+owo*0.72+owi*1.12+oco*0.72+oci*1.12-pol*0.1	"clothwash"	1
32			"cookprep"	
33			"washbath"	
34	"e equation"	(totalmoist+ach*v*24*(go-gi)/spv)*lhg		
35				
36	"totals"	R(-12)C+R(-12)C(+2)+R(-12)C(+4)	R(-2)C(-1)	R(-10)C+R(-9)C(-2)

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44	"energy "	"summary"	"of house4"
45	"heat gain"	"ventltn "	R(-21)C(-1)
46		"walls "	R(-21)C(+2)
47		"roof "	R(-21)C(-1)
48		"floor "	R(-22)C(+1)
49		"window "	R(-22)C(-1)
50		"sol glaze"	R(-22)C(+3)
51			
52	"internal"	"heat gain"	
53		"a:people "	R(-24)C(-1)
54		"b:cooking"	R(-24)C(+1)+R(-24)C(+3)
55		"c:appl/lts"	R(-25)C(-1)
56	"total int"	"heat gain"	R(-26)C(+4)
57			
58	"moisture"	"input "	
59		"a:people "	R(-28)C(-1)
60		"b:wash/bth "	R(-27)C(+2)
61		"c:clth/wsh "	R(-30)C(+2)
62		"d:cooking "	R(-30)C(+2)
63	"total mst"	"heat gain"	R(-31)C(+4)
64			
65	"total heat"	" extracted"	R(-29)C(+4)
66	"act energy"	"consumed"	R(-49)C(+2)
67			
68	"coeff of"	"performnce"	R(-51)C(+4)

B.1.1.7

SAMPLE OF HOUSE 6 Calculation Procedures 134/144

	1	2	3	4	5	6	7
1	ti	to	ach	rhi	rho	gi	go
2	25	25.7	1	40	61.3	0.008063	0.01289
3	gl h rad	6056	n factor	0.336	ew factor	0.408	s factor V
4	gl diff	2189	g reflect	0.2	solabs	0.8	0.41
5	v n rad	124.9755	v s rad		v ew rad		
6	u-values	walls	windows	roof	floor	solair-rf	fn
7		1.7	4.48	3.35	1.13		10
8	areas n	43.2	3	solair-n		asgf-n	0.2
9	areas e	37.9	6.5	solair-e		asgf-e	0.2
10	areas s	43.2	3	solair-s		asgf-s	0.2
11	areas w	37.9	6.5	solair-w		asgf-w	0.2
12	occupants	man out	man in	women out	women in	child out	child in
13		4	1	3	1	0	1
14	pleasure o ut >		7				
15	misc gainsgas cook		3.26	elec cook	0	appl/light	.4
16	latent heat gain >0.678275			cold area	96.66	cold vol	289.98
17	heat extra cted..		8516.3449	eng used	6567.85	coeff perf1.2966716	
18	volume	289.98	aroof	96.66	absroof	0.5	136.5765
19	spec vol	0.8563					
20	formulas	below			0.004827		136.89875
21	fl-n	124.9755	136.89875	136.5765	radiation on vert su rfaces		
22	solair	35.69804	36.62612	36.6519	solair n e & w s		
23	solairf	38.316667	info > area roof		96.66	area floor	96.66
24	ventilatio	1.6222641	wall gain	75.348514	roof gain	103.49	
25	qwlgain	18855.937	35955.404	20537.173	75.348514		
26	qrfgain	103.49	qflgain	1.8349934			
27	qglgain	1.430016					
28	glsol	3.3365093	1.5435608	1.4091238	3.3365093	9.6257031	
29	inthtgain	11.2					totalapplV
30	appliances	4	cook gas	3.26	cook elec	0	52.59
31	moistgain	7.7	clothwash	1	2		total mois
32			cookprep		5		16.7
33			washbath		2		
34	e equation	37.936676					
35							
36	totals	180.46077	37.936676	3.2650094	9.6257031	52.59	8516.3449
37							
38							
39							
40							
41							
42							
43							
44	energy	summary	of house 6				
45	heat gain	ventltn	1.62				
46		walls	75.35				
47		roof	103.49				
48		floor	1.83				
49		window	1.43				
50		sol glaze	9.63				
51							
52	internal heat gain						
53		a:people	11.20				
54		b:cooking	3.26				
55		c:appl/lts	4.00				
56	total int heat gain		52.59				
57							
58	moisture input						
59		a:people	7.70				
60		b:wash/bth	2.00				
61		c:clth/wsh	2.00				
62		d:cooking	5.00				
63	total mst heat gain		16.70				
64							
65	total heat extracted		8516.34				
66	act energy consumed		6567.85				
67							
68	coeff of performnce		1.2967				

B.1.1.8

SAMPLE OF HOUSE 6 Formula Procedures 142/144

	1	2	3	4
1	"ti"	"to"	"ach"	"rhi"
2	25	25.7	1	40
3	"gl h rad "	6056	"n factor "	0.336
4	"gl diff "	2189	"g reflect"	0.2
5	"v n rad "	vnr	"v s rad "	
6	"u-values"	"walls"	"windows"	"roof"
7		1.7	4.48	3.35
8	"areas n"	43.2	3	"solair-n"
9	"areas e"	37.9	6.5	"solair-e"
10	"areas s"	43.2	3	"solair-s"
11	"areas w"	37.9	6.5	"solair-w"
12	"occupants"	"man out"	"man in"	"women out"
13		4	1	3
14	"pleasure out"	"ut >"	7	
15	"misc gains"	"gas cook "	3.26	"elec cook"
16	"latent heat"	"t gain >"	0.678275	"cold area"
17	"heat extracted"	"cted.."	R(+19)C(+4)	"eng used"
18	"volume"	R(-2)C(+5)	"aroof"	R(-2)C(+1)
19	"spec vol"	0.8563		
20	" formulas bel"	"below"		
21	"fl-n"	((h-hd)*nr+hd/2+gr*h/2)/24	((h-hd)*sr+hd/2+gr*h/2)/24	((h-hd)*ewr+hd/2+gr*h/2)/24
22	"solair"	to+vnr*a/fn	to+vewr*a/fn	to+vsr*a/fn
23	"solairf"	to+(h*abrf/fn)/24	"info >"	"area roof"
24	"ventilation"	24*0.333*v*(to-ti)*0.001	"wall gain"	24*uw*((an*(soln-ti)+((ae+aw)*(solew-ti))+as*(sols-ti)))*0.001
25	"qwlgain"	24*uw*((an*(soln-ti)))	24*uw*(((ae+aw)*(solew-ti)))	24*uw*((as*(sols-ti)))
26	"qrfgain"	24*ur*arf*(solrf-ti)*0.001	"qflgain"	24*uf*af*(to-ti)*0.001
27	"qglgain"	24*ug*(wn+we+ws+ww)*(to-ti)*0.001		
28	"glsol"	24*vewr*gfe*we*0.783*0.001	24*vsr*gfs*ws*0.783*0.001	24*vnr*gfn*wn*0.783*0.001
29	"inthtgain"	omo*1+omi*1.9+owo*0.8+owi*1.5+oco*0.6+oci*1.4		
30	"appliances"	4	"cook gas"	mgc
31	"moistgain"	omo*0.72+omi*1.12+owo*0.72+owi*1.12+oco*0.72+oci*1.12-pol*0.1	"clothwash"	1
32			"cookprep"	
33			"washbath"	
34	"e equation"	(totalmoist+ach*v*24*(go-gi)/spv)*lhg		
35				
36	"totals"	R(-12)C+R(-12)C(+2)+R(-12)C(+4)	R(-2)C(-1)	R(-10)C+R(-9)C(-2)
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44	"energy "	"summary"	"of house 6"	
45	"heat gain"	"ventltn "	R(-21)C(-1)	
46		"walls "	R(-21)C(+2)	
47		"roof "	R(-21)C(-1)	
48		"floor "	R(-22)C(+1)	
49		"window "	R(-22)C(-1)	
50		"sol glaze"	R(-22)C(+3)	
51				
52	"internal"	"heat gain"		
53		"a:people "	R(-24)C(-1)	
54		"b:cooking"	R(-24)C(+1)+R(-24)C(+3)	
55		"c:appl/lts"	R(-25)C(-1)	
56	"total int"	"heat gain"	R(-26)C(+4)	
57				
58	"moisture"	"input "		
59		"a:people "	R(-28)C(-1)	
60		"b:wash/bth "	R(-27)C(+2)	
61		"c:clth/wsh "	R(-30)C(+2)	
62		"d:cooking "	R(-30)C(+2)	
63	"total mst"	"heat gain"	R(-31)C(+4)	
64				
65	"total heat"	" extracted"	R(-29)C(+4)	
66	"act energy"	"consumed"	R(-49)C(+2)	
67				
68	"coeff of"	"performnce"	R(-51)C(+4)	

FIGURE B1.2.1: THE RELATIONSHIP BETWEEN THE MEASURED AND THE OVER ESTIMATED ENERGY CONSUMED BY HOUSE 2

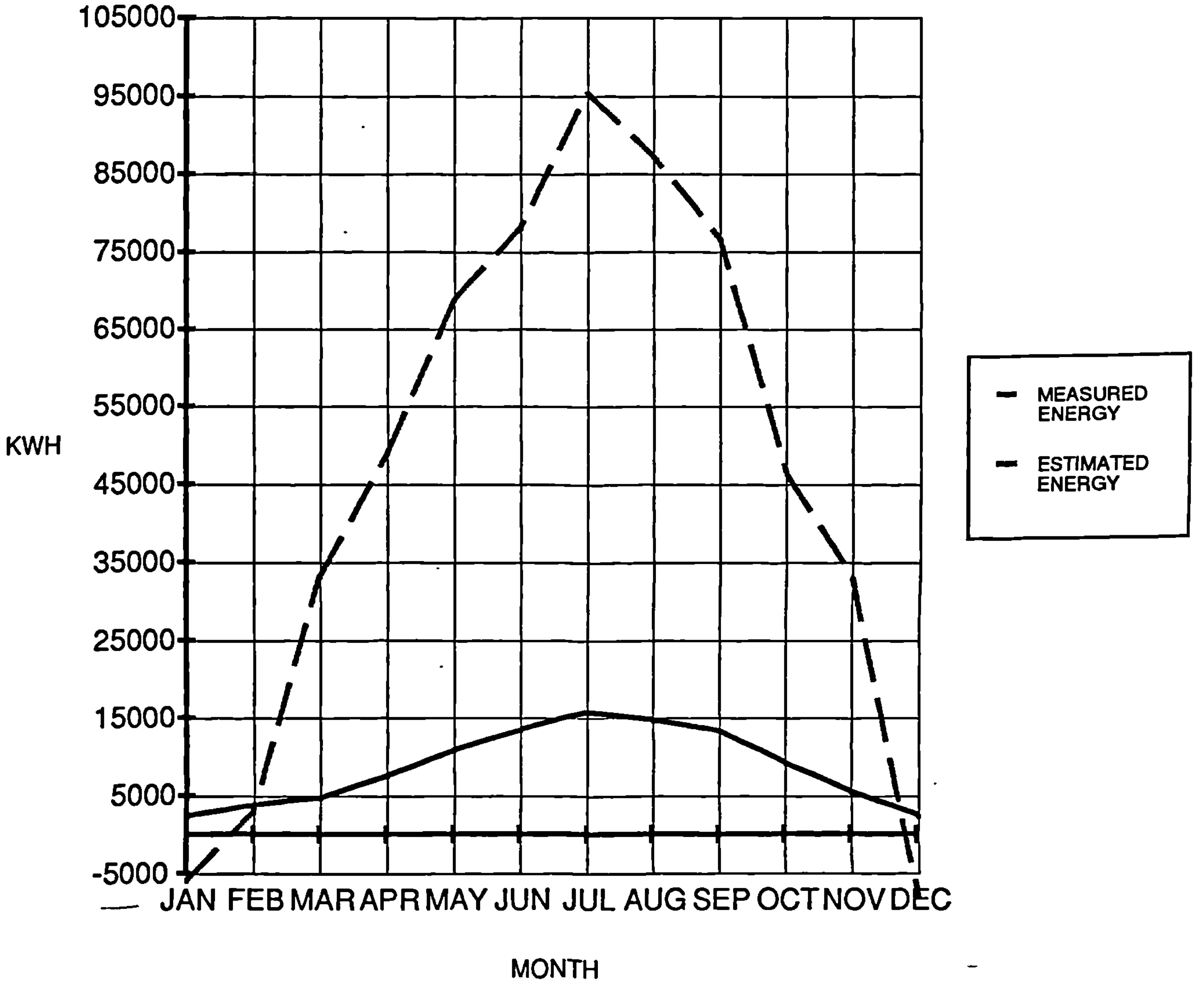

FIGURE B1.2.2: THE RELATIONSHIP BETWEEN THE MEASURED AND THE OVER ESTIMATED ENERGY CONSUMED BY HOUSE 3

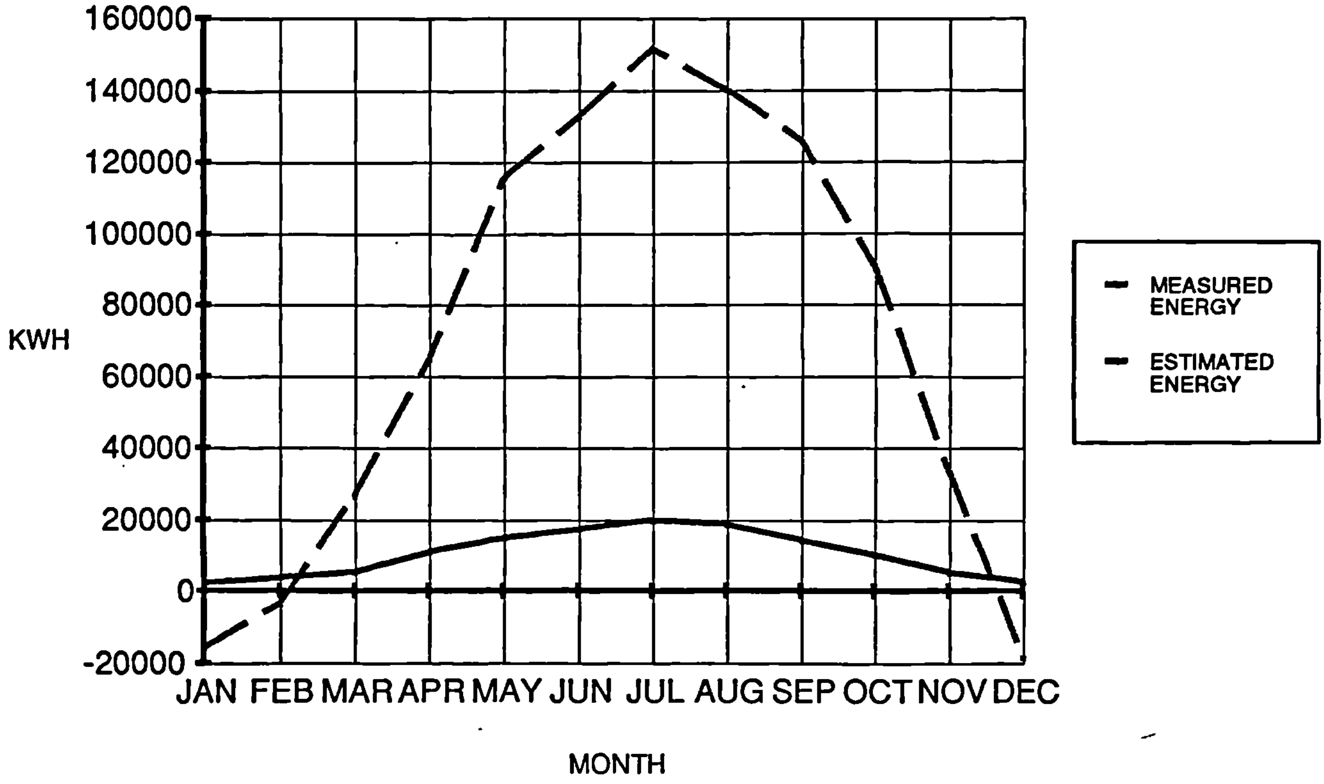

FIGURE B1.2.3: THE RELATIONSHIP BETWEEN THE MEASURED AND THE OVER ESTIMATED ENERGY CONSUMED BY HOUSE 4

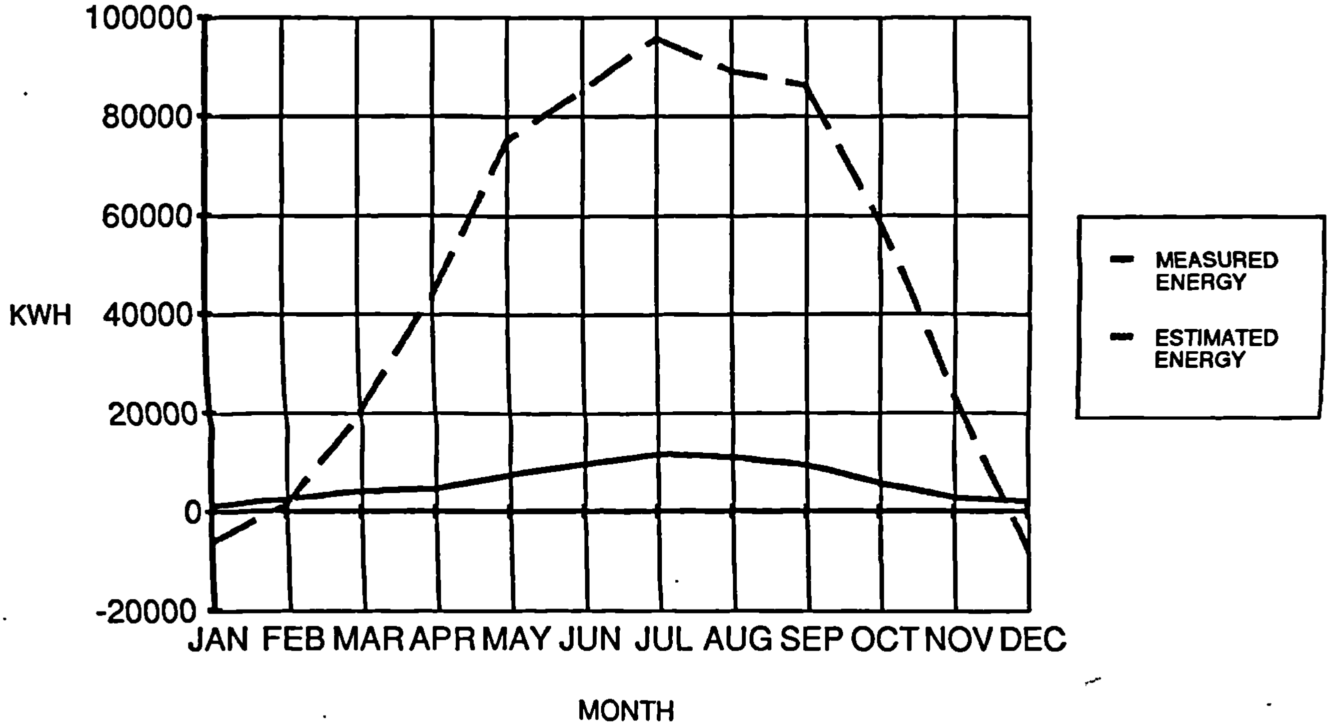

FIGURE B1.2.4: THE RELATIONSHIP BETWEEN THE MEASURED AND THE OVER ESTIMATED ENERGY CONSUMED BY HOUSE 5

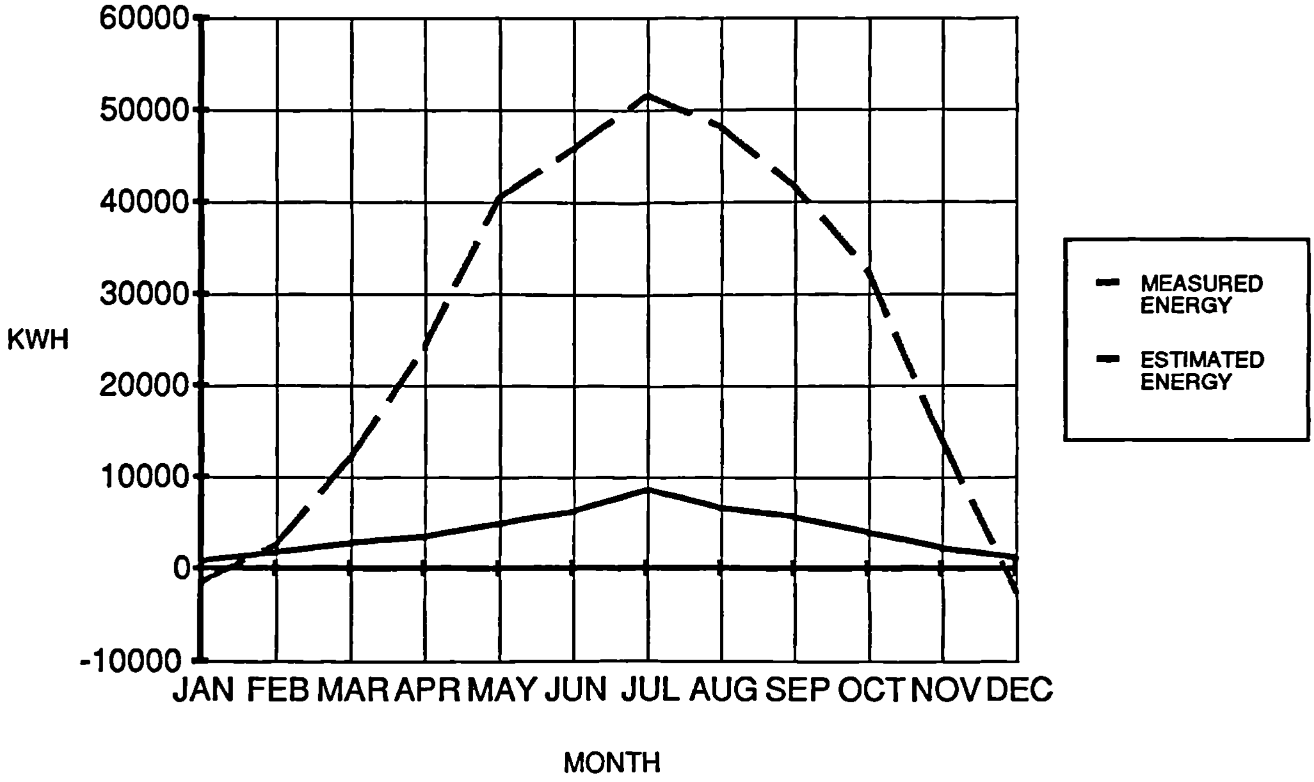

FIGURE B1.2.5: THE RELATIONSHIP BETWEEN THE MEASURED AND THE OVER ESTIMATED ENERGY CONSUMED BY HOUSE 6

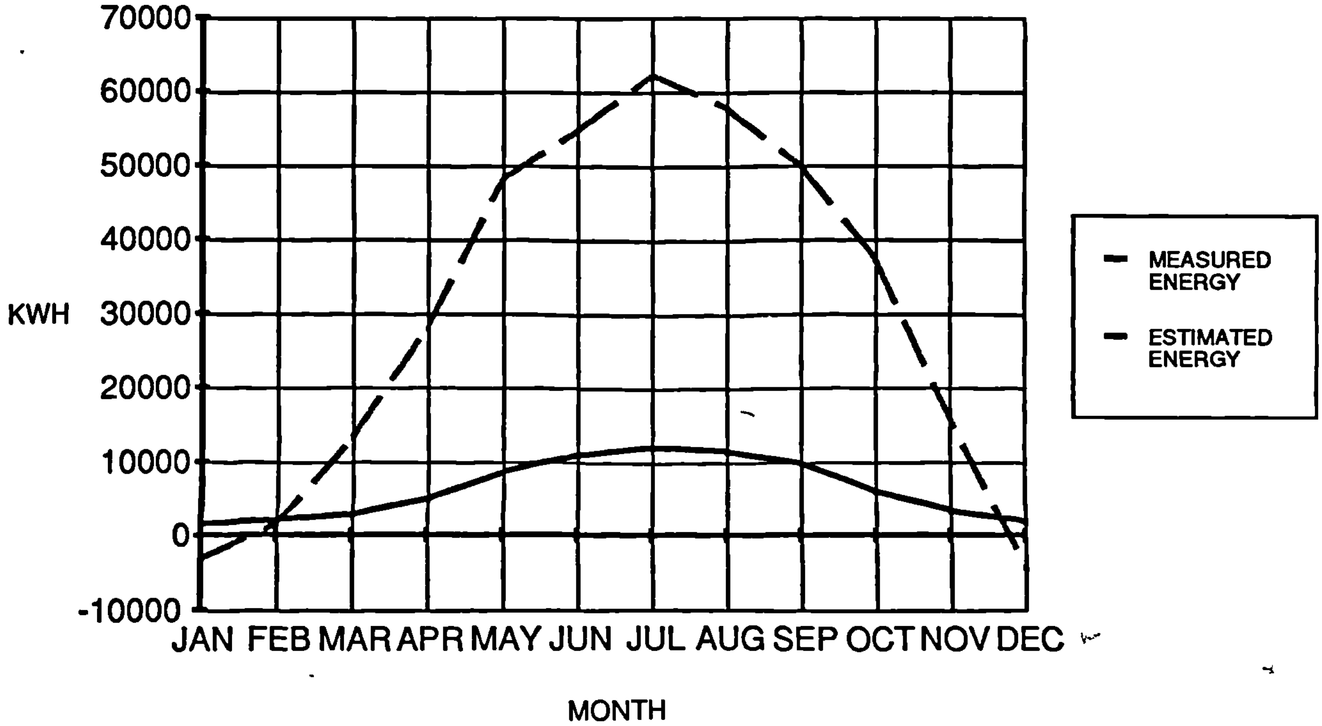

Table B.2.1

Various Tables Used in the Calculation Procedures

THERMAL CHARACTERISTICS OF BUILDING MATERIALS

TYPICAL USE	MATERIAL	EMISS-IVITY	DENSITY	CONDUCTIVITY	SPECIFIC HEAT
UNITS			Kg/m^2	W/m^oC	J/Kg^oC
EXTERNAL FINISH	Sand/Cement Binder	High		1.07	
	Timber Weather Boarding	High		1.0	
	Slate or Tile Hanging	High	1900	0.84	800
	Steel Cladding	Low		1.0	
INTERNAL	Gypsum Plaster & skim coat	High		0.57	
	Gypsum Plasterboard on Plaster dabs	High		0.5	
	Gypsum Plasterboard on studs	High		0.57	
INNER/OUTER LEAF	Clay Facing Brick Inner Leaf	High	1700	0.84	800
	Clay Facing Brick Outer Leaf	High	1700	0.62	800
	Natural Stone	High		1.4	
	Random Rubble	High		1.0	
	Calcium Silicate Brick	High		1.3	
	Concrete Brick	High		1.63	
	Concrete Block Heavy	High	1400	1.63	1000
	Medium	High	600	0.51	1000
	Light	High	300	0.19	1000
	Reconstructed Stone	High		1.4	
	Timber Frame Ply & Stud	High		0.037	
INSULATION					
EXTERNAL INSULATION	Mineral Wool lathed & rendered	High	30	0.033	1000
	Expanded Polystyrene (EPS) panels lathed & rendered	High	25	0.035	1400
	EPS boards lathed & rendered	High	25	0.037	1400
	Foamglass lathed & rendered	High		0.045	
	Glass fibre slabs	High	25	0.034	1000
	Rockwool fibre slabs	High	30	0.035	1000
CAVITY INSULATION	Polyisocyanurate boards			0.02	
	Polyurethane foam boards	High	40	0.022	1130
	Lapped EPS Boards	High	25	0.028	1400
	Glass fibre slabs	High		0.033	
	" " blown	High		0.037	
	Rockwool fibre slabs	High		0.033	
	" " blown	High		0.037	
	Interlocking EPS boards	High	25	0.034	1400
	EPS boards	High	25	0.037	1400
	Urea Formaldehyde foam	High	10	0.04	1400
	Mineral fibre blown	High	96	0.04	795
	Polystyrene beads	High	24	0.038	1400
	Polyurethane foam	High	40	0.02	1130
	Shredded glass fibre	High	96	0.037	795
	Expanded polystyrene beads & binding agent	High	24	0.038	1400
	Expanded polystyrene	High	24	0.04	1400
	Granulated glass wool fibre	High	96	0.04	795

INTERNAL INSULATION	Glass fibre batts	High	50	0.04	795
	Mineral wool batts	High	96	0.037	795
	Polyisocyanurate board	High		0.02	
	Polystyrene closed cell board	High	25	0.03	1400
	Polystyrene expanded board	High	25	0.037	1400
	Polyurethane board	High	30	0.02	1400
	PVC rigid board	High		0.027	
MISCELLANEOUS	Asbestos cement sheet	High	1521	0.29	837
	Asphalt	High	2242	1.23	
	Chipboard	High	688	0.14	1926
	Cork (tiles)	High	529	0.084	1800
	Felt roofing	High	1153	0.37	
	Hardboard	High	561	0.079	1424
	Linoleum		1217	0.2	
	Plywood	High	561	0.14	1926
	Steel	High	7849	46.14	490
	Timber softwood	High	560	0.14	1926
	hardwood	High	720	0.21	2303
	Vermiculite	High	128	0.065	

THERMAL RESISTANCES

EXTERNAL SURFACE RESISTANCE R_{so}

Building	Surface Resistance $m^2{}^oC/W$ Sheltered	Normal	Severe
Wall	0.08	0.055	0.03
Roof	0.07	0.045	0.02

INTERNAL SURFACE RESISTANCES R_{si}

Building Element	Heat Flow	Surface Resistance $m^2{}^oC/W$
Walls	Across	0.123
Ceilings Roof & Floors	Up	0.106
Ceilings Floors	Down	0.15

For common materials of emissivity 0.85-0.95

THERMAL RESISTANCES OF CAVITIES VENTILATED/UNVENTILATED $m^2{}^oC/W$

UNVENTILATED

Thickness of air space	Surface Emissivity	Heat Flow Horizontal/Up	Vertical
5.0mm >	High	0.1	0.1
"	Low	0.18	0.18
20.0mm >	High	0.18	0.21
"	Low	0.35	1.06

VENTILATED

Standard Thermal Resistance of Ventilated Airspace

Airspace Thickness 20.0 mm >	Thermal Resistance $m^2{}^oC/W$
Airspace in cavity wall	0.18

Table B.2.2

Values used in calculating U- and Y- values

Material	Density (kg/m^3)	Thermal Conductivity (W/m K)	Specific Heat Capacity (J/kg K)
Walls			
(External and Internal)			
Asbestos cement sheet	700	0·36	1050
Asbestos cement decking	1500	0·36	1050
Brickwork (outer leaf)	1700	0·84	800
Brickwork (inner leaf)	1700	0·62	800
Cast concrete (dense)	2100	1·40	840
Cast concrete (lightweight)	1200	0·38	1000
Concrete block (heavyweight)	2300	1·63	1000
Concrete block (mediumweight)	1400	0·51	1000
Concrete block (lightweight)	600	0·19	1000
Fibreboard	300	0·06	1000
Plasterboard	950	0·16	840
Tile hanging	1900	0·84	800
Surface Finishes			
External rendering	1300	0·50	1000
Plaster (dense)	1300	0·50	1000
Plaster (lightweight)	600	0·16	1000
Roofs			
Aerated concrete slab	500	0·16	840
Asphalt	1700	0·50	1000
Felt/Bitumen layers	1700	0·50	1000
Screed	1200	0·41	840
Stone chippings	1800	0·96	1000
Tile	1900	0·84	800
Wood wool slab	500	0·10	1000
Floors			
Cast concrete	2000	1·13	1000
Metal tray	7800	50·00	480
Screed	1200	0·41	840
Timber flooring	650	0·14	1200
Wood blocks	650	0·14	1200
Insulation			
Expanded polystyrene (EPS) slab	25	0·035	1400
Glass fibre quilt	12	0·040	840
Glass fibre slab	25	0·035	1000
Mineral fibre slab	30	0·035	1000
Phenolic foam	30	0·040	1400
Polyurethane Board	30	0·025	1400
Urea formaldehyde (UF) foam	10	0·040	1400

Note:
Surface resistances have been assumed as follows:

External walls
$R_{so} = 0.06\,m^2\,K/W$
$R_{si} = 0.12\,m^2\,K/W$
$R_a = 0.18\,m^2\,K/W$

Roofs
$R_{so} = 0.04\,m^2\,K/W$
$R_{si} = 0.10\,m^2\,K/W$
$R_a = 0.18\,m^2\,K/W$ (pitched)
$R_a = 0.16\,m^2\,K/W$ (flat)

Internal walls
$R_{so} = R_{si} = 0.12\,m^2\,K/W$
$R_a = 0.18\,m^2\,K/W$

Internal floors
$R_{so} = R_{si} = 0.12\,m^2\,K/W$
$R_a = 0.20\,m^2\,K/W$

Source: CIBSE Guide A3.

Table B.2.3

External walls - Single leaf construction

No.	Construction (outside to inside)	U-value (W/m² K)	Admittance: Y-value (W/m² K)	Admittance: ω/h	Decrement factor: f	Decrement factor: φ/h	Surface factor: F	Surface factor: φ/h
Brickwork								
1. (a)	105 mm brickwork, unplastered	3·3	4·2	1	0·88	3	0·54	1
(b)	220 mm brickwork, unplastered	2·3	4·6	1	0·54	6	0·52	2
(c)	335 mm brickwork, unplastered	1·7	4·7	1	0·29	9	0·51	2
2. (a)	105 mm brickwork, 13 mm dense plaster	3·0	4·1	1	0·83	3	0·56	1
(b)	220 mm brickwork, 13 mm dense plaster	2·1	4·4	1	0·49	7	0·53	1
(c)	335 mm brickwork, 13 mm dense plaster	1·7	4·4	1	0·26	10	0·53	1
3. (a)	105 mm brickwork, 13 mm light plaster	2·6	3·3	1	0·82	3	0·63	1
(b)	220 mm brickwork, 13 mm light plaster	1·9	3·6	1	0·46	7	0·61	1
(c)	335 mm brickwork, 13 mm light plaster	1·5	3·6	1	0·24	10	0·60	1
4. (a)	105 mm brickwork, 10 mm plasterboard	2·7	3·5	1	0·83	3	0·61	1
(b)	220 mm brickwork, 10 mm plasterboard	2·0	3·8	1	0·47	7	0·59	1
(c)	335 mm brickwork, 10 mm plasterboard	1·6	3·8	1	0·25	10	0·58	1
5.	220 mm brickwork, 25 mm airgap 10 mm plasterboard (on dabs)*	1·5	2·5	1	0·40	7	0·72	0
6.	220 mm brickwork 25 mm airgap, 10 mm foil-backed plasterboard (on dabs)	1·2	1·8	1	0·37	7	0·78	0
7. (a)	220 mm brickwork, 20 mm glass fibre quilt, 10 mm plasterboard	1·0	1·4	1	0·34	7	0·84	0
(b)	As 7(a) but with 20 mm EPS slab	0·93	1·3	2	0·33	7	0·85	0
(c)	As 7(a) but with 25 mm EPS slab	0·82	1·2	2	0·32	8	0·87	0
(d)	As 7(a) but with 25 mm polyurethane slab	0·66	0·98	2	0·31	8	0·90	0
8. (a)	220 mm brickwork, 25 mm airgap, 25 mm EPS slab, 10 mm plasterboard	0·71	1·0	2	0·31	8	0·89	0
(b)	As 8(a) but with 25 mm polyurethane slab	0·59	0·91	2	0·30	8	0·91	0
9. (a)	19 mm render, 25 mm mineral fibre slab, 220 mm brickwork, 13 mm lightweight plaster	0·73	3·4	1	0·17	10	0·62	1
(b)	As 9(a) but with 40 mm EPS slab	0·56	3·4	1	0·15	10	0·62	1
Concrete Blockwork								
10.	200 mm heavyweight concrete block, 25 mm airgap 10 mm plasterboard (on dabs)	1·8	2·5	1	0·35	7	0·64	0
11.	200 mm heavyweight concrete block, 25 mm cavity, 10 mm foil-backed plasterboard (on dabs)	1·5	1·9	1	0·33	7	0·76	0
12. (a)	200 mm heavyweight concrete block, 20 mm glass fibre quilt, 10 mm plasterboard	1·2	1·5	1	0·34	7	0·83	0
(b)	As 12(a) but with 20 mm EPS slab	1·1	1·4	1	0·33	7	0·84	0
(c)	As 12(a) but with 25 mm EPS slab	0·93	1·2	2	0·32	7	0·87	0
(d)	As 12(a) but with 25 mm polyurethane slab	0·73	1·0	2	0·31	7	0·90	0
13. (a)	200 mm heavyweight concrete block, 25 mm airgap, 25 mm EPS slab, 10 mm plasterboard	0·79	1·1	2	0·29	7	0·89	0
(b)	As 13(a) but with 25 mm polyurethane slab	0·65	0·91	2	0·29	7	0·91	0
14. (a)	19 mm render, 25 mm mineral fibre slab, 200 mm heavyweight concrete block, 13 mm lightweight plaster ...	0·88	4·2	1	0·15	8	0·51	1
(b)	As 14(a) but with 40 mm EPS slab	0·64	4·2	1	0·14	8	0·51	1
15.	200 mm lightweight concrete block, 25 mm airgap 10 mm plasterboard (on dabs)	0·68	1·8	2	0·47	7	0·82	1
16.	200 mm lightweight concrete block, 25 mm airgap, 10 mm foil-backed plasterboard (on dabs)	0·62	1·6	2	0·44	8	0·84	0
17. (a)	200 mm lightweight concrete block, 20 mm glass fibre quilt, 10 mm plasterboard	0·56	1·3	2	0·40	8	0·87	0
(b)	As 17(a) but with 20 mm EPS slab	0·54	1·2	2	0·39	8	0·88	0
(c)	As 17(a) but with 25 mm EPS slab	0·50	1·1	2	0·37	8	0·89	0
(d)	As 17(a) but with 25 mm polyurethane slab	0·44	1·0	3	0·34	8	0·91	0
18. (a)	200 mm lightweight concrete block, 25 mm airgap, 25 mm EPS slab, 10 mm plasterboard	0·46	1·0	3	0·35	8	0·90	0
(b)	As 18(a) but with 25 mm polyurethane slab	0·40	0·89	3	0·33	8	0·92	0
19. (a)	19 mm render, 25 mm mineral fibre slab, 200 mm lightweight concrete block, 13 mm lightweight plaster ...	0·48	2·2	2	0·30	9	0·78	1
(b)	As 19(a) but with 40 mm EPS slab	0·40	2·2	2	0·26	10	0·78	1

Table B.2.3 (Continued....)

No.	Construction (outside to inside)	U-value (W/m² K)	Admittance Y-value (W/m² K)	Admittance ω/h	Decrement factor f	Decrement factor ϕ/h	Surface factor F	Surface factor ϕ/h
	Cast Concrete and Pre-cast Panels							
20. (a)	150 mm cast concrete, unplastered	3·5	5·2	1	0·71	4	0·44	2
(b)	200 mm cast concrete, unplastered	3·1	5·4	1	0·57	5	0·42	2
21. (a)	150 mm cast concrete, 50 mm wood wool slab, 13 mm dense plaster	1·2	2·3	3	0·50	7	0·80	1
(b)	200 mm cast concrete, 50 mm wood wool slab, 13 mm dense plaster	1·2	2·3	3	0·36	8	0·79	1
22. (a)	150 mm cast concrete, 50 mm wood wool slab, 13 mm lightweight plaster...	1·2	1·7	2	0·49	6	0·82	0
(b)	200 mm cast concrete, 50 mm wood wool slab, 13 mm lightweight plaster...	1·1	1·7	2	0·35	8	0·82	0
23.	75 mm pre-cast concrete panels (consisting of three 25 mm sheets)	4·3	4·9	1	0·92	2	0·43	1
24.	75 mm pre-cast concrete panels (incorporating 5 mm asbestos cement sheet), 25 mm airgap 25 mm EPS slab, 10 mm plasterboard	0·83	1·0	2	0·82	3	0·90	0
25.	250 mm pre-cast sandwich (consisting of 75 mm cast concrete, 25 mm EPS slab, 150 mm lightweight concrete)	0·74	3·8	2	0·28	10	0·62	1
	Tile Hanging							
26. (a)	10 mm tile on battens (combined resistance = 0.12 m² K/W), breather paper, 25 mm airgap, 50 mm glass fibre quilt, 10 mm plasterboard	0·56	0·78	3	0·99	1	0·93	0
(b)	As 26(a) but with 50 mm EPS slab	0·51	0·77	3	0·99	1	0·94	0
(c)	As 26(a) but with 75 mm glass fibre quilt	0·41	0·70	3	0·99	1	0·95	0
(d)	As 26(a) but with 75 mm EPS slab	0·37	0·72	4	0·99	1	0·95	0
(e)	As 26(a) but with 100 mm glass fibre quilt	0·33	0·66	4	0·99	1	0·96	0
(f)	As 26(a) but with 100 mm EPS slab	0·29	0·71	4	0·99	1	0·96	0

Source: CIBSE Guide A3.

Table B.2.4
Heat input to dwelling from occupants

Occupant	Occupancy Pattern	Heat input kWh/day
Man	Out during the day	1.0
Woman	Out during the day	0.8
Child	Out during the day	0.6
Man	At home during the day	1.9
Woman	At home during the day	1.5
Child	At home during the day	1.4

Assumptions:

(1) Sleeping period for adults: 8 hours
Sleeping period for child: 10 hours
(2) 'Out during the day' means dwelling unoccupied from 0900 to 1800 (Heating off from 0900 to 1700).
(3) Adults assumed to be relatively active; for elderly persons, reduce useful gain by 10 per cent.

Table B.2.5
Heat Input to Dwelling from Incidental Gains

Source	Heat Input kWh/day	Notes
Water heating	0.254 N + 0.403	N = no. of persons in household = efficiency of water heating
		(0.5 for water heating by gas or oil
Cooking - electric	2.60	= (
- gas	3.26	(0.65 for water heating by electricity
Other electrical appliances and lighting	2.6 to 6.2	Variation is between household with 'essential' items only and household with 'luxury' items in addition. For detailed breakdown see reference (35)

Source: Uglow, C.

Table B.2.6
Sources of Moisture within Buildings

Source	Amount of Moisture
Household activities:	
Cooking (3 meals)	0.9 to 3.0 kg per day
Dish washing (3 meals)	0.15 to 0.45 kg per day
Clothes washing	0.5 to 1.8 kg per day
Clothes drying indoors	5.0 to 14.0 kg per day
Baths and showers	0.75 to 1.5 kg per day
Floor washing	1.0 to 1.5 kg per $10m^2$
Indoor plants	Up to 0.8 kg per day
Perspiration and respiration of building occupants	0.04 to 0.1 kg/h per person
Direct penetration of rain groundwater or moist ambient air	Variable

Source: CIBS Guide Book A.

Table B.2.7
Absorbance and emittance of surfaces

Surface	absorbance for solar radiation	a and e 10 to 40 C
Black, non-metallic	0.85-0.98	0.90-0.98
Red brick, stone, tile	0.65-0.80	0.85-0.95
Yellow and buff brick, stone	0.50-0.70	0.85-0.95
Cream brick, tile plaster	0.30-0.50	0.40-0.60
Window glass	Transparent	0.90-0.95
Bright aluminium, gilt bronze	0.30-0.50	0.40-0.60
Dull brass, aluminium, galvanised steel	0.40-0.65	0.20-0.30
Polished brass, copper	0.30-0.50	0.02-0.05
Polished aluminium chromium	0.10-0.40	0.02-0.04

Source: Manual of Tropical Housing and Building.

Table B.2.8 : Transmission, absorption and reflection data for a range of glasses (continued...)

Glass type	Specification	Light		Solar radiant heat				Shading coefficient			U-value ($Wm^{-2} K^{-1}$)	Unit descriptive code
		Transmittance	Reflectance	Direct transmittance	Reflectance	Absorptance	Total transmittance	Short wavelength	Long wavelength	Total		
'Insulight' double glazing with clear flat inner pane; outer glass as listed												
Clear flat	4 mm†	0.80	0.14	0.67	0.12	0.21	0.75	0.78	0.09	0.87	2.9	80/75
	6 mm	0.76	0.14	0.61	0.11	0.28	0.72	0.70	0.12	0.82	2.9	76/72
Spectrafloat	6 mm 51/66 (Bronze)	0.45	0.12	0.42	0.12	0.46	0.54	0.48	0.14	0.62	2.9	45/54
Antisun float	6 mm 72/62 (Green)	0.63	0.10	0.36	0.06	0.58	0.49	0.41	0.16	0.57	2.9	63/49
	6 mm 50/62 (Bronze)	0.44	0.07	0.36	0.06	0.58	0.49	0.41	0.16	0.57	2.9	44/49
	6 mm 41/61 (Grey)	0.36	0.06	0.35	0.06	0.59	0.48	0.40	0.15	0.55	2.9	36/48
Reflectafloat	6 mm 33/53 (Silver)	0.30	0.44	0.34	0.29	0.37	0.44	0.40	0.10	0.50	2.9	30/44
Suncool float	6 mm 10/23 (Silver)	0.09	0.38	0.06	0.32	0.62	0.16	0.07	0.11	0.18	2.3	9/16
	6 mm 20/34 (Silver)	0.18	0.23	0.13	0.18	0.69	0.25	0.15	0.14	0.29	2.5	18/25
	6 mm 10/24 (Bronze)	0.09	0.19	0.05	0.21	0.74	0.16	0.06	0.12	0.18	2.3	9/16
	6 mm 20/33 (Blue)	0.18	0.20	0.12	0.21	0.67	0.24	0.14	0.13	0.27	2.5	18/24
	6 mm 30/39 (Blue)	0.27	0.17	0.17	0.18	0.65	0.29	0.19	0.14	0.33	2.6	27/29
	6 mm 40/50 (Blue)	0.35	0.11	0.25	0.11	0.64	0.38	0.29	0.15	0.44	2.7	35/39
'Insulight' double glazing with 'Kappafloat' inner pane; outer glass as listed												
Clear float	4 mm‡	0.63	0.14	0.50	0.19	0.31	0.66	0.58	0.18	0.76	1.9	63/66
	6 mm	0.60	0.14	0.46	0.17	0.37	0.63	0.53	0.20	0.73	1.9	60 63
Spectrafloat	6 mm 51/66 (Bronze)	0.35	0.12	0.32	0.15	0.53	0.47	0.37	0.18	0.55	1.9	35.47
Antisun float	6 mm 72/62 (Green)	0.49	0.10	0.27	0.08	0.65	0.42	0.31	0.18	0.49	1.9	49'42
	6 mm 50/62 (Bronze)	0.34	0.07	0.27	0.08	0.65	0.42	0.31	0.18	0.49	1.9	34 42
	6 mm 41/61 (Grey)	0.28	0.06	0.26	0.08	0.66	0.41	0.30	0.17	0.47	1.9	28 41
Reflectafloat	6 mm 33/53 (Silver)	0.23	0.44	0.26	0.31	0.42	0.39	0.30	0.15	0.45	1.9	23.39
Suncool float	6 mm 10/23 (Silver)	0.07	0.38	0.05	0.32	0.63	0.14	0.06	0.10	0.16	1.8	7 14
	6 mm 20/34 (Silver)	0.14	0.23	0.10	0.18	0.72	0.21	0.11	0.13	0.24	1.9	14 21
	6 mm 10/24 (Bronze)	0.07	0.19	0.04	0.21	0.75	0.13	0.04	0.11	0.15	1.8	7 13
	6 mm 20/33 (Blue)	0.14	0.20	0.09	0.22	0.69	0.20	0.11	0.12	0.23	1.9	14 20
	6 mm 30/39 (Blue)	0.21	0.17	0.13	0.19	0.68	0.24	0.15	0.13	0.28	1.9	21 24
	6 mm 40/50 (Blue)	0.28	0.11	0.19	0.12	0.69	0.33	0.22	0.16	0.38	1.9	28 33

† 4 mm clear float inner; other combinations 6 mm clear float inner.
‡ 4 mm 'Kappafloat' inner; other combinations 6 mm 'Kappafloat' inner.

Table B.2.8 : Transmission, absorption and reflection data for a range of glasses.

Glass type	Specification	Light		Solar radiant heat				Shading coefficient			U-value ($Wm^{-2} K^{-1}$)	Unit descriptive code
		Transmittance	Reflectance	Direct transmittance	Reflectance	Absorptance	Total transmittance	Short wave-length	Long wave-length	Total		
Single glazing												
Clear float	4 mm	0.89	0.08	0.82	0.07	0.11	0.86	0.94	0.04	0.98	5.4	—
	6 mm	0.87	0.08	0.78	0.07	0.15	0.83	0.90	0.05	0.95	5.4	—
Spectra-float	6 mm 51/66 (Bronze)	0.51	0.10	0.54	0.10	0.36	0.66	0.62	0.14	0.76	5.4	—
	6 mm 72/62 (Green)	0.72	0.06	0.46	0.05	0.49	0.62	0.53	0.19	0.72	5.4	—
	6 mm 50/62 (Bronze)	0.50	0.05	0.46	0.05	0.49	0.62	0.53	0.19	0.72	5.4	—
	10 mm 33/51 (Bronze)	0.33	0.04	0.29	0.04	0.67	0.51	0.23	0.26	0.59	5.3	—
	6 mm 41/61 (Grey)	0.41	0.05	0.44	0.05	0.51	0.61	0.51	0.19	0.70	5.4	—
	10 mm 24/50 (Grey)	0.24	0.04	0.27	0.04	0.69	0.50	0.31	0.26	0.57	5.3	—
Reflecta-float	6 mm 33/53 (Silver)	0.33	0.43	0.43	0.28	0.29	0.53	0.49	0.12	0.61	5.4	—
Suncool float	6 mm 10/23 (Silver)	0.10	0.38	0.08	0.32	0.60	0.23	0.09	0.17	0.26	4.0	—
	10 mm 10/23 (Silver)	0.10	0.37	0.08	0.30	0.62	0.23	0.09	0.18	0.27	4.0	—
	6 mm 20/34 (Silver)	0.20	0.23	0.16	0.18	0.66	0.34	0.18	0.21	0.39	4.4	—
	10 mm 10/34 (Silver)	0.20	0.22	0.15	0.16	0.69	0.34	0.17	0.22	0.39	4.3	—
	6 mm 10/24 (Bronze)	0.10	0.19	0.06	0.21	0.73	0.24	0.07	0.20	0.27	4.0	—
	10 mm 10/24 (Bronze)	0.10	0.18	0.05	0.19	0.76	0.24	0.06	0.21	0.27	3.9	—
	6 mm 20/33 (Blue)	0.30	0.20	0.15	0.21	0.64	0.33	0.17	0.21	0.38	4.5	—
	10 mm 20/33 (Blue)	0.20	0.20	0.15	0.19	0.66	0.33	0.17	0.21	0.38	4.4	—
	6 mm 30/39 (Blue)	0.30	0.16	0.21	0.18	0.61	0.39	0.24	0.21	0.45	4.7	—
	10 mm 30/38 (Blue)	0.30	0.15	0.20	0.17	0.63	0.38	0.23	0.21	0.44	4.6	—
	6 mm 40/50 (Blue)	0.40	0.10	0.32	0.10	0.58	0.50	0.38	0.19	0.57	4.9	—
	10 mm 40/49 (Blue)	0.40	0.09	0.31	0.09	0.60	0.49	0.36	0.20	0.56	4.8	—

Source: Applications Manual, Window Design (CIBSE)

Table B.2.9

U-values at normal exposure and 12 mm air space, and T for a selection of glazing types*

Glazing Type	U $Wm^{-2} K^{-1}$	T
Single clear	5.6	0.87
Double clear	3.0	0.76
Triple clear	2.0	0.66
Double clear and low-E coating	1.8	0.69

T takes account of the shading of a window and dirt deposits etc. It is given by T = MA.M is a maintenance factor for vertical glazing (Table B.2.9). A is an obstruction factor.

Table B.2.10

Maintenance factors for vertical glazing

Location	M
Clear	0.9
Industrial	0.8
Very dirty	0.7

Source: Applications manual, Window Deisgn (CIBSE)

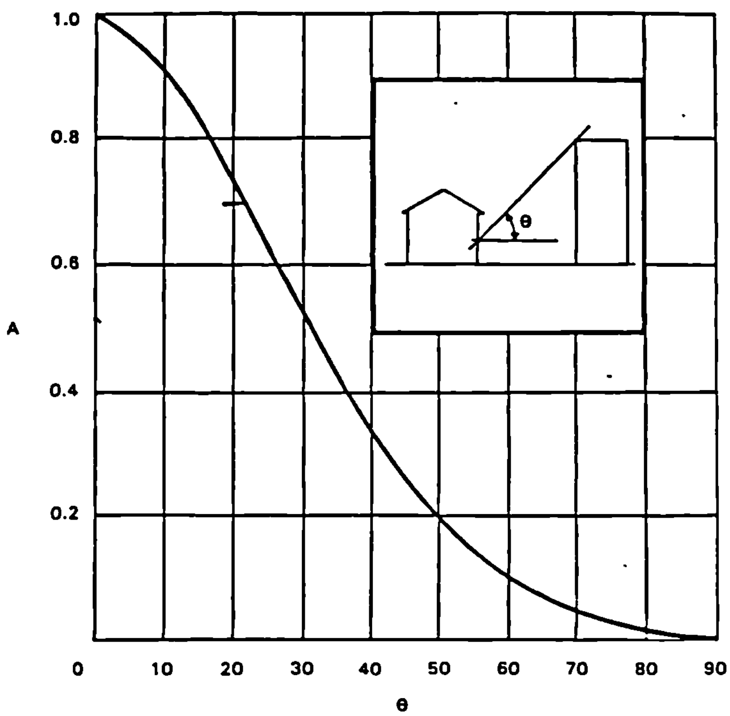

FIGURE B 2.1: SHADOW FACTOR