ENERGY EFFICIENT HOUSING
FOR AL-RIYADH
SAUDI ARABIA

By

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I want to dedicate this work to my father, my mother, for her prayers, patience, and the tender moral support with which she always surrounded me; also to my loving brothers, Adil, Osama and my sisters, to my uncles and aunts, to my brother-in-law Mahmmod, and last but not least to Maram, Tariqe, Hassan, Rayan, Adil, Hanneen and Ramy with my love.

ABSTRACT

For developing countries such as the Kingdom of Saudi Arabia, oil revenue after 1970 set the need for a National program of urban development, aimed at achieving optimum investment for a flourishing situation.

The construction industry and housing projects were prioritised in the urbanisation plans. From 1980, the international oil market curtailed profits. Thus the policy has changed to conservation of energy consumption and searching for alternative power resources.

The objective of this work is to investigate the thermal behaviour of housing model with reference to the physical environment in Al-Riyadh, in order to establish design criteria and look for partial passive cooling techniques as a substitute for active systems.

Analysis embraces both traditional and modern architectural policy in terms of urban planning and housing characteristics. Climate analysis of Al-Riyadh, a typical hot arid region, sets the design parameters in relation to human comfort.

A computer program, Calpas3,[1] complemented by standard CIBS[2] dynamic methodology and quasi - steady - state heat balance equations were used to investigate the thermal behaviour of building components, i.e. roof, wall, and windows, with respect to orientation, ventilation, and materials.

The performance of both traditional and modern materials is assessed particularly in relation to thermal damping and time - lag.

The conclusion emphasises the potential for passive evaporative cooling in conjunction with insulated construction and night ventilation. A system of house design is proposed which integrates passive thermal strategies and which respects religious, social, and local architectural characteristics .

1- Barkeley Solar Group, CALPAS3 Manual,1982.
2- CIBS GUIDE, A3 Thermal Properties of Building Structures, Appendix 5, 1980.

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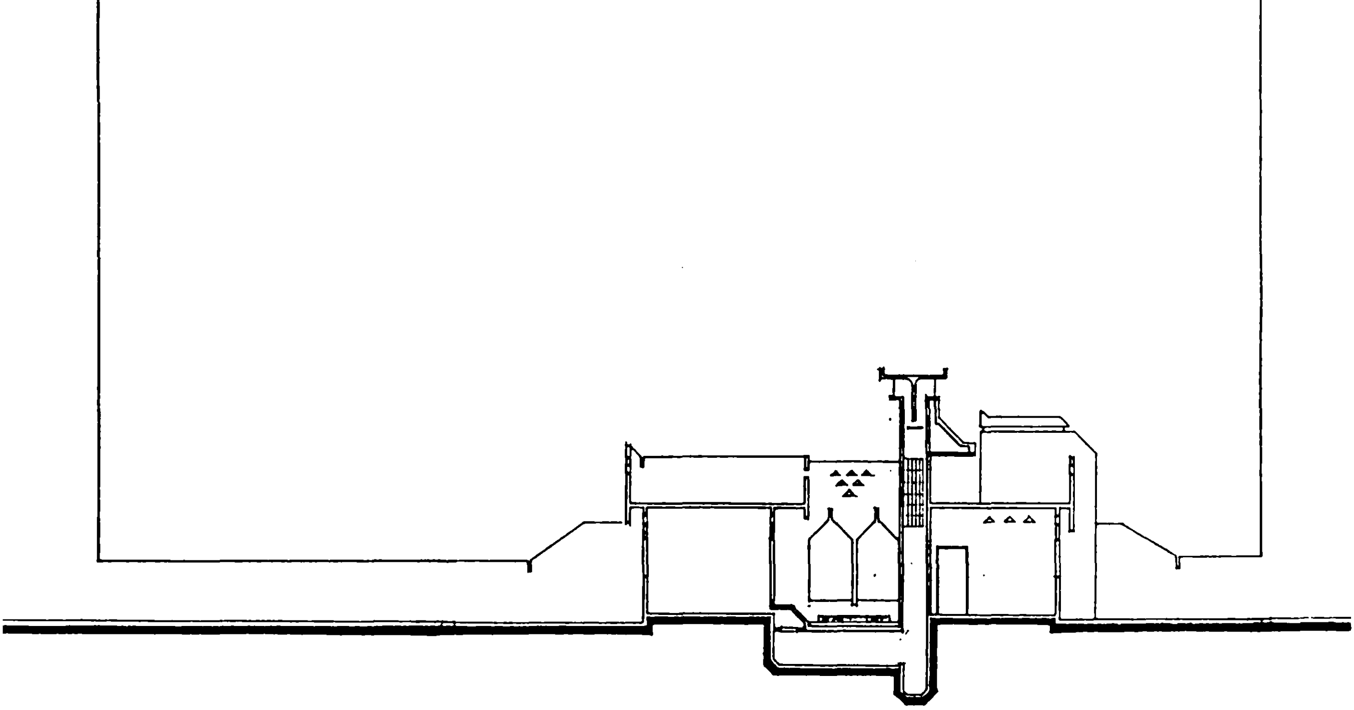
CHAPTER I



CHAPTER I

INTRODUCTION

I.1 Overview:

Energy consciousness is a national task which local achitects, engineers, planners, and land developers have yet to accomplish. The extensive use of new building materials, techniques and equipment as an alternative to traditional building approaches has not appeared to satisfy the harsh nature of the local climate.

Urban growth in Saudi Arabia, in tandem with a steadily increasing population, has placed new demands on building programmes. Unfortunately, the recent buildings have lost their local identity and have become hybrids of exotic character in their architectural form, concepts, and organization of elements.

A significant increase in domistic energy consumption has also been recorded, from 4.236GWh in 1981 to 11.148GWh in 1986.(1) The statistical record indicated that 65% of the total energy produced in Saudi Arabia is now being utilized by houses,(2) and the rest consumed by industrial, agricultural, and communication parties.

Frequent power failure during the peak hours of summer days is another indication of the huge reliability on mechanical or 'active' cooling systems required to offset climatic stress on buildings.

The process of building technology has taken a different path, away from the traditional characteristics of the city and village. The replacement has come with expensive imported ideas and thus does not help to improve the situation of conserving energy.

From another point of view, the majority of Saudi people find it difficult to pay the electrical bills, and cannot afford to provide or run air conditioning units in their dwellings. People have a Hobson's choice - either to live in uncomfortably hot conditions or to exhaust their budget.

This problem needs further study to elicit compromise solutions which can act in harmony with climate and economically meet peoples' needs. The Kingdom of Saudi Arabia is now paying exceptional attention to supporting research into renewable energy sources. This effort is represented by the National Research Centre which is working on developing and constructing many projects in various fields,specially the application of solar energy for generating electricity and for building technology. The main target is to change the dependance attitude on oil, by conserving energy, and looking for new power resources.

This research is directed to a study and analysis of the physical configuration of indigenous architectural features and the thermal performance of houses in a hot arid area. It is the aim of this work to demonstrate that traditional building techniques with appropriate support of modern technology and rational use of energy can create a comfortable living environment.

Special attention will be directed to passive energy techniques utilizing natural power to enhance housing design in harmony with the local climate.

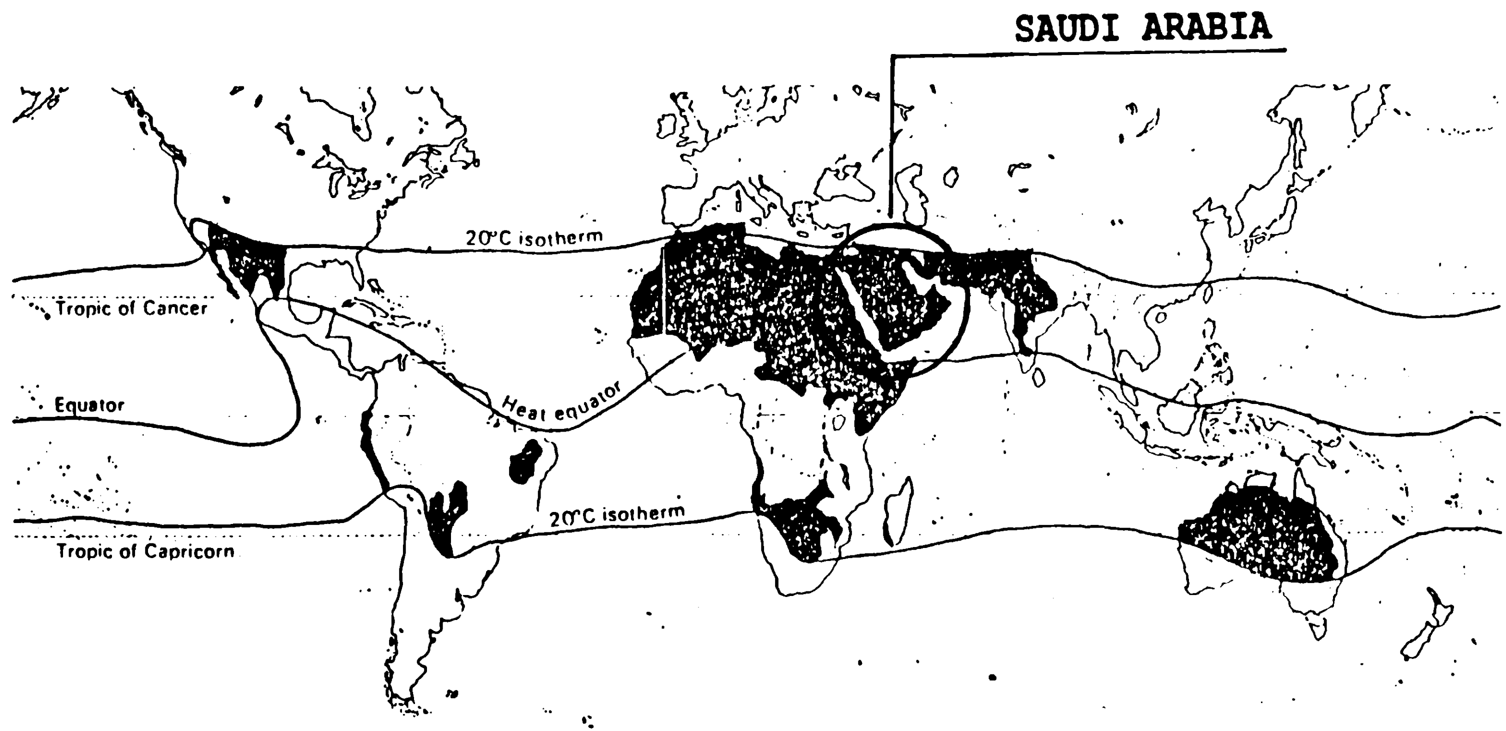
I.2 Historical Background :-

Hot dry regions occupy one-fifth of the earth's surface. They mostly lie in a narrow belt which straddles the Tropic of Cancer and the Tropic of Capricorn with occasional deviation towards or away from the equator. Fig.(1.1)

The hot tropical and the sub tropical regions contain most of the world population. Humankind's physical flexibility and capacity for adaptation is relatively feeble compared to many other creatures who possess natural defenses against a large range of unfavourable climates.[3]

However, human inventiveness has enabled an understanding of environmental rigours and development of various forms of shelter to satisfy the need for protection from extremes of climate and other sources of danger and discomfort.

Historically, buildings in different climatical regions have frequently incorporated ingenious environmental and thermal solutions in order to sustain indoor comfort.



WORLD HOT ARID ZONES

Fig. 1.1

Source : Balwant S. Saini. Building in Hot Dry Climate.
John Wiley & Sons Ltd., 1980.

In North Africa and other arid regions the development of the courtyard system as a thermal regulator and socialization space, represents th interface between natural environmental systems and indigenous materials such as adobe, bricks, stones, and local timber.

Similar adaptation accounts for the development of underground shelters, artificial caves, and ventilated basements in other arid areas. Such architectural adaptation illustrates how the selection of building design and construction materials can effectively improve the thermal performance of the dwellings.

I.3 Saudi Arabia :-

The position of Saudi Arabia as one of the largest oil exporters makes it of special interest to the rest of the world. For the Islamic world, Saudi represents an important entity not only with respect to religion, but also with respect to its political and economical basis.

The policy of Saudi Arabia is based on principles of law, justice, respect for human rights and opposition to all forms of aggression.

Only since World War II,[4] has the Kingdom begun to emerge from the economy imposed by the hostile, arid terrain of the Arabian peninsula. For thousand of years the economy consisted basically of autonomous clusters of people around wells and oases.

Most of the population was engaged in agriculture, including nomads who raised livestock by moving it to the limited forage produced by infrequent rains. The long arid distances separating sources of water isolated inhabitants from one to another and from the out-side world. Trade was mainly limited to camel caravans and the annual influx of pilgrims visiting the holy places.

Discovery of oil in 1938 started a transformation of this primitive, isolated economy. An indirect contribution to this transformation was the modern equipment and techniques which accompanied the oilmens' entrance to the Kingdom.

The discovery of oil also contributed directly to a high rate of growth for the Kingdom economy. As a result of the huge revenues from oil production, the government began a massive development effort affecting all sectors.

The transition required building most facilities where there had been nothing, and construction was a substantially larger sector of the economy then any other.

The huge building boom undertaken by international foreign architects was too fast to be relevant to the local image of the Kingdom's architecture. Although the construction process has been slowing down recently and its importance might decline somewhat during the rest of this decade, planners still expect construction to remain an important part of the development of a non-oil economy.

I.3.1 Country Profile :-

Formal name	- Kingdom of Saudi Arabia
Short name	- Saudi Arabia
Capital	- Al-Riyadh
Flag	- horizontal sword beneath inscription in fabric-white on green field proclaiming there is no God but Allah, and Mohammed is the Messenger.
Population	- about 8 million
Religion	- Islam, and all Saudi are Arab Muslims

I.3.1 Geography :-

Saudi Arabia enjoys a unique location between Asia and Africa, it covers about 22° of longitude and 17° of latitude, with approximate size of 2,331,000 km^2.

The topography is mainly desert, with low costal sandy plains with sedimentary rocks, and a series of mountains, but no rivers or permanent bodies of water and very small green areas. Figs.(1.2 & 1.3)

I.3.2 Climate :-

The location of Saudi Arabia between 16° and 32° of latitude north falls within the tropical zone, the general feature of the climate being high temperature everywhere. The following are the climatical regions in Saudi Arabia :-

1- West coast region, mainly hot in summer and relatively warm in winter, (composite).
2- Western mountainous region, mainly cool in summer and winter, (up-land).
3- The interior plateau region, a continental climate extremely hot in summer and cool in winter, (hot-dry).
4- East coast region, hot in summer with high humidity, and cool in winter, (hot-humid).

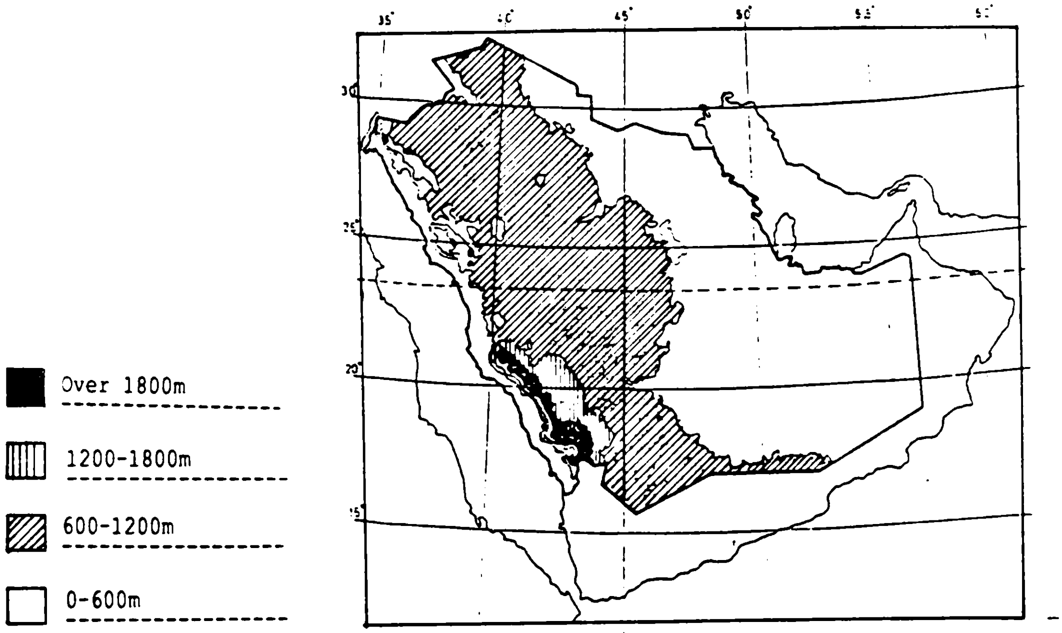
Fig.(1.4,1.5,1.6,&1.7), illustrate the general climatical characteristics of Saudi Arabia.

I.3.4 Economy :-

The oil industry is the main backbone of national support. Saudi is the third largest producer, the largest exporter, and has the worlds largest reserves.

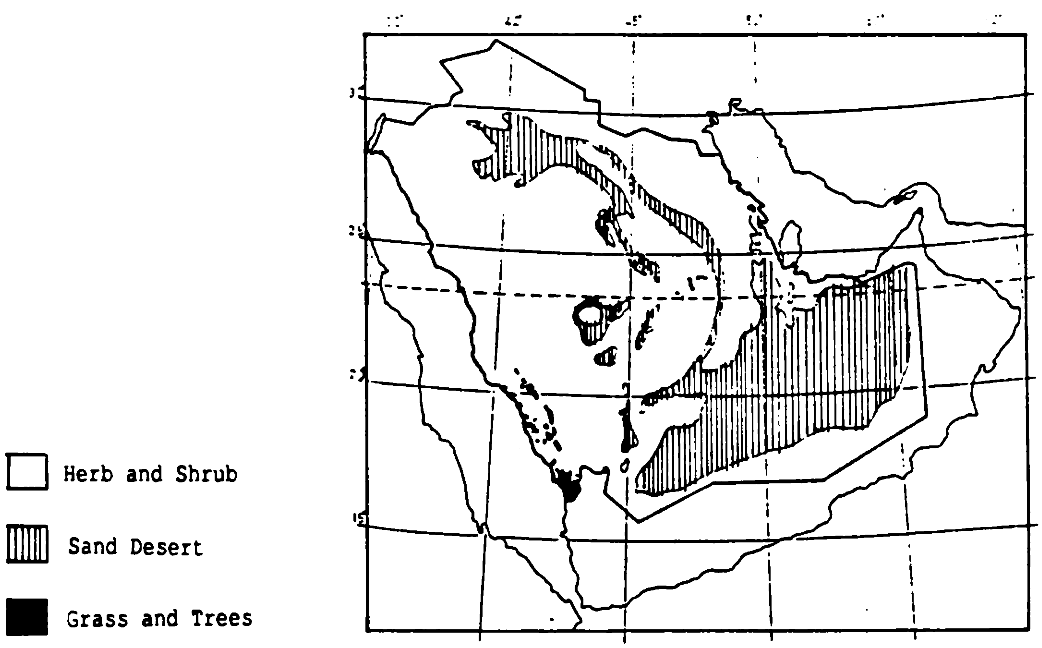
Beside oil as a principle base in the national economy, other resources are agriculture, trade, light industries, and pilgrimages.

Although there are still tremendous reserves of oil, there is new pressure to explore the unlimited solar and geothermal energy resources.



. **RELIF MAP**

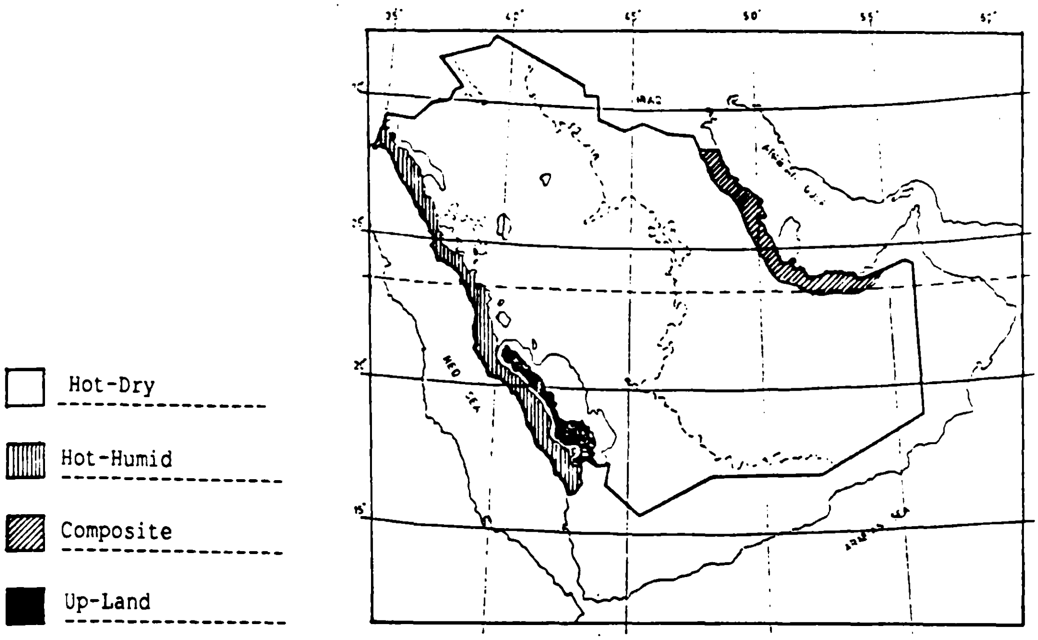
Fig. 1.2



. **NATURAL VEGETATION**

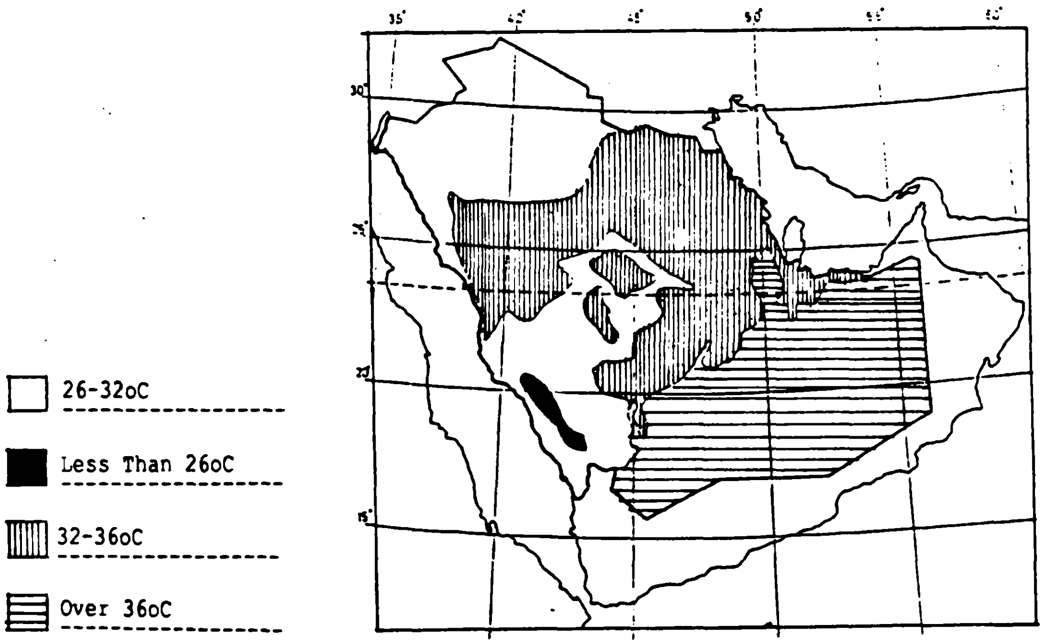
Fig. 1.3

Source : Dr. Hussein Bidagji. Atlas of Saudi Arabia. Oxford University Press, 1978.



. CLIMATIC ZONES

Fig. 1.4



. AVERAGE SUMMER TEMPERATURE

Fig. 1.5

Source : Dr. Hussein Bidagji. Atlas of Saudi Arabia.
Oxford University Press, 1978.

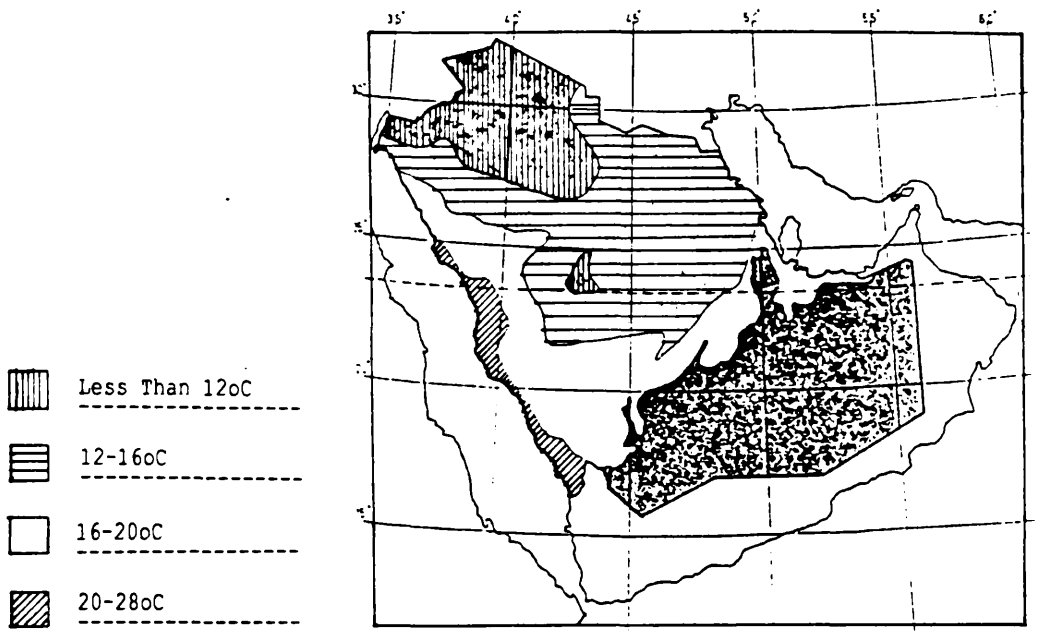


Fig. 1.6 . AVERAGE WINTER TEMPERATURE

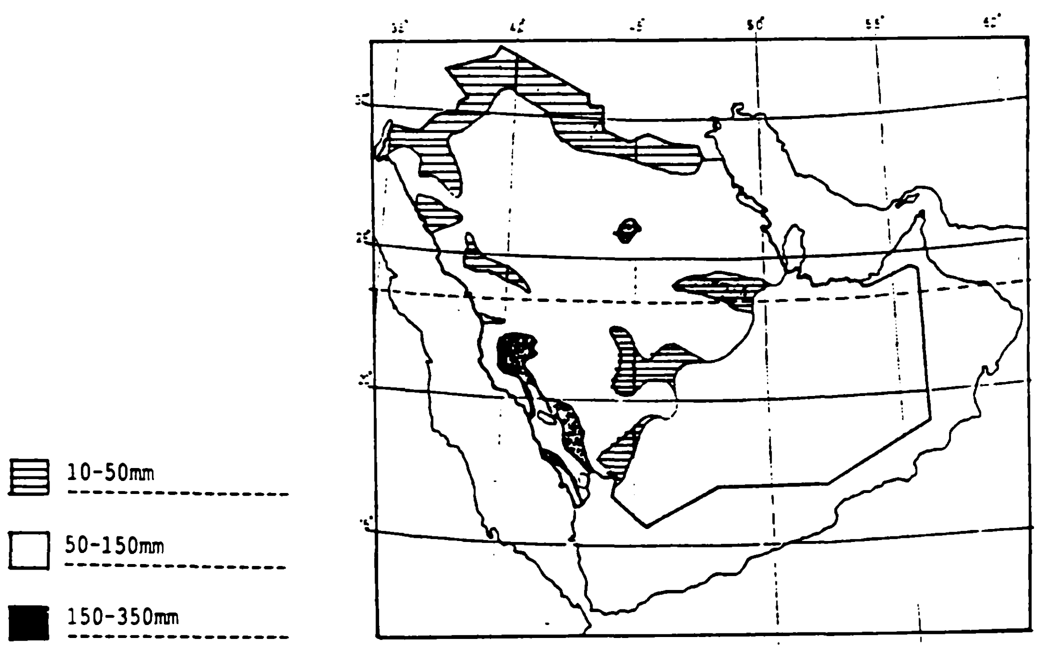
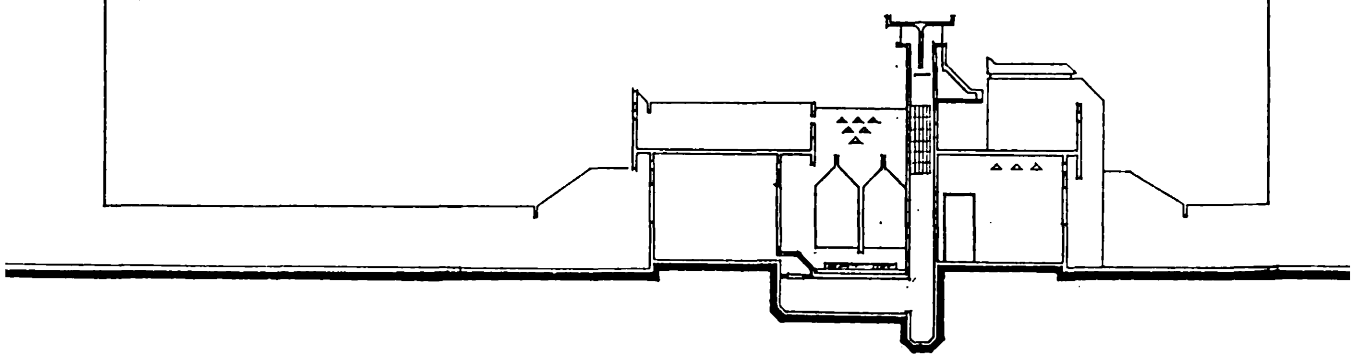


Fig. 1.7 . MEAN ANNUAL RAINFALL

Source : Dr. Hussein Bidagji. Atlas of Saudi Arabia.
Oxford University Press, 1978.

CHAPTER II



CHAPTER II

AL-RIYADH

II.1 Introduction :-

Riyadh is the capital and the largest city in Saudi Arabia. It is located in the central region of the country at the intesection of major travel routes which link the Arabian gulf to Red Sea. The city is situated on a plateau which is 600m above the sea level, at latitude 24° 38′ north, longitude 46° 43′ east.[1]

II.2 Urban Topography and Circulation :-

Riyadh was built between the Wadi Haniva, Aysan, and Batha, in order to profit from available water sources. Other natural features of the surrounding area are two rows of hill rocks to east and west.

The built up area is contained within approximately 15km from north to south, and 10km from east to west.[2] Fig.(2.1)

II.3 Urban Land Use Pattern :-

Residential areas exist throughout the city, the old section consisting mainly of mud houses. Apartment blocks have developed within the central business district and to the north.

New residential areas, which developed after 1945, generally house middle and high income groups. The industrial area is located to the east of the city.[2] Fig.(2.2)

II.4 Urban Density Pattern :-

The estimated population of Riyadh in 1968 was 300,000 inhabitants. The average annual rate of increase since 1960 has being 8.5 %. High population density is concentrated in the city center and in the low income neighborhood.

The new residential area in the northern and eastern parts of the city have low population densities.[2] Fig.(2.3)

II.5 Urban Growth Pattern :-

Some records of ancient history, the earliest dating back to 715 B.C., mention the existence of Hajiar in the general area where Riyadh was later founded. Around 1730 Riyadh became the capital of the Kingdom under the Ibn Saud family, but the capital was subsequently moved to Daraiya, 20 km to the north. In 1818, the Kingdom was defeated and the capital destroyed.

In the beginning of the 20th century King Abdulaziz Ibn Saud liberated and unified many areas of the peninsula from the control of the Ottoman empire. At the end of World War II, Riyadh became the capital of Saudi Arabia.[2] Fig.(2.4)

II.6 Urban Income Pattern :-

The very low income sector is concentrated in the city centre and to the south of it. Some small squatter settlements are located in the upper class neighbourhood.

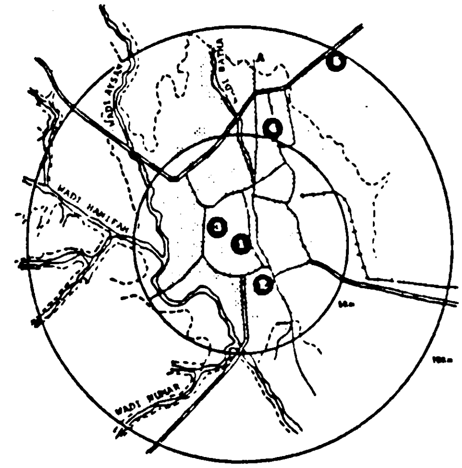
The middle income group lives in walk-up apartment buildings. There is a concentration of the high income sector in neighbourhoods towards the west and north west of the city.[2] Fig.(2.5)

1 . Built-Up Area

2 . Air Port

3 . Primary Road

4 . Rail Road



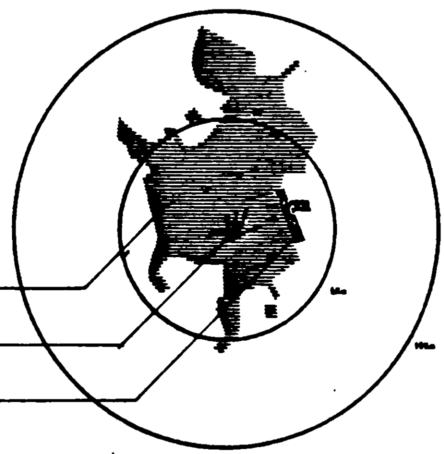
URBAN TOPOGRAPY AND CIRCULATION

Fig. 2.1

. Residential

. Commercial

. Industrial



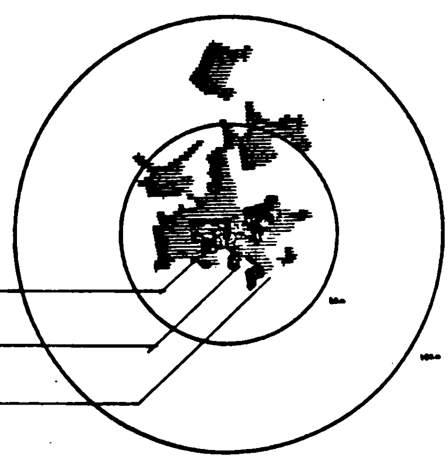
URBAN LAND-USE PATTERN

Fig. 2.2

. 200-400 P./Ha.

. 100-200 P./Ha

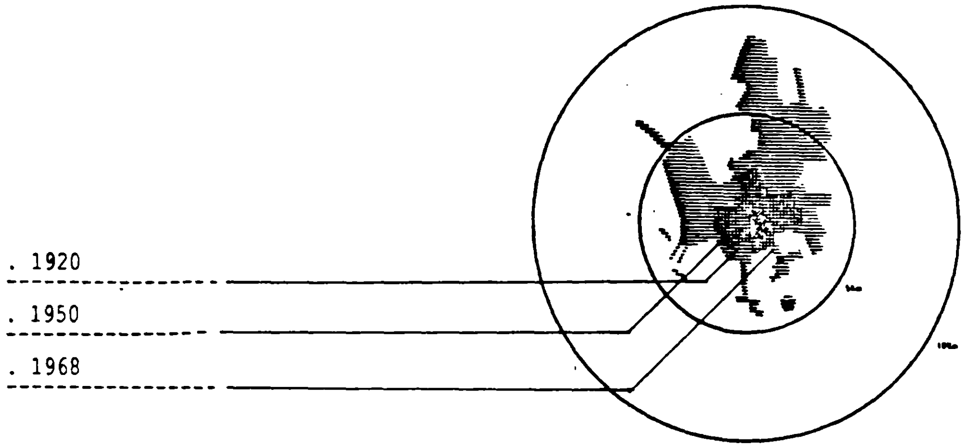
. Less Than 100 P./Ha.



URBAN DENSITY PATTERN

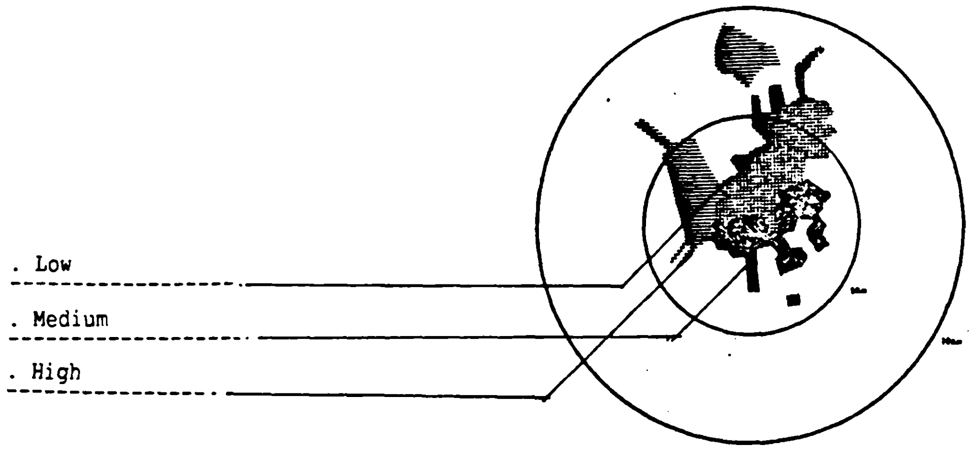
Fig. 2.3

Source : S.Al-Hathloul,M.Al-Hussayen,and A.Shuaibi. Urban Land Utilization, Case Study; Al-Riyadh, Saudi Arabia, M.I.T., 1975.



URBAN GROWTH PATTERN

Fig. 2.4



URBAN INCOME PATTERN

Fig. 2.5

Source : S.Al-Hathloul,M.Al-Hussayen,and A.Shuaibi. Urban Land Utilization, Case Study; Al-Riyadh, Saudi Arabia, M.I.T., 1975.

II.7 Housing Typology in Al-Riyadh

Since we are concerned in this research with thermal improvement and energy conservation for residential units to cut down expenditure on electrical air conditioning units, a brief statement of housing classification illustrates the developing path of the dwelling from traditional to modern morphology.

Housing types in Riyadh are numerous, and each is distiguished by different characteristics. The major housing types identified here are the following[3] :-

II.7.1 Traditional housing

- Rural housing, isolated houses, or houses grouped into small villages.
- Uncontrolled, low income housing, isolated shelters or randomly scattered slums with animal enclosure.
- Old mud buildings covering 40 to 70 % of lots larger than $400m^2$, one to three stories, courtyard often with colonnade, resulting in area of medium density.
- Recent mud and concrete block buildings covering 80 to 100 % of the lot, one or two stories, small courtyard without garden, on regular, orthogonal street network.

II.7.2 New house type :-

- Medium-Income villas built of concrete blocks covering 70 to 90 % of lot smaller then $500m^2$, one to two stories, generally without garden.
- High-Income villas in concrete, on lot smaller than $1000m^2$, often with garden.
- palaces.
- Compound grouped single family houses.

II.7.3 Apartment building :-

- Low-Rise apartment building of three to five stories.
- High-Rise apartment building of six to twelve stories.

The traditional type of houses are located in the centre. Some of these units are fully occupied, and some are vacant and in poor condition. The increased level of income and the availability of modern technology and materials have helped the ascending demands for housing to be accomplished.

Considerable changes have occurred in the local design of houses, in particular the recently constructed villas and apartment buildings, which assume to a great extent air-conditioning units from the first stage of the design process.

94 % of house-holds in new villas, 87 % of the apartment buildings and 57% of traditional dwellings have active cooling devices.[3]

This perhaps reflects the low income levels of the inhabitants, and the good thermal properties of mud and adobe construction, when consolidated with courtyard layout. The latter is a particularly popular feature in terms of bringing the exterior inside the unit and permitting orientation of family activities inwards. As well as the high degree of privacy offered by the courtyard, it functions well climatically.

In the classification of housing types, two main categories are relevant to this analysis :-

- Traditional architecture and local style.
- Modern architectural style .

The transitional period between these two stages has been so short that it has made it difficult for a concerned designer to explore and manipulate indigenous architectural values.

These values and concepts are part of the heritage from one generation to another; but Saudi's architects were few at a time of rapid growth, allowing a completely new architecture to be imported. New Saudi graduates are now emerging and recently have taken a place in decision making, trying to correct past blunders or at least put their feet on the right path of re-evoking a local identity.

Formerly, the door was wide open for foreign architects, who forced in many exotic architecture styles, with no consideration of religious, cultural, and environmental characteristics.

In this period, local identity was struggling among these styles, and due to this absence many problems have come to the surface. The contemporary situation thus needs an overall re-evaluation to avoid repeating mistakes in planning and designing new homes.

II.8 Traditional Architecture and the Local Style

The vernacular architecture of Saudi tends to be immutable, since it serves its purpose to satisfaction. The previous people have learnt how to live in full compatibility with the evironment, with limited facilities and limited alternatives.

Trial and error procedures have developed their awareness and improve their response to climate from simple tensile tents, to mud houses.

Al-Riyadh conveys a desert image in planning and design of buildings, coping with harshness of the climate and consistent with religious and cultural values.

The following is a brief summary of the main characteristics of traditional architecture :-

II.8.1 Housing pattern and urban tissue

The traditional basic planning and urban forms in Al-Riyadh correspond to most old arab cities with a similar climate. Key factors such as religion, cultural customs, and natural environment have influenced development of the urban fabric; and the latter seems to be dominant, not only in Riyadh but also in any small or large development.

The result of natural awareness of the surrounding environment is that simple houses fulfill physical needs and provide reasonable protection against outside climatical conditions.

The residential quarters in Al-Riyadh comprise a series of attached dwelling units of irregular shape and forms. These share two or three walls with other units, and hence minimize the surface area exposed to sun and wind with penetration of sun-light limited to the courtyard during the afternoon period. Figs.(2.6,2.7,2.8,2.9, & 2.10)

An irregular lay-out of narrow alleys for pedestrian circulation provides protection from dust storms while at the same time the shade cast from surroundings building makes it reasonable to walk even at the peak heat hours of the day.Figs.(2.11,2.12,& 2.13)

The local standard for the width of these alleys was determined by the width of a camel carrying a load of wood. The width also suits human scale and the walking distances are appropriate to different daily activities.

This kind of urban tissue adds strength to social relationships as well as being in sympathy with religious beliefs and needs. Usually the mosque is in the heart of any residential neighborhood and associated with a vast open space used for public gatherings.

Also in this kind of settlement there is no visual differentiation of high class or low class housing units. All units look similar.

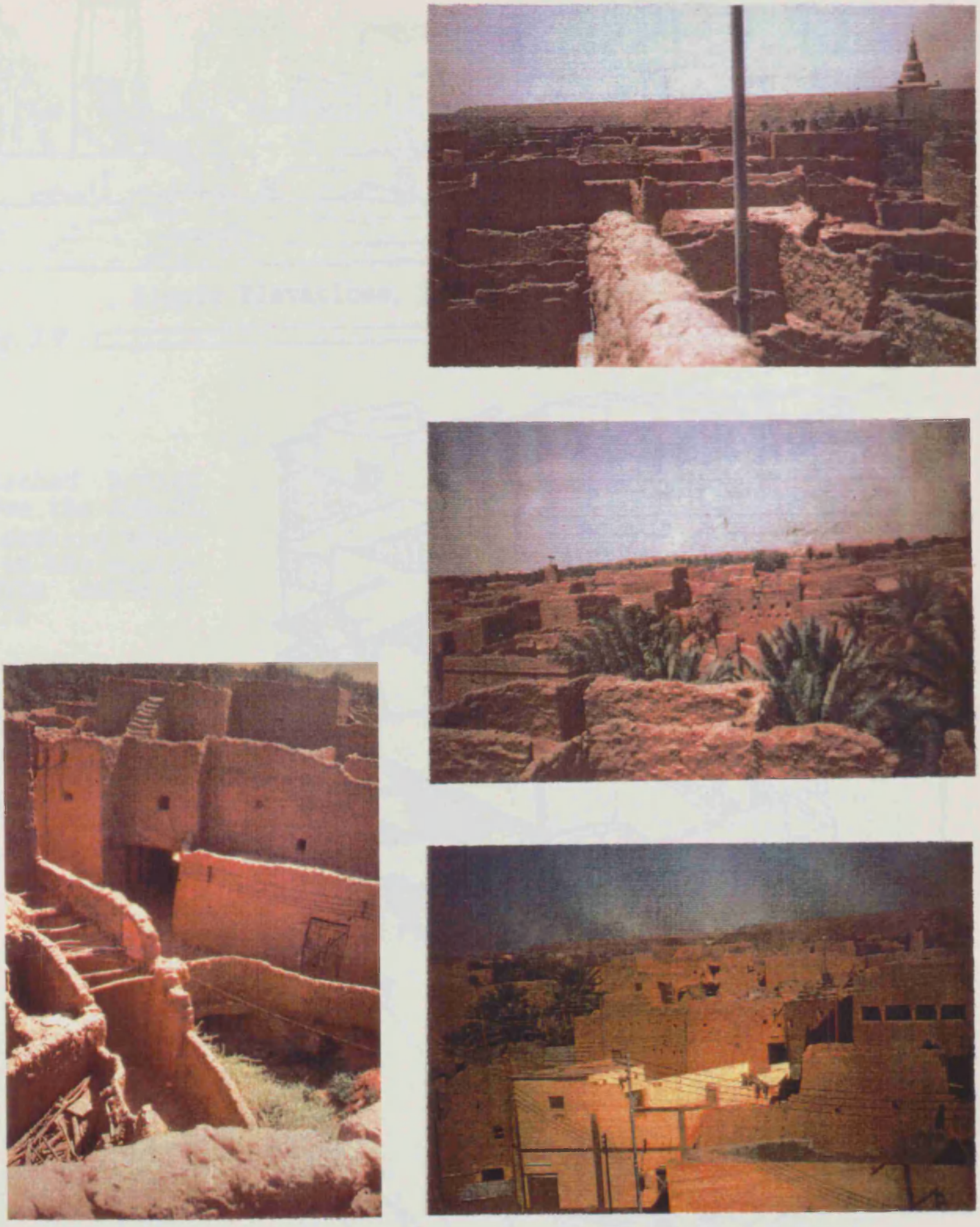
Aerial photo. showing high density housing clusters and irregular st. pattern

Fig. 2.6

. Traditional Urban Fabric

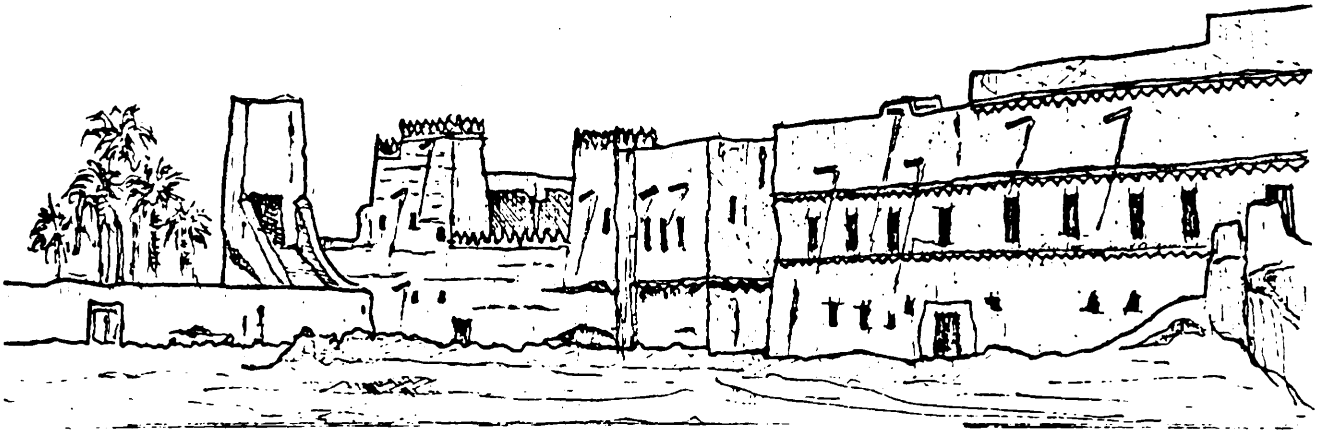
Fig. 2.7

Source : S.Al-Hathloul,M.Al-Hussayen,and A.Shuaibi. Urban Land Utilization, Case Study; Al-Riyadh, Saudi Arabia, M.I.T., 1975.



Wall defining streets are characterised by
a continuous, compact and solid apearance.

Fig. 2.8



. Simple Elevations, Limited Openings

Fig. 2.9

Attached houses shows the amount of casting shadow on the surrounding exterior walls.

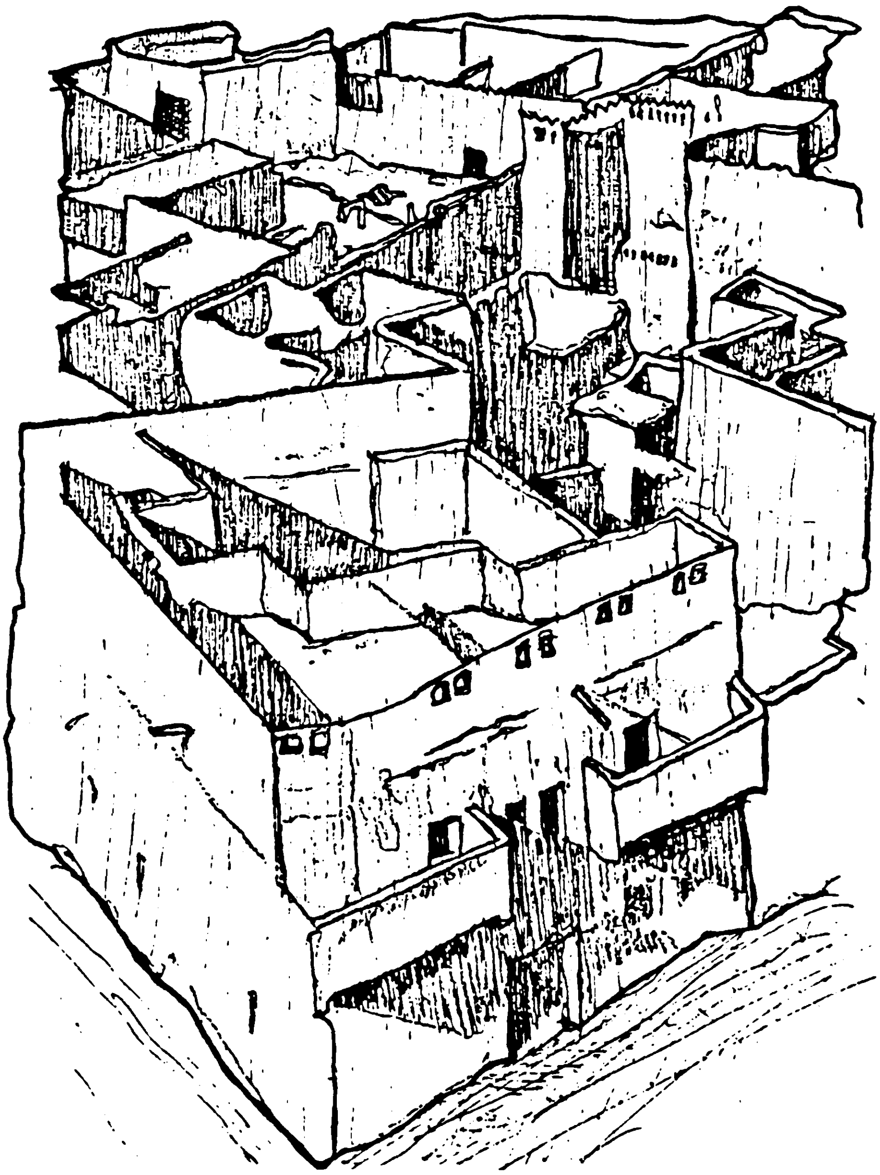
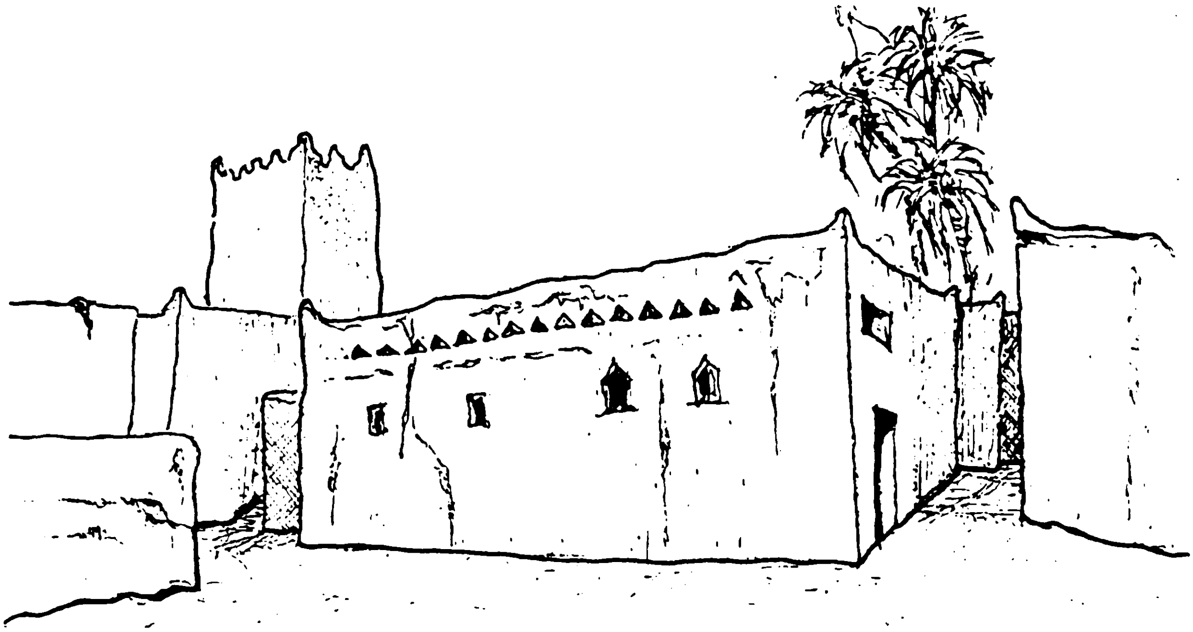
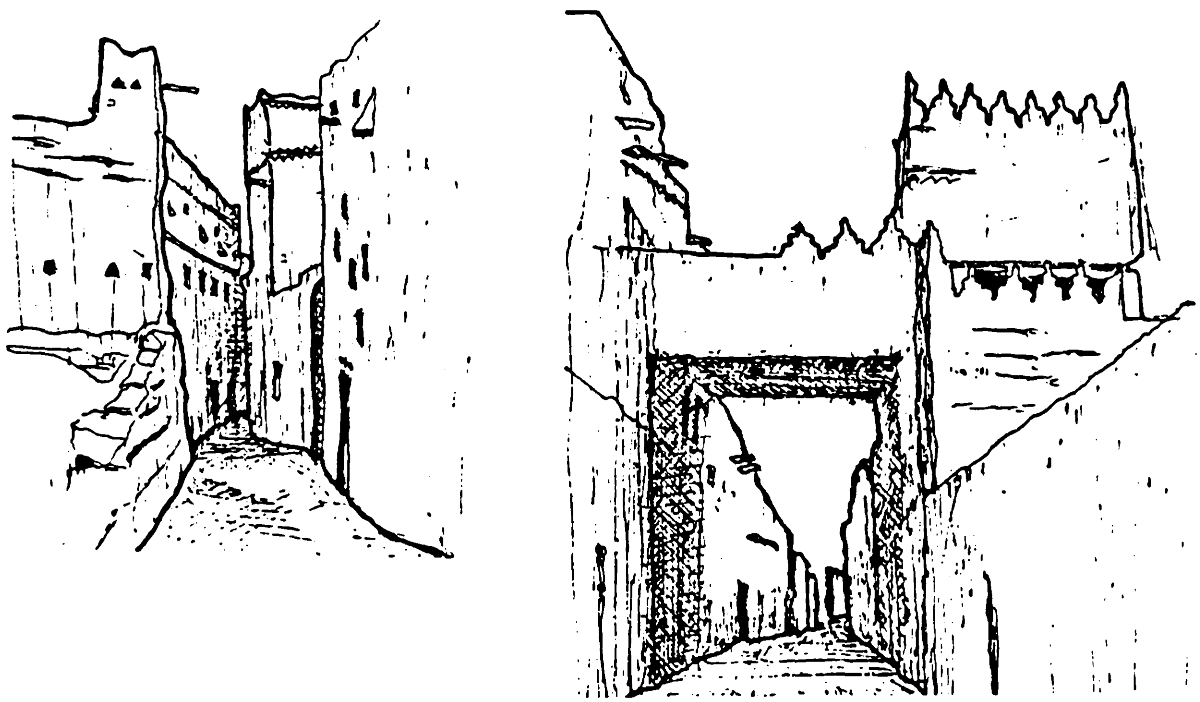


Fig. 2.10



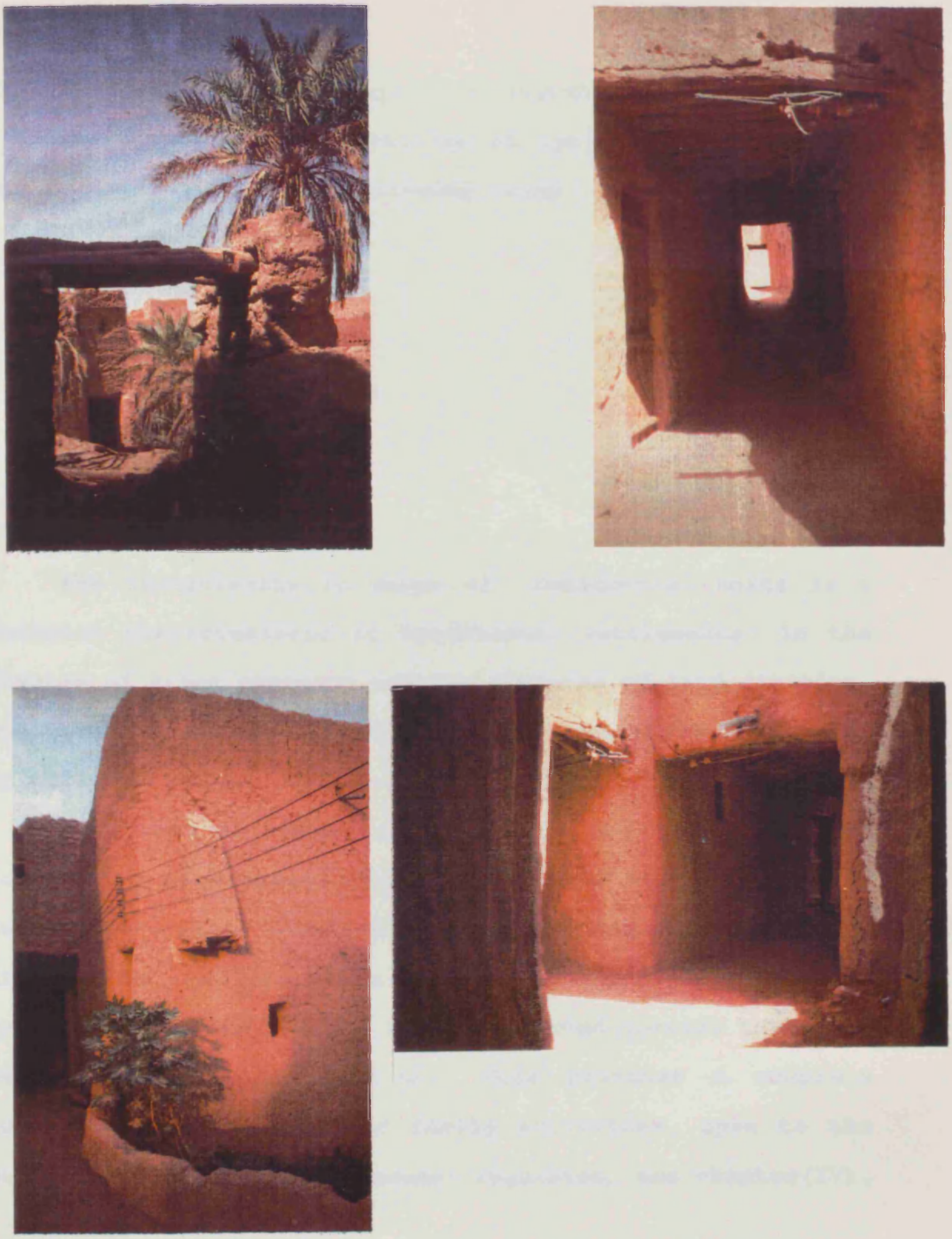
Typical pedestrian alley between houses

Fig. 2.11



The upper level connection by bridges represent a typical feature of the indigenous urban pattern and provide shade for pedestrian.

Fig. 2.12



Traditional streets system, looks like deep trench in which maximum shade is achieved.

Fig. 2.13

II.8.2 Traditional Dwellings in Al-Riyadh

The organizational features of typical dwelling units can be expressed in the following terms :-

- Building form
- Massive wall
- Roof
- Materials
- Decoration

II.8.2.1 Building form :-

The irregularity in shape of residential units is a dominant characteristic in traditional settlements. In the absence of urban planning and new theories of land division, the people were accustomed to building on a lot surrounded by attached houses. Fig.(2.14)

They used to respect the right of way and provide an access to each house. The road patterns were defined according to this arrangement, great consideration being directed to neighbours as this relationship is controlled by religion. So houses are always directed inwards towards a central courtyard, fig.(2.15). This provides a complete private outdoor space for family activities, open to the sky and functioning as a thermal regulator, see chapter(IV).

II.8.2.2 Massive wall :-

Another distinct feature of traditional building is the thick massive wall, built of mud and brick, the thickness of the wall is entirely for structural purposes, to support the roofs, but it also acts as a heat store and hence helps to moderate thermal extremes.

The mass delays solar heat reaching the interior during the hot day period, but permits warming of the internal space in the relatively cool night period. Also external walls rarely have any large windows, thus reducing heat gain through solar radiation to the minimum. The typical wall thickness is approximately 50cm at ground level getting narrower towards the parapets. Fig.(2.16)

II.8.2.3 Roof :-

The roof is a very active family gathering area. It is used as an out-door space to spend the afternoon period or for sleeping during hot summer nights.

High parapets surrounding the roof area provide privacy and some morning and afternoon shade. They also help to reduce heat transmission to the interior, and people used to splash water on the surface to help it cool down by the process of evaporation.

II.8.2.4 Materials :-

The primary building materials used in traditional houses were :-

. mud and mud blocks.

. adobe.

. palm tree trunks, branches, leaves, trees.

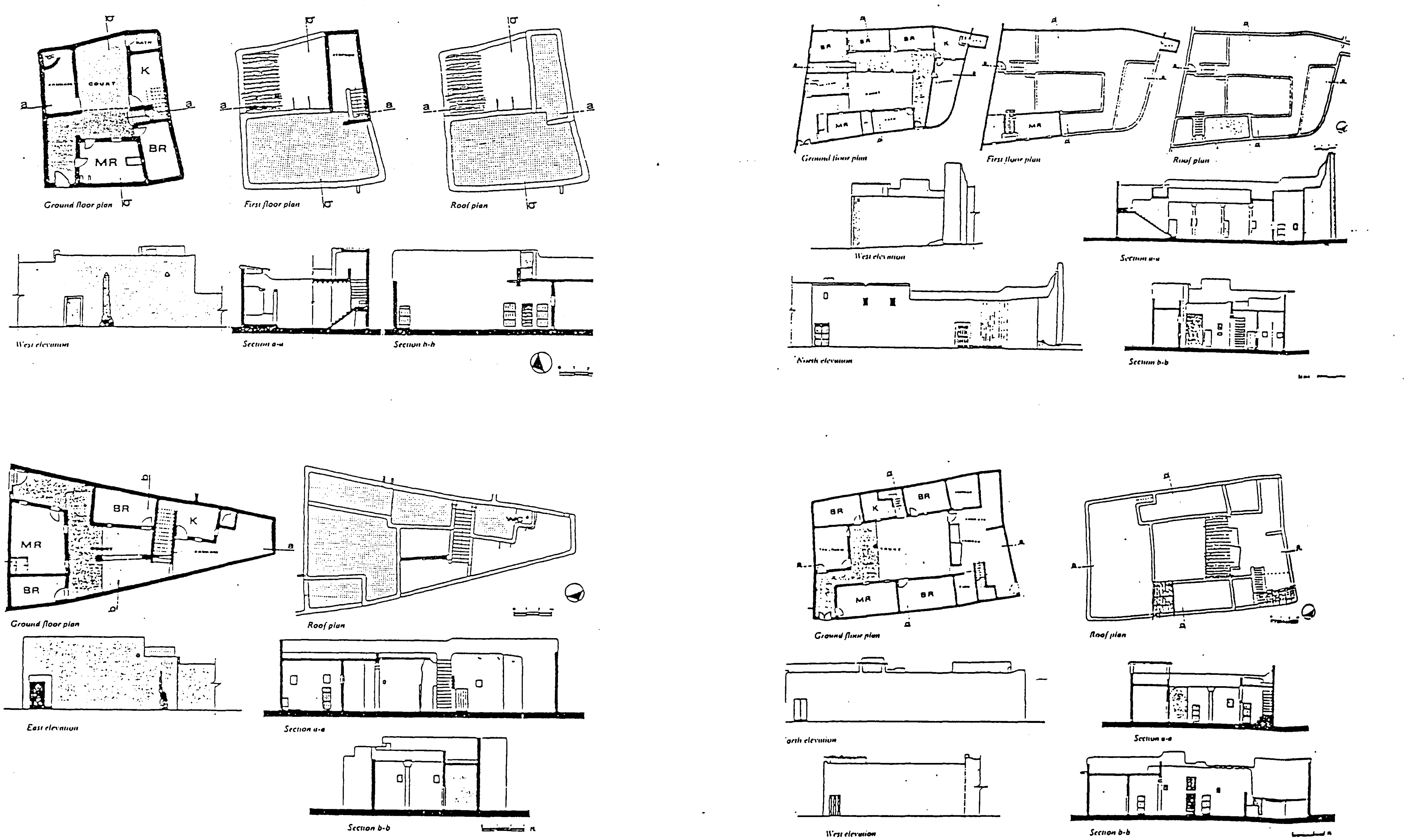
Relativly low conductivity is a common factor between all of those materials. They are also locally available, and with appropriate usage in construction, an excellent thermal performance may be achieved, see chapter (V).

II.8.2.5 Decoration :-

A series of small triangles pointed up are often used in very simple and elegant way, to break the rigidity of the mass walls and often to define the structural level.

The parapet is also sometimes decorated by triangular frames arranged horizontally as one straight line. The arrangement of small windows with no systematical scenario functions as a decorative feature.

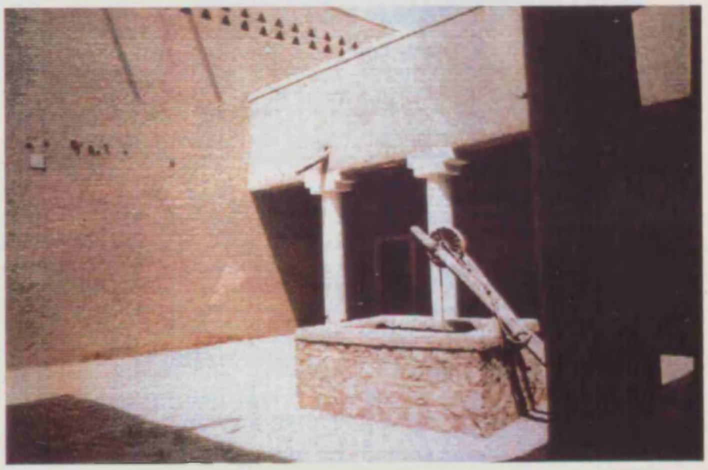
The building corners are emphasized by an elevating projection directed to the sky. This has the function of protecting the materials against damage when it is raining and gives a strong massive impression of structure. Fig.(2.17 & 2.18)



. Al-Riyadh Traditional Dwelling Units

Fig. 2.14

Source : Dr. Adil Al-Kilical. Traditional Architecture
in Riyadh, Al-Benaa, No.28, Vol.5, 1986.

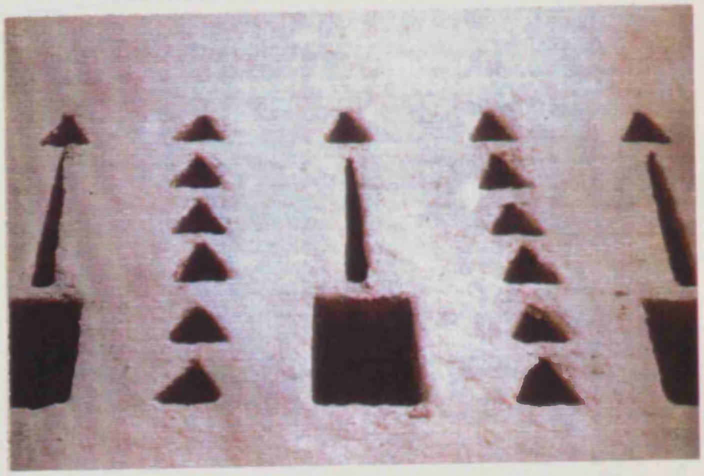


Internal views shows the house directed inwards with very open facade to the courtyard.

Fig. 2.15

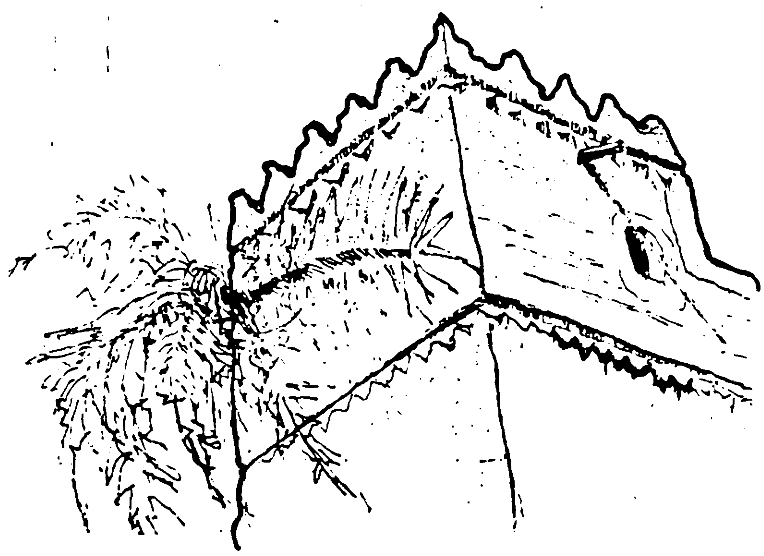
Heavy construction of mud-blocks and straw express the thermal resistance of these natural materials and explain the good thermal performance of traditional houses.

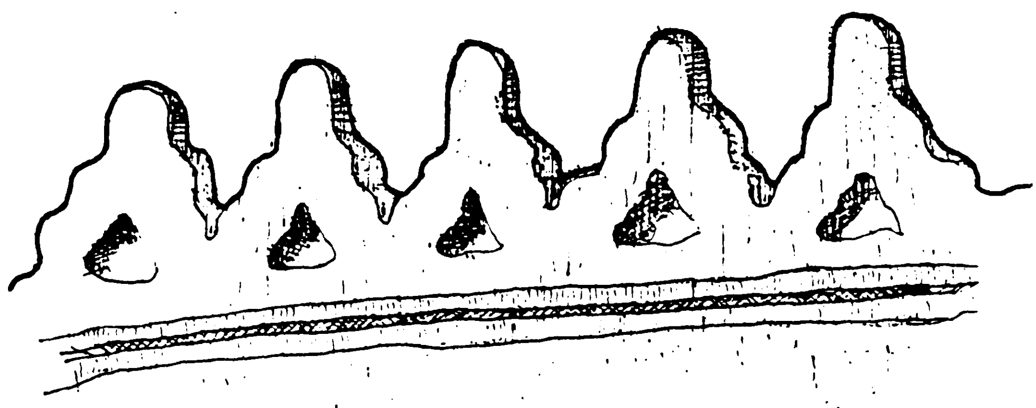
Fig. 2.16



Small Triangular openings for light, ventilation and decoration.

Fig. 2.17





Traditional decoration:
elegant uses and arra-
ngment of triangles,as
openings and textures.

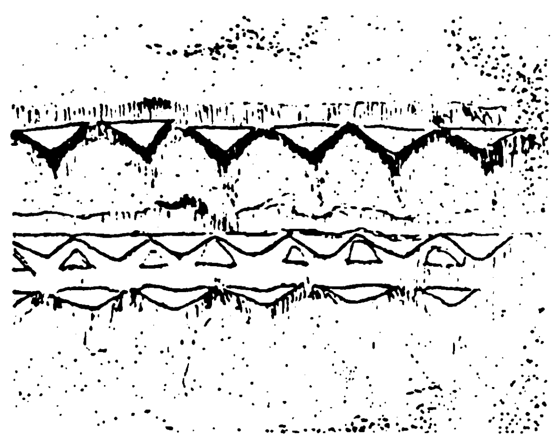


Fig. 2.18

II.9 Modern Architecture Style

II.9.1 Urban fabric and land subdivision :-

The two features of contemporary physical environment in Al-Riyadh, the grid pattern and the villa on a square lot, were institutionalized through master plans, zoning regulations, decrees, directives and circulars.

To insure the constitutionality of these measures, statutes were issued periodically by the Council of Ministers. These statues regulate the procedures and the methods to be followed in developing plans and regulations.

Doxiadis Associates[5] were the consultants responsible for the formulation of the master plan and programme that would guide the development of the city of Al-Riyadh up to the year 2000.

The square lot continued to be the model for land subdivision by institution, the way was clearly established for the development of the villa as a preferred dwelling type, and set back requirements were established, fig.(2.19). Hence the villa became the only dwelling type for the people of AlRiyadh and of the other cities as well.

Climatically, this kind of development has produced an urban tissue with poor thermal protection. Fig.(2.20).

Building surfaces became more exposed to the outer environment; walking distances increased and became unshaded; travelling distance from home to work has increased due to the expansion of the city; and mobilization requirements such as roads and parking have added heating load to the micro-climate.

II.9.2 Building design :-

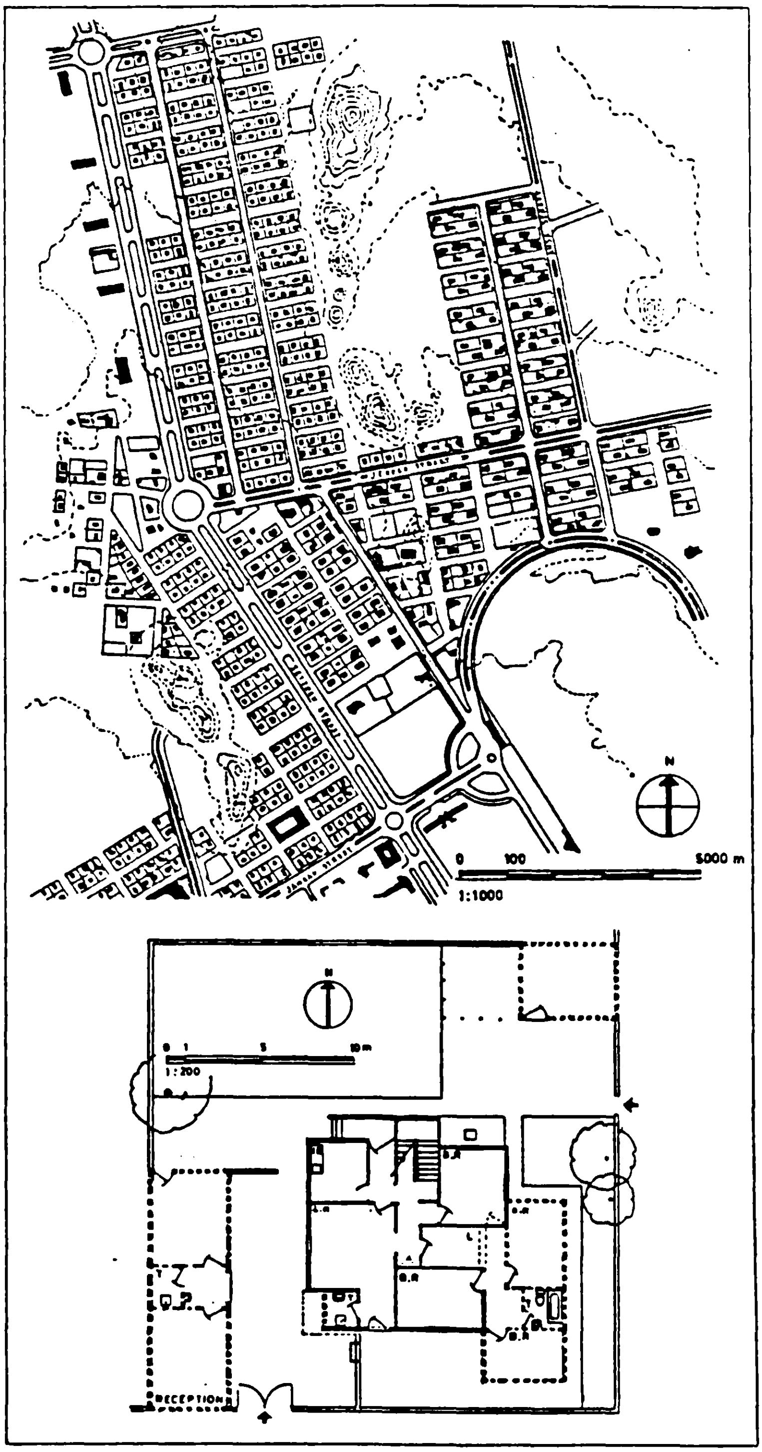
The modern movement of architecture has effected building design in Al-Riyadh through the following channels:-

- New modern architectural style
- New spatial concepts
- New building materials

All respond less favourably to local climate, and increase dependance on mechanical solutions for cooling or heating the building interior. The modern style denotes imitation of western values, which are completely different in cultural as well as in environmental terms.

New spatial requirements to suite modern lifestyle increase the building area, and hence increase the energy required for mechanical systems, particulary cooling.

New building materials, though providing a wide range of choice to cope with different construction systems, can still be disadvantageous when misplaced, for example, using large glazed surfaces.



MODERN LAND SUBDIVISION

Fig. 2.19

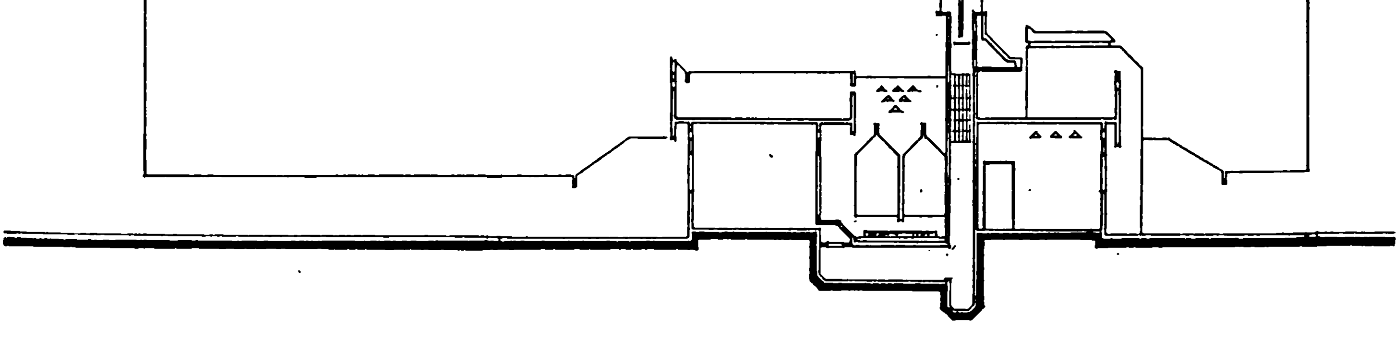
Source : Dr. Saleh Al-Hathloul. Development of the Contemporary Physical Environment in Al-Riyadh, Al-Benaa, No.28, Vol.5, 1986.

Aerial Photo. of New Urban Fabric.

Fig. 2.20

Source : S.Al-Hathloul,M.Al-Hussayen,and A.Shuaibi.
Urban Land Utilization, Case Study; Al-Riyadh,
Saudi Arabia, M.I.T., 1975.

CHAPTER III



CHAPTER III

THE CLIMATIC CONTEXT

III.1 Characteristics of a Hot Dry Climate

Hot dry deserts are found in the Sub-Tropical regions of Africa, Central and Western Asia, North Western and Southern America, and in central and Western Australia.

These regions are accompanied by several characteristics of importance to human comfort and building design.

Direct solar radiation is intense on the horizontal surface and this is further augmented by radiation reflected from adjacent light colour terrain.

The sky is without cloud for the greater part of the year. However, dust and storms are frequent, caused by convection currents due the intensive heating of the air near the ground, mainly in the afternoon.

The low humidity and absence of cloud result in very wide temperature range. In summer the unobstructed solar rays heat the land surface up to about 70°C at midday.

At night the rapid loss of this heat by long wave radiation cools the surfaces to 15°C or below.

The fluctuation in air temperature is much smaller, but even so a daily range of 20°C is common. The summer temperature during the day is around 40-50°C, and at night the range is 15-25°C.

The vapour pressure is fairly steady, varying with the location and season from about 0.7-2.0 kPa. The relative humidity fluctuating with air temperature, then ranges from below 20% in the afternoon to over 40% at night.[1]

Rains are few, and far between. Although precipitation sometimes starts at high altitude, the water evaporates completely before reaching the ground. Wind speed are generally low in the morning, rising towards noon to reach maximum in the afternoon, and are frequently accompanied by dust and sand.

III.2 Climatic Elements and Building Design

The aspects of climate of immediate interest to the thermal design of buildings situated under these circumstances are: -

- Air Temperature
- Solar Radiation
- Wind
- Humidity and Rain Fall

These together, are linked into a global system which is the result of the constant radiation of energy from the sun and the 24-Hours rotation and the planetary movement in the solar system.

It is the correlation of these components, which effects thermal load input and output at the interior surface after transmission through the building structure.

The desirable procedure would be to work with, not against the natural forces, and make use of their potential to create better living conditions.

'Climate balanced'(2) is a term used to express a structure which can reduce undesirable climate stress, and make full utilization of the natural resources in such a way that human comfort is nearly maintained.

It is difficult to achieve a perfect balance, especially in such harsh climate. But a house of good thermal performance and low cost energy consumption is possible, if a systematic approach to climate balance is followed.

III.3 Al-Riyadh Climate Analysis

A hot dry continental desert climate is the distinct feature of AlRiyadh city, located just over 2° north of the Tropic of Cancer and about 500 km from the nearest seaboard.

As stated, the problem of this kind of climate is excessive heat for most of the year, with a high fluctuation between diurnal and nocturnal temperatures.

The location is also affected by a hot wind blowing from the south and carrying sand and dust as it passes through the empty desert quarter. Precipitation is seldom available especially rain, with no fixed time or quantity recorded. Rates of evaporation are high and relative humidity correspondingly low.

In order to establish an overall understanding of the problem, the following is a brief description of climatic elements and their inter-relation related to aspects of building design.

III.3.1 Air temperature :-

The rate of heating and cooling of the surface of the earth is the main factor determining the temperature of the air above. The air layer in direct contact with warm ground is heated by conduction, hot air rise up and transfer heat to the upper layer by convection.

During winter at night, the ground surface is usually colder than air, on account of long wave radiation to the sky, so that the net heat exchange is reversed and the air in contact with ground is cooled.

The annual and daily patterns of air temperature thus, depends on the variations in surface temperature, and the state of the sky.

On a clear day large amounts of incoming radiation produce a wide daily temperature range, while on overcast days the variation is less. On a seasonal basis the same holds true - clear days in summer are warmer because more solar energy is received.

The aridity of the desert zone is caused by low rain-fall and subsequent absence of permanent water bodies, such as rivers and lakes.

The high ambient temperature effects buildings from all sides, but particularly roof surfaces during the central diurnal period.

Usually the following data is required to give a good understanding of air temperature influence on building design :-

a. monthly mean temperature
b. monthly mean of maximum and minimum temperature
c. monthly absolute maximum and minimum temperature
d. 24 hour profiles of b & c

The declination angle of sun plays an important role in terms of the amount and intensity of the insolation received on the earth, the maximum received in summer when the sun is approximately normal to Al-Riyadh.

June, July and August representing the summer period are the hottest months of the year.

Average temperature range from 36-38°C and the maximum temperature recorded is 46°C in shade. In winter (i.e. December, January, and February), the air temperature averages from 15-17°C compared to summer average of 35-38°C from June till August. Ground temperature are somewhat higher than air temperatures in summer due to the solar intensity, while the converse tends to be the case in winter. Fig.(3.1). The daily temperature profile of the coldest month represented by January and the hottest month represented by July is plotted in fig.(3.2 & 3.3). A large daily range of 20°C can be notice in both cases.

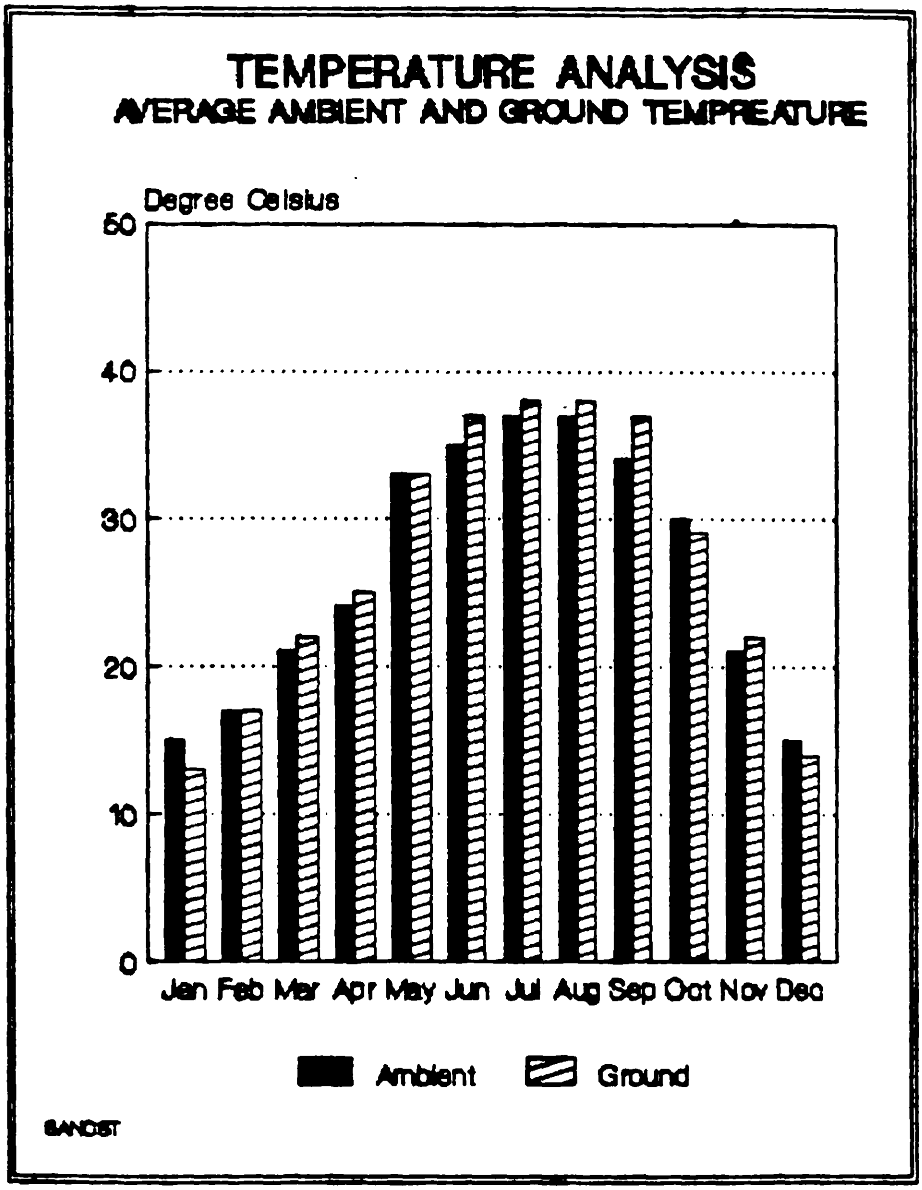

TEMPERATURE ANALYSIS
AVERAGE AMBIENT AND GROUND TEMPREATURE
Degree Celsius
50
40
30
20
10
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Ambient
Ground
SANCST

Fig. 3.1

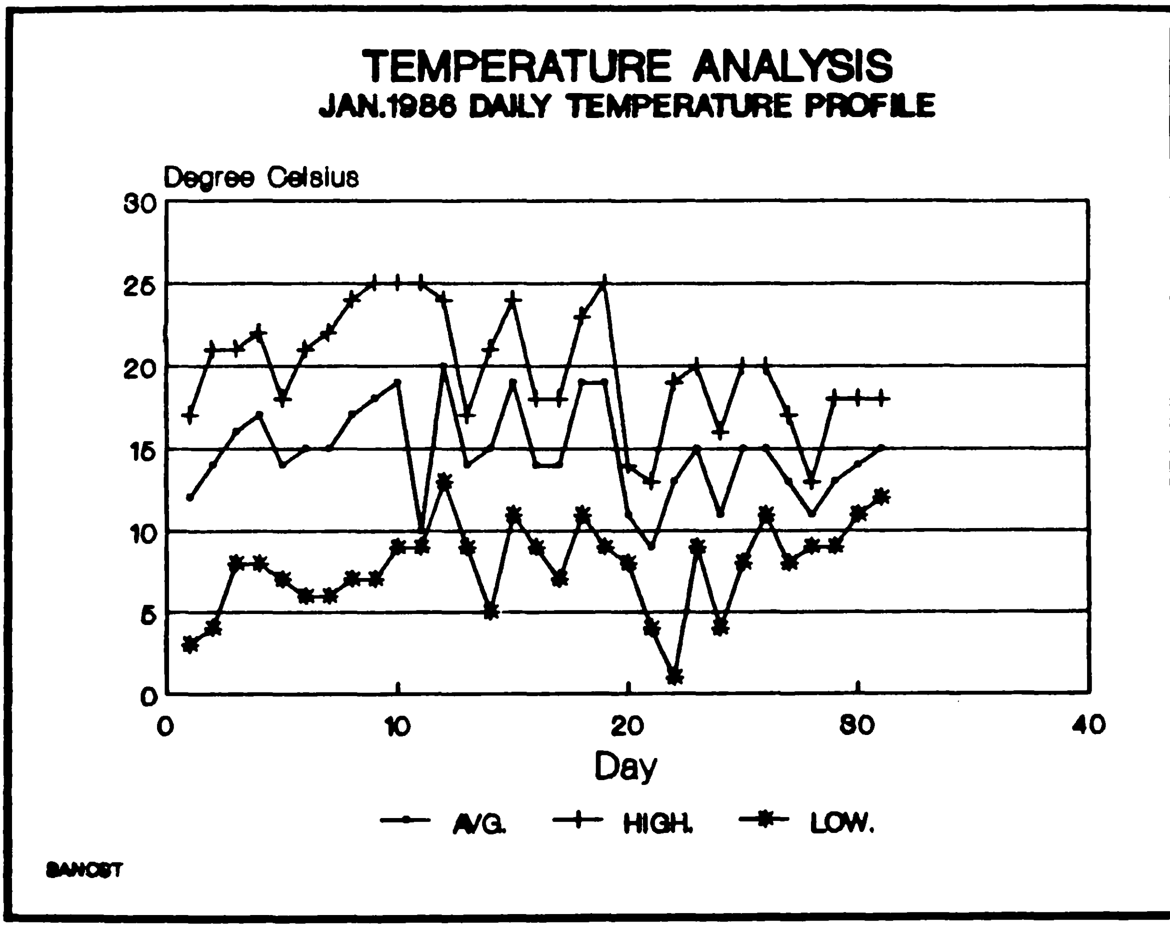

TEMPERATURE ANALYSIS
JAN.1986 DAILY TEMPERATURE PROFILE
Degree Celsius
30
25
20
15
10
5
0
0
10
20
30
40
Day
AVG.
HIGH.
LOW.
BANCOST

Fig. 3.2

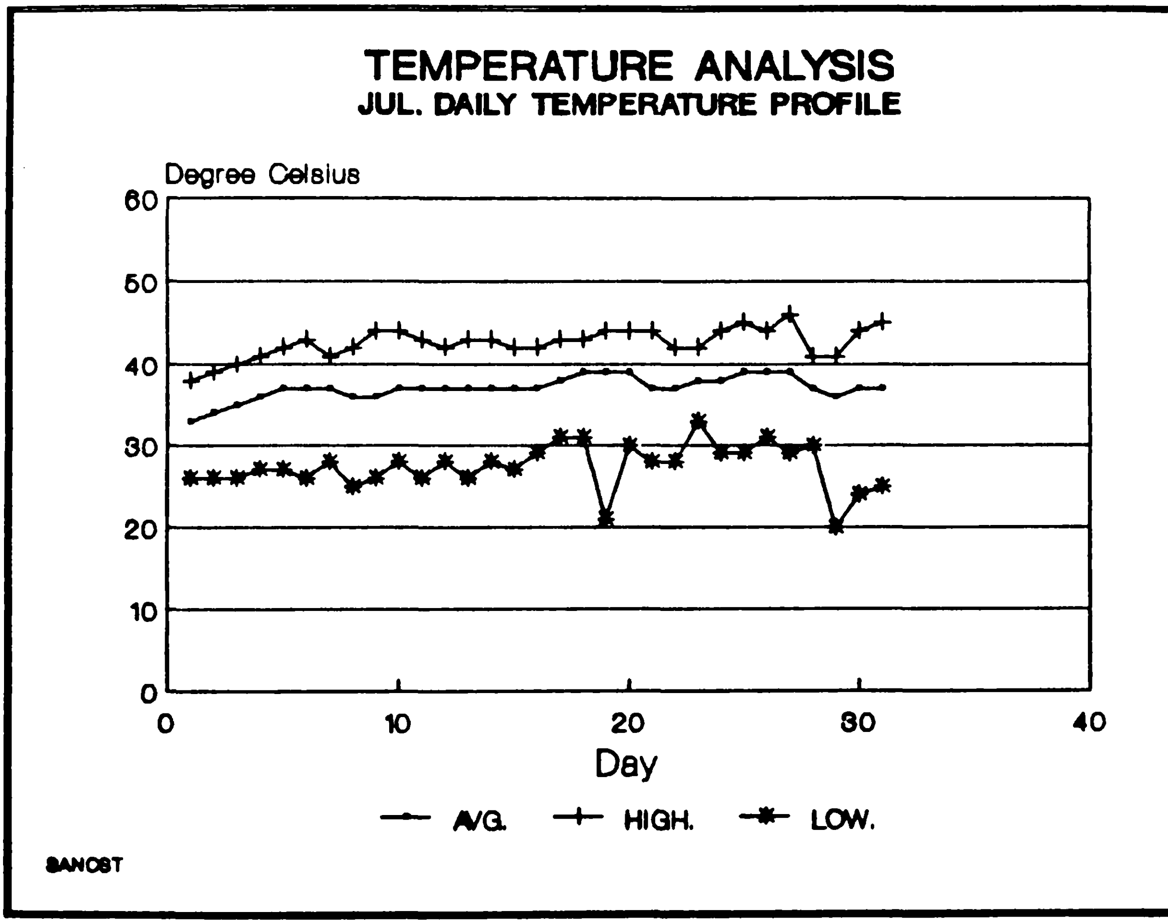

TEMPERATURE ANALYSIS
JUL. DAILY TEMPERATURE PROFILE
Degree Celsius
60
50
40
30
20
10
0
0
10
20
30
40
Day
AVG.
HIGH.
LOW.
SANCST

Fig. 3.3

III.3.2 Solar radiation :-

Solar radiation is an electromagnetic radiation emitted from the sun. As radiation penetrates the earth's atmosphere its intensity is decreased and the spectral distribution is altered by absorption, reflection, and scattering.

Clouds reflects back a significant fraction of the solar radiation to outer space, but the remainder reaches the earth's surface in a diffused form. Fig.(3.4)

The diurnal and annual pattern of incident solar energy depends on the depth of atmosphere through which the rays must penetrate, and is determined by solar geometry for a particular time and location. Fig.(3.5)

However, the amount of solar energy actually reaching earth also depends on the sky clarity with respect to clouds, and the purity of the air with respect to dust or water vapour. The energy absorbed changes to heat and raises the temperature of the air, the ground, and the surrounding objects.

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

- direct short wave radiation from the sun.
- diffuse short wave radiation from the sky vault.
- short wave radiation reflected from surrounding surfaces.
- long wave radiation from heated ground/objects.
- out-going long wave radiation exchange from building to sky.

Direct and diffuse radiation have a substantial natural contribution to heat gain in dwellings. Their impact varies according to orientation - east and west vertical sides are the most active solar receivers, while it less on the the other sides due to the duration of exposure and the incident angle of the sun.

There are several factors which determine the quantity of incident solar radiation as follows :-

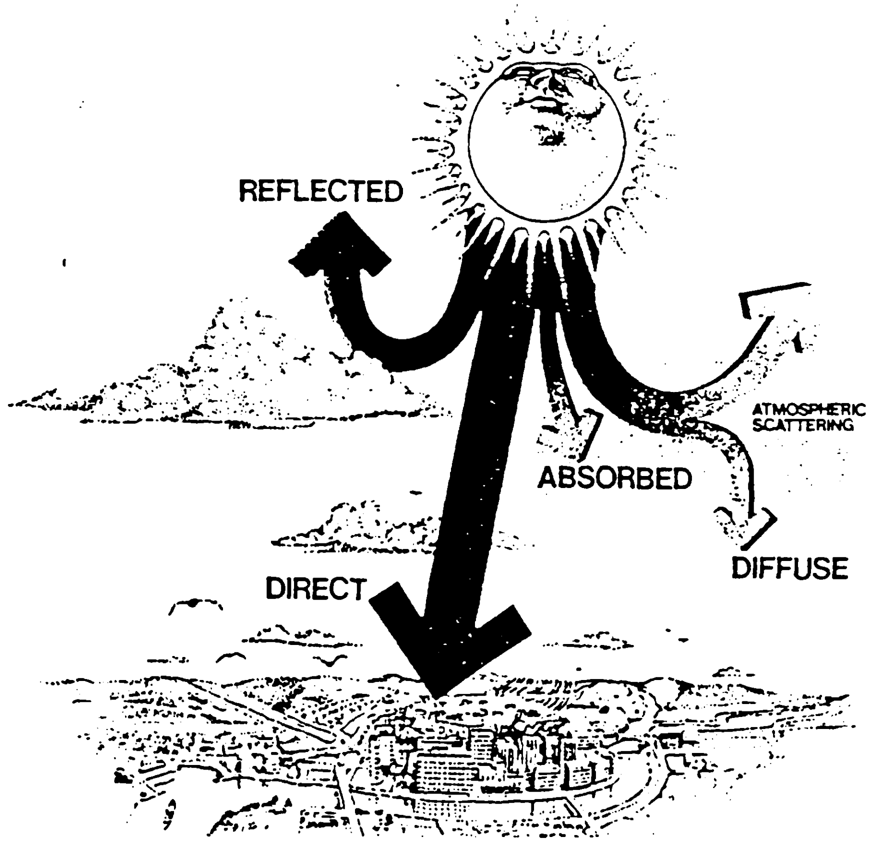
. Sunshine duration
. Intensity
. Incident Angle. Fig. (3.6)

the number of sunshine hours per day is linked to the atmospheric condition of whether the sky is clear or not. Predictably the three summer months have the longest period of sunshine, approximately 360 Hours. Fig.(3.7)

The same months have the highest irradiance,* peak intensity occurring when the sun is normal to the surface of the earth on the tropical zone, and with the sun rays penetrating a minimum distance through atmosphere to reach ground.

In the June summer solstice, the zenith of sun is almost 90° providing a zero incident angle to flat roof surfaces, and the highest reading of solar irradiation recorded in this month is 230 kWh/m^2. Fig.(3.8)

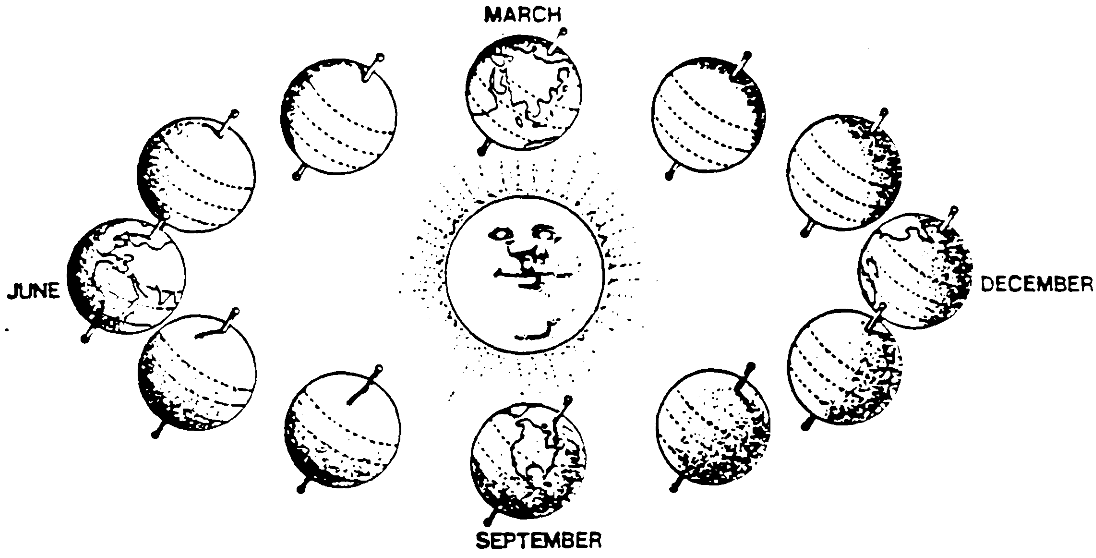
* Irradiance denotes flow or intensity (unit W or kW).
  Irradiation denotes quantity (unit Wh or kWh).

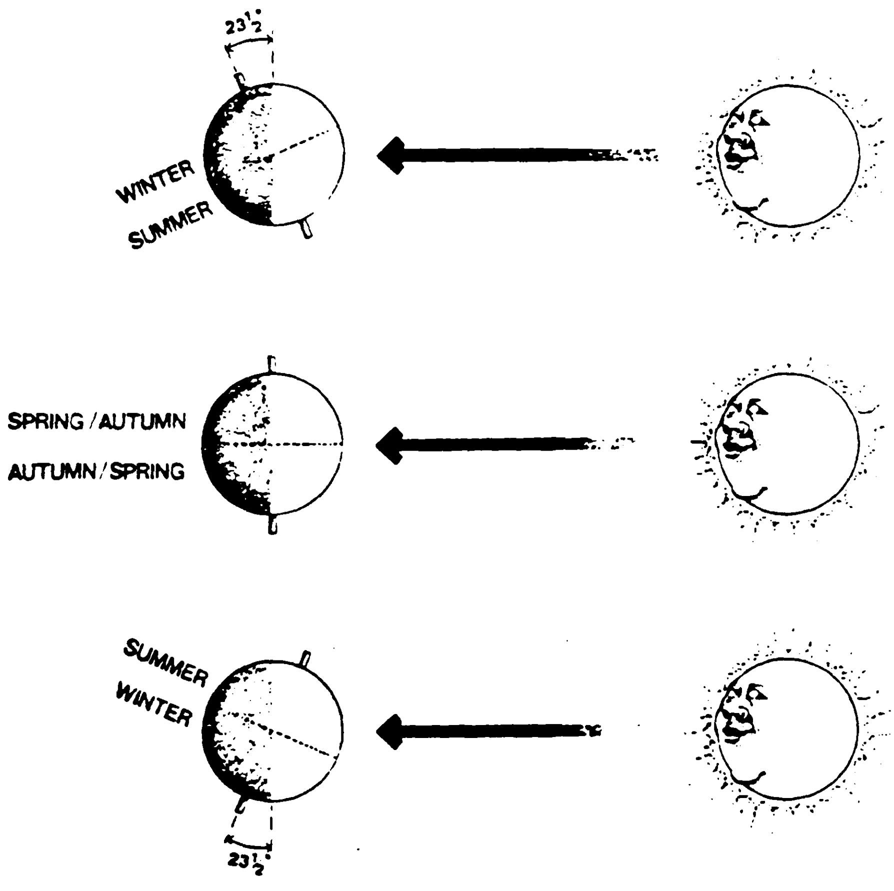


SOLAR RADIATION PATTERN

Fig. 3.4

Source : E. Mazria, The Passive Solar Energy Book,
Rodale Press, Emmaus, Pa. 1979.





The tilt creates the seasons.

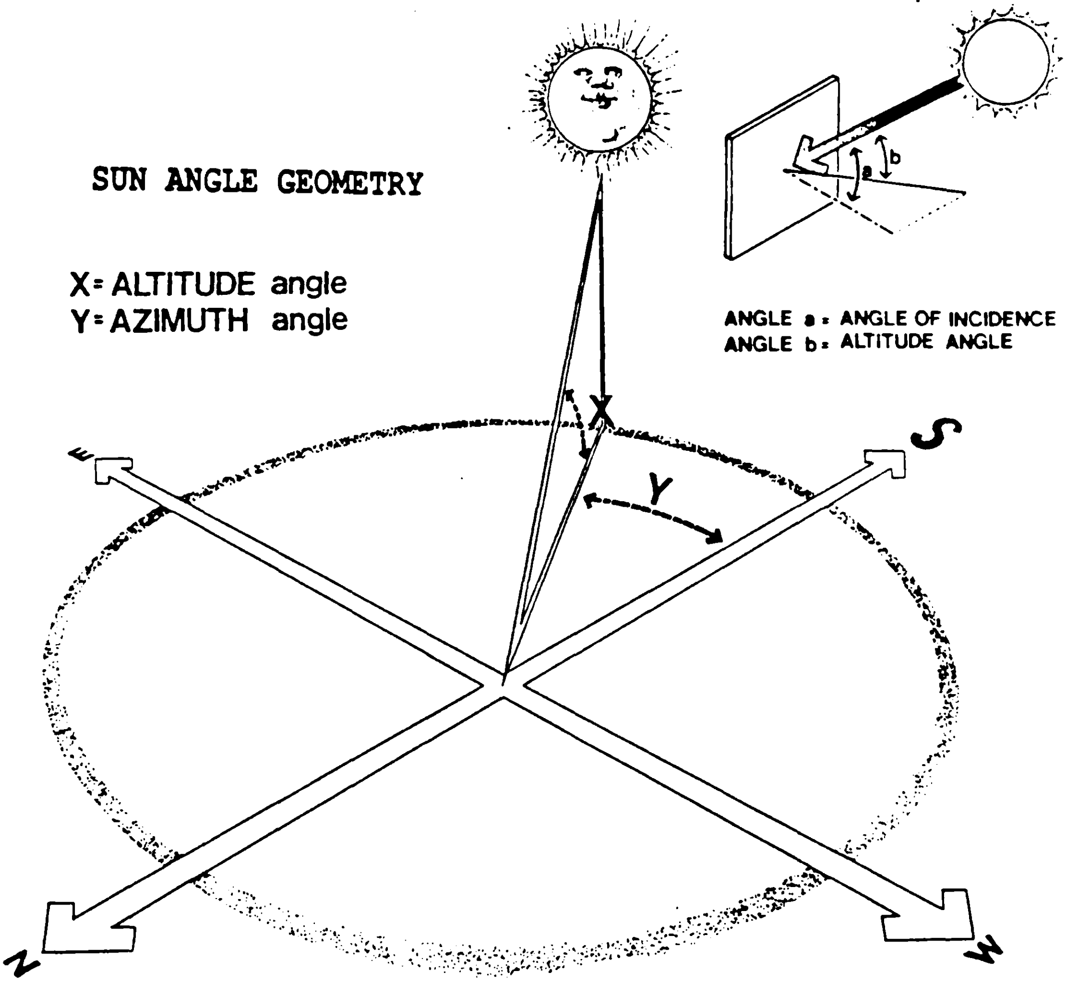
EARTH MOVEMENT PATTERN

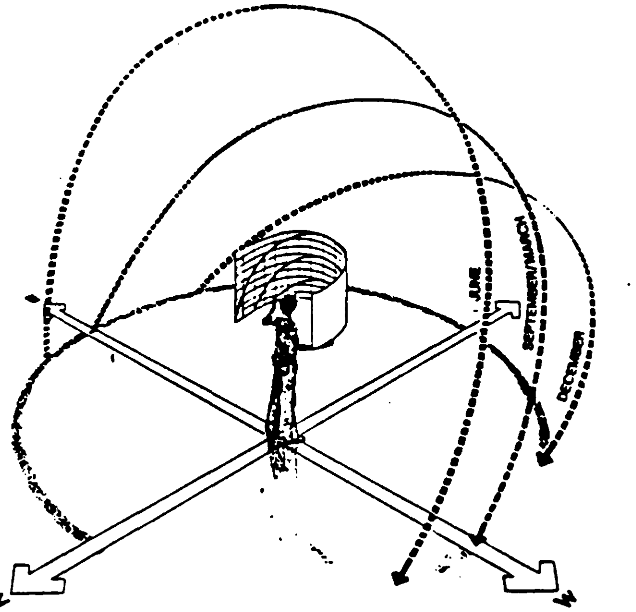
Fig. 3.5

Source : E. Mazria, The Passive Solar Energy Book, Rodale Press, Emmaus, Pa. 1979.

SUN ANGLE GEOMETRY

X= ALTITUDE angle
Y= AZIMUTH angle





SUN MOVEMENT PATTERN

Fig. 3.6

Source : E. Mazria, The Passive Solar Energy Book, Rodale Press, Emmaus, Pa. 1979.

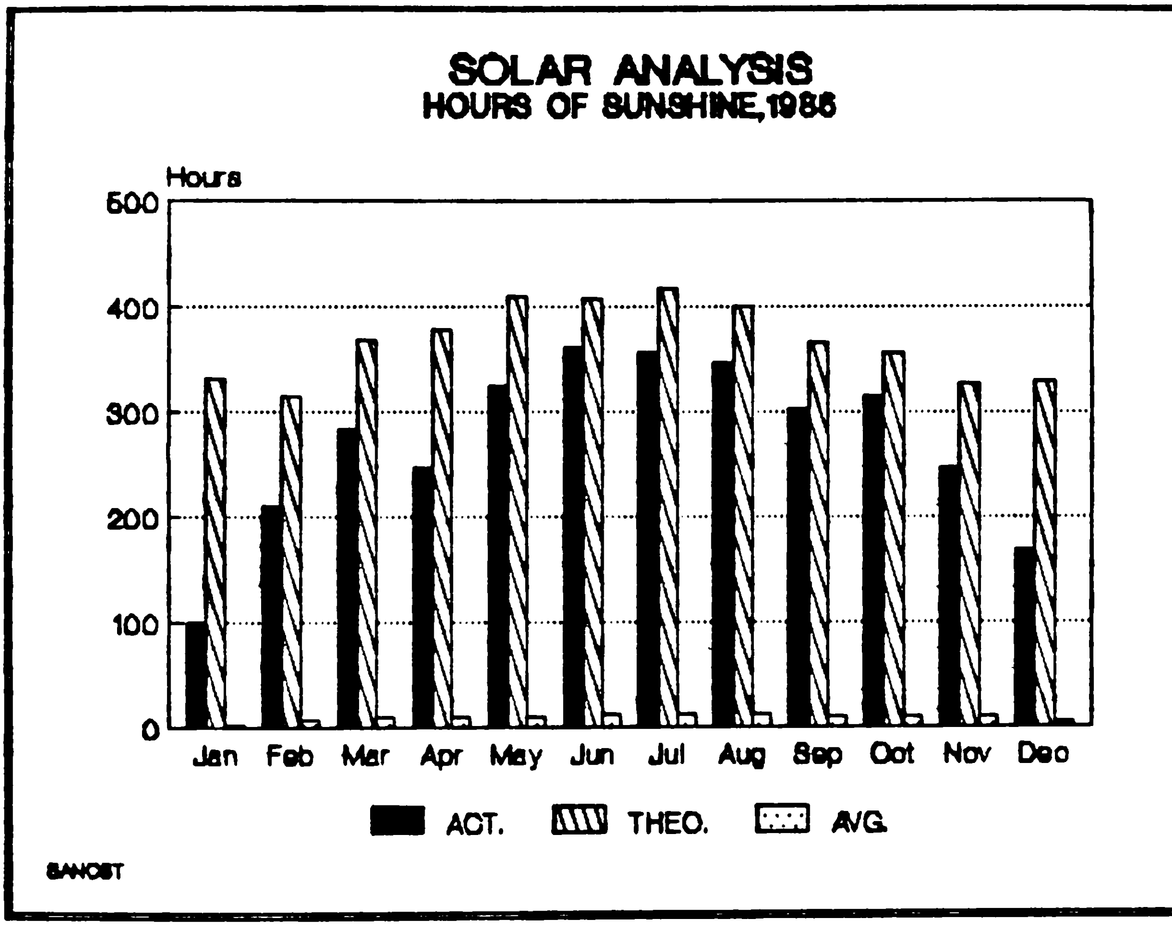

SOLAR ANALYSIS
HOURS OF SUNSHINE,1986
Hours
500
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
ACT. THEO. AVG.
SANCST

Fig. 3.7

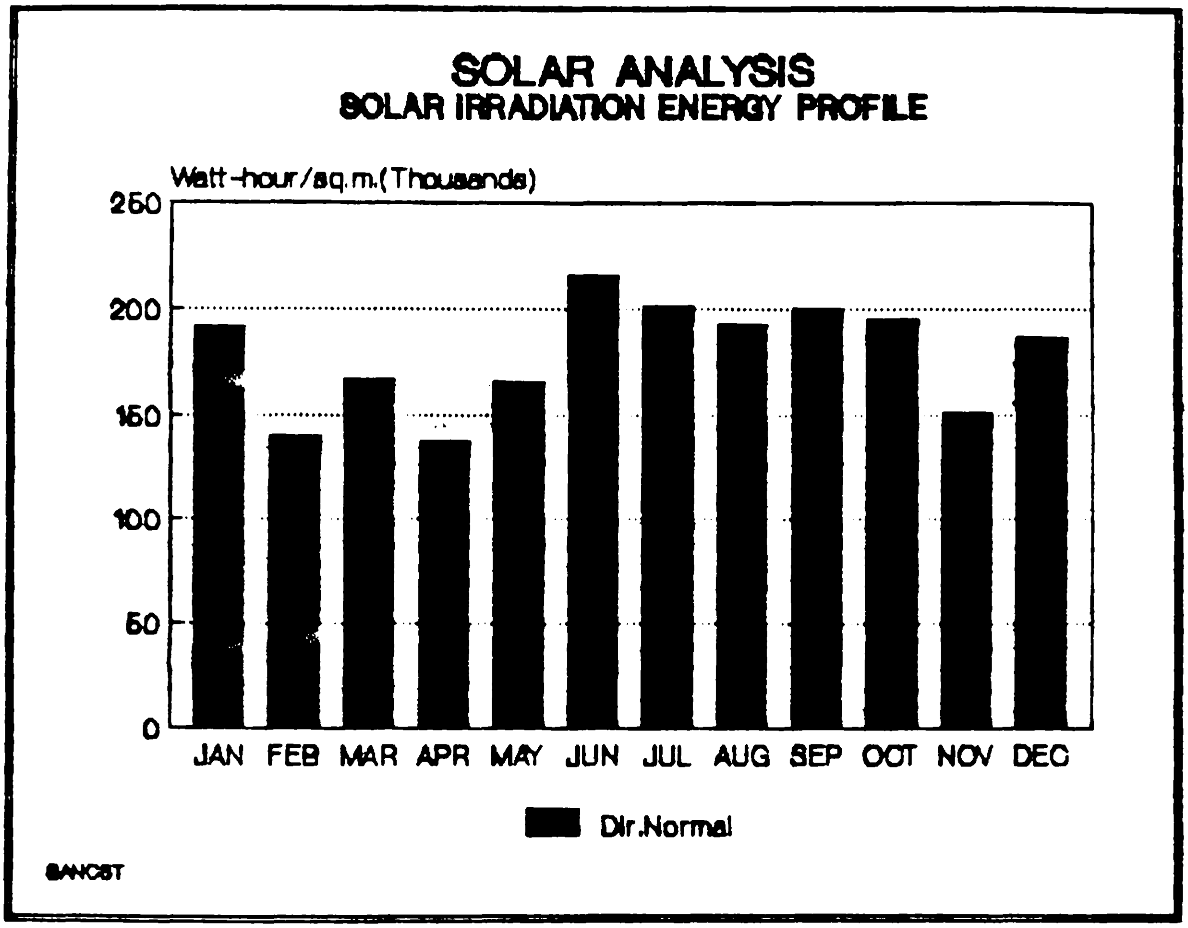

SOLAR ANALYSIS
SOLAR IRRADIATION ENERGY PROFILE
Watt-hour/sq.m.(Thousands)
250
200
150
100
50
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Dir.Normal

Fig. 3.8

III.3.3 Wind :-

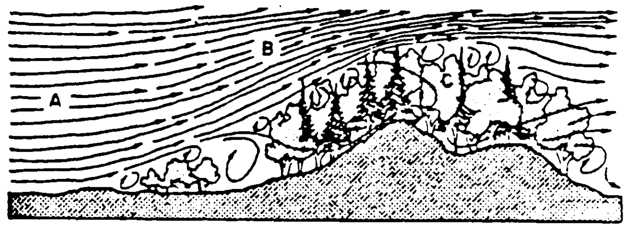
Wind is caused by differences in atmosphere pressure, the air flowing from higher pressure to lower pressure zones. Several factors may influence the thermal significance of wind :-

- wind vector, i.e. velocity + direction
- local geography and immediate surroundings
- comfort evaluation

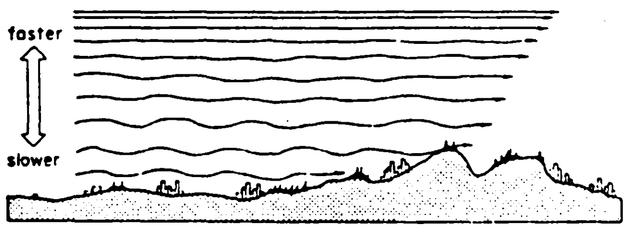
Wind tends to slow down at low levels, with the air almost at rest at the ground surface, while at high level wind is more strong and effective due to the absence of obstacles. Fig.(3.9)

Wind affects housing, both outside through surface convection and inside through infiltration and ventilation. Pressure is positive on the windward and negative on the leaward sides of a building. Fig.(3.10)

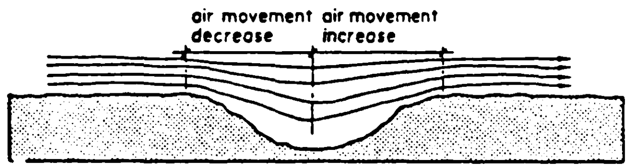
It represents a conventional natural power which can be utilized to relieve an overheated stress period in hot climate, for example by night ventilation and/or evaporative cooling. The wind pattern of AlRiyadh is fairly constant. The average speed is 5 m/s and the prevailing direction mostly south to south west. Since this direction is coming from the desert, the main characteristic of the wind is hot and dusty, with occasional sand storms. Maximum wind speed reading recorded in 1986 14 m/s, while the minimum is 0 m/s with all months tending to similar values.



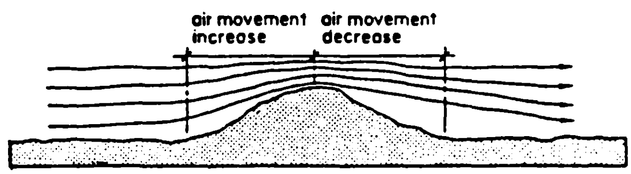
Air movement patterns change from one classification to another depending on internal and external factors. Here air movement varies from (a) laminar to (b) separated to (c) turbulent.



Friction reduces the movement of air by creating a drag effect.



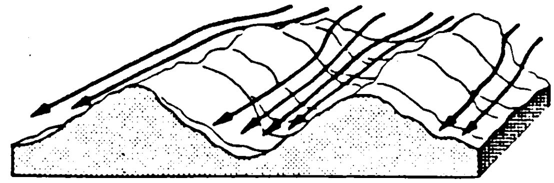
Concave surfaces such as valleys may vary the perceived velocity of the air movement. The airflow velocity decreases as the lines become farther apart and increases as the lines become closer together.



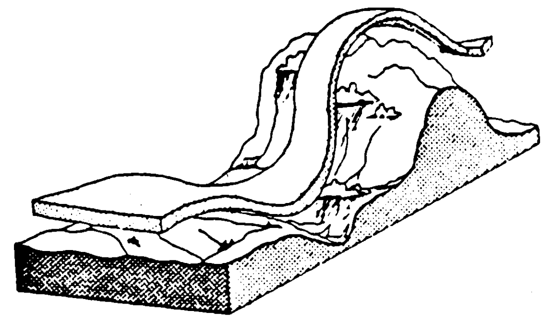
Convex surfaces such as hills may alter the apparent velocity of the air movement. The airflow velocity increases as the lines become closer together and decreases as the lines become farther apart.

Fig. 3.9 **AIR MOVEMENT PATTERN**

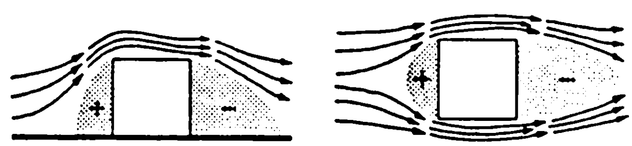
Source : Terry S.Boutet. Controlling Air Movement.
A manual for architects and builders,
McGrow-Hill Book Comany, 1987.



The pattern of air movement is altered by the presence of concave and convex elements. The airflow tends to concentrate in the concave forms, and the convex forms appear to separate the airstreams.



A moving air mass usually picks up moisture from concave surfaces and precipitates the same moisture onto convex surfaces.



Air movement around a building creates positive and negative pressure zones.

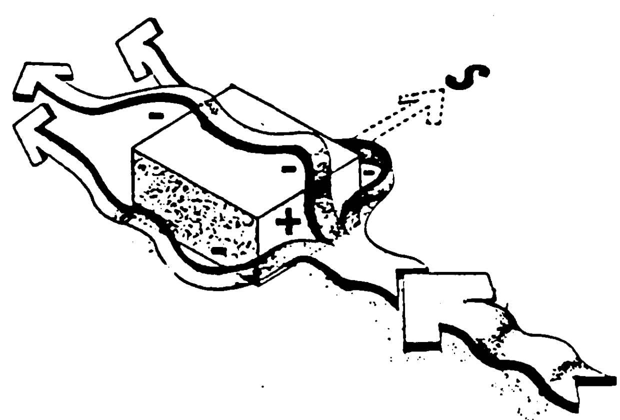


Fig. 3.10 **AIR MOVEMENT PATTERN**

Source : E. Mazria, The Passive Solar Energy Book, Rodale Press, Emmaus, Pa. 1979.

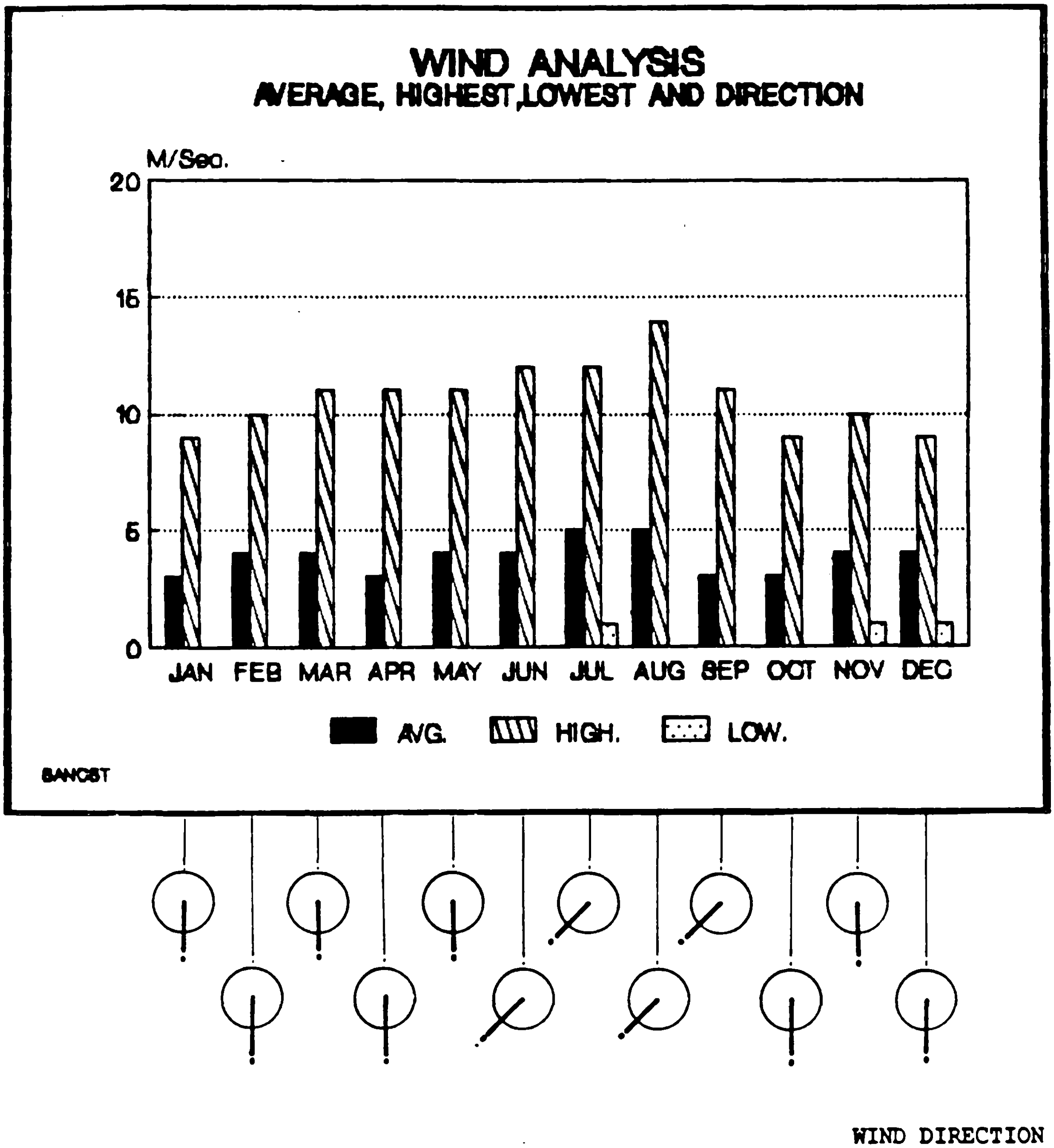

WIND ANALYSIS
AVERAGE, HIGHEST,LOWEST AND DIRECTION
M/Sec.
20
15
10
5
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
AVG. HIGH. LOW.
BANCST
WIND DIRECTION

Fig.3.11

III.3.4 Humidity :-

Atmospheric humidity refers to the water vapour content in the atmosphere due to the evaporation process from water surfaces and vapour entry to the air. Increasing temperature increases the water vapour capacity of air.

Relative humidity is a term to express the ratio of the absolute humidity to the saturated moisture capacity of the air at a particular temperature. Vapour pressure is another convenient way by which to express the humidity condition, i.e. ratio actual vapour pressure : saturated vapour pressure = RH, at a particular temperature. The rate of evaporation from the body is proportional to the vapour pressure differences between the skin surface and the ambient air.

In the desert zone although the vapour pressure is very low, the level is subjected to significant seasonal variations, usually higher in summer than in winter.

The concentration of water vapour decreases with latitude. The relative humidity is very low in the early afternoon as the air temperature is at a maximum, while at night it increases when the temperature drops.

The annual average relative humidity for Al-Riyadh is low, 40% in 1986,[3] and this dryness encourages the investigation of an evaporative cooling strategy.

Maximum relative humidity recorded for the 1986 was in April 80%, and the minimum in August 24%. Fig.(3.12)

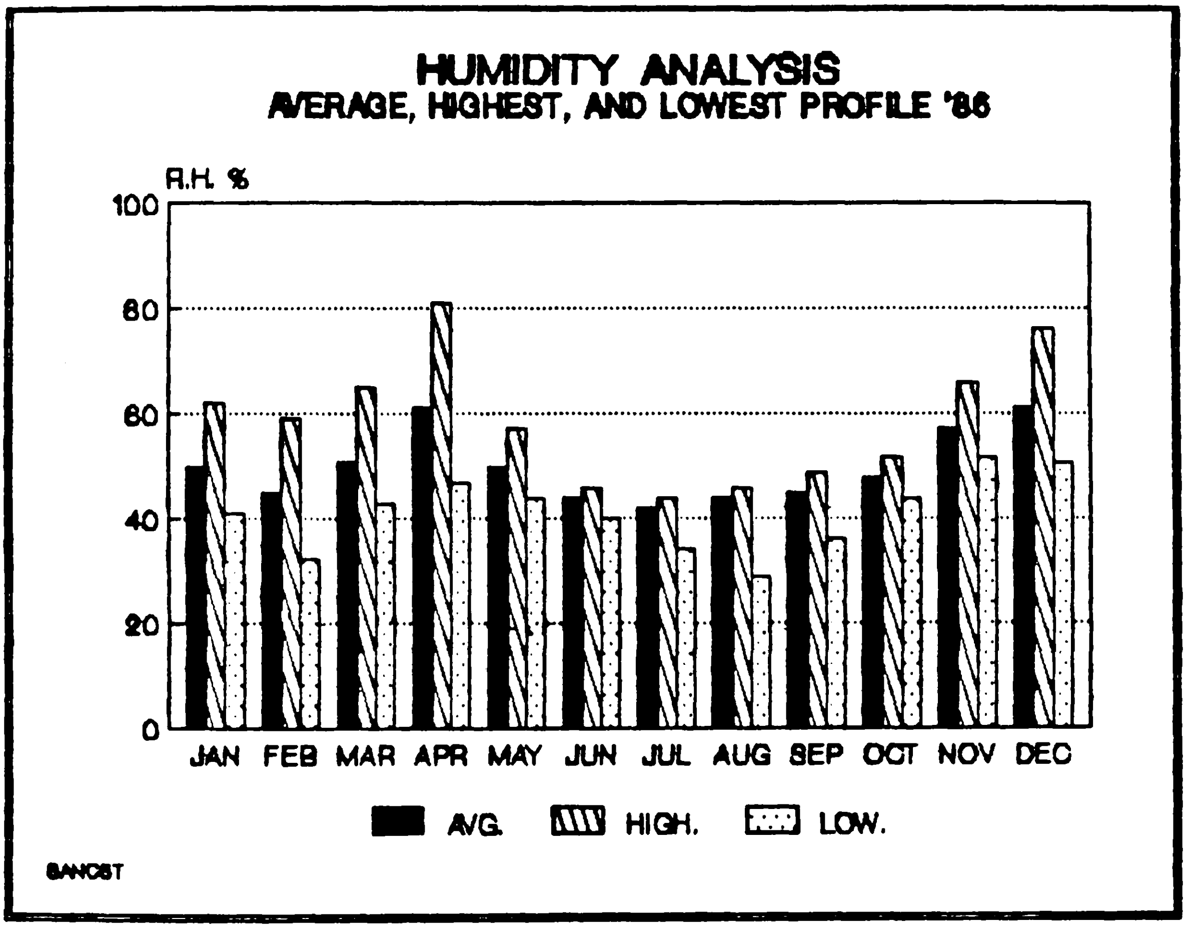

HUMIDITY ANALYSIS
AVERAGE, HIGHEST, AND LOWEST PROFILE '86
R.H. %
100
80
60
40
20
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
AVG. HIGH. LOW.
BANCST

Fig. 3.12

III.3.5 Rain fall :-

When an air mass becomes saturated and its temperature drops to a critical point, condensation then occurs in cloud form.

Wind blows it to warmer land, the system then becomes unstable, air expands, and releases its moisture as conventional precipitation.

The desert maintains its dryness characteristic due to the clear sky condition and low possibility of cloud formation. The effect of this element is very limited on a building's thermal behaviour, but can be significant with respect to environmental comfort.

The nature of Al-Riyadh as a desert zone, free from any surface water, is well known. The total amount of rainfall is very low, with an irregular pattern and has no significant effect on surface dryness.

The total recorded in 1986 was 25mm, January having the highest reading of 9mm, while in June, September, and October there was nothing. Fig.(3.13)

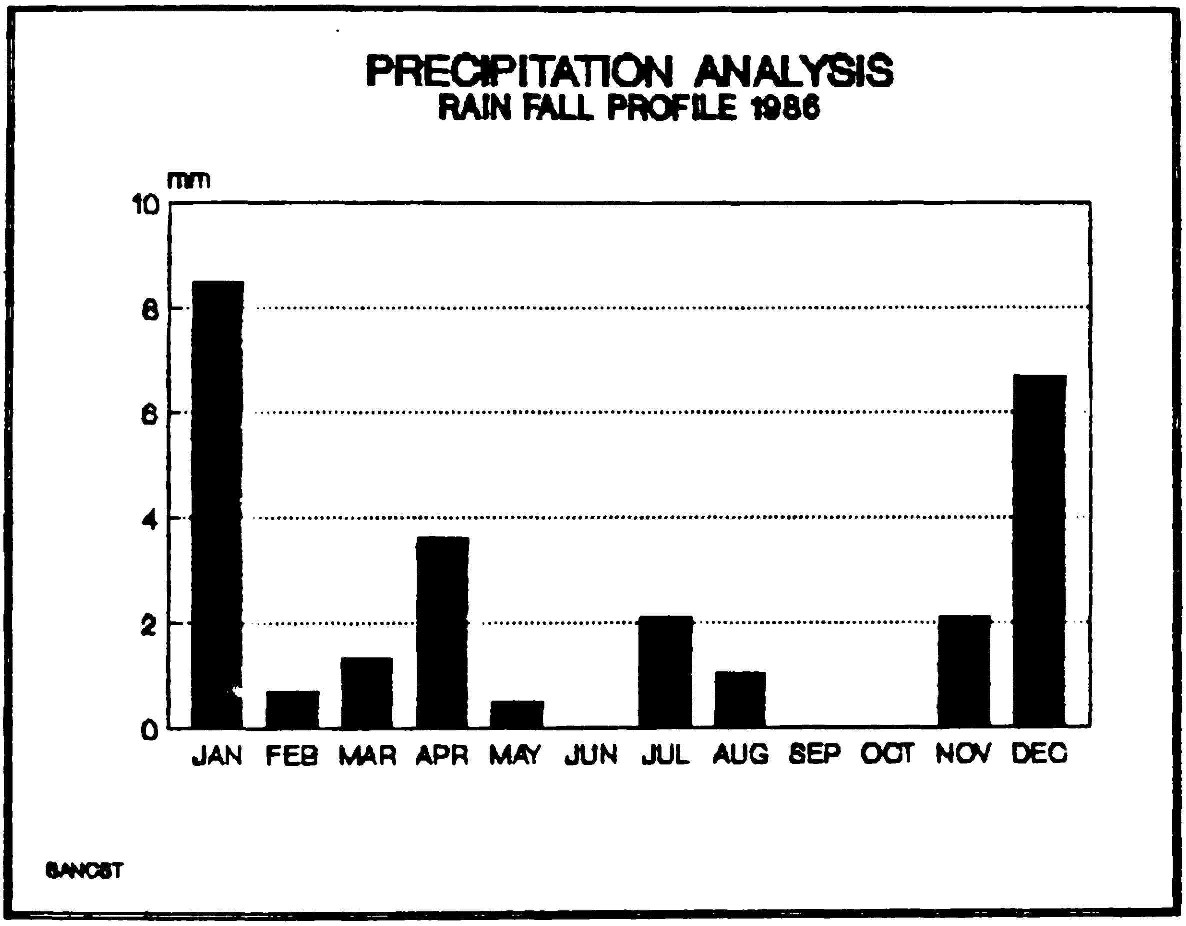

PRECIPITATION ANALYSIS
RAIN FALL PROFILE 1986
mm
10
8
6
4
2
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
SANCST

Fig. 3.13

III.4 Human Requirement for Comfort

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

The human thermal comfort zone is subject to complex parametric relationships.

Equations by MacFarlane[(4)] from Fanger assume that during rest or exercise, comfort is associated with thermal equilibrium, and with a mean skin temperature of 33°C.

But field studies emphasise the fact that the heat equation approach to comfort such as that of Fanger, does not adequately cope with acclimatisation and the time sequence of changes that takes place in people living in hot or cold regions.

Humphreys[(5)] has analysed many of the completed questionnaire studies of comfort, and found the face value of comfort zones ranged from 17°C in England to 30°C in Iraq and India. This variation of comfort level is attributed to the following factors :-

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

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

III.4.1 Physiological Responses

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

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

The scaling method shown in fig.(3.14), for charting thermal sensation was developed by several investigators.[6] This expresses thermal sensation of pleasantness or its opposite as functions of air temperature. The figure also indicates that the feeling of comfort is spread over a wide span of air temperatures, for, sensing temperature as neutral, we tend to accept it as pleasant. The neutral and pleasant air temperature is between of 28°C and 30°C.

There is also a wide range of comfort/discomfort perception - for example at 40°C one curve signifies 'very uncomfortable' and another 'comfortable'. The precise source of each curve is not given and neither is there information with respect to other parameters such as wind, RH, metabolic activity and clothing.

Steven's[7] chart in fig.(3.15), runs contrary to previous finding. The chart dicusses cold and hot discomfort in terms of power laws, indicating that the magnitude of sensations are power functions of the stimulus.

Steven's operative temperature (a temperature indicating dry heat exchange of the body) is 22°C, discomfort produced by cold increase as 1.7 power of the difference between an operative temperature and the actual temperature.

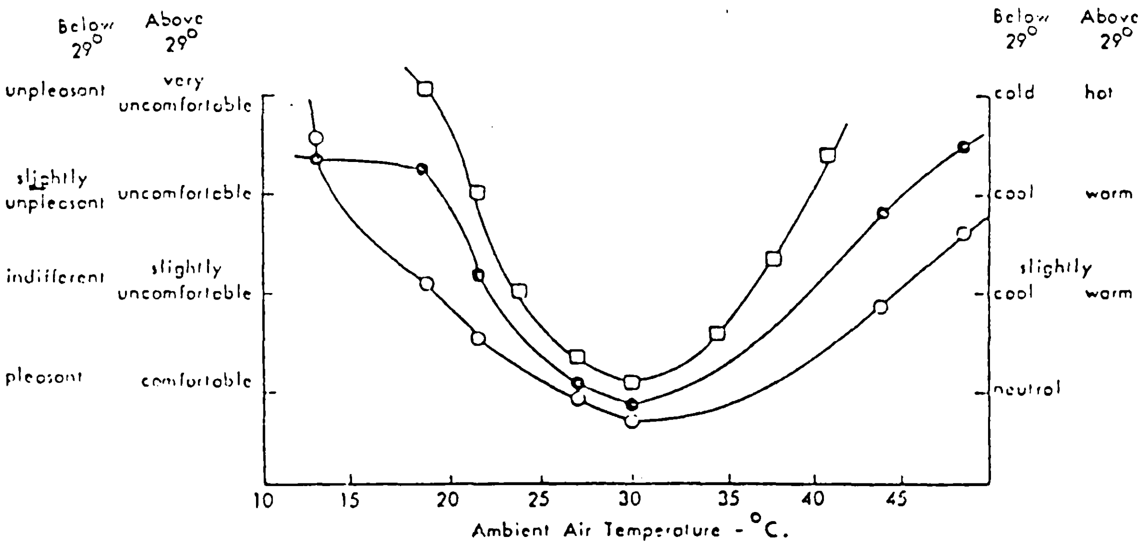
On the other hand discomfort due to heat increase as 0.7 power of the difference bettween the ambient temperature and an operative temperature of 22°C.

Wyon[8], adapted another comfort relationship with thermal environment by expressing task performance by 'arousal' level as a function of ambient temperature, i.e. people tend to be soporific at high temperature and alert at lower temperature.

The theory is that, for every activity there is an appropriate level of arousal, levels above or below tends to depress performance.

Wyon's chart in fig.(3.16), expresses this relationship, with a comfort span between 18°C at the lower level and 27°C at upper level. Sensation of heat discomfort starts beyond the upper level and cold discomfort starts below the lower level.

Going through the findings, we can notice the variation in determining the comfort point, and hence the complexity of the human sensation system with respect to the thermal environment.



COMFORT SCALE

Fig. 3.14

Source : A. P. Gagge, J.A.J. Stolwijk,and J.D.Hady. Comfort and thermal sensations and associated physiological responses at various ambient temperatures, Environmental research, 1967.

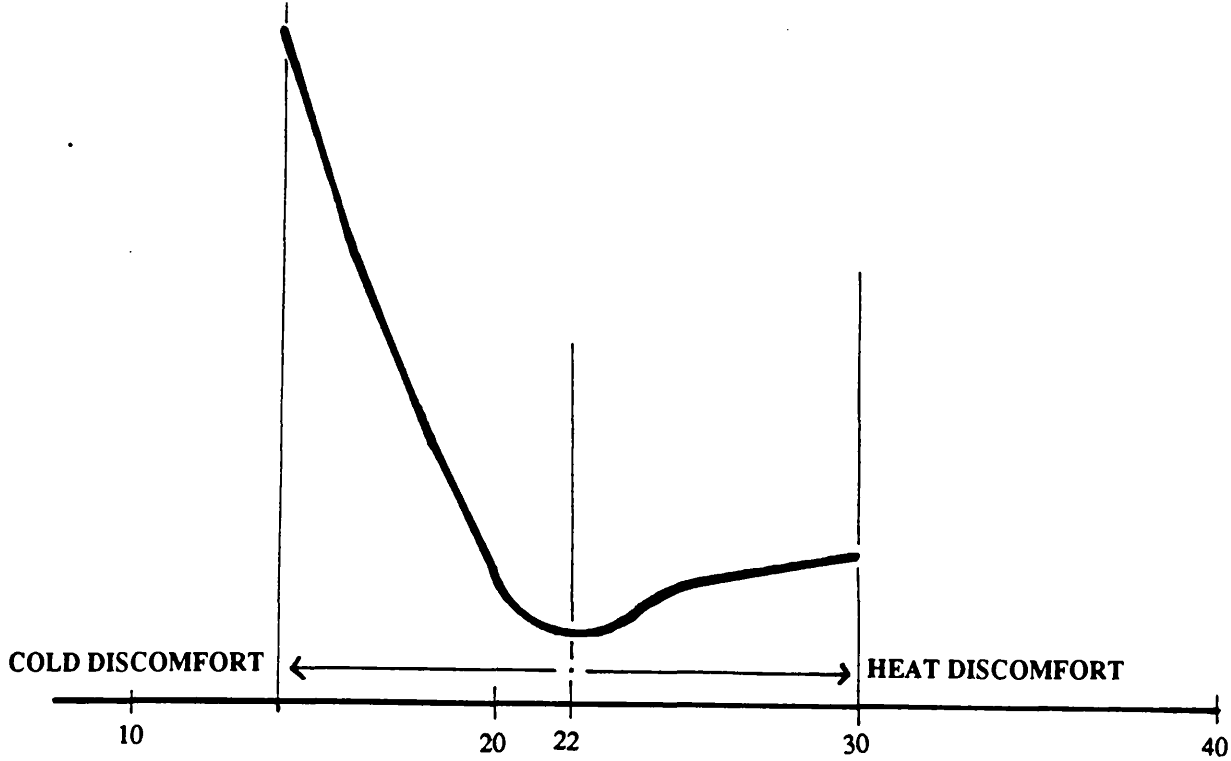


Fig. 3.15

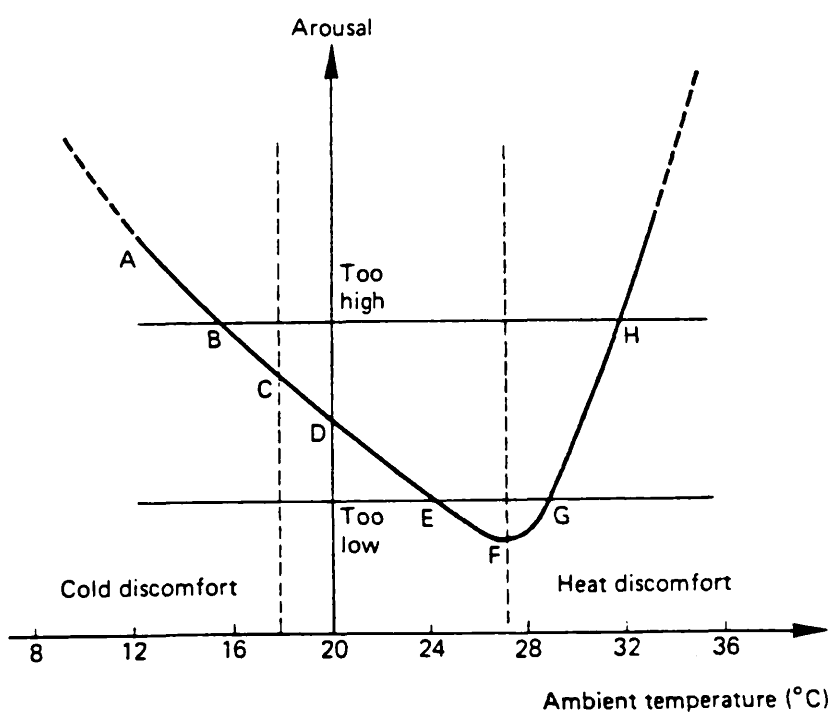


Fig. 3.16

Source : T.A.Markus and E.N.Morris, Buildings, Climate and Energy, 1980.

III.4.2 Behavioural Responses and adaptation

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

Taking a prolonged rest at midday and delaying some demanding activities until evening are matters of course in hot climates, taking off clothing, drinking to compensate for sweat loss, moving from sun to shade, and turning on air conditioning plants, are different forms of behavioural responses.

Such behavioural adjustment may differ from one person to another or from one nation to another due to a process known as habituation.

III.4.3 Habituation

According to Macfarlane[4],the habituation effect on comfort perception arises from repeated exposure of the nervous system to stimuli and thus reduction of central neuronal response.

The frequency of firing from skin receptors for heat does not decrease in habituation, but the amount of information passing through the spinal cord into the brain is reduced significantly.

For example Giles[9] noted that, during hot desert nights, he as an Englishman was unable to sleep because of the heat, yet the Aboriginals slept soundly through the night on the hard substrate, exposed to same hot environment.

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

III.4.4 Acclimatisation

Regular exposure to heat also improves tolerance in that automatic physiological responses reveal reduced strain. The lungs are less active, the skin more so and circulation lessens. The ability to adapt upon transition from one temperature zone to another is called acclimatisation.

Kamon(6) infers that acclimatisation alters the habituation system and modifies it to cope with new environmental circumstances. Europeans going to live in the tropics habituate to the temperature so that after 2 or 3 years exposure they accept environment that were initially difficult and unpleasant, and the converse hold true, for people from tropics going to live in cold climate.

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

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

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

The acclimatisation process has long been acknowledged in the sense of climate and thermal comfort, but not in health influence. For example, Parkes[10] in 1878 pointed out that there is no acclimatisation in any sense of the word for malaria, and recommended to discontinue use of the term 'acclimatisation' which has several meanings in favour of 'accommodation'.

Hence, it is difficult to determine the comfort zone precisely, but generally speaking the human comfort zone in the desert climate is somewhat different from the other climatic zones. The margin of permissible condition for summer comfort is generally set higher than other climate zones by two or three degrees.

The summer comfort zone range given by Kamon[6] is 26-

30°C , but for acclimatised people at rest or engaged in sedentary activity, the winter level is 21-20°C .

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

At certain times of the year and 24 hour cycle natural ventilation can help to maintain the internal temperature at a tolerable level. At other times, particularly during the day time, ambient air temperature may be critically high and thus undesirable with respect to evaporative cooling and convective heat exchange with human skin.

Therefore, humidification of the incoming hot and dry air during the day time could help to alter the internal temperature by a few degrees.

At night when the ambient temperature drops below the internal, ventilation may enable cooling of the interior space. In well cross ventilated buildings, the average in-door speed may be taken as 30% of the prevailing wind speed quoted by meteorological data.

Therefore, efficient cross ventilation would be about 3.5 m/s, and a poor level would be 1.5 m/s at an outdoor wind velocity of (10 m/s) [1].

III.5 Strategies of Climate Control

The appropriateness of a building design in terms of climate control is determined by the key ambient parameters and requirements for human comfort.

The concept of relating coincident temperature and humidity conditions to the needs for climate control in building design was first given a well-defined structure by Olgyay[11].

The Bioclimatic chart is a Temperature-Humidity diagram used to display the comfort needs of a sedentary person. Work has done in this field by several researchers. An important extension of the original work by Olgyay, was made by Givoni[11], who determined limits of effectiveness of different building practices in meeting bioclimatic comfort needs. A new diagram produced by Givoni was termed "Building Bioclimatic Chart".

In this chart the limits of climate control strategy, identified by the organization chart, fig.(3.18), is plotted on a standard psychrometric chart*.

Each strategy is delineated by an effectiveness zone which can be visualized as an extension of the comfort zone.

The Building Climatic Chart indicates that whenever ambient outdoor temperature and humidity conditions fall within the designated limits of control strategy, then the interior of the building designed to execute that strategy will remain comfortable. Seventeen zones can be read from the chart. One of these is the comfort zone, while the others indicate the relevance and appropriateness of specific climatic control strategies to achieve comfort.

* Water vapour/moisture as a function of temperature.

Table no.(3.1), gives identification of these zones and table no.(3.2) with fig.(3.17), gives the control strategies :-

Table (3.1)

BIOCLIMATIC NEEDS ANALYSIS	CONTROL STRATEGIES
Total Heating < 20°C	1-5
Total Cooling > 26°C	9-17
Total Comfort from 20 to 26°C ET - 0.7 kPa to 80% RH	7
Dehumidification > 2.0 kPa or 80% RH	8-9,15-16
Humidification < 0.7 kPa	6A,6B,14

Table no.(3.2)

STRATEGIES OF CLIMATE CONTROL	ZONE
Restrict Conduction	1-5,9-11,15-17
Restrict Infiltration	1-5,16-17
Promote Solar Gain	1-5
Restrict Solar Gain	6-17
Promote Ventilation	9-11
Promote Evaporative Cooling	11,13-14,6B
Promote Radiant Cooling	10-13
Mechanical Cooling	17
Mechanical Cooling & Dehumidification	15-16

III.6 Responding to Climatic Analysis

An average reading of temperature and relative humidity is plotted on the modified Building Bioclimatic Chart. The meteorological data of year 1986 was taken mainly in this analysis. figs.(3.18 & 3.19)

As the charts illustrates, we can notice that part of February, all March, part of November, and part of December are falling in zone no.7 which is considered to be the comfort one. Table no.(3.3), summarizes the situation for the entire year :-

Table no.(3.3)

MONTH	EFFECTIVENESS ZONE	CONTROL STRATEGY
JANUARY	4,5	Refer to table No.(3.2)
FEBRUARY	5	
MARCH	7	
APRIL	7,9,10,11,16	
MAY	16	
JUNE	16	
JULY	16	
AUGUST	16	
SEPTEMBER	16,10	
OCTOBER	11,7	
NOVEMBER	7,5,4	
DECEMBER	4	

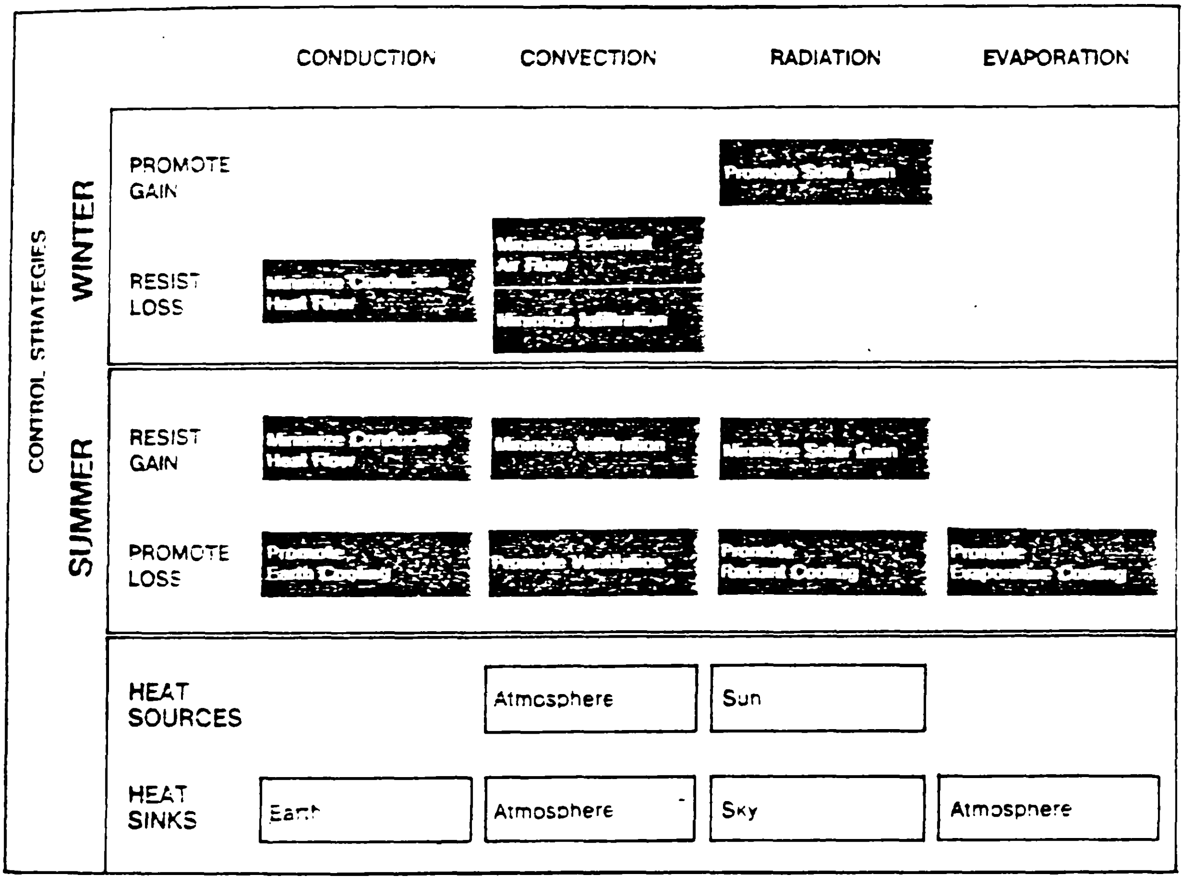


Fig. 3.17 CONTROL STRATEGIES

Source : D. Waston, Faia, and K.Labs, Energy Efficient Building Principles and Practice, Climate Design, 1983.

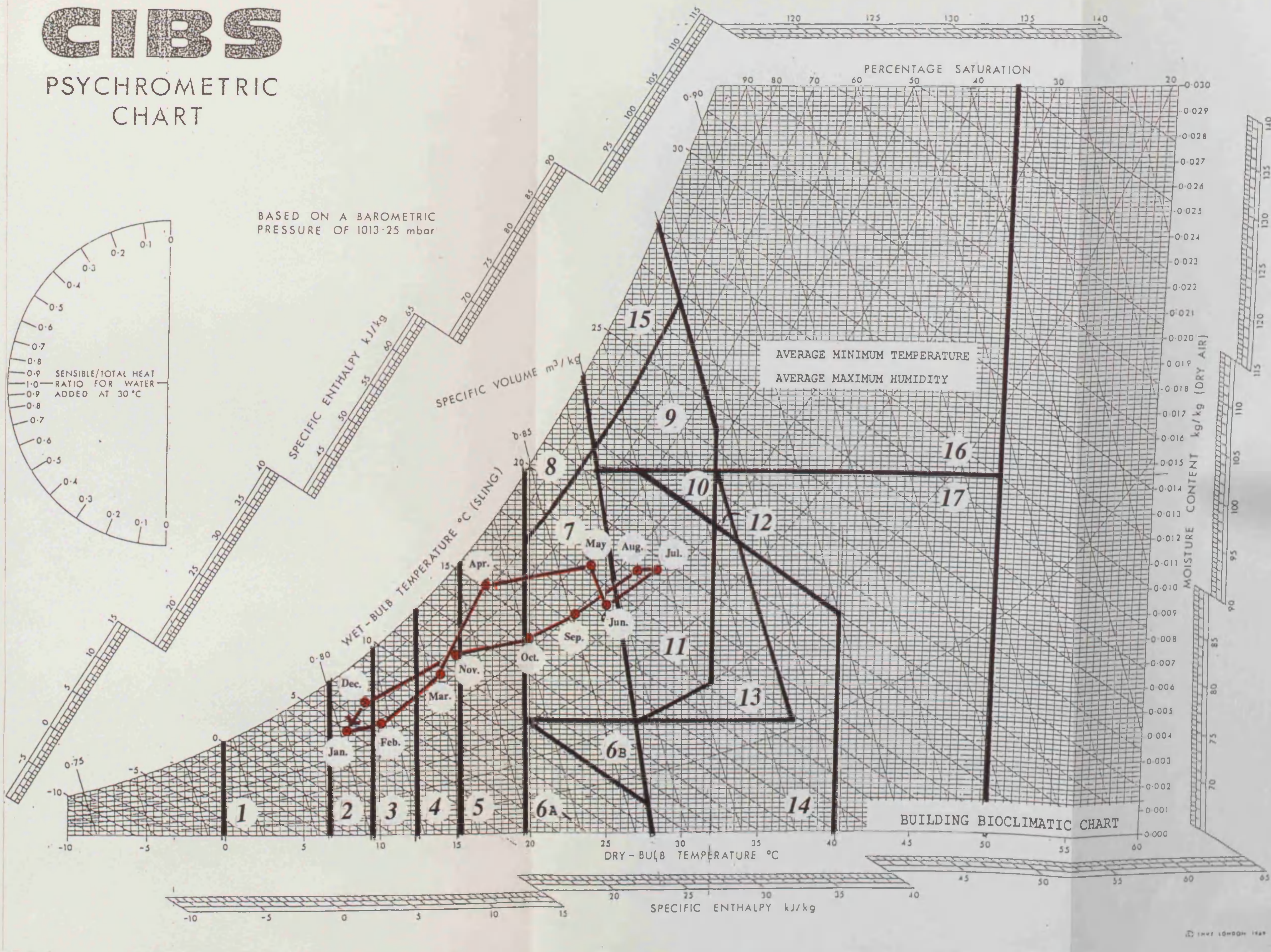
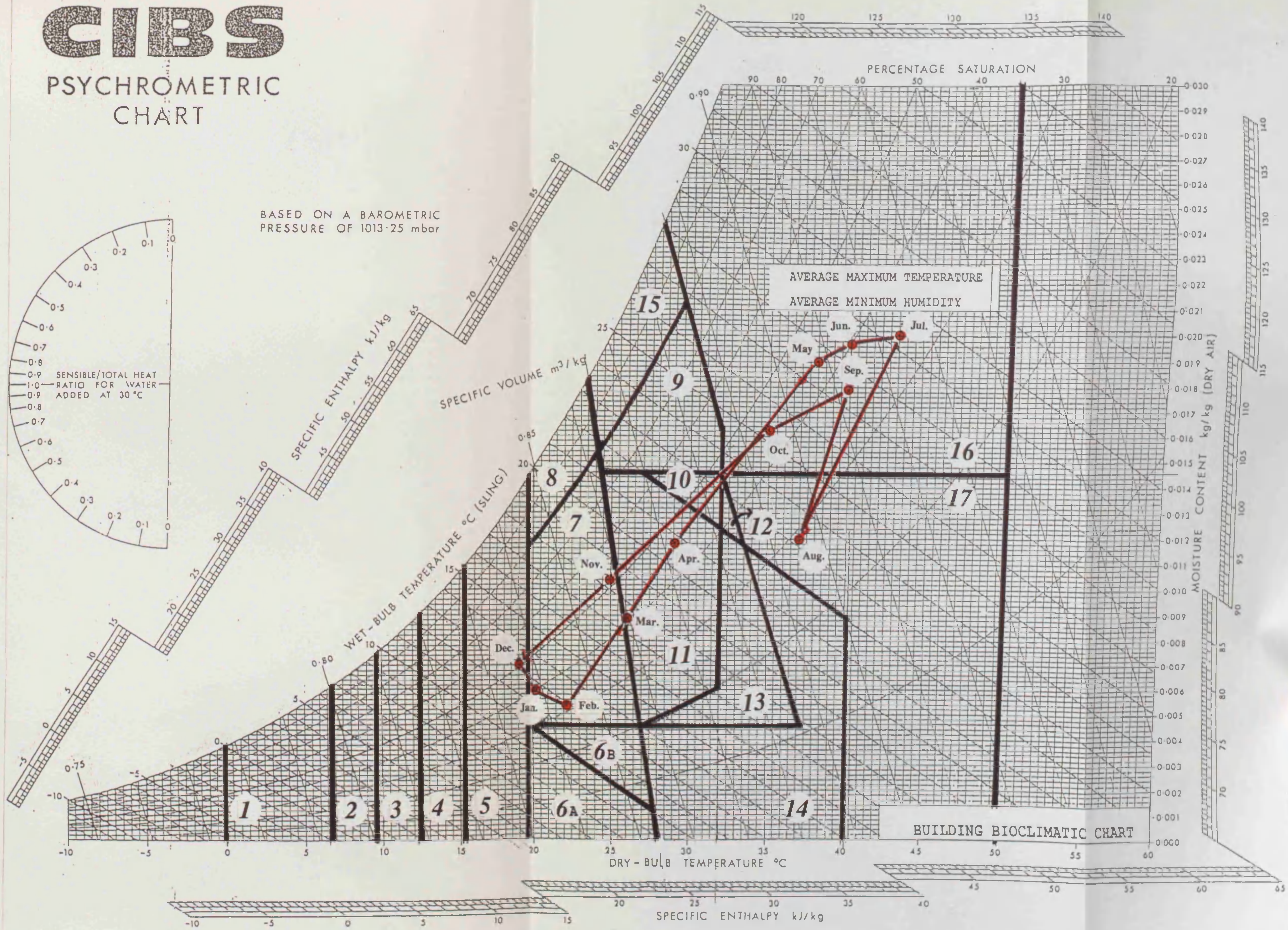

CIBS
PSYCHROMETRIC CHART
BASED ON A BAROMETRIC PRESSURE OF 1013·25 mbar
SENSIBLE/TOTAL HEAT RATIO FOR WATER ADDED AT 30 °C
SPECIFIC ENTHALPY kJ/kg
SPECIFIC VOLUME m³/kg
WET-BULB TEMPERATURE °C (SLING)
PERCENTAGE SATURATION
AVERAGE MINIMUM TEMPERATURE
AVERAGE MAXIMUM HUMIDITY
MOISTURE CONTENT kg/kg (DRY AIR)
DRY-BULB TEMPERATURE °C
BUILDING BIOCLIMATIC CHART
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
1
2
3
4
5
6A
6B
7
8
9
10
11
12
13
14
15
16
17

Fig. 3.18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PERCENTAGE SATURATION
AVERAGE MAXIMUM TEMPERATURE
AVERAGE MINIMUM HUMIDITY
MOISTURE CONTENT kg/kg (DRY AIR)
DRY-BULB TEMPERATURE °C
BUILDING BIOCLIMATIC CHART
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
1
2
3
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6A
6B
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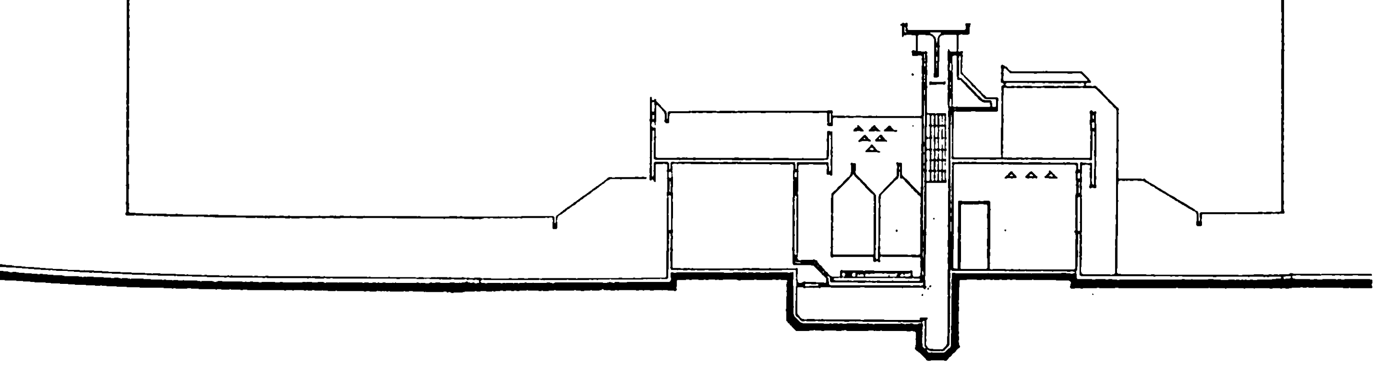
Fig. 3.19

CHAPTER IV



CHAPTER IV

DESERT ARCHITECTURE

IV.1 Overview

Over one third of the earth's land mass and fifteen percent of the world's population currently live in arid regions. Global population growth is placing increasing demands on utilizing these regions more efficiently.

The natural indigenous architecture has been effected by the recent technological change. The introduction of mobilization into the urban pattern has drastically altered the traditional context. Together with the other products of modern technology such as large paved surfaces to accommodate cars, air-conditioners, and building materials,this has resulted in adverse changes to the micro-climate of the urban situation.

This chapter highlights some examples of the environment - responsive design in different parts of the Islamic world which share the same climatic character; and the recent approaches of modern architecture, which can be a creative aspiration for contemporary design solutions.

IV.2 Indigenous Architectural Approaches

Traditional building, has served Islamic principles and climate needs as well. It developed intuitive responses to these varying constraints, with a humble supply of local materials and simple techniques. Over the centuries of refinements based on experience, the previous people were able to a achieve reasonable degrees of human comfort.

IV.2.1 Courtyard houses :-

Courtyard houses have an ancient history, examples have been found excavated at Kahun, Egypt that are believed to be five thousand years old[1].

Essentially, the courtyard house which consists of rooms on three or all sides of an open atrium, is associated with Arab culture, but its distribution extends between Sale and Marrakesh in Morocco to the west, and India to the east where the Haveli or atrium house is common in the cities developed under Moghul influence.

Courtyard houses with local variations are to be found in Arab and Persian communities throughout the Middle East, but their plans and use of space may vary considerably. Some are single storeyed, some are several stories high, but in principle the courtyard performs a climatically similar role.

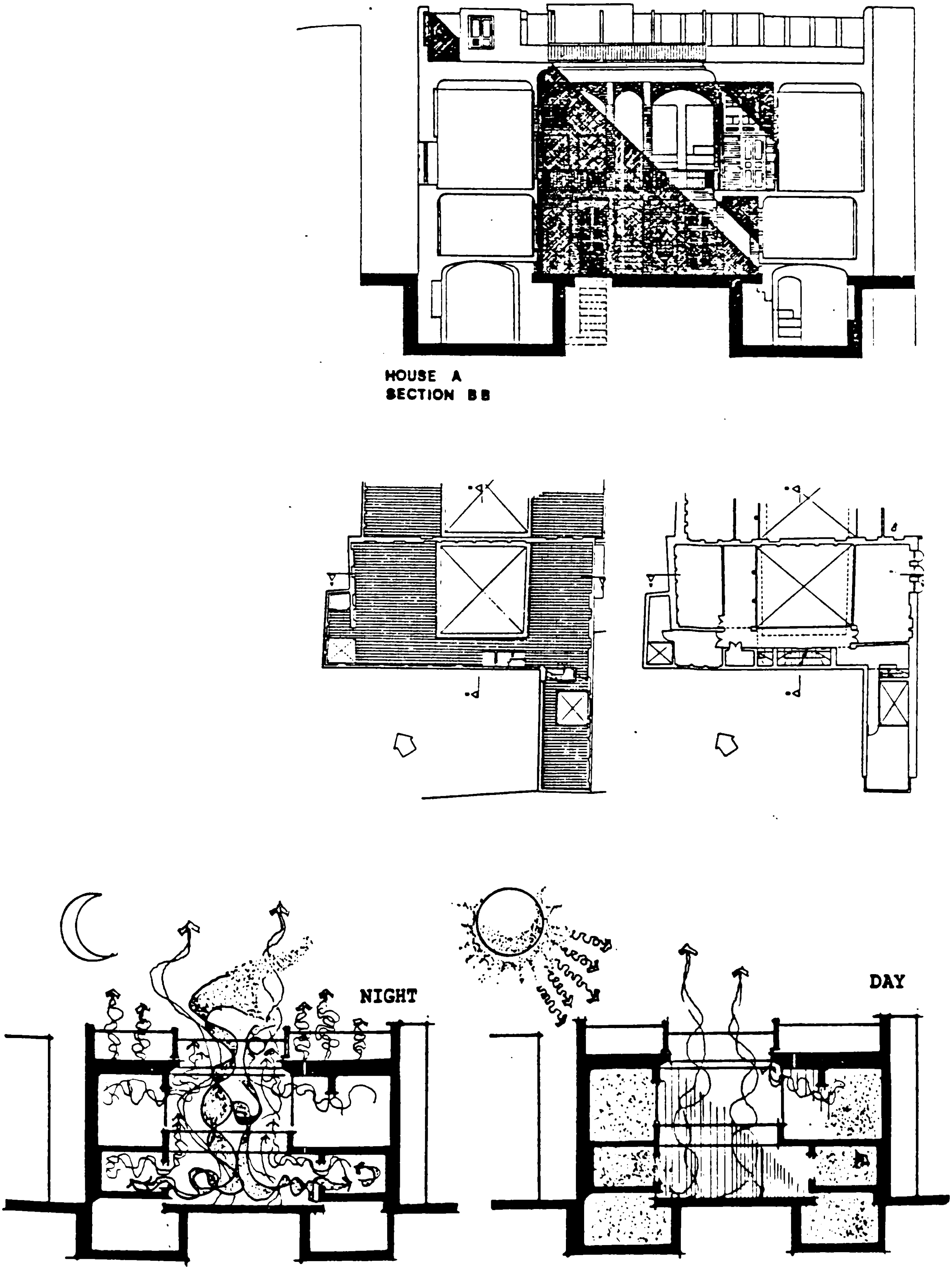
Dunham[2] points out that the high walls on all sides shade the court and protect it from direct sunlight during the greater part of the day; but leave it open to the coldest part of the sky, the zenith, to which it loses heat all night and day, unless in direct radiant view of the sun. The greatest radiation loss occurs towards the zenith because the depth of atmosphere to be traversed is a minimum.

The earth beneath the courtyard becomes a heat sink, which in turn receives heat from the surrounding areas in contact with it. This process is reinforced by the uni-directional heat transfer that occurs on rooftops.

During the day, the air heated there rises, but during the cool hours of the night the benefit of the heat exchange is transferred by convection to the lower regions of the house as newly formed layers of cooled air sink through the courtyard.

The collected cold air flows into the rooms surrounding the courtyard and withdraws heat from massive interior wall and roof elements. These elements are protected from incoming radiant heat by being in shade, and from the rising temperature of the air outside by the resistance of the structure to the effects of exterior air movement.

By remaining cool, walls and floors help to reduce the interior air temperature as well as the mean radiant temperature of the living areas. fig.(4.1)



COURTYARD HOUSES

Fig. 4.1

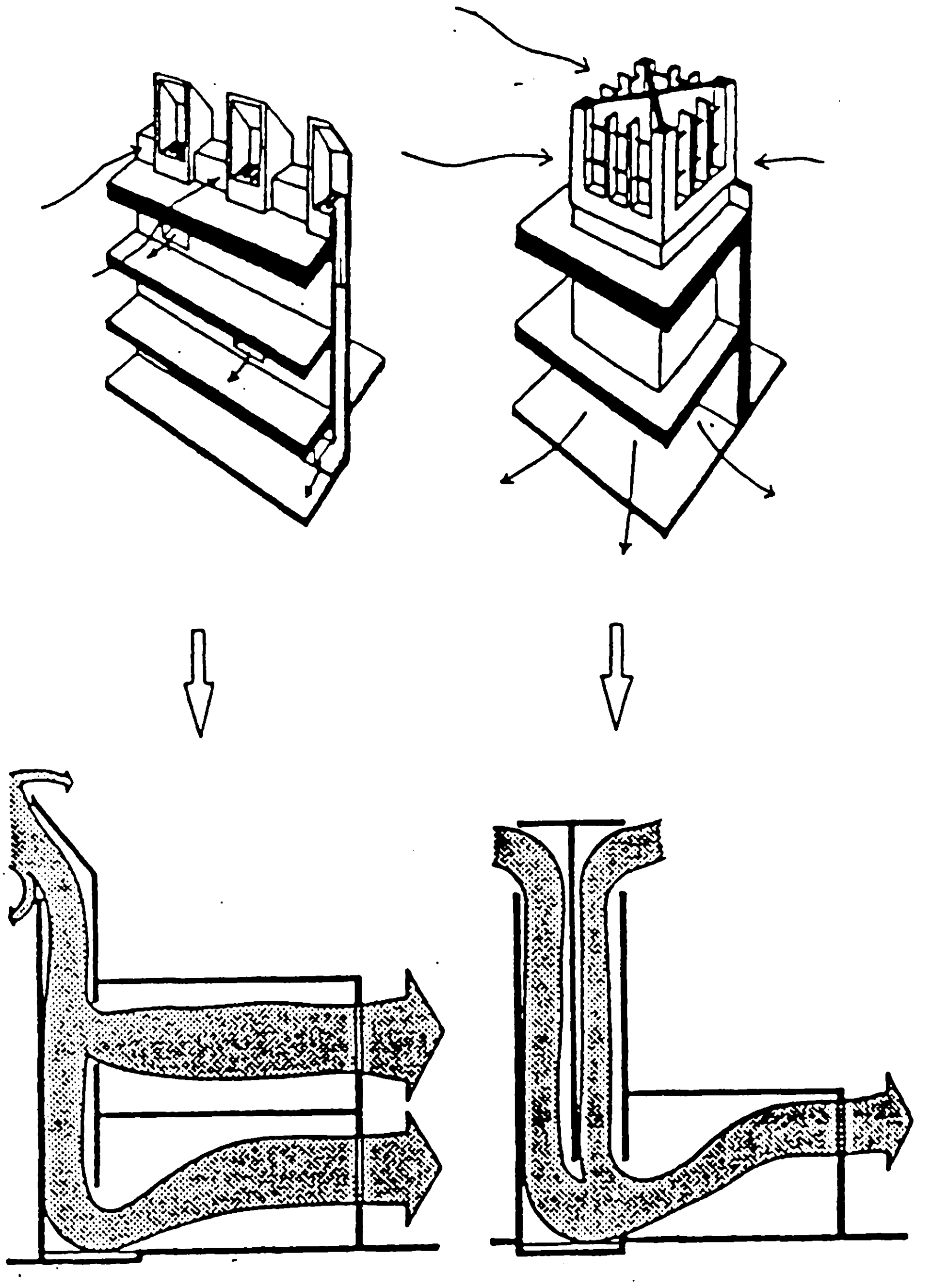
IV.2.2 Wind scoops :-

One of the most widely used climate modifiers is the wind scoop or wind catcher device. It collect the breezes above the roof level and transmits them to the living quarters, fig.(4.2). It can also function without wind due to thermal buoancy or stack effect if designed and constructed in a suitable manner. It is also possible for the flow to reverse in day and night situation used in conjunction with a courtyard, fig.(4.3).

In common use from North Africa to Pakistan, wind scoops take a variety of form. Those in Pakistan are stretched fabric over a cruciform frame adjusted to deflect breeze down a ventilating shaft. A cover can be lowered or closed during the cool season. It should be noted that such a technique implies an equilibrium period when no thermo syphoning can take place.

In Egypt the 'malqaf' is still functioning in numerous houses, its equivalent the 'badgir' of Iraq, Iran, and the Gulf areas. Sophisticated structures of unknown date, have been described as early as the fourteenth century.

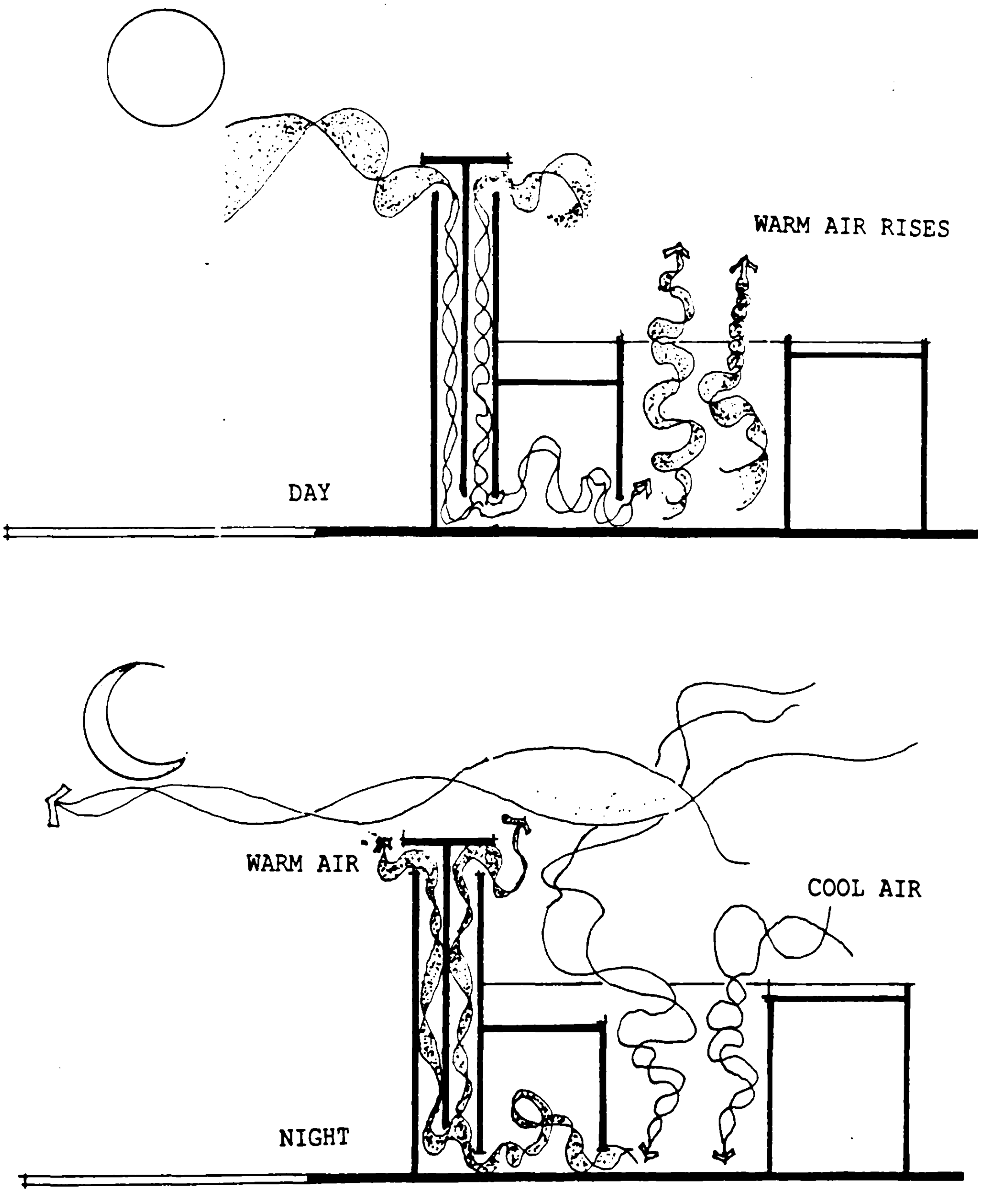
The Iranian type is a tower with a row of tall slots,or vents, which admit the prevailing wind and deflect it down the shaft. High pressure on the windside and low pressure on the leeward side of the house is a common arrangement of openings to ensure the movement of the air.



WIND SCOOP

Fig. 4.2

Source : Dr.S. Al-Wakeel and Dr.M.Suraje. Climate and the Architecture of Hot Zones, Ciro, 1985.



WIND SCOOP WITH STACK EFFECT

Fig. 4.3

IV.2.3 White painted surfaces :-

Another simple, widespread and economical technique for arid climate modification applied throughout most of the North African countries is the coating of a building envelope with reflective surfaces. Groundchalk mixed with thin glue or a solution of quicklime whitewash painted over walls and roofs can have significant results in terms of reflecting the sun's rays.

This accounts for the habitual whitewashing of walls such as Mzab in Algeria, and generally in the Mediterranean countries.

IV.2.4 Earth sheltered dwellings:-

One of the primitive architectural forms is the underground settlement. People from the past have used the underground structure throughout history for a wide variety of practical purposes, most of which have involved defense and protection from an extremely stressful climate.

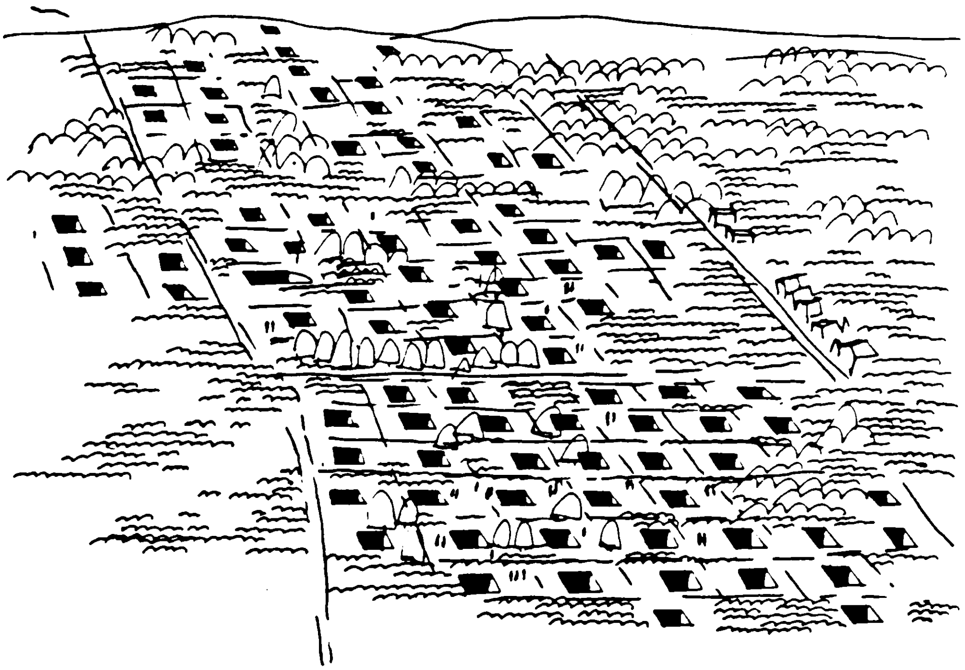
Existing natural land forms, and ideal soil/rock conditions, have often made subterranean structures the most practical alternative for human shelter.

The most commonly known of the underground settlements are those of North Africa, China, Cappadocia in Turkey, and others in south western parts of the United States.(3)

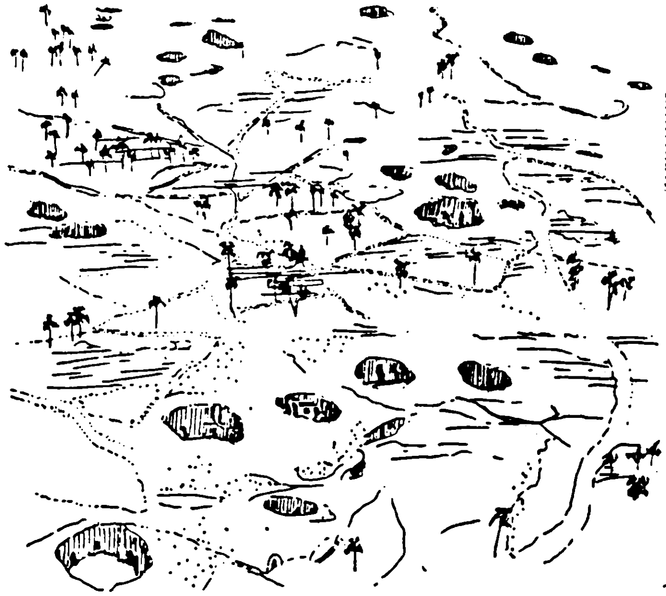
The settlement in these villages have been built deep within the earth.

The earth's layers form a thick and high resistance fabric, and help to stabilize the temperature level downward and also provide thermal protection from the ambient environment.

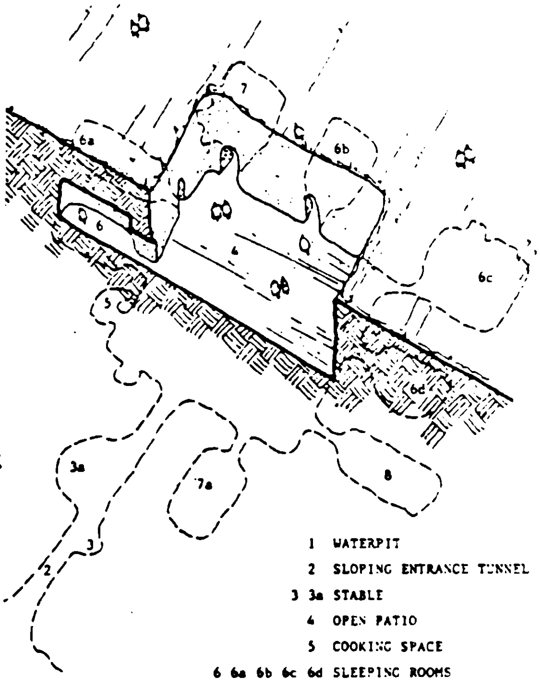
The general house design is a deep patio surrounded by rooms on different levels, for living and storage areas. Entrance to these shelters is through the stairways or graded tunnels. Fig.(4.4).



An overall view of a Chinese subterranean settlement built within loess soil. The spaces include dwellings, storage areas, schools, government offices and hotels. The surface is reserved for agricultural use.



. Overall view of Matmata, a subterranean settlement in Tunisia bordering the Sahara desert. Adapted from a publication of the Tunisian Tourist Information Office.



1 WATERPIT
2 SLOPING ENTRANCE TUNNEL
3 3a STABLE
4 OPEN PATIO
5 COOKING SPACE
6 6a 6b 6c 6d SLEEPING ROOMS
7 7a GRANARIES

. Plan of a Berber subterranean house at Matmata village. The central patio is used for family activities. Note that the tunnel leading to the patio has side spaces used for animal stables. Adapted from a number of sources.

EARTH SHELTERED

Fig. 4.4

Source : G.Golany, Earth Sheltered Habitat, History, Architecture and Urban Design, 1983.

IV.3 Modern Architectural Approaches

The morphology of the contemporary urban environment, has changed to meet the need of modern mobility and international lifestyle. The cars preclude narrow streets, society no longer accepts the idea of sleeping on the roof, and many mechanical devices have been introduced into the home, each generating additional heat and hence more energy consumption. Also with the presence of a wide choice of new materials to respond to new and specific needs, vernacular materials are no longer acceptable to society.

The need for decreasing the demands of energy consuption all over the world is well known. In response to higher energy costs the nations focused attention on researches leading to more energy efficient buildings which can reduce the loads either for cooling or heating purposes.

Many of these solutions implemented can trace their origins to solutions developed in the traditional architecture a thousand years ago.

As result of research into thermal behavior, many building techniques have been tested and show a good response under specific circumstances. Constraints for such techniques vary from one place to another, according to climate, technical expertise and available finance. The common factor is that uptake is based on individual research work or experiment, and is not yet being introduced as large scale settlements.

Some of these system, which may be promising as new additions to energy efficient housing design, are :-

IV.3.1 Roof pond system :-

This system was first designed and built by Harold R. Hay in Auscadero, California.[4] A four apartment house utilizes a roof pond with movable insulation for solar heating and cooling. The system known as 'Skytherm', provides 100% heating and cooling efficiency in area where temperature extremes give significant loads in both winter and summer seasone.

Fundamentally, the Skytherm system uses a metal roof deck which also serves as the ceiling of the room below, while water ponds supported by the roof deck are encased in thin plastic bags. During the winter, sliding insulating panels expose the bags to sunlight during the day and cover them at night, controlling heat loss. The bags is turn radiate their heat directly to the space below through the metal roof.

During the summer, the panels protect the water bags from the sun during the day but expose them to the sky at night, when they radiate their heat outwards and thereby cool the house below. Fig.(4.5)

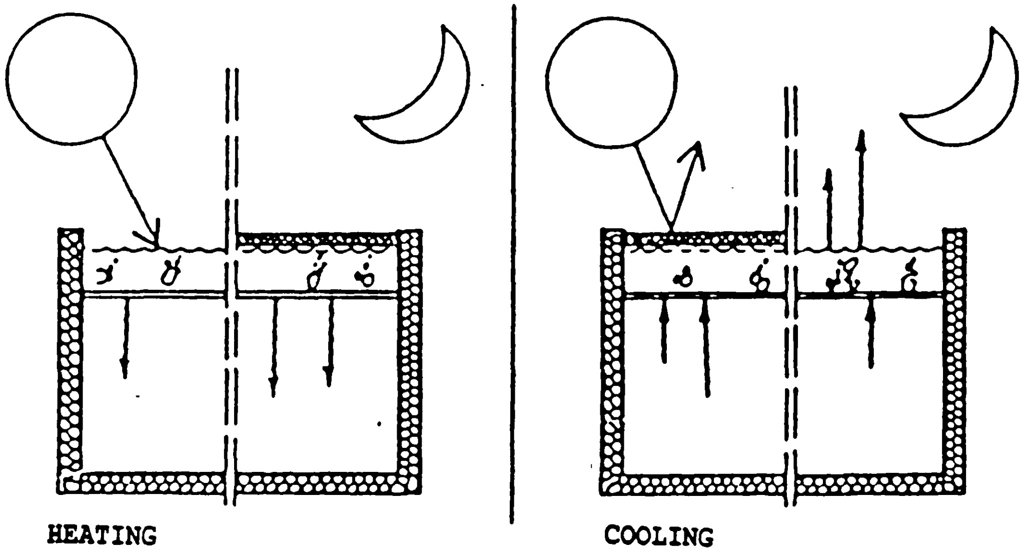
In winter, by exposing the ceiling ponds to solar radiation, water has attained a temperature of 29.4°C[5] before it is covered by the insulation to allow night - time heat loss to the house interior.

The downward radiation from the ceiling kept the room in a 23°C range, when outside temperature fell to freezing point. Summer cooling resulted a range of 23-25°C[5] through the night period,when the outside temperature was about 38°C and the 24h average was 29°C.

IV.3.2 Roof radiation trap system :-

Another system which uses the roof for heating and cooling was developed by Givoni in 1976.[6] In this system, solar energy for winter heating is absorbed directly at the roof's surface beneath a fixed insulation layer. Part of the heat is transferred into the occupied space by conduction across the roof. The other part of the collected solar energy is transferred by convection, from the hot air space between the absorbing roof and the insulating layer, to thermal storage (gravel) under the floor of the building or inside the occupied space. During summertime, a corrugated metal sheet located over the north sloping panel of the roof trap will be cooled by night outgoing longwave radiation so that its temperature can be lowered by several degrees below the temperature of ambient air.

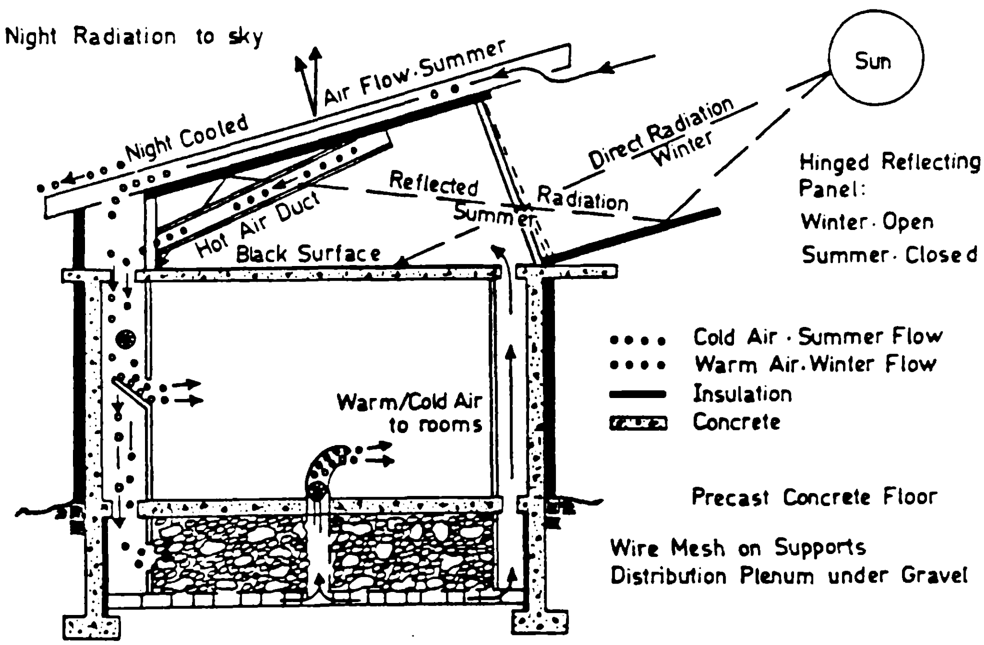
Air allowed to flow under this corrugated sheet is consequently cooled. Then the air may by drawn by means of a fan into a storage unit where gravel will be cooled. So during the day, the air drawn through may thus be cooled and even partly dehumidified before cooling the rooms, Fig.(4.6)



ROOF POND PASSIVE SYSTEM

Fig. 4.5

Source : Dr.S. Al-Wakeel and Dr.M.Suraje. Climate and the Architecture of Hot Zones, Ciro, 1985.



The roof radiation trap

ROOF RADIATION TRAP SYSTEM

Fig. 4.6

Source : M.S.Sodha, N.K.Bansal, P.K.Pnsal and M.A.Malik. Solar Passive Building, Pergaman Press,1986.

IV.3.3 Thermal storage walls :-

This system works firstly for heating the space during the cool winter by exposing the south wall to insolation and by storing the heat within the mass of the wall for later tranfer to the interior, as well as inducing thermo-circulation controlled by vents; and secondly for cooling, mainly by reverse thermo-circulation.

There are two main types of thermal storage walls usually termed Trombe[7] after the innovator of the technique. One uses thick, heavy masonry materials such as, concrete, adobe, and brick. The second general type of thermal storage wall uses water contained in drums or modules of cast fiberglas reinforced polyester.

Such system may be adapted for use in conjunction with sunspaces with the storage mass lined with insulation. In this case transfer to the heated interior is almost entirely by thermo-circulation. Fig.(4.7)

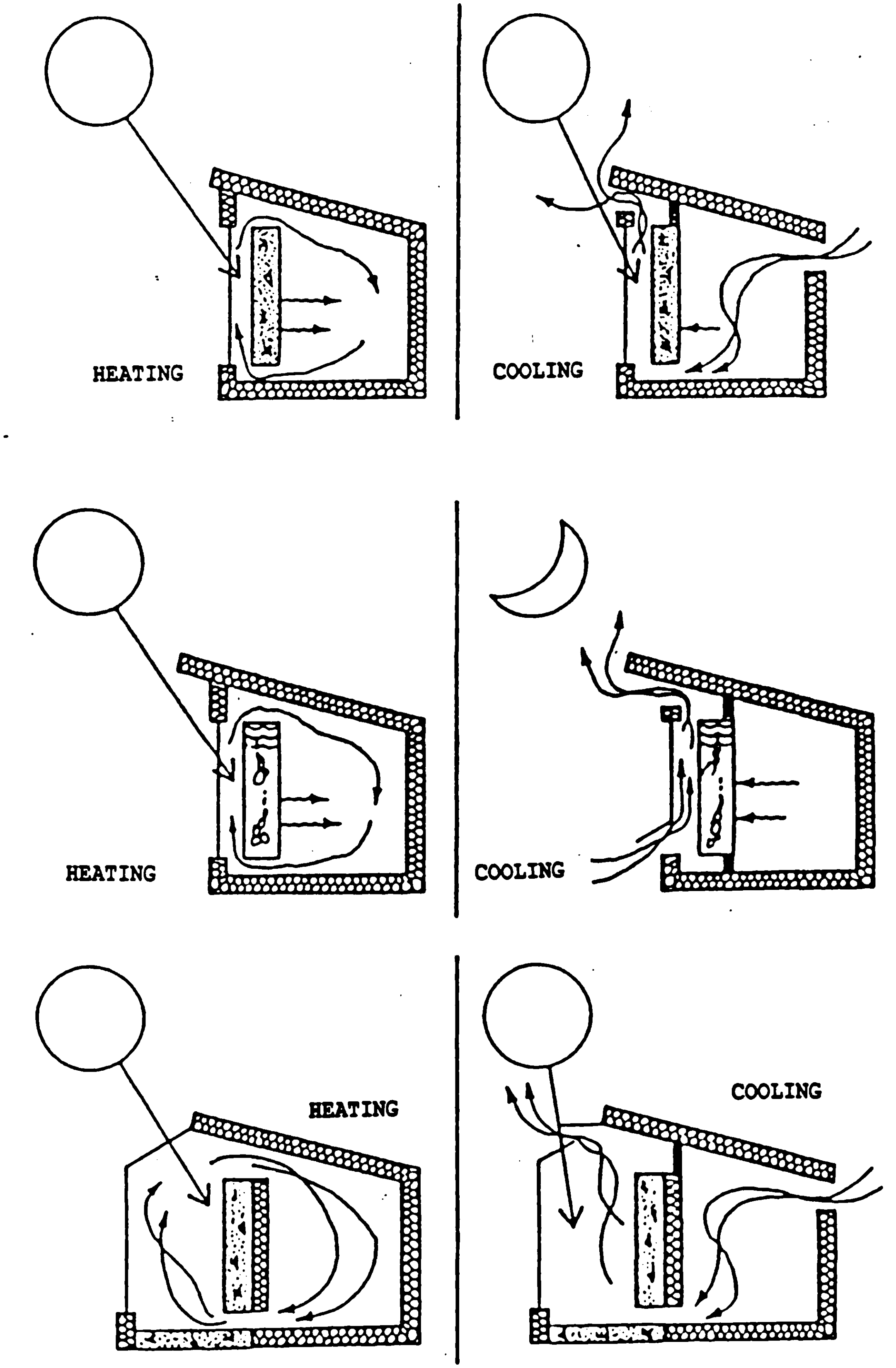
IV.3.4 Double roof dwelling :-

The principle of this system for passive cooling is to provide a permanent shading cover to the exposed roof surfaces, with the outer weather roof preventing direct radiation from reaching the inner ceiling layer, and the thermo-circulation of air travelling through the gap enabling exhaust of accumulated heat.[7] Fig.(4.8)

IV.3.5 Solar chimney :-

Heating air and releasing it from upper level openings can draw outside air through desirable circulation channels, where it can be conditioned.

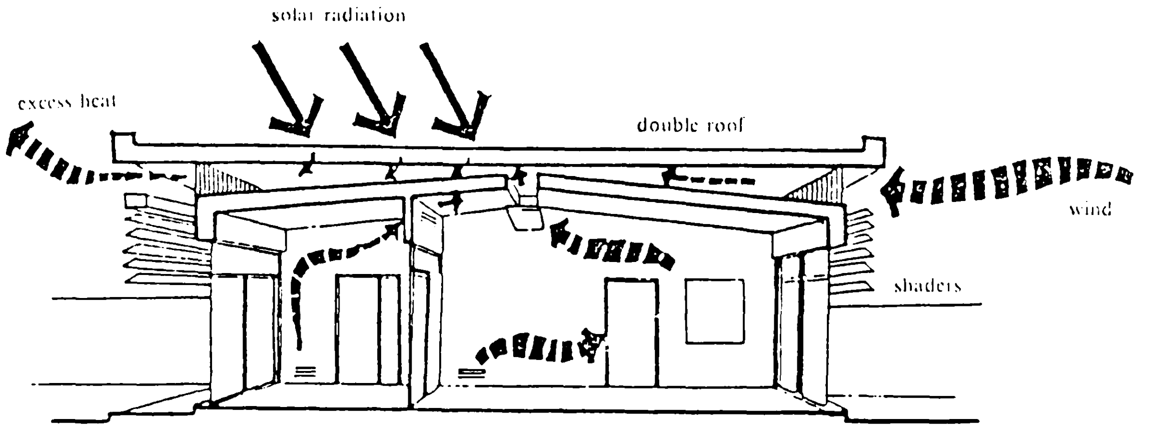
This system again functions by thermo buoyancy like a chimney, and can be used to draw air from outside through an underground duct where it is cooled and humidified or dehumidified as appropriate. Air then circulates through the house and out by aid of exhaust vents in a clerestory space.[7] Fig.(4.9).



THERMAL STORAGE WALLS

Fig. 4.7

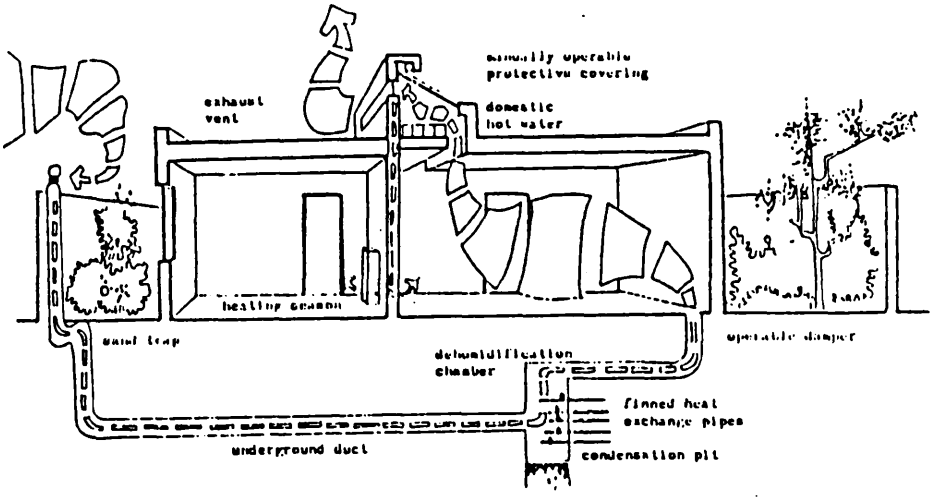
Source : Dr.S. Al-Wakeel and Dr.M.Suraje. Climate and the Architecture of Hot Zones, Ciro, 1985.



DOUBLE ROOF SYSTEM

Fig. 4.8

Source : A.A.Al-Bis, An Energy Urban Center in the Egyptian Desrt, Ph.D. Theses, 1984.

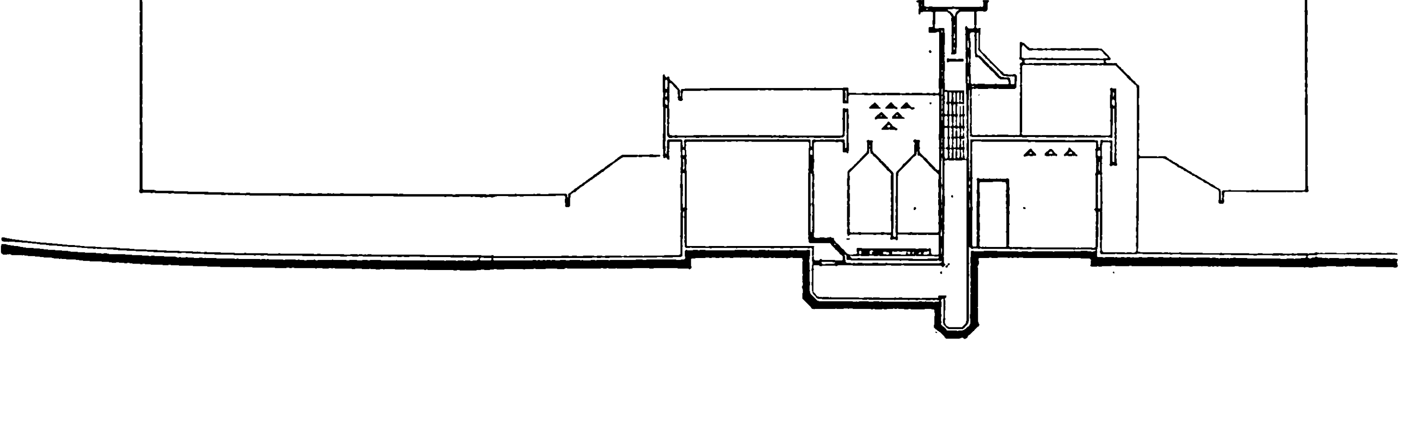


SOLAR CHIMNEY

Fig. 4.9

Source : A.A.Al-Bis, An Energy Urban Center in the Egyptian Desrt, Ph.D. Theses, 1984.

CHAPTER V



CHAPTER V

THERMAL PERFORMANCE ANALYSIS

V.1 Analysis Methodology

In this section a comprehensive testing plan is followed. The analyses is mainly based on a computer related software called CALPAS3, released by Barkeley Solar Group, (U.S.A.).[1]

CALPAS3, is an hourly time-step simulation for analysis of the energy performance of passive solar and conventional residential buildings. It is more error-resistant and time saving than hand-held calculator methods. The program computes the heating and cooling loads, space and storage temperature, heat gain and loss, on hourly, daily, monthly, and yearly increments. The principle structure of CALPAS3 is built using :-

- (ASHRAE)[2] heat transfer and ventilation algorithms.
- Backward implicit differencing equation for modelling transient heat conduction in mass elements, to eliminate stability problem and allow constant use of one hours time-step.
- Combined radiant-convective coefficients which allow fast execution and little loss of accuracy.

V.2 Analysis Objectives

The aim of this testing procedure utilizing CALPAS3 is to establish key guidelines relevant to the thermal performance of the building envelope under static physical reality, and hence to fulfill the following objectives :-

1- Determination of the most efficient design criteria for building in the physical environment of Al-Riyadh.

2- Evaluation of the thermal performance of conventional local techniques and materials.

3- To conserve energy through improved passive building design techniques including use of materials.

V.3 Analysis Constraints

CALPAS3 is a convenient simulation tool able to predict certain aspects of a building's thermal behavior. However the following constraints are relevant :-

- The program uses American climate data, the closest fit to Al-Riyadh being Phoenix Arizona at 32° N latitude in a continentally influenced region.
- The mathematical model treats the entire building as a one-room enclosure, i.e. a single thermal zone; except for specific passive solar features such as a sunspace coupled with the heated zone.
- Temperature distribution is assumed to be uniform and one dimensional.
- Thermal diffusivity, and hence time-lag and damping, pertaining to multi-layer bounding construction is not evaluated.
- Dynamic behavior is limited to specific passive solar elements such as Trombe Walls.

To over-come the latter constraint, a micro-soft program "THERMAL" is used to analysis the cyclic thermophysical behavior of particular bounding construction elements, determining the time lag, decrement factor and "equivalent"(3) outside temperature (see section V.5.4 below).

V.4 Analysis Structure

A simple model of one room dimension (3x3x3m) is tested in relation to four basic components of the building envelope.The testing procedure is divided in to the following stages:-

1- Window effect

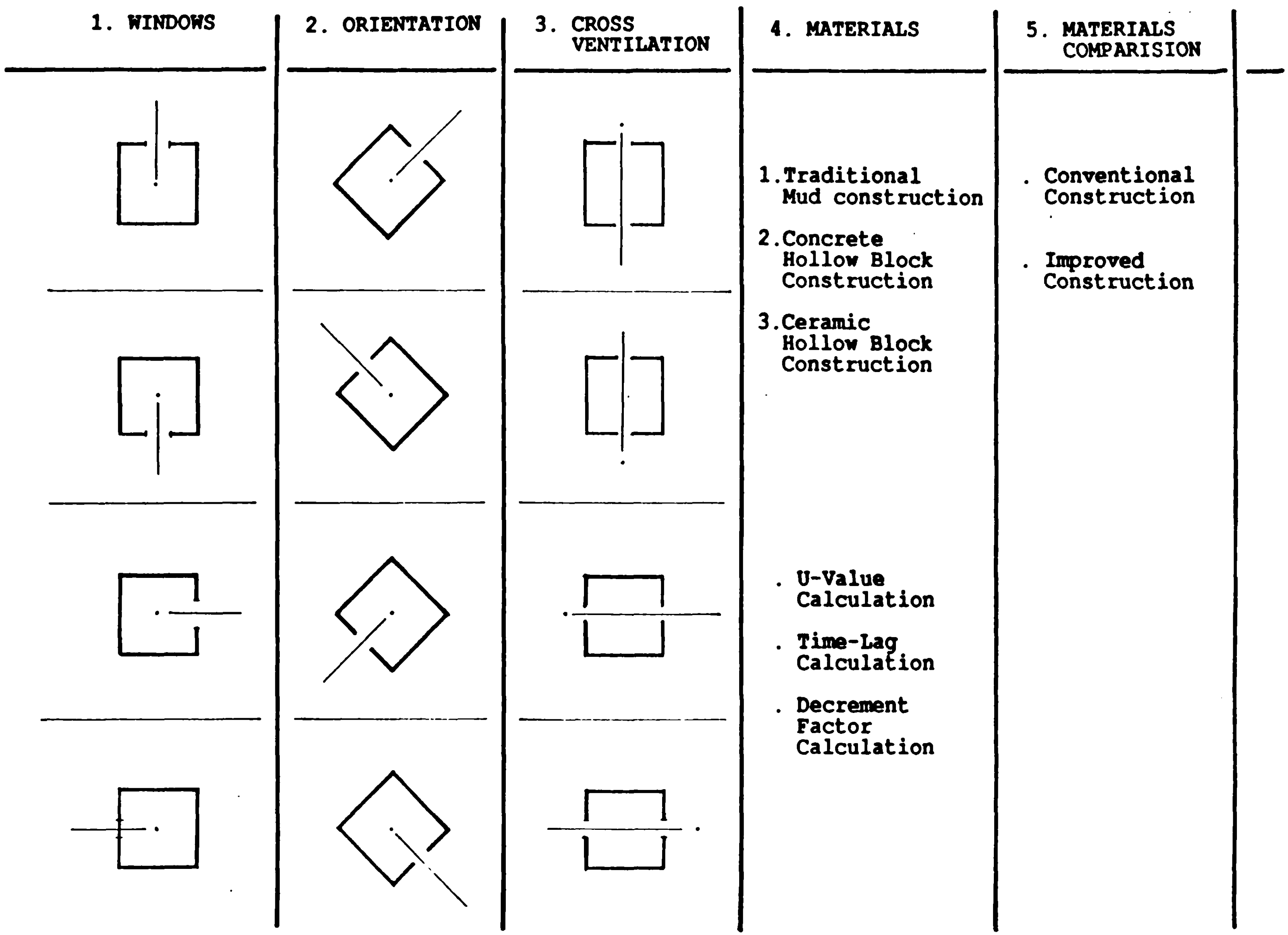
2- Orientation effect

3- Ventilation effect

4- Material effect

The analysis scheme is illustrated graphically in figure (5.1). A comparative study of some of the conventional construction systems selected according to their logical applicability to Al-Riyadh physical environment, and according to their availability, is prepared to investigate the effect of insulation to each system.

Fig. 5.1 **ANALYSIS SCHEME**



V.5 Observations and Guide Lines

V.5.1 Window effect

The first stage deals with windows, which is one of the characteristics of modern architecture. These important elements can cause remarkable changes in relationships between interior and ambient climate. The problem of the direct heat gain to the internal conditioned space is inevitable. Since glass is transparent to direct penetration of short-wave solar radiation, but almost opaque to the outgoing longwave radiation, internal temperatures will become elevated.

The aim of this simple model is to determine the thermal effect of varying window orientation. The out-put values of the total solar gain through the year is summarized in table no.(5.1).

Table no.(5.1)

Solar gain totals through double glazed windows, Calpas3, Arizona climate data.

Orientation	Total Annual	Summer (Jun.-Aug.)	Winter (Dec.-Feb.)
North	346.8 kWh	119.6 kWh	50.9 kWh
South	920.9 kWh	141.6 kWh	288.3 kWh
East	784.0 kWh	242.5 kWh	119.8 kWh
West	757.0 kWh	242.5 kWh	118.9 kWh
North East	690.7 kWh	232.3 kWh	90.0 kWh
North west	667.0 kWh	232.0 kWh	89.9 kWh
South East	930.2 kWh	278.2 kWh	278.2 kWh
South West	920.2 kWh	277.7 kWh	277.7 kWh

The north window permits the lowest annual amount of solar gain which make it an appropriate direction to have an opening. South has a higher annual total than east or west, but in summer, which is the main concern for overheating, south receives little more than north.

In winter, the south window has the maximum solar gain which can then be utilized for heating the conditioned space. East and west windows have approximately the same amount of solar gain, the difference is due to solar/clock time difference in Calpas with high levels in summer.

The asymmetrical values around 13.00, are due to the clock time differences from the true solar time.[4]

Calpas is using the clock time in its calculation, which is approximately one hour ahead of the true solar time due to the summertime clock shift.

For instance in Phoenix Arizona which Calpas uses in the weather file, the true solar noon on 10th of June would be calculate as follows :-

Phoenix longitude = 108 ° W
Reference longitude = 110 ° W
Equation of Time (E.T.) = +1 min. Fig.(5.2)
Solar-Clock Difference (D) = [4 (P-R)] + E.T. minutes
Where
P = Actual longitude, including allowance for local summertime,eg. Greenwich summertime $P=-15^{\circ}$ (1°=4minutes) as clocks move forward 1 hour relative to 0° meridean.

Then P= - if to the west of Greenwich
+ if to the east of Greenwich

R= Reference longitude, - if to the west of Greenwich
for local clock-time + if to the east of Greenwich

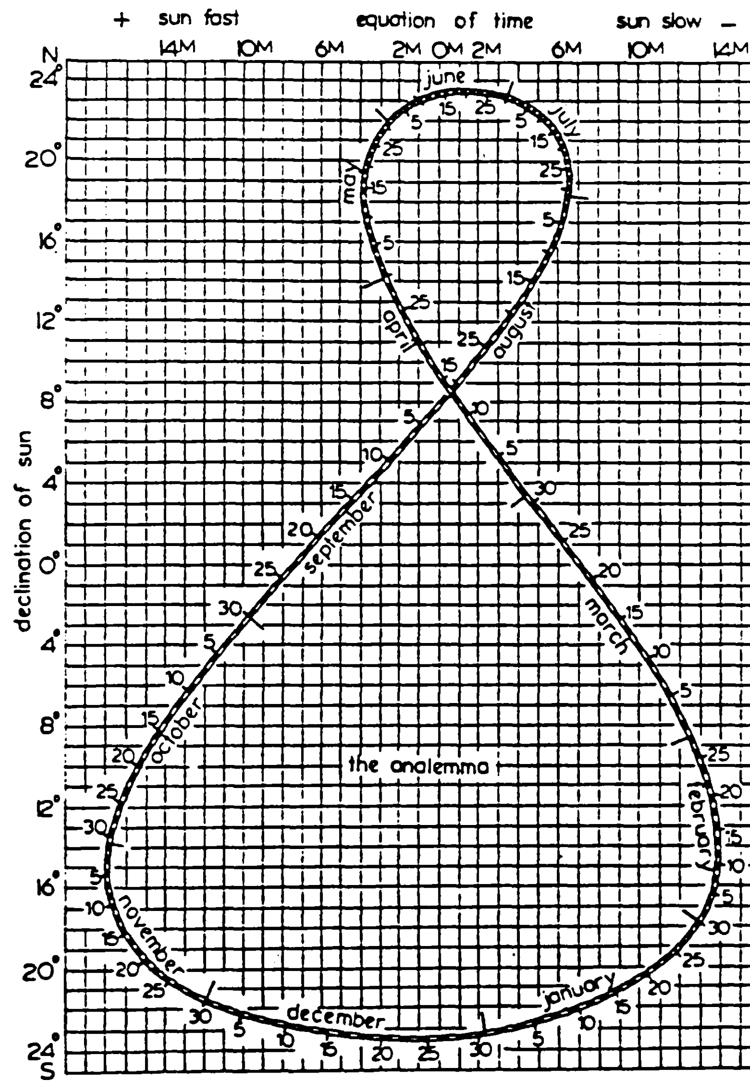


Fig. 5.2

Source : E.l.Harkness and M.L.Mehta, Solar Radiation Control in Buildings, Architecture sceince series, Applied sceince publishers ltd, 1978.

Then (D) for Phoenix = [4(-123 - (-110)] + 1

D = [4(-13)] + 1

= - 51 min.

A true solar time = clock time + D

A true solar noon = 12 + 51 min. = 12.51 h

The same procedure goes for Al-Riyadh, Saudi Arabia.

P for Al-Riyadh = 147 °

R for Al-Riyadh = 145 ° E

Then D = [4(+132 - (+145)] + 1

= [4(-13)] + 1

= - 51 min.

True solar noon = 12 + 51 min. = 12.51 h

When we compare both cases, we find that they match.

The (NE,NW,SE,SW) oriented windows express higher readings of solar energy especially in summer time. Figs.(5.3,5.4&5.5) represent the typical daily pattern of solar energy experienced by different windows.

In the traditional building style, the window element was brought to a minimum, in numbers, and in size. Natural day light and natural ventilation, and the view are the main desirable aspects of windows. Unfortunately even small windows in such a hot arid climate may increase excessive radiation, conduction, and convection heat transfer to the interior. Application of a shading device can modify adverse thermal effects without sacrifying the other advantages of windows . Shading devices may perform a variety of functions such as controlling heat gain either constantly or selectively (e.g. eliminating the sun in an overheated period and admitting it in an underheated period).

The disadvantage of diurnal use of devices such as shutters is reduced daylight & loss of view, although reduced glare may be advantageous.

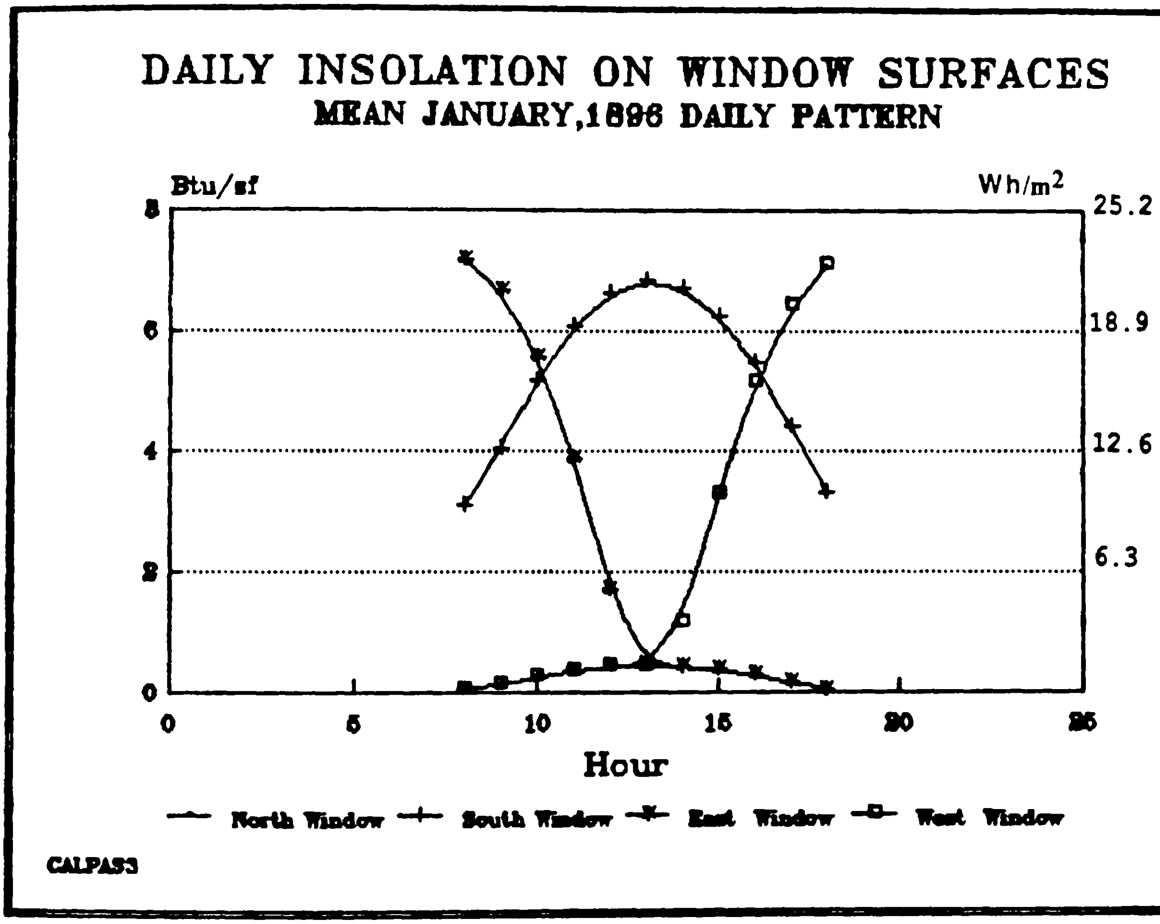

DAILY INSOLATION ON WINDOW SURFACES
MEAN JANUARY,1896 DAILY PATTERN
Btu/sf
Wh/m2
25.2
18.9
12.6
6.3
0
2
4
6
8
0
5
10
15
20
25
Hour
North Window
South Window
East Window
West Window
CALPAS3

Fig. 5.3

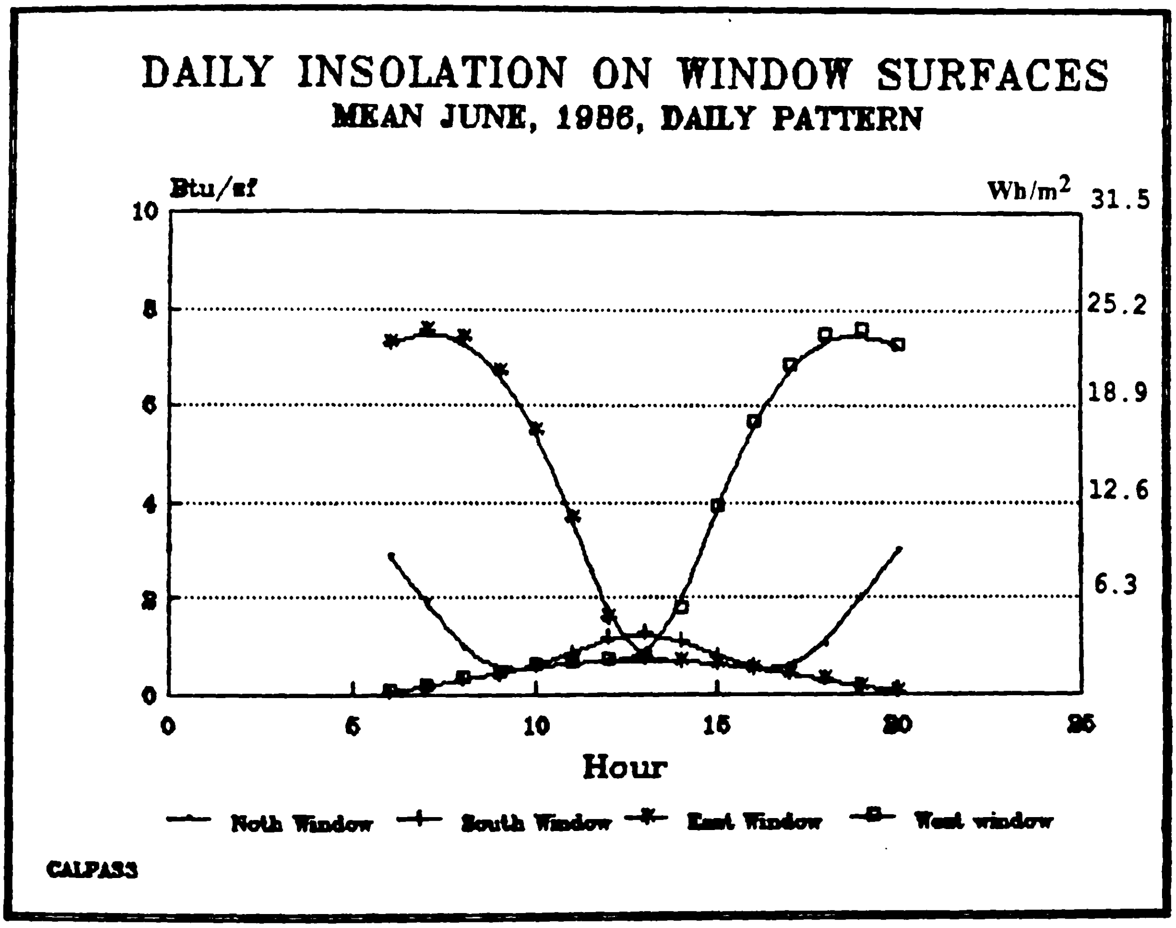

DAILY INSOLATION ON WINDOW SURFACES
MEAN JUNE, 1986, DAILY PATTERN
Btu/sf
Wh/m2
10
8
6
4
2
0
31.5
25.2
18.9
12.6
6.3
0
5
10
15
20
25
Hour
Noth Window
South Window
East Window
West window
CALPASS

Fig. 5.4

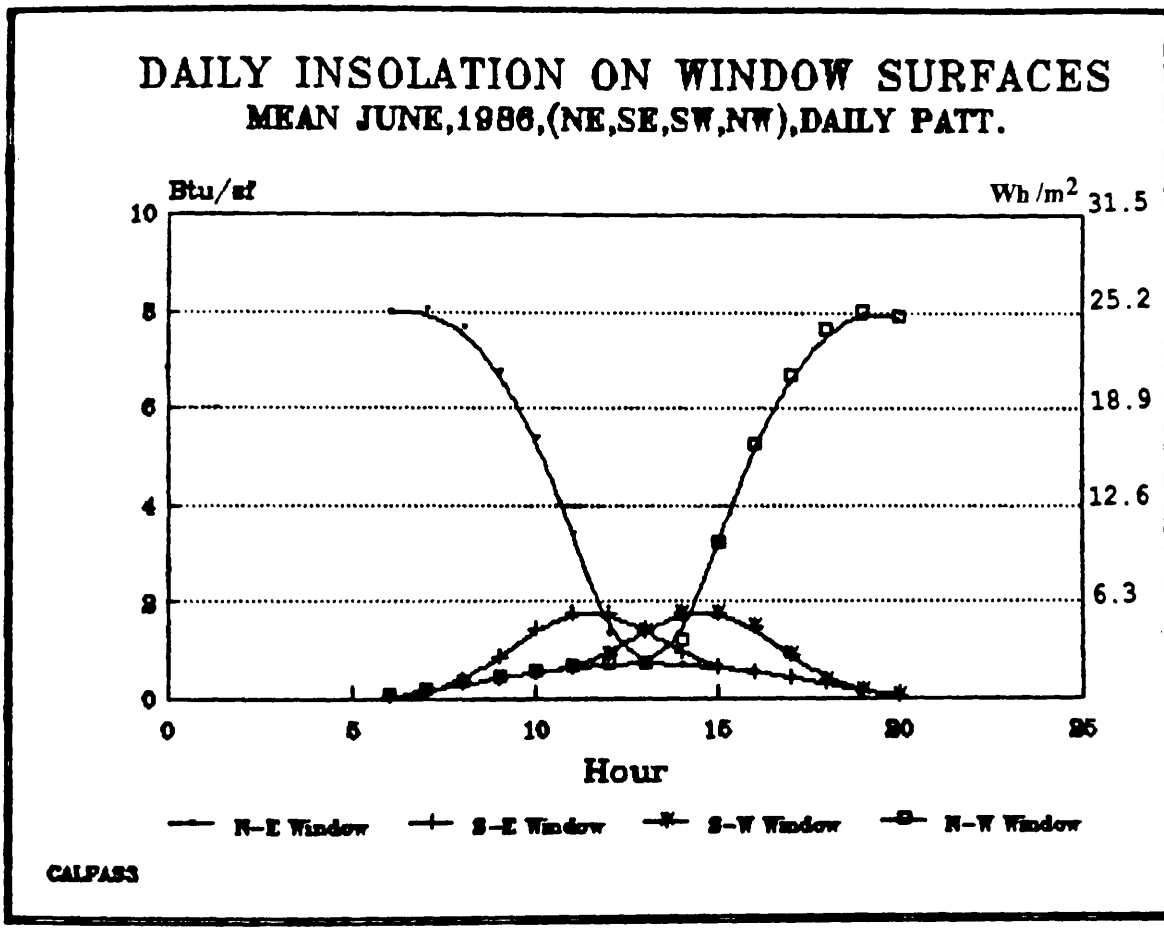

DAILY INSOLATION ON WINDOW SURFACES
MEAN JUNE,1986,(NE,SE,SW,NW),DAILY PATT.
Btu/sf
Wh /m2
10
8
6
4
2
0
31.5
25.2
18.9
12.6
6.3
0
5
10
15
20
25
Hour
N-E Window
S-E Window
S-W Window
N-W Window
CALPASS

Fig. 5.5

Manually adjustable shading devices are generally necessary to fulfill the changing requirements at will; and in order to arrive at a suitable design many factors have to be taken into consideration, such as the geometrical configuration, orientation, and the diurnal and annual pattern of sun movement.

Their efficiency depends mainly on their position with respect to glass. For example, external shutters are more efficient than internal since they block incoming short-wave radiation before it enters the habitable space. The efficiency of fixed shading devices is also determined by solar geometry relative to the building facade.

Adequate shading devices for east and west windows are those which can reject low morning and afternoon insolation. This may be difficult to achieve. An egg-crate shading device, especially if the vertical members are oblique at 45° to the south has been found to be the most appropriate configuration.(5) The horizontal shading is required to complement the vertical, particular in summer. Fig.(5.6).

South orientation can more simply be protected by horizontal members blocking the high summer insolation, and permitting low angle winter insolation when some space heating is required.

Thus external shading devices, both fixed and movable, can take many shapes and mass in the forms of shutters, overhangs, and a variety of louvers - vertical, horizontal and combinations of both.

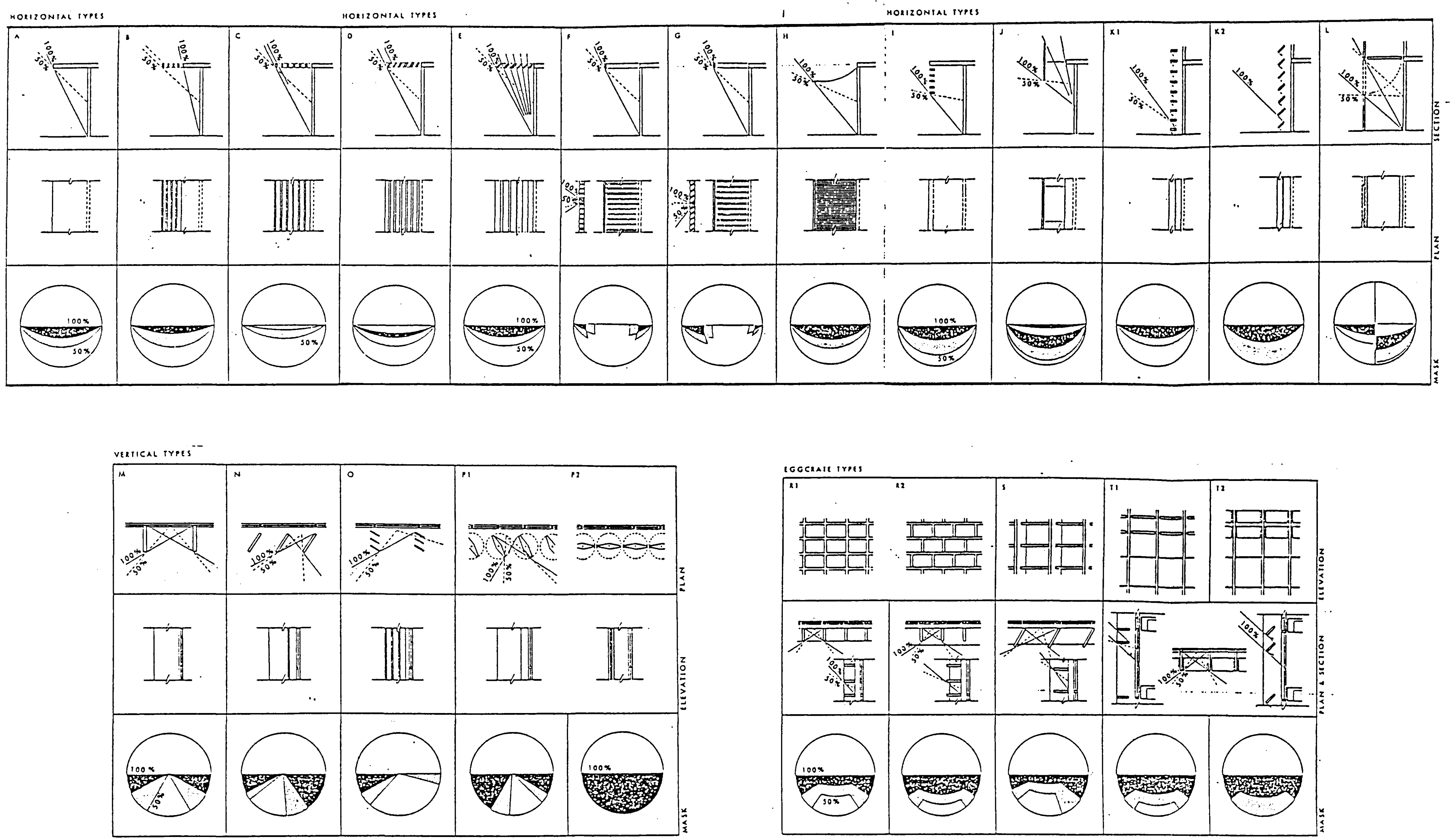
The use of the external shading devices in a hot and dry climate has several limitations, particularly if they are made of heavy materials - for example, precast concrete louvers fixed to protect a glass window. This kind of heavy mass can store up solar heat during the day and steadily warm the cool night air on its way into the building.

The efficiency of the shading devices can also be increased with a darker color. The darker color reflects less amount of radiation to the building facade, hence allow less heat to be accumulated.

Dark colors can be effective only when windows are closed, but with open windows the effect of color depends to a great deal on their orientation with regard to wind direction and their construction isolation from the building elevations. Fig.(5.7)

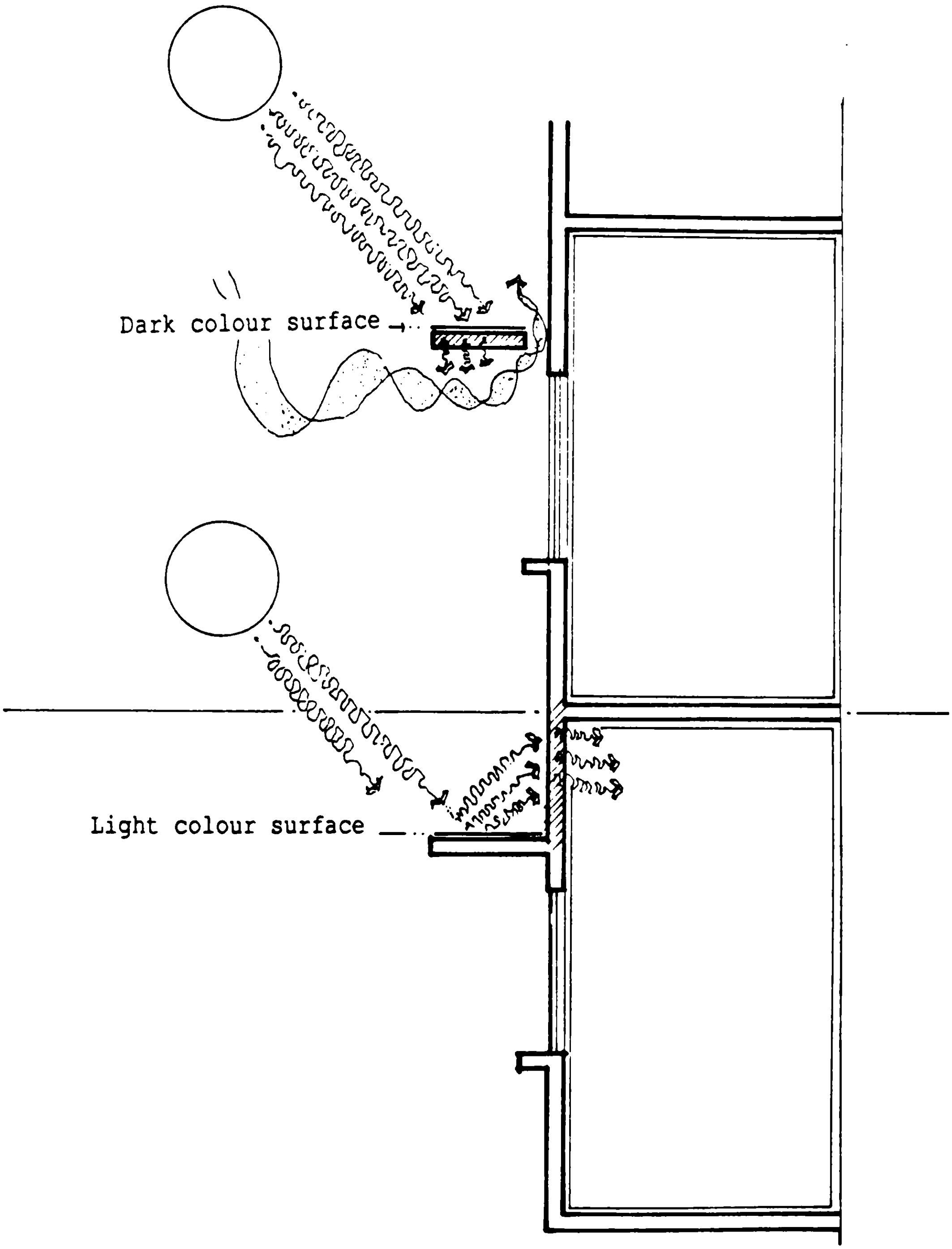
For instance, when wind in the afternoon blows from the west, and windows are open, dark color shading devices on this window may heat the incoming air which flows over them; and when the shading device has a large heat capacity, the heating effect may continue long after sunset.

The design in this case should be in such a way that direct contact of the louvers to building facade is avoided. The isolation of this membrane would create a continuance exhaust of heat that may accumulate under the shading devices and in front of the window.



SHADING DEVICES PATTERNS

Fig. 5.6



COLOURS EFFECT ON SHADING DEVICES

Fig. 5.7

To calculate efficiency of different shading devices based on the assumptions that the sky has equal luminance of radiation at all points, no reflections from surroundings or louvers are received, and louvers are so long that light entering from ends can be neglected. Olgyay[6] devised the following equations :-

1- For horizontal overhangs or horizontal louvers the efficiency can be expressed by

$$\text{Efficiency} = [\sqrt{(1+(c/h)^2)} - (c/h)] \times 100\ \%$$

2- For tilted horizontal overhangs or louvers the efficiency can be expressed as

$$\text{Efficiency} = [\sqrt{(1-2(c/h)\sin a + (c/h)^2)} - (c/h)\cos a] \times 100\%$$

3- For vertical fins, perpendicular to elevation or tilted the efficiency is

$$\text{Efficiency} = 1/2[\sqrt{(1-2(c/w)\sin a + (c/w)^2)} - \sqrt{(1+2(c/w)\sin a + (c/w)^2)} - (c/w)] \times 100\%$$

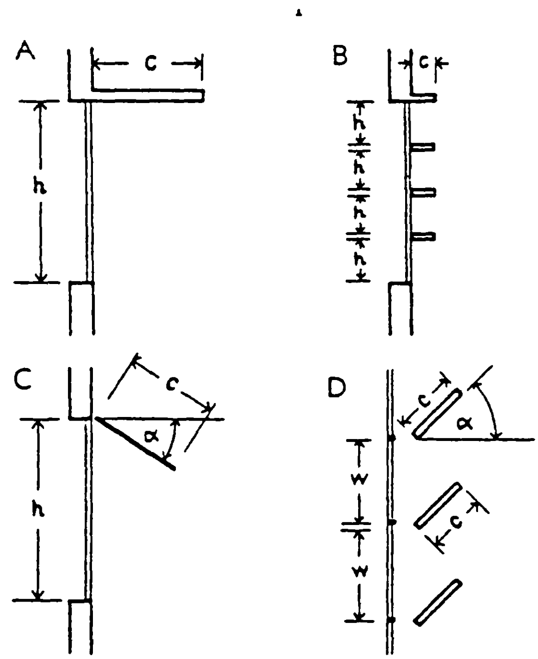
Fig.(5.8&5.9)

It should be emphasised that such evaluation appears to be independent of site location and orientation, with for example Olgyey setting a notional efficiency index of 100% in the case of a simple overhang equal to hight of the window.

c/h	Efficiency %	c/h	Efficiency %
0	100.0	0.6	56.5
0.1	90.5	0.7	52.0
0.2	81.9	0.8	48.0
0.3	74.3	0.9	44.4
0.4	67.6	1.0	41.4
0.5	61.7	2.0	23.6

SHADING EFFICIENCY

Fig. 5.8



SHADING EFFICIENCY CALCULATION METHOD

Fig. 5 .9

One of the successful traditional solutions dealing with this matter is called the Mashrabia, this term is used to define an opening with a wooden lattice screen composed of small wooden balusters arranged at specific regular intervals, often in a decorative and intricate geometric pattern.

The Mashrabia concept has been universally used in hot arid areas, particulary through the Middle East and North Africa. It has five functions,(7) and different patterns have been developed to satisfy a variety of conditions that require emphasis on one or more of these functions. The functions are as follow :-

. Controlling the passage of light

. controlling air flow

. Reducing the temperature of air current

. Increasing the humidity of the air current

. Ensuring privacy

Mashrabias can combine the two main types of shading devices, fixed and adjustable, with great flexibility and ability to fulfill different functions for different orientations. Fig.(5.10).

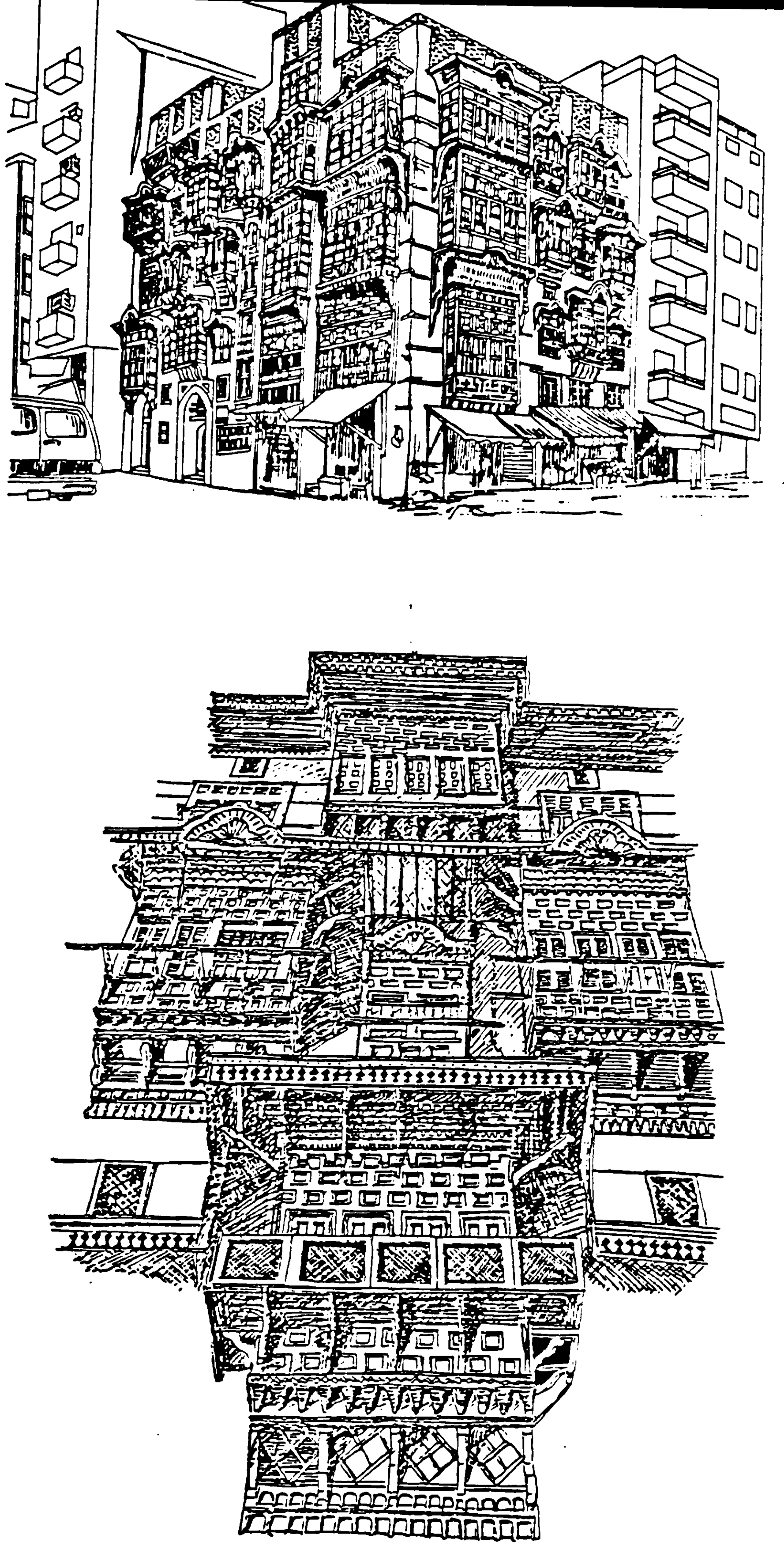


Fig. 5.10 TRADITIONAL MASHRABIA

Source : K.Talib. Shelter in Saudi Arabia,
Martin's Press. 1984.

V.5.2 Orientation effect :-

The second stage demonstrates the effect of opaque surface orientation on the thermal performance. The solar gain to wall and roof elements through the diurnal period in a typical summer, and winter day is plotted in figs.(5.11, 5.12,& 5.13), and the data in figs.(5.14&5.15) shows the factors used by the program to calculate solar gain through opaque elements due to absorption of radiation on their outside surfaces.

The factors are multiplied by the diffuse and direct solar radiation from the weather file to arrive at the hourly valuse used in the heat balance equations of the main simulation.

The diagrammatic guide shows the gain to each mass element from each surface and thus can be used to identify surfaces responsible for excessive solar gains. The factors are the gain in Wh when the direct normal beam intensity is $1W/m^2$. Units are $Wh/(W/m^2)$, (values have been converted from Calpas output in Btu/(Btu/sf), multiplying each value by .924=1/3.414x1/.317).

As showed by the values, there is a significant variation between the amounts of the solar radiation falling on the different surfaces of the building.

The horizontal surface (i.e. roof) receives the highest amount in summer at approximately 13.00 (solar noon) which is the same peak hour for a south wall. Together southern and northern walls receive low amounts of radiation.

The radiation on the eastern wall and western wall are approximately symmetrical, peaking at approximately 2/3 of the solar noon roof value, 6 hours before and after.

The 45° oriented model test show slight differences in the solar pattern of the south-east and south-west wall. The curve has increased slightly in the magnitude, maximum peak of south-east moved towards the noon around 11.30 a.m., while the south-west the maximum occurs at 14.00 p.m.

The winter situation illustrates that the south wall now exceeds the roof in receiving radiation, while in the case of the east and west wall there is almost no change compared with summer in distribution and in magnitude, with the maximum values now close to the roof and south wall solar noon peaks.

It may be noted that the problem of orientation of buildings could be exacerbated by use of long blocks, and planning to avoid exposing the longest facade to east and west would be advantageous.

In the case of a square block differences are relatively small, but could still be critical, depending on construction and distribution of openings. Fig.(5.16).

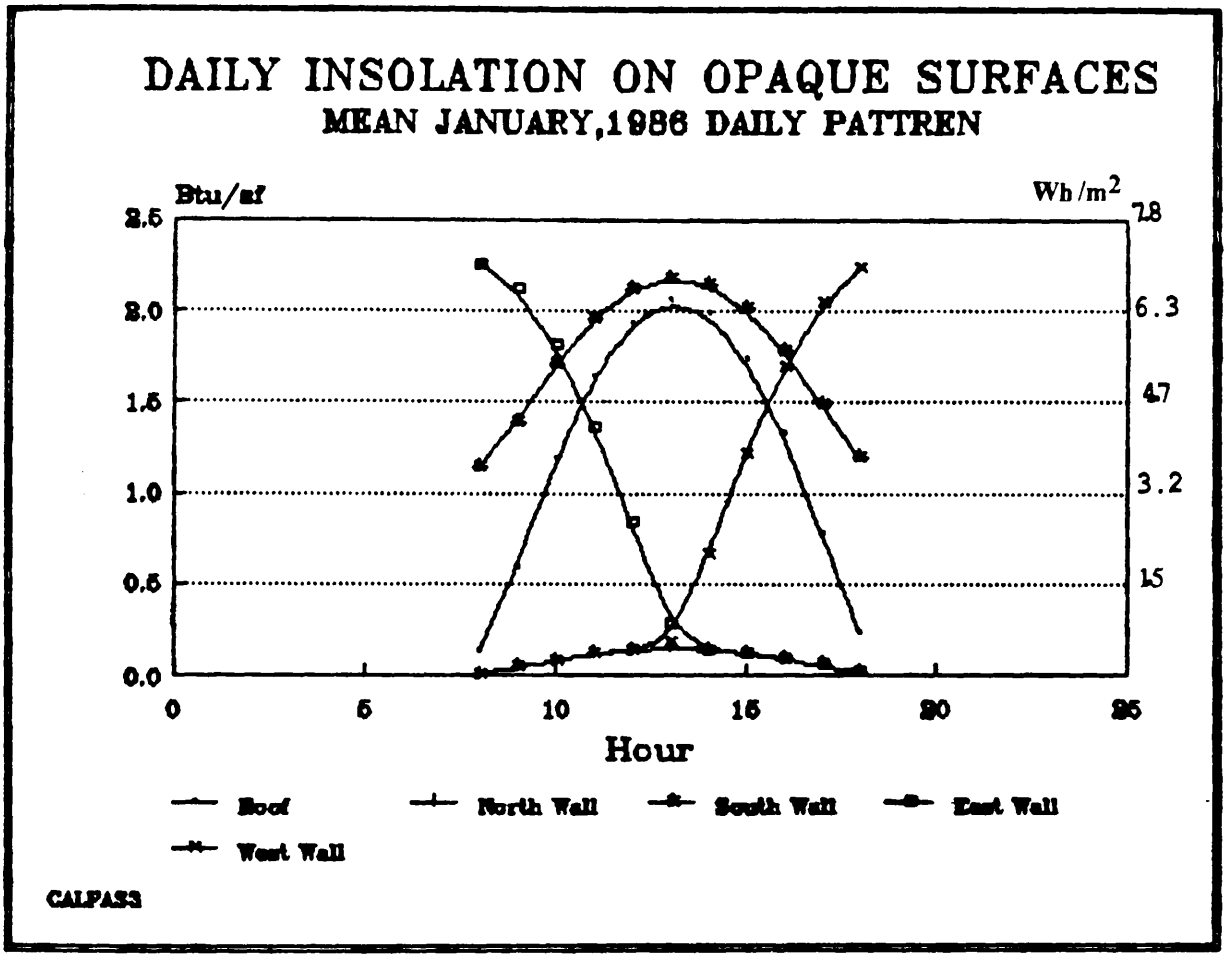
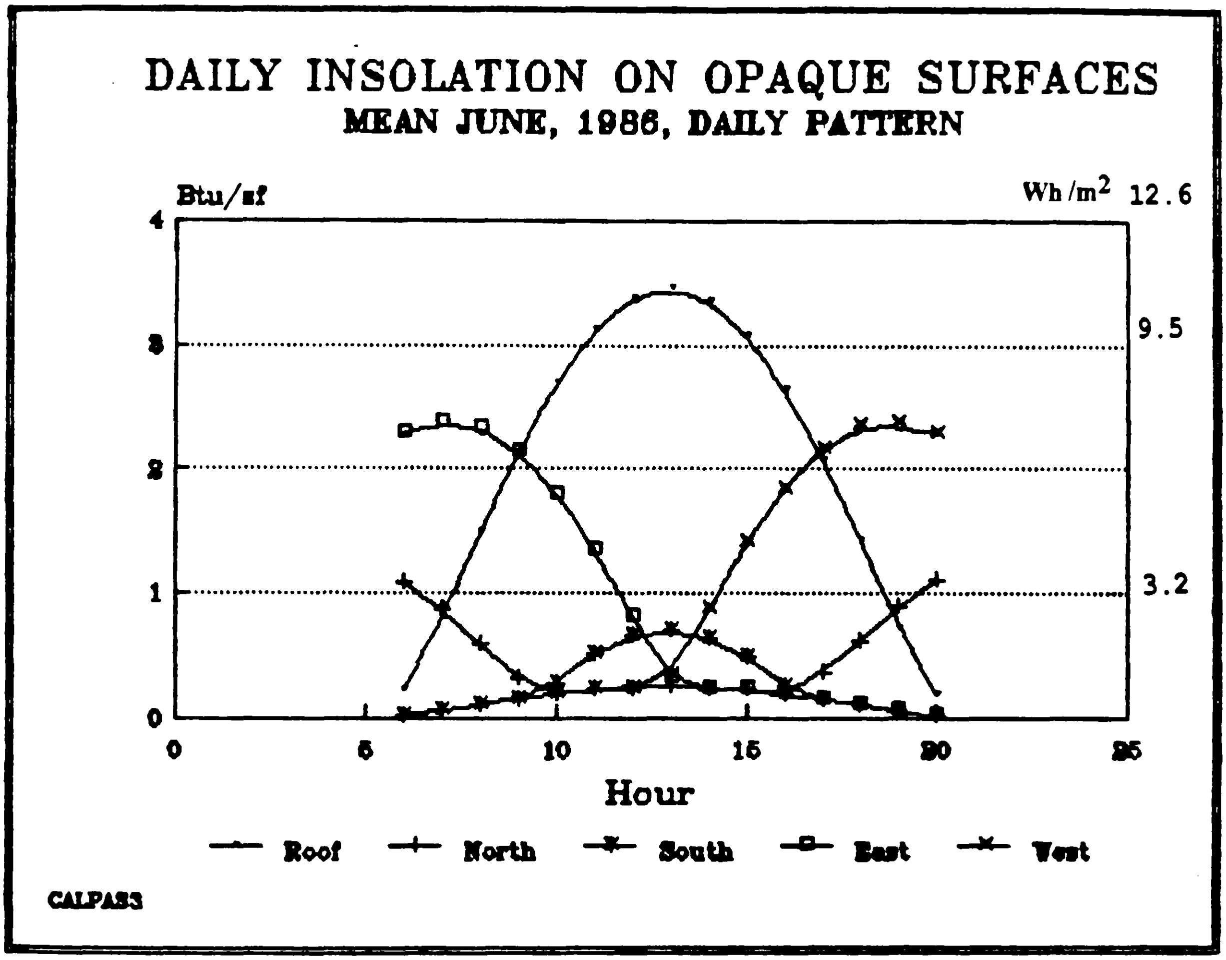

DAILY INSOLATION ON OPAQUE SURFACES
MEAN JANUARY,1986 DAILY PATTREN
Btu/sf
Wh/m2
2.5
2.0
1.5
1.0
0.5
0.0
7.8
6.3
4.7
3.2
1.5
0
5
10
15
20
25
Hour
Roof
North Wall
South Wall
East Wall
West Wall
CALPAS3

Fig. 5.11



DAILY INSOLATION ON OPAQUE SURFACES
MEAN JUNE, 1986, DAILY PATTERN
Btu/sf
Wh/m2
12.6
9.5
3.2
4
3
2
1
0
0
5
10
15
20
25
Hour
Roof
North
South
East
West
CALPAS3

Fig. 5.12

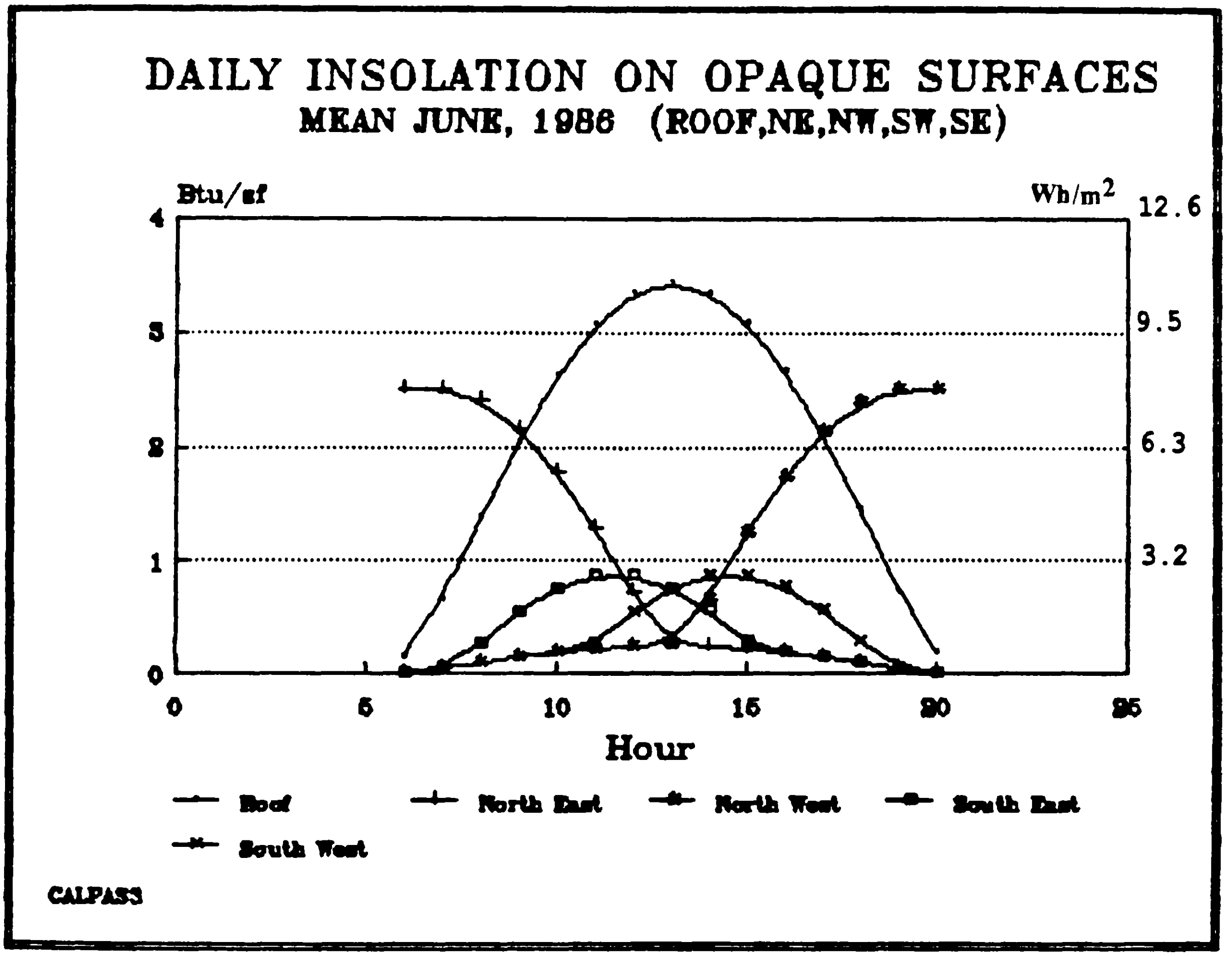
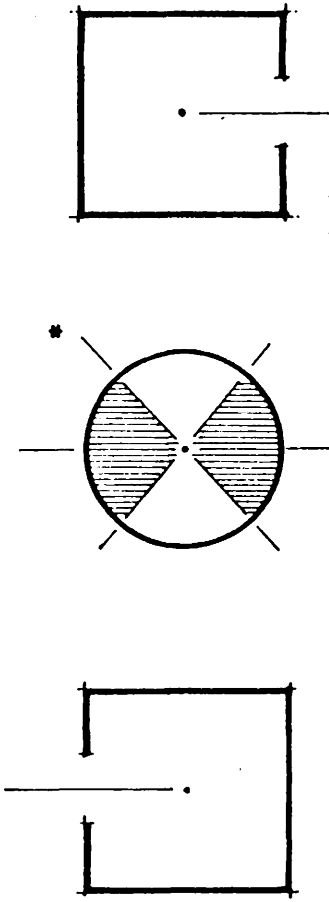
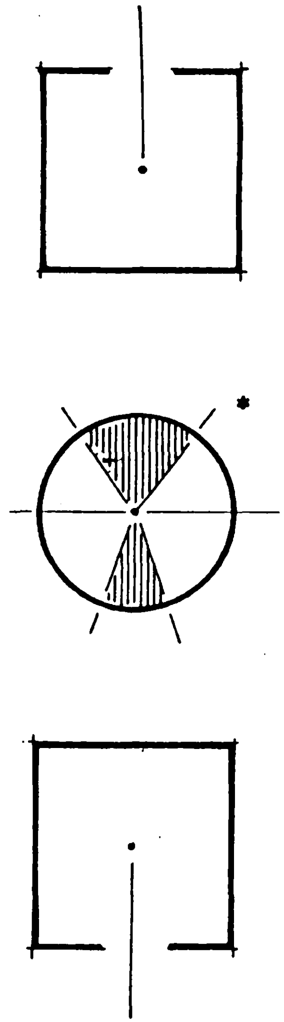

DAILY INSOLATION ON OPAQUE SURFACES
MEAN JUNE, 1986 (ROOF,NE,NW,SW,SE)
Btu/sf
Wh/m2
12.6
9.5
6.3
3.2
4
3
2
1
0
0
5
10
15
20
25
Hour
Roof
North East
North West
South East
South West
CALPAS3

Fig. 5.13



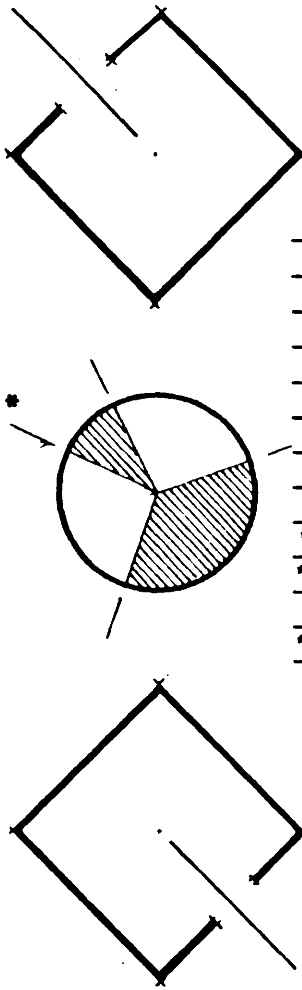
Hourly insolation factor on building surfaces. Wh/(W/m^2 incident)
Typical Summer Day, June.

Time	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ROOF	0.21	0.73	1.4	1.89	2.5	2.9	3.12	3.2	3.11	2.84	2.44	1.92	1.32	0.67	0.17
NORTH	1.01	0.8	0.54	0.3	0.18	0.21	0.22	0.23	0.22	0.2	0.18	0.33	0.57	0.83	1.03
SOUTH	0.01	0.05	0.1	0.14	0.26	0.47	0.6	0.64	0.59	0.45	0.24	0.14	0.09	0.05	.012
EAST	2.11	2.2	2.2	1.98	1.7	1.25	0.75	0.28	0.22	0.2	0.17	0.14	0.09	0.05	.012
WEST	0.01	0.05	0.1	0.14	0.18	0.21	0.22	0.31	0.8	1.3	1.71	2	2.17	2.18	2.1
*NORTH	0.91	0.72	0.5	0.27	0.16	0.19	0.2	0.21	0.2	0.18	0.16	0.29	0.51	0.74	0.92
*SOUTH	.038	0.05	0.09	0.13	0.23	0.42	0.54	0.58	0.53	0.41	0.22	0.12	0.09	0.04	.010
* EAST	1.9	1.97	1.94	1.8	1.5	1.12	0.67	0.26	0.2	0.18	0.16	0.12	0.09	0.04	.010
* WEST	.013	0.05	0.09	0.13	0.16	0.19	0.2	0.28	0.72	1.17	1.54	1.8	1.97	1.97	1.89



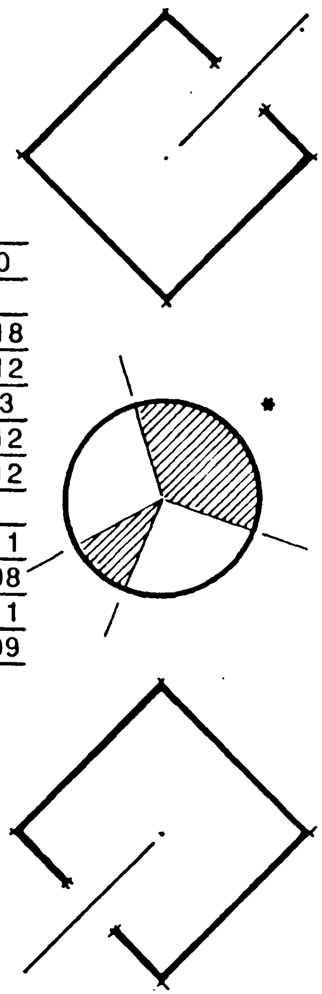
* Wall with window
* Diagramatic guide to insolation distribution

Fig. 5.14



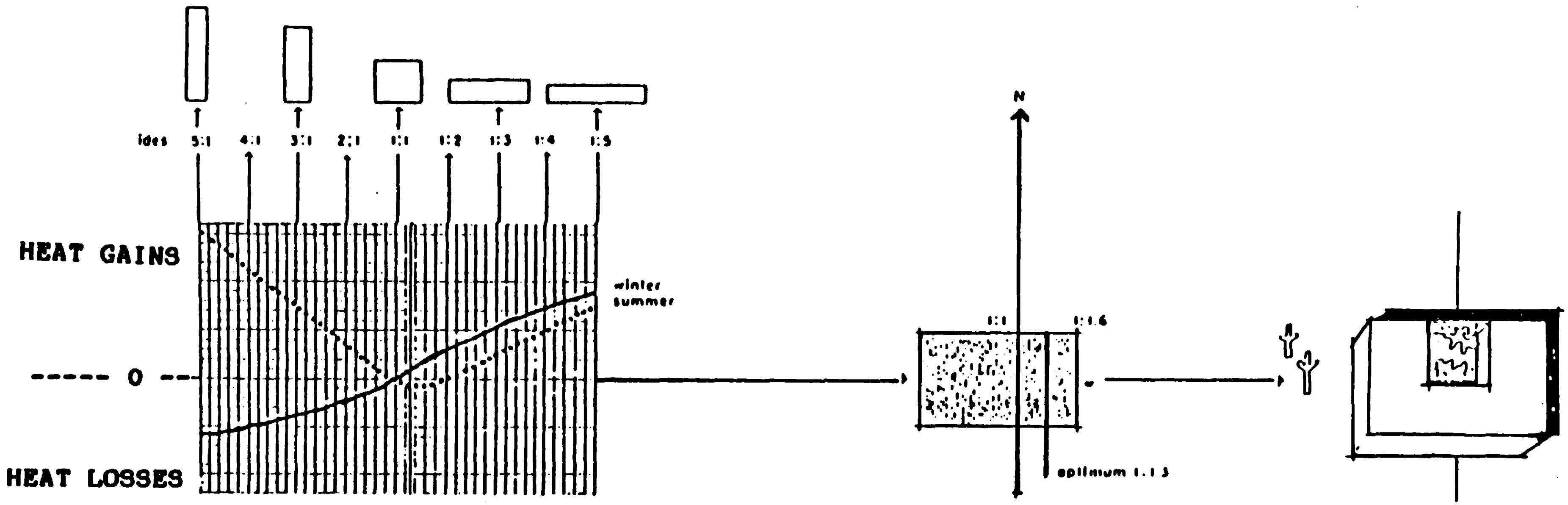
Hourly insolation factor on building surfaces. Wh/(W/m^2 incident)
Typical Summer Day, June.

Time	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ROOF	0.14	0.62	1.27	1.9	2.42	2.82	3.08	3.18	3.1	2.86	2.46	1.94	1.34	0.68	0.18
N.E Wall	2.31	2.32	2.22	1.99	1.6	1.19	0.67	0.26	0.22	0.2	0.18	0.14	0.1	0.05	.012
N.W Wall	.010	0.04	0.09	0.14	0.17	0.2	0.22	0.24	0.62	1.14	1.6	1.96	2.21	2.32	2.3
S.E Wall	.010	0.04	0.24	0.51	0.7	0.8	0.8	0.71	0.52	0.27	0.18	0.14	0.1	0.05	.012
S.W Wall	.010	0.04	0.09	0.14	0.17	0.25	0.5	0.69	0.8	0.8	0.77	0.54	0.27	0.05	.012
*N.E Wall	2.08	2.1	2	1.79	1.47	1.1	0.61	0.23	0.2	0.18	0.16	0.12	0.09	0.04	.011
*N.W Wall	.010	.43	.09	0.13	0.16	0.18	0.2	0.23	0.61	1.07	1.47	1.79	2	2.1	2.08
*S.E Wall	.009	0.04	0.21	0.46	0.63	0.72	0.72	0.64	0.47	0.24	0.16	0.13	0.09	0.04	.011
*S.W Wall	.010	0.04	0.09	0.13	0.16	0.24	0.47	0.64	0.72	0.72	0.63	0.46	0.21	0.04	.009



* Wall with window
* Diagramatic guide to insolation distribution

Fig. 5.15



BUILDING SHAPES RATIO IN HOT ARID ZONE

Fig. 5.16

Source : V.Olgyay, Design with Climate, Bioclimatic Approach to Architectural Regionalism, 1968.

V.5.3 Ventilation effect :-

The third stage tests the effect of cross ventilation on the internal conditioned space. Two ventilation openings with the same area and opposite position on each wall are assumed. The Calpas simulation 'opens' these windows as required to achieve a heat balance - i.e. typically during the night during summer. The air inlet opening is 2m lower than the air outlet, so that stack effect may dominate wind induced airflow. In each test the air inlet azimuth is changed to allow different air direction.

As illustrated in fig.(5.17), the internal temperature curve of the ventilated model is slightly modified compared to the model without cross ventilation. Both of the curves are above the outside temperature curve, enabling nocturnal cross ventilation to reduce the internal temperature by a few degrees. The need to control the timing and the quality of incoming air is therefore critical in order to reach a satisfactory result.

Examining the hourly profiles, figs.(5.18,5.19,& 5.20), for a selected day in each month, we discern a commonality for all months that the amount of ventilation permitted to the space is encouraged during the night hours, while the ventilation process is blocked out during the hottest hours of midday.

In January ventilation is zero, to prevent unecessary increase of the heating load. In February some afternoon/ evening ventilation is permitted; in March this extends with the night period; but in April where diurnal ventilation is minimal, there is now considerable scope for night cooling.

This pattern continues throughout the summer period and into the autumn from May until October with peak night ventilation occurring in June. In November, diurnal ventilation is again beneficial, and December is virtually as January with only a minimal amount of afternoon ventilation.

It should be noted that, ventilation at night and day achieves a thermal balance but does not guarantee comfort. e.g. July average temperature without ventilation is 40.5°C, and 34.7°C with ventilation, while the ambient temperature is 32°C.

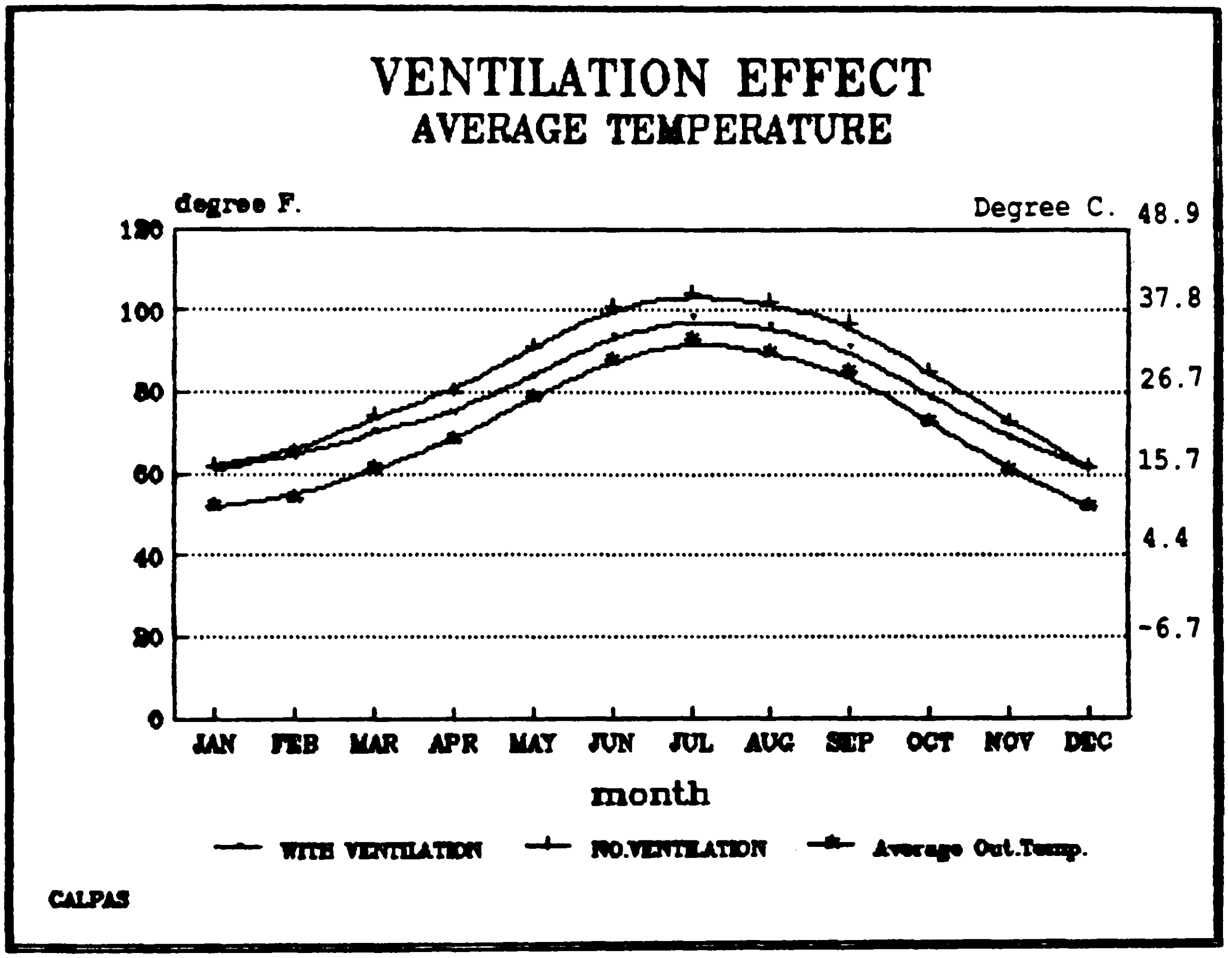
The Calpas simulation simply confirms that a continual 24 hour ventilation strategy is inappropriate, resulting in an internal environment close to ambient and even more, but infers the viability of a night ventilation strategy.

A manual calculation for prediction of the effect of night ventilation is introduced at the end of this chapter. This is crude, and for convenience and comparative purposes uses output/input from a Calpas3 simulation for terms in a heat balance equation.

However, specific Al-Riyadh temperature and solar data could readily be substituted, (for example, the average temperature of Al-Riyadh in June is 40°C, and for Phoenix Arizona, it is 41.7°C).

Thus it would appear logical to block ventilation by day, unless mechanically cooled; but to use prevailing winds and/or thermal buoyancy to enable night ventilation, perhaps assisted by passive evaporative cooling.

Suitable location of openings, with an appropriate height differential and possibly further assisted by passive solar devices as described in section IV.3.5 above, can make ventilation more stack than wind dependent.



VENTILATION EFFECT
AVERAGE TEMPERATURE
degree F.
Degree C.
120
100
80
60
40
20
0
48.9
37.8
26.7
15.7
4.4
-6.7
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
month
WITH VENTILATION
NO.VENTILATION
Average Out.Temp.
CALPAS

Fig. 5.17

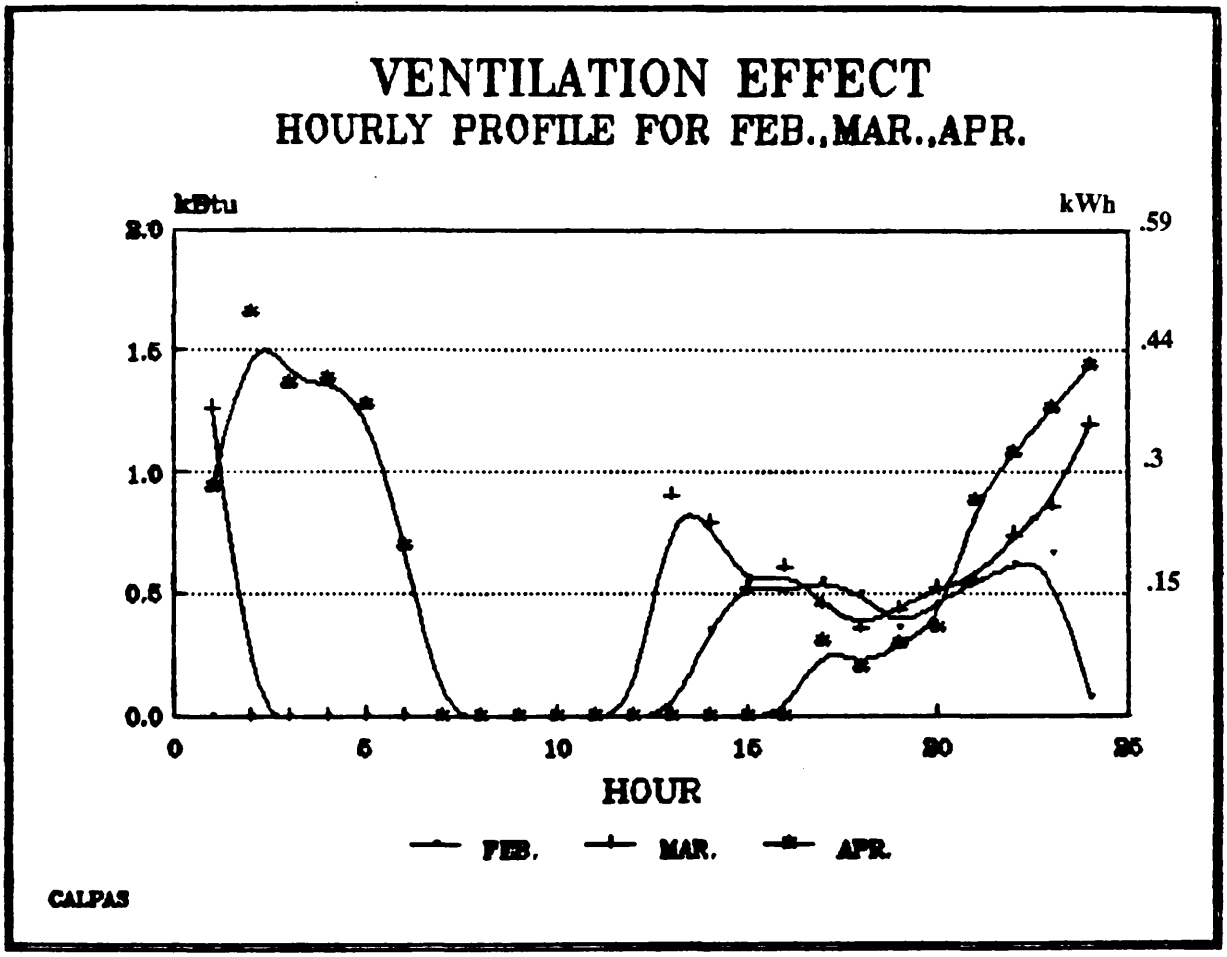
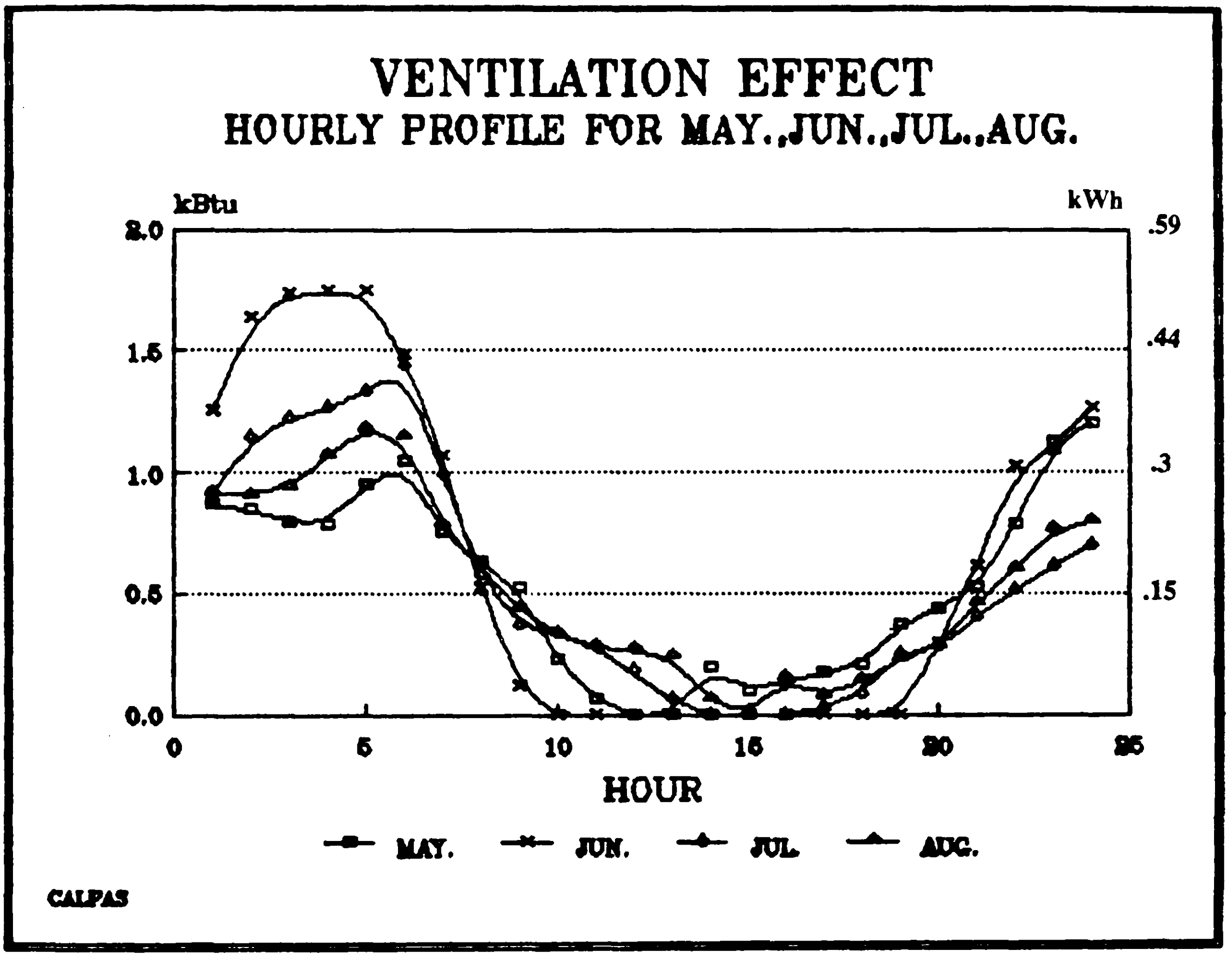

VENTILATION EFFECT
HOURLY PROFILE FOR FEB.,MAR.,APR.
kBtu
kWh
2.0
1.5
1.0
0.5
0.0
.59
.44
.3
.15
0
5
10
15
20
25
HOUR
FEB.
MAR.
APR.
CALPAS

Fig. 5.18



VENTILATION EFFECT
HOURLY PROFILE FOR MAY.,JUN.,JUL.,AUG.
kBtu
kWh
2.0
1.5
1.0
0.5
0.0
.59
.44
.3
.15
0
5
10
15
20
25
HOUR
MAY.
JUN.
JUL.
AUG.
CALPAS

Fig. 5.19

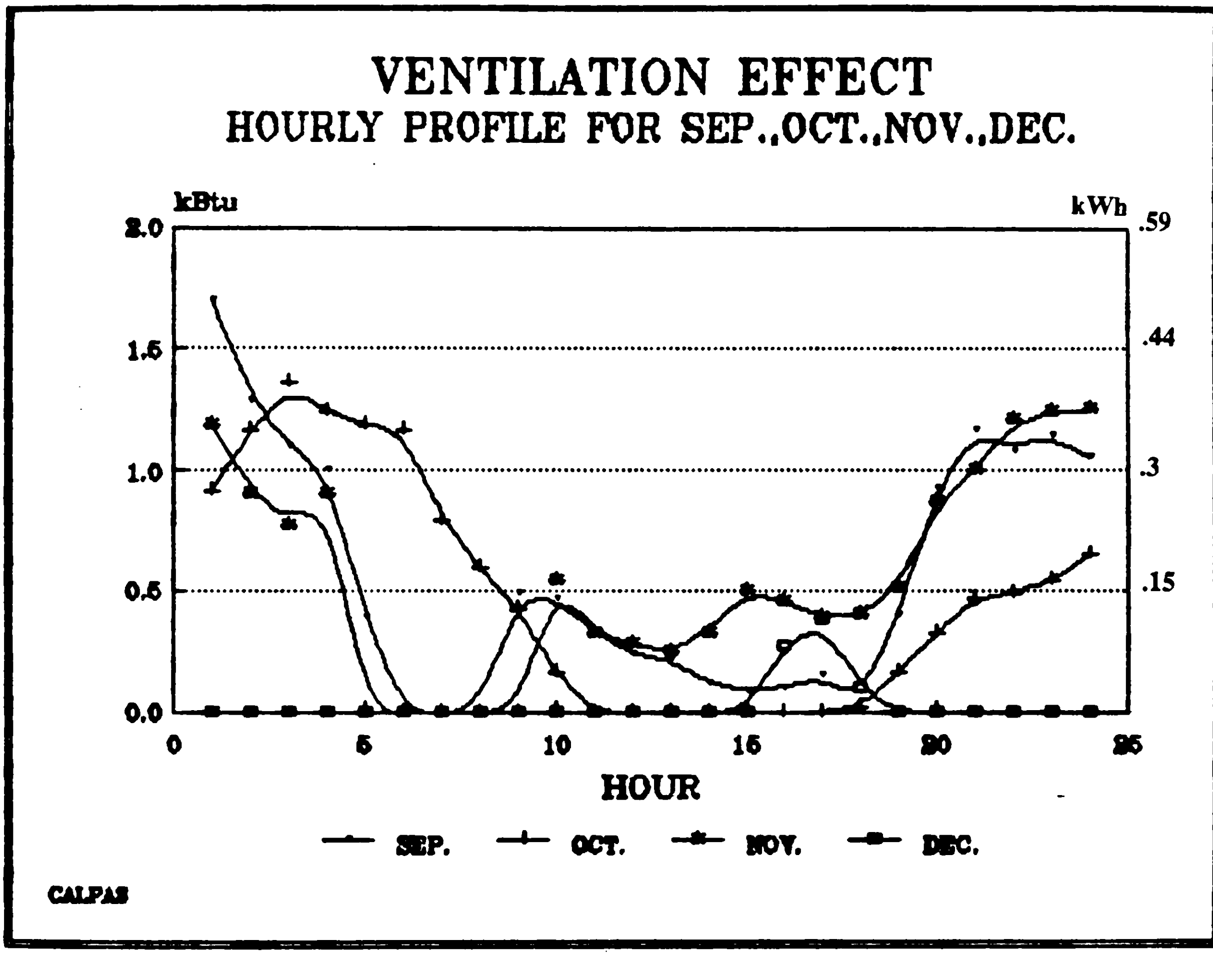

VENTILATION EFFECT
HOURLY PROFILE FOR SEP.,OCT.,NOV.,DEC.
kBtu
kWh
2.0
1.5
1.0
0.5
0.0
.59
.44
.3
.15
0
5
10
15
20
25
HOUR
SEP.
OCT.
NOV.
DEC.
CALPAS

Fig. 5.20

V.5.4 Materials effect :-

The fourth step examines the effect of building materials on the building envelope. The principal process of heat flow through a 24 hour period can be expressed as follows :-

Before sunrise both outdoor air and the external surfaces of the building envelope are at their minimum temperature. After sunrise the outdoor air temperature increases, reaching the maximum usually in the early afternoon. The heat flow process caused by this elevation of outdoor air temperature starts affecting the external surfaces of the building, raising their temperature.

This effect of outdoor temperature is almost identical for all surfaces regardless of their position. What makes it different is the asymmetrical effect of solar radiation heating surfaces above a level induced simply by air temperature. We know from previous tests the relative intensity of incident solar radiation on surfaces of varying orientation and tilt.

Starting from the outside, each construction layer having reached maximum thermal storage capacity relative to the solar input, passes heat subsequently to the next colder layer, and so on . Each layer receives less heat than the one before and is thus subjected to a smaller rise in temperature. Heat is stored within the structure of the envelope during this process, and consequently less heat reaches the inner surface than is input at the outer.

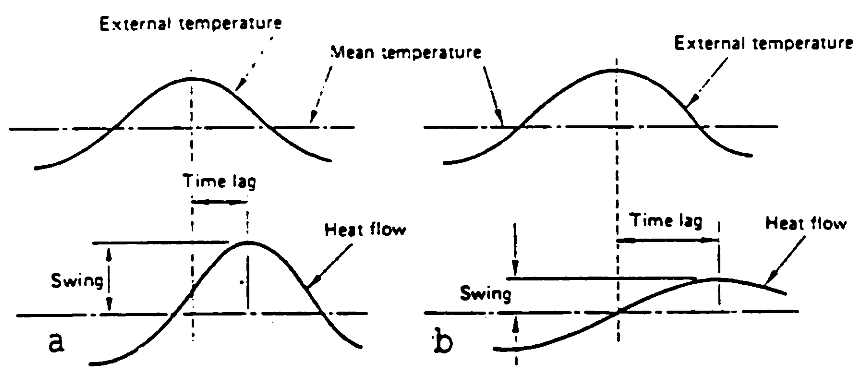
After the external surface reaches a maximum and starts to cool down, the process of heat flow is now reversed. At first the entire heat accumulated in the wall flows in two directions, inward and outwards. Later the entire flow is outwards in a successive cooling process of the various layers, corresponding to the earlier heating process.

In this way, any construction system undergoes wave-like cycles of heating and cooling. The amplitude of the internal wave expressed as heat flux or temperature is smaller than the that of the outer. Fig.(5.21).

The ratio of internal to external heat flux and temperature waves is known as decrement factor and damping factor respectively. The time-lag between peaks and troughs is the time taken for an input on the outside to be felt in the inside. Decrement factor, damping factor, and time-lag are dependent on the thickness of the structure and the thermophysical properties of successive layers, especially the square root of the ratio of volumetric heat capacity, (c.r), to conductivity (l), or inverse of thermal diffusivity $\sqrt{(c.r/l)}$, where (c) is specific heat capacity and (r) is density.

The greater the thermal diffusivity, the smaller the time-lag and great the amplitude of the internal wave (i.e. high decrement factor & small thermal damping). The inverse thermal diffusivity ratio can hence produce some unexpected results.

Effect of (a) lightweight and (b) heavyweight structure on heat flow variation.



TIME-LAG AFFECT

Fig. 5.21

Source : T.A.Markus and E.N.Morris, Buildings, Climate and Energy, 1980.

If we compare 200mm of timber, as in a cordwood or logend house found in the U.S. to a 200mm dense concrete wall, we find that timber has almost twice the time-lag and thermal damping, (i.e. lower decrement factor) compared with 200mm dense concrete :-

200mm Timber (softwood), (low thermal diffusivity)

c= 1200 J/kgK r= 650 kg/m^3 l= .14 w/mK

$\sqrt{(c.r/l)}$ = 2360

time-lag = 10.9 hrs decrement factor= 0.36

200mm Dense concrete, (medium thermal diffusivity)

c= 840 J/kgK r= 2100 kg/m^3 l= 1.4 w/mK

$\sqrt{(c.r/l)}$ = 1122.5

time-lag = 5.2 hrs decrement factor= 0.61

A high thermal diffusivity material such as fibreglass will further reduce time-lag and damping effect:-

200mm Fibreglass

c= 840 J/kgK r= 12 kg/m^3 l= .04 w/mK

$\sqrt{(c.r/l)}$ = 502

time-lag = 2.3 hrs decrement factor= 0.80

On the other hand another common insulation material, EPS or Polystyrene, has a comparable thermal diffusivity to concrete:-

200mm EPS

c= 1400 J/kgK r= 25 kg/m^3 l= .035 w/mK

$\sqrt{(c.r/l\ )}$ = 1000

time-lag = 4.6 hrs decrement factor= 0.65

Another natural material, cork, behaves in a similar manner to timber with:-

c= 1806 J/kgK r= 145 kg/m^3 l= .042 w/mK

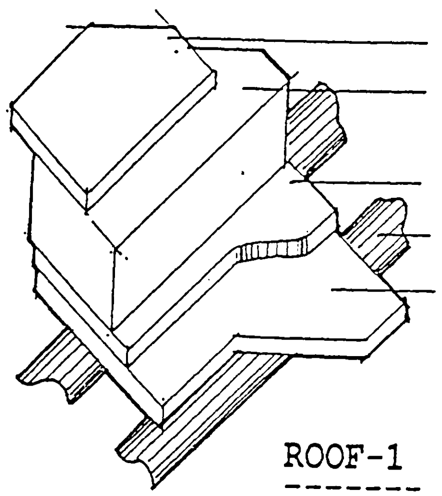
$\sqrt{(c.r/l\ )}$ = 2492

time-lag = 11.5 hrs decrement factor= 0.34

The dynamic thermophysical effect may then be simply summarised; as the thickness and ratio of volumetric heat capacity of the structure to the thermal conductivity of the material increases, the amplitude of the internal wave diminishes (smaller decrement factor), and the timing of the maximum and minimum is more retarded (greater time-lag).

This test examines three kinds of construction widely used in Saudia Arabia regions. Each construction type comprises wall and roof elements, and insulation is added as a variant in each case, Figs.(5.22, 5.23, & 5.24).

The major phase of this test have been simulated in relation to the thermophysical properties of materials, i.e. time-lag and decrement factor.

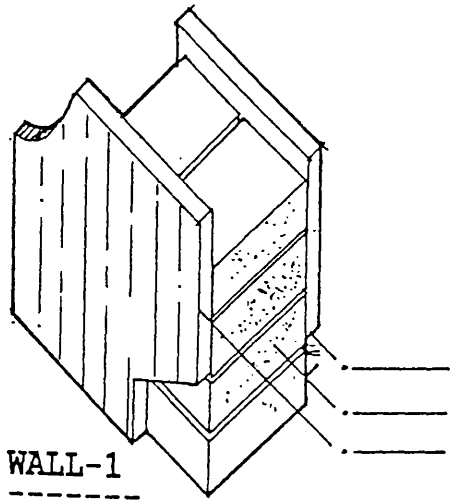


Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	900	0.130	2000	0.040
2	1730	0.298	1000	0.300
3	1570	0.526	1000	0.020

Number of layers = 3
No.Constructions = 1
Construct Name No. 1 ROOF 1
Surface Resistances
Internal < 12> :
External < 06> :

Properties

u-value	:	0.653
Decrement factor	:	0.036
Admittance	:	2.897
Surface Factor	:	0.712
Calculating.....		
Time Lag Out/In		8.857



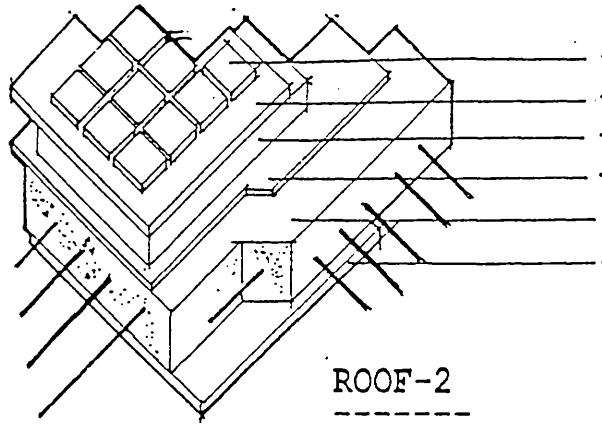
Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	1730	0.298	1000	0.400
3	1570	0.526	1000	0.020

Number of layers = 3
No.Constructions = 1
Construct Name No. 1 WALL 1
Surface Resistances
Internal < 12> :
External < 06> :

Properties

u-value	:	0.626
Decrement factor	:	0.020
Admittance	:	4.080
Surface Factor	:	0.806
Calculating.....		
Time Lag Out/In		10.369

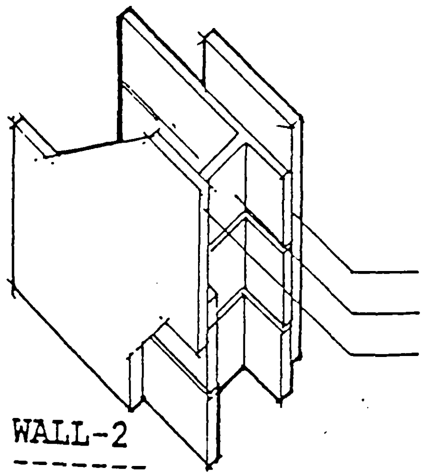
Fig. 5.22 CONSTRUCTION NO.1



Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	2400	1.728	960	0.200
3	1700	0.500	1000	0.010
4	1800	1.790	1196	0.030
5	1500	0.360	1000	0.010
6	2100	1.100	837	0.020

Number of layers = 6
No.Constructions = 1
Construct Name No. 1 ROOF 2
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 2.401
Decrement factor : 0.255
Admittance : 5.206
Surface Factor : 0.417
Calculating.....
Time Lag Out/In 5.263



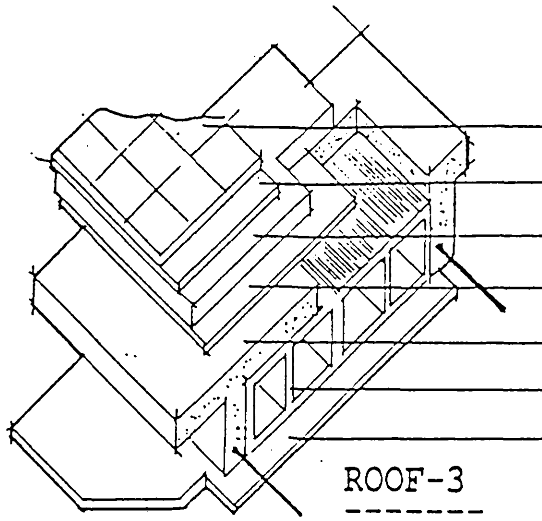
Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	1403	0.600	840	0.200
3	1570	0.526	1000	0.020
4				

Number of layers = 3
No.Constructions = 1
Construct Name No. 1 WALL 2
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 1.697
Decrement factor : 0.455
Admittance : 4.277
Surface Factor : 0.577
Calculating.....
Time Lag Out/In 4.570

CONSTRUCTION NO.2

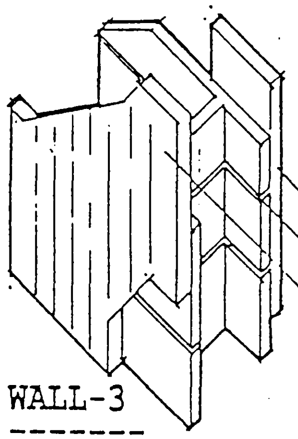
Fig. 5.23



Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	1303	0.634	864	0.200
3	2400	1.728	960	0.050
4	1700	0.500	1000	0.010
5	1800	1.790	1196	0.030
6	1500	0.360	1000	0.010
7	2100	1.100	837	0.020

Number of layers = 7
No.Constructions = 1
Construct Name No. 1 ROOF 3
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 1.550
Decrement factor : 0.246
Admittance : 4.235
Surface Factor : 0.579
Calculating.....
Time Lag Out/In 5.386



Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	1029	0.360	840	0.200
3	1570	0.526	1000	0.020

Number of layers = 3
No.Constructions = 1
Construct Name No. 1 WALL 3
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 1.232
Decrement factor : 0.485
Admittance : 3.814
Surface Factor : 0.657
Calculating.....
Time Lag Out/In 4.769

Fig. 5.24 CONSTRUCTION NO.3

Tables in the previous figures, summarize the characteristics of each construction and the effect of the thermal insulation on the behavior for the first phase of this test.

Construction no.1 (the traditional mud building), is demonstrated to give a better thermal performance for a hot climate than more modern construction (no.2, and no.3), both in terms of thermal resistance and capacitance, the former reducing rate of heat flux and the latter giving long time-lag and greater damping. The delay in heat flow peak outside to inside is 10.4 hours for the wall and 8.9 hours for the roof.

The heavy construction thus smoothes over the fluctuations of heat flows and stabilises the internal temperature profile.

Almost all the examined constructions express relatively low decrement factor but significantly higher than the mud construction.

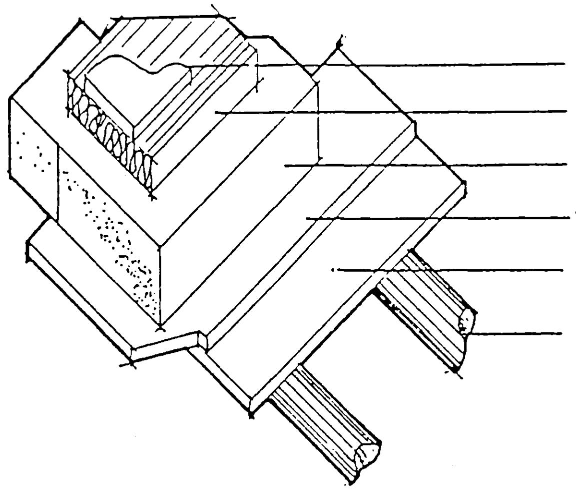
For example, with respect to U values, modern wall construction no.2 is almost 3 times that of the traditional, while its time-lag is less than half. These performance factors are summarized in table no.(5.2).

Table no.(5.2)

Performance Factors of the examined construction

	U.value Factor	Time-lag Factor
Construction no.(1)		
Wall	1	1
Roof	1	1
Construction no.(2)		
Wall	3	0.4
Roof	4	0.6
Construction no.(3)		
Wall	2	0.4
Roof	2	0.6

Each construction is tested once again to demonstrate the effect of adding exterior thermal insulation. The result shows a pronounced enhancement particularly for the modern construction. Almost twice the time-lag period has been achieved for each construction as illustrated in figs.(5.25, 5.26, & 5.27). The main benefit for traditional construction lies more in improved thermal resistance than in increased time-lag. The extra 6 hrs for the roof would also be of benefit in delaying heat input from the afternoon period. For the modern construction both aspects are an essential improvement.

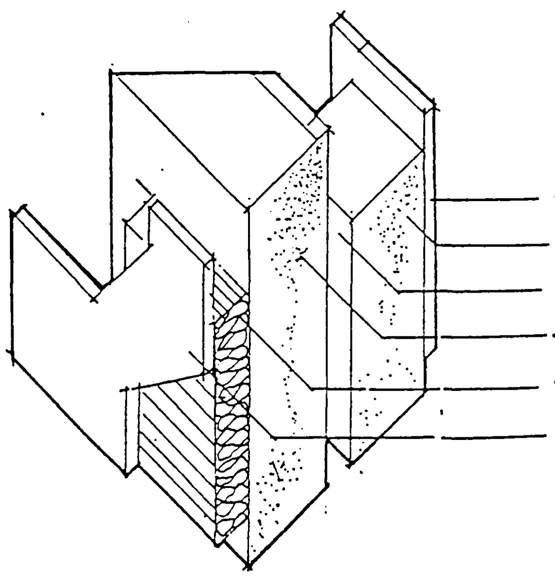


INSULATED ROOF-1

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	900	0.130	2000	0.040
2	1730	0.298	1000	0.300
3	25	0.030	1000	0.050
4	1570	0.526	1000	0.020

Number of layers = 4
No.Constructions = 1
Construct Name No. 1 INROOF1
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 0.313
Decrement factor : 0.010
Admittance : 2.897
Surface Factor : 0.712
Calculating.....
Time Lag Out/In 15.406



INSULATED WALL-1

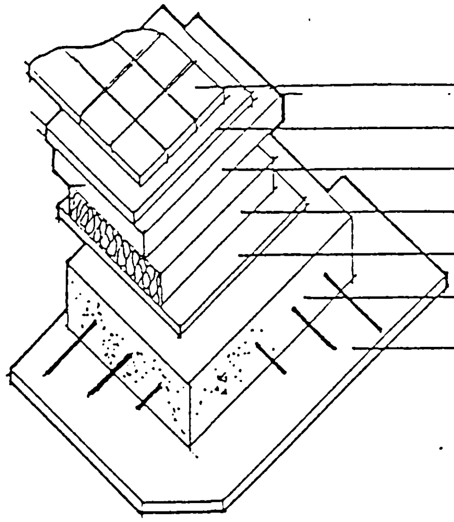
Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	1730	0.298	1000	0.200
3	1.2000000	0.02516	1000	0.050
4	1730	0.298	1000	0.200
5	25	0.030	1000	0.050
6	1570	0.526	1000	0.020

Number of layers = 6
No.Constructions = 1
Construct Name No. 1 INWALL
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 0.190
Decrement factor : 0.001
Admittance : 4.071
Surface Factor : 0.607
Calculating.....
Time Lag Out/In 20.391

CONSTRUCTION NO.1

Fig. 5.25

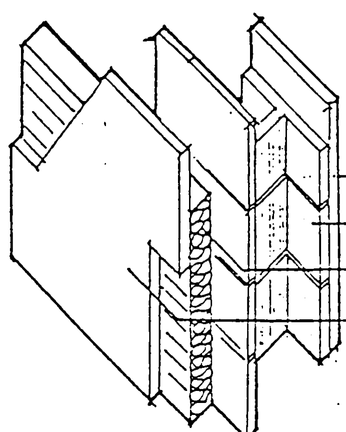


INSULATED ROOF-2

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	2400	1.728	960	0.200
3	1700	0.500	1000	0.010
4	25	0.030	1000	0.050
5	1800	1.790	1196	0.030
6	1500	0.360	1000	0.010
7	2100	1.100	837	0.020

Number of layers = 7
No.Constructions = 1
Construct Name No. 1 INROOF2
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 0.480
Decrement factor : 0.117
Admittance : 5.272
Surface Factor : 0.407
Calculating.....
Time Lag Out/In 13.024



INSULATED WALL-2

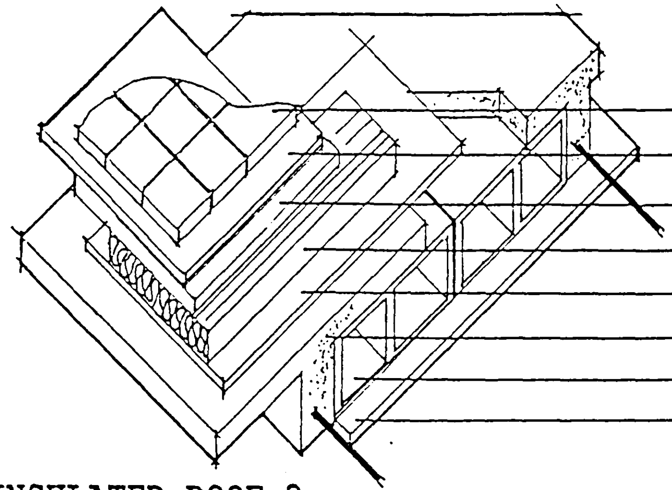
Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	1403	0.600	840	0.200
3	25	0.030	1000	0.050
4	1570	0.526	1000	0.020

Number of layers = 4
No.Constructions = 1
Construct Name No. 1 INWALL2
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 0.443
Decrement factor : 0.208
Admittance : 4.317
Surface Factor : 0.564
Calculating.....
Time Lag Out/In 9.921

CONSTRUCTION NO.2

Fig. 5.26

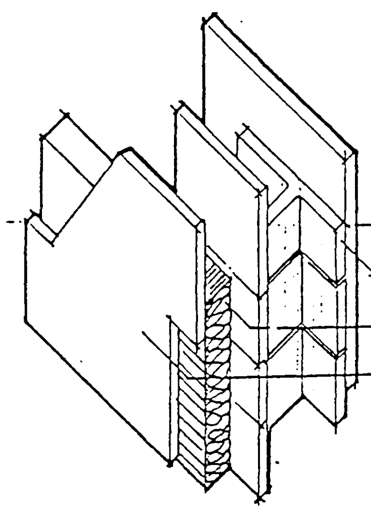


INSULATED ROOF-3

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	1029	0.360	840	0.200
3	2400	1.728	960	0.050
4	1700	0.500	1000	0.010
5	25	0.030	1000	0.050
6	1800	1.790	1196	0.030
7	1500	0.360	1000	0.010
8	2100	1.100	837	0.020

Number of layers = 8
No.Constructions = 1
Construct Name No. 1 INRO
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 0.39
Decrement factor : 0.07
Admittance : 3.77
Surface Factor : 0.65
Calculating.....
Time Lag Out/In 11.23



INSULATED WALL-3

Layer Number	Density kg/m^3	Thermal Conduct. W/m K	Specific Heat cap. J/kg K	Layer Thickness (mm)
1	1570	0.526	1000	0.020
2	1029	0.360	840	0.200
3	25	0.030	1000	0.050
4	1570	0.526	1000	0.020

Number of layers = 4
No.Constructions = 1
Construct Name No. 1 INWALL3
Surface Resistances
Internal < 12> :
External < 06> :

Properties
u-value : 0.404
Decrement factor : 0.225
Admittance : 3.819
Surface Factor : 0.648
Calculating.....
Time Lag Out/In 9.090

CONSTRUCTION NO.3

Fig. 5.27

The typical daily pattern of temperature for different constructions is illustrated in figs.(5.28, 5.29, 5.30, 5.31,5.32, & 5.33), for a hot summer day, e.g. June. Each graph shows the actual outside temperature (T_o) and the equivalent outside temperature (T_{eo}) relative to the particular construction element.

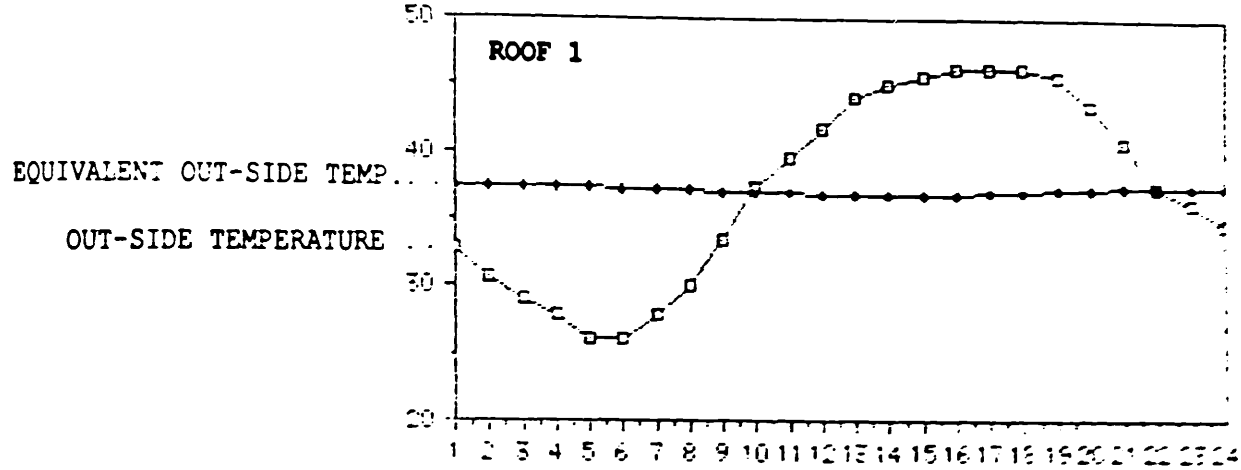
The (T_{eo}) curve simply express the time-lag and damping effect of the construction. In other words the (T_{eo}) values at a particular time is how the internal environment perceives the outside, and thus enables cyclical heat load to be calculated using a simple temperature difference (T_i-T_{eo}) corresponding to (T_i-T_o) in steady state analysis.

T_{eo} is found by $(m)(T_o^* - T_o) + T_o$

where T_o^* = is the outside temperature time-lag hours before the time in question.

T_o = is the mean outside temperature for cyclical period, usually 24 hours.

m = decrement factor.



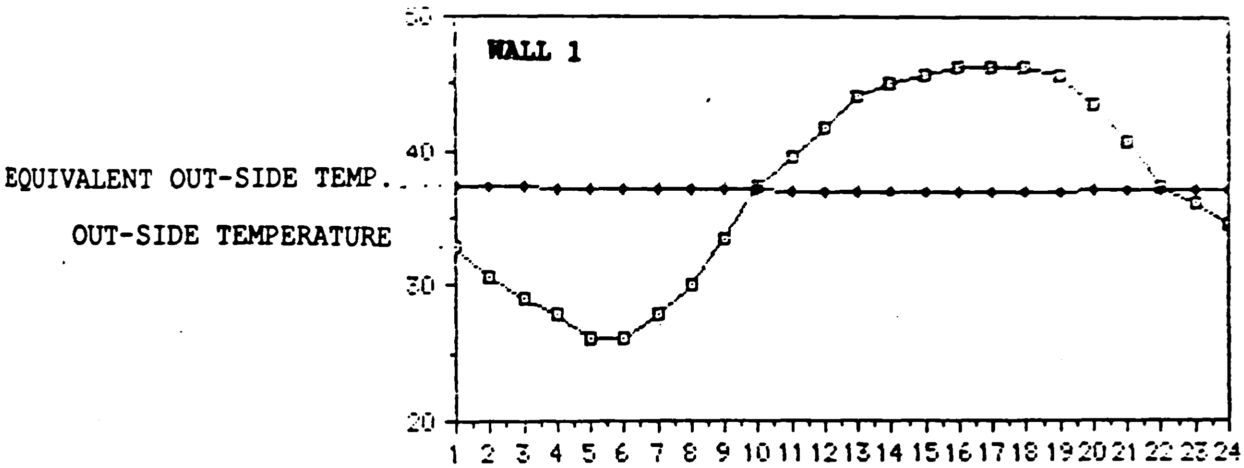
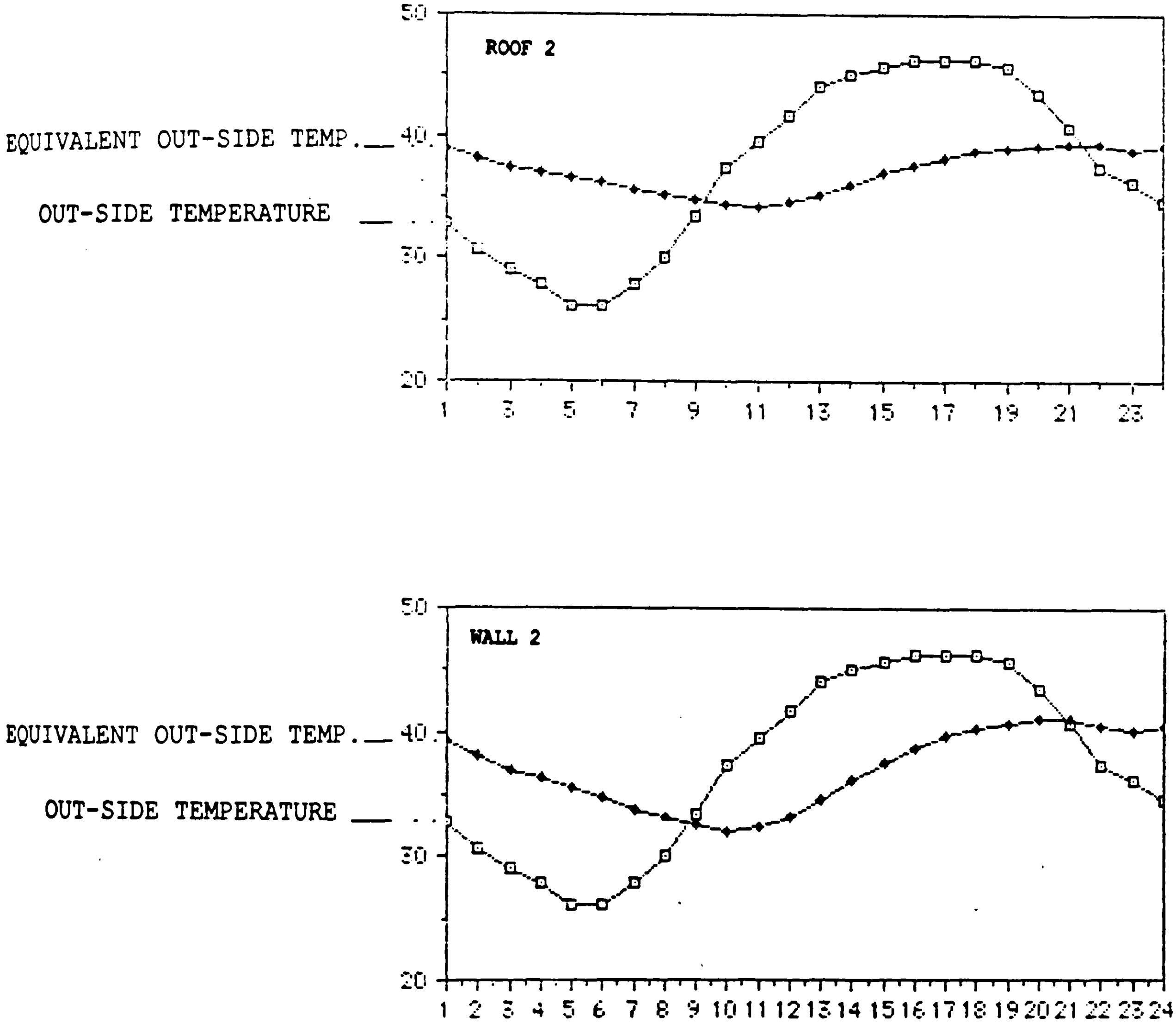


Fig. 5.28 CONSTRUCTION NO.1 **Mean June day**



CONSTRUCTION NO.2 Mean June day

Fig. 5.29

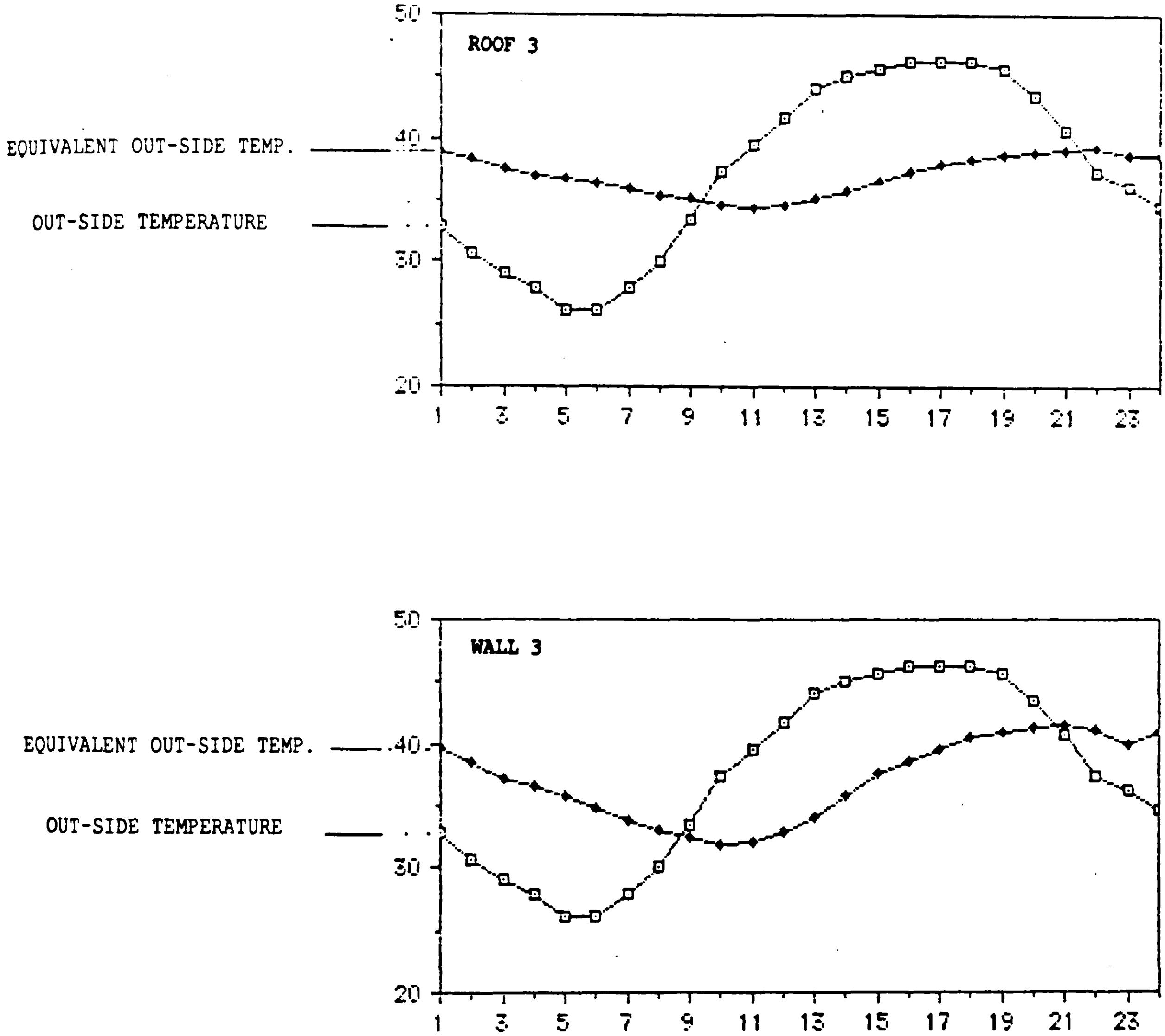
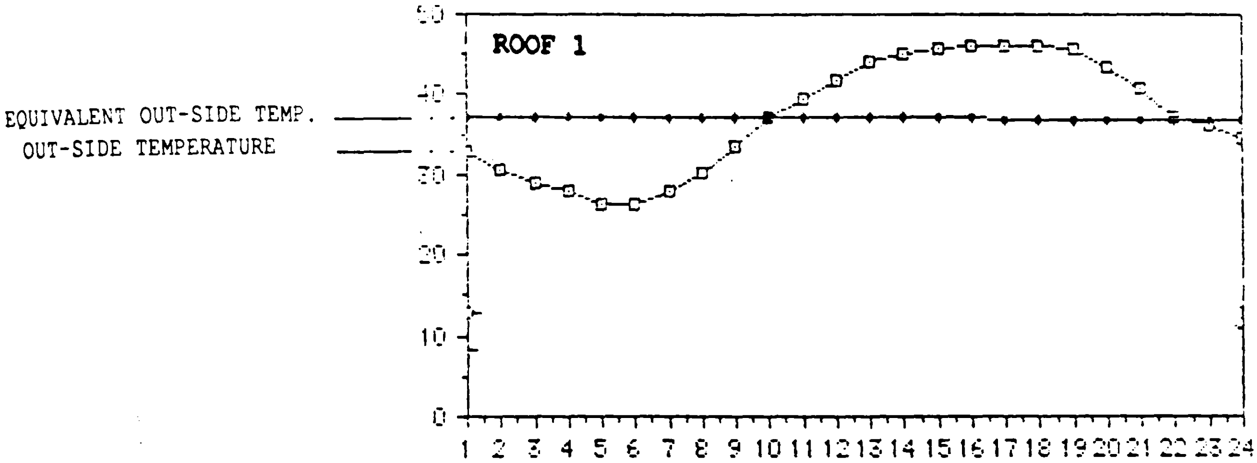


Fig. 5.30 **CONSTRUCTION NO.3 Mean June day**



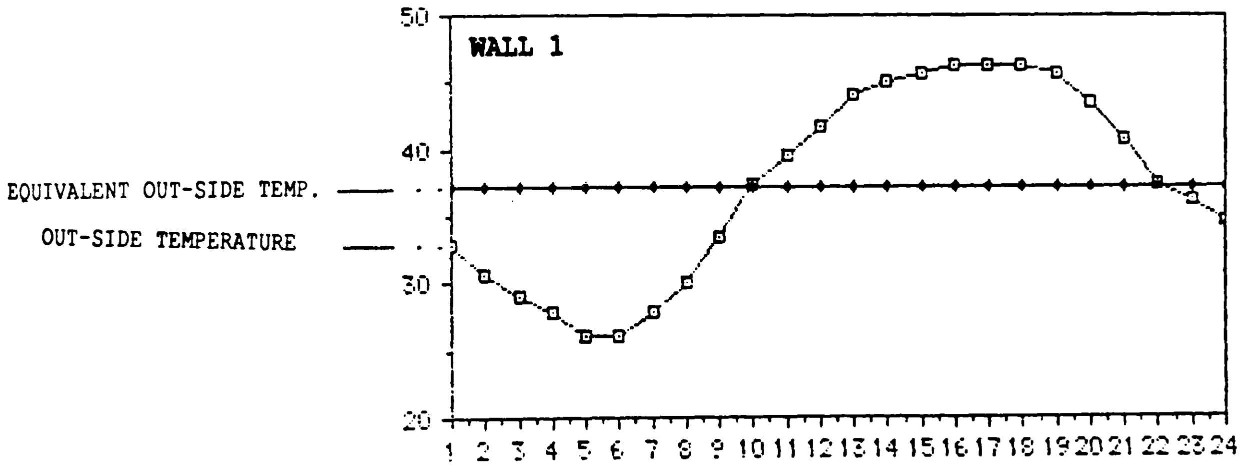
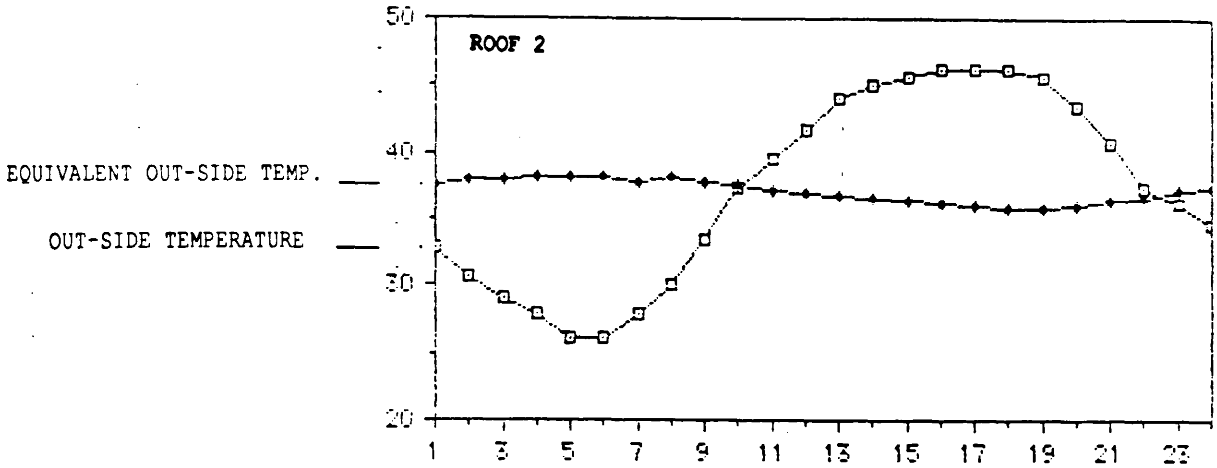


Fig. 5.31 INSULATED CONSTRUCTION NO.1 **Mean June day**



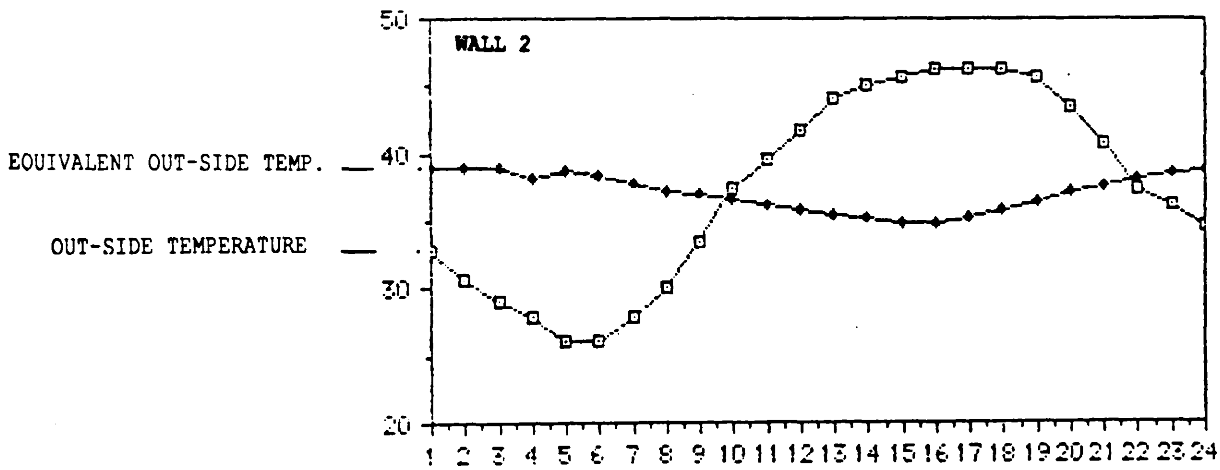
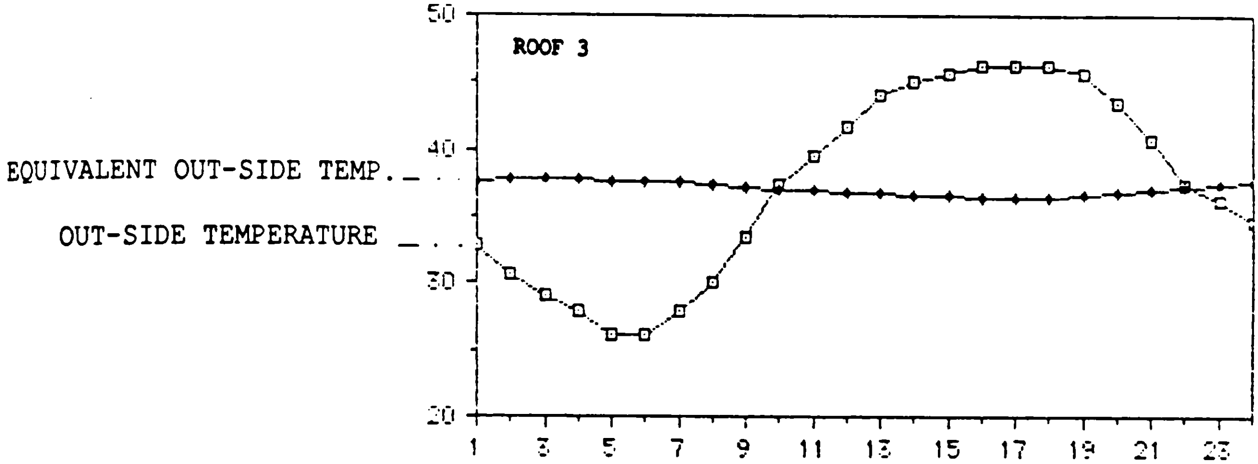


Fig. 5.32 **INSULATED CONSTRUCTION NO.2 Mean June day**



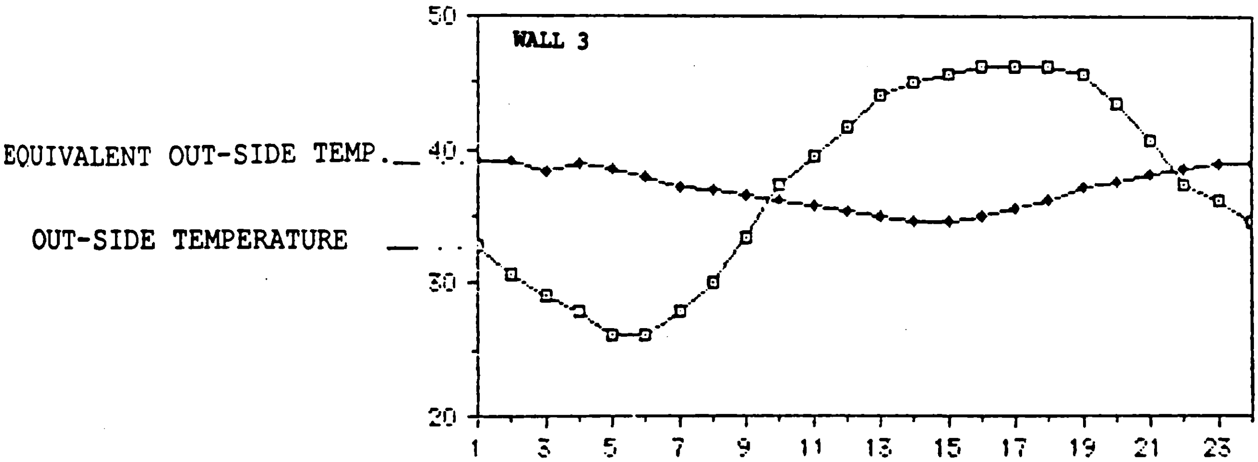


Fig. 5.33 **INSULATED CONSTRUCTION NO.3 Mean June day**

V.6 Heat Distribuation Balance And Time-Lag

It can be seen from the previous figures, that a time-lag in excess of 12 hours with a low decrement give a flat curve (i.e. if inside temperature is constant we have a steady-state temperature difference which expresses the storage effect of the construction. However time-lag in ex-ess of 12 hours may still be relevant in term of unwanted transmission of stored heat to particular interior spaces.

Thus the reality of dynamic thermal behaviour, with the structural elements acting as storage heat emitters; is more complex than indicated by a simple $T_i - T_{eo}$ temperature difference.

The low diffusivity characteristic of material, (i.e. the ratio of conductivity to volumetric thermal capacitance), can then be used effectively to equalize and displace in time the daily thermal impacts.

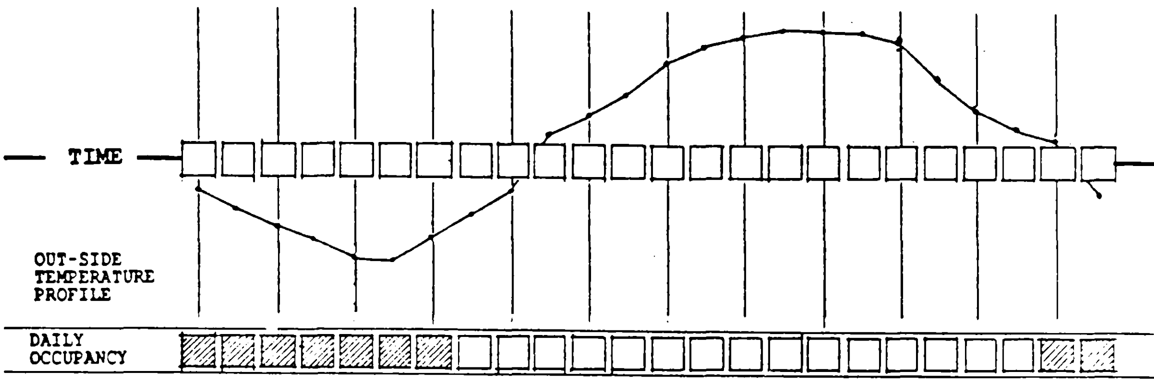
The daily cooling load distribution can be balanced by shifting the impacts to the off-load hours. The desirable time-lag characteristics for Al-Riyadh physical environment can be expressed according to the coordinate locations of the building components.

In general, the large diurnal variation demands a heavy structure. The delay effect of roofs in particular is critical, since a roof is exposed to maximum effects of the solar radiation in the overheating season.

A delay of 10-15 hours can strongly influence the internal space in relation to time occupancy of different activities. Fig.(5.34) summarizes the desirable time-lag of different house activities and their proper location in plan organization.

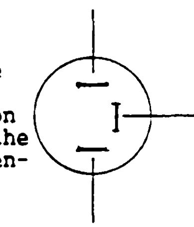
The north wall is of lesser importance in delaying the heat flow compared with the other sides, but damping characteristics are relevant even without direct insolation due to diurnal rise in temperature all round a building.

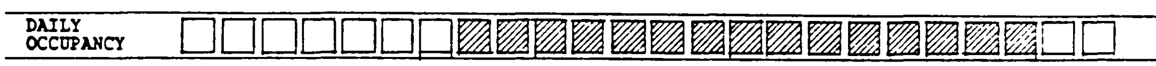
A general cooling strategy to take advantage of the thermophysical properties of the building materials in the Al-Riyadh environment is to protect the day time living areas with heavy and heat delaying masses, and less thermal capacity for the night time areas, so that they may respond readily to the coolness.



BED-ROOM -- Total occupancy 9 hours, recomended position are to the East, North, and South respectivily, to give the structure a chance to cool before using time

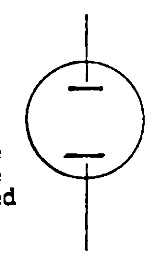
TIME-LAG -- The usage of this activity starts late afterenoon the desirable time-lag strategy is to avoid the reradiation of heat at this time, with night ventilation to help structure cooling down.

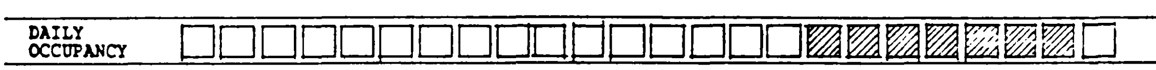




LIVING ROOM -- Total occupancy is approximately 16 hours, all day long. It is the most important house activity that need special handling. Proper location is to the north and south direction.

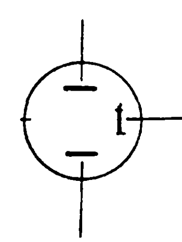
TIME-LAG -- Heavy structure with good thermal resistance should be allocated here, to delay heat despatch to the end of the occupancy time. Time-lag of up to 15hrs could be required from the structural elements.





GUESTS ROOM -- Total occupancy is 7hours, afternoon occupation usual, and frequent usage is rare. East, South or North location is preferable.

TIME-LAG -- Transmission during afternoon period to be avoided with not less then 6hrs is recomended.



KITCHEN -- Has 8hours total occupancy, spread along the day-time. The problem of this space is the internal heat generating from fire places, which is a very pronounced addition. The proper location is to north or any position not in direct exposure

TIME-LAG -- Need long time-lag of up to 15hrs with good ventilation to decrease the combined effect of out-side heat flow, and the internal heat gain.

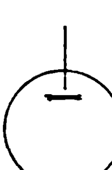


Fig. 5.34

V.7 Theoretical Analysis of the Combined Effect of U-Value and Night Ventilation on the Internal Temperature

For a steady state condition (i.e. the situation where temperature differences between internal and the external temperature is constant), the following theoretical calculation is made to check the effect of the thermal transmission coefficient and night ventilation on the internal air temperature.

A standard thermal balance equation is implemented on a typical hot sample day from the computer program Calpas3 using Ceramic hollow block construction no.3.

Thermal Balance Equation :-

$$Q_c + Q_i + Q_s + Q_{so} = AU\,(t_i - t_{eo}) + .3nV\,(t_i - t_o) \quad (W)$$

Where the :-

- Q_c = The rate of heat flow (negative for cooling) (W)
- Q_i = Incidental heat gain (W)
- Q_s = Solar heat gain through the openings (W)
- Q_{so} = Solar heat gain through opaque surface (W)
- A = Area of the elements (m^2)
- U = Thermal Transmittance coefficient (W/m^2K)
- t_i = Internal temperature (°c)
- t_{eo} = Equivalent outside temperature averaged for external surfaces (°c)
- n = No. of air changes per hour (ac/h)
- V = Volume of the space (m^3)

CALPAS3 sample example on June-10 gives the following information :-

For construction without insulation

Q_c = -1500 (W) Q_i = 150 (W) Q_s = 71 (W)

Q_{so}= 2053 - 57 T_i calculated from the following

equation $Q_{so} = AU_o \; (T_{eo} + a.R_{so} - T_i)$

Where a = Absorptivity of opaque surface

R_{so}= Opaque surface resistance

AU= 60.4   U-value wall= 1.23   U-value roof=1.55

V = 27   n = 1

$t_{eo(0-6)}$ = 37°C $t_{o(6-24)}$= 29°C

$t_{eo(6-24)}$= 39°C $t_{o(6-24)}$= 36°C

The day is divided into two periods, from (0-6 a.m.), and from (6-24 p.m.). The thermal balance equation is then applied in several stages with and without cooling plant :-

. with given construction and background infiltration.

. with modification in U-value and ventilation rate.

$t_{i\ 0-6\ a.m.}$:-

$$-1500 +150 + 0 + 0 = 60.4\ (t_i - 37) + \ (.3x1x27)\ (t_i - 29)$$

$$-1350 = 60.4\ t_i -2234.8 + 8.1\ t_i - 234.9$$

$$t_i \quad = 1119.7\ /68.5 = 16.3\ ^oC$$

$t_{i\ 6\text{-}24\ p.m.}$:-

$$-1500 + 150 + 71 + 2053 - 57t_i = 60.4(t_i-39) + 8.1(t_i-36)$$

$$774 - 57\ t_i = 60.4t_i - 2355 + 8.1t_i - 291.6$$

$$3421.2 = 125.5\ t_i$$

$$t_i = 3421.2\ /\ 125.5 = 27.3°c$$

With a large cooling load of 36kWh, average 1500 W over 24 hours, the t_i is lower than the upper tolerable level for comfort, particulary during the night period, and therefore not economic. Holding t_i to a notional upper level of the tolerable comfort, say t_i=29°C we may find the lowest Q_c to achieve this mean temperature level during both periods.

$t_{i\ 0\text{-}6}$:-

$$Q_c + 150 = 60.4\ (29-37) + 0$$

$$Q_c = -\ 633.2\ W$$

$t_{i\ 6\text{-}26}$

$$Q_c + 150 + 71 + 2053 - 57(29) = 60.4(29-39) + 8.1(29-36)$$

$$Q_c + 150 + 71 + 2053 - 1653 = -604 - 56.7$$

$$Q_c = -1168.3\ W$$

Allowed to free-float with no cooling, i.e. Q_c=0, $t_{i0\text{-}6}$ & $t_{i6\text{-}24}$ can then be found and compared to the Calpas3 output.

t_{i0-6}

$0 + 150 + 0 + 0 = 68.5\ t_i - 2469.7$ (+105.75)

$t_i = 2319.7 / 68.5 = 33.9\ °C$

Calpas3 output for this period = 36.7 °C

The difference can be explained by energy in storage of +105.75 on the right hand side in of the equation (in parenthesis).

t_{i6-24}

$0 + 150 + 71 + 2053 - 57t_i = 60.4t_i - 2355.6 + 8.1t_i - 291.6$

$2347 = 125.5t_i$ (+127.1)

$t_i = 39.2°C$

Calpas3 output for this period = 38.2°C

This time the difference can be explained by energy in storage of +127.1 W (in parenthesis). Night ventilation, say 4 ac/h, does not significantly improve this situation :-

$150 = 92.3\ t_i - 3174.4$

$t_i = 35.8\ °C$

Returning to a Q_c= -633 & -1168.3 W, increased ventilation and improved insulation are applied, and the reduction in t_i evaluated.

Q_c=-1168 U-value wall=.4 U-value roof=.39

AU=20.9 AU_o=17.5

$Q_{so} = 647.8 - 17.5\ t_i$

$t_{eo(0-6)} = 39$ $t_{o(0-6)} = 39$ n= 4 ac/h

$t_{eo(6-24)} = 37$ $t_{o(6-24)} = 36$ n= 1 ac/h

t_{i0-6}

$$-633 + 150 + 0 + 0 = 20.9(t_i-39) + (.3x4x27)(t_i-29)$$

$$-483 = 53.3t_i - 1754.7$$

$$t_i = 1271.7 / 53.3 = 23.9\ ^oC$$

t_{i6-26}

$$-1168 + 150 + 71 + 647.8 - 17.5t_i = 20.9(t_i-37) + 8.1(t_i-36)$$

$$-299.2 -17.5t_i = 20.9t_i -773.3+ 8.1t_i - 291.6$$

$$t_i = 765.1 / 46.5 = 16.5^oC$$

Next we may determine the t_i in the new situation where there is no cooling input Q_c=0, in order to establish the range of temperature that could then possibly be reduced passively.

t_{i0-6}

$$0 + 150 + 0 + 0 = 20.9(t_i-39) + 32.4(t_i-29)$$

$$150 = 20.9\ t_i - 815.1 + 32.4t_i - 939.6$$

$$t_i = 1904.7 / 53.3 = 35.7^oC$$

Note - This is very similar to the value for uninsulated construction, but with night ventilation.

t_{i6-26}

$$0 + 150 + 71 + 647.8 - 17.5t_i = 20.9(t_i-37)+8.1(t_i-36)$$

$$868.8 - 17.5t_i = 29t_i - 1024.9$$

$$t_i = 1893.7 / 46.5 =40.7^oC$$

This value is also marginally higher than the uninsulated construction, but could be slightly modified downwards by diurnal use of window shutters.

Next we may find the lowest Q_c that can achieve a temperature of 29°C, with the improved construction and increased ventilation.

t_{i0-6}

$Q_c + 150 + 0 + 0 = 20.9(29-39) + 32.4(29-29)$

$Q_c + 150 = -209 + 0$

$Q_c = -359$ W

Now with Q_c= -359, a temperature of 29°C can be achieved, while when Q_c=0, t_i was 35.7°C. The difference between the two situations is 6.7 K, which may be provided either by an active or passive cooling system.

t_{i6-24}

$Q_c + 150 + 71 + 647.8 - 17.5t_i = 20.9(29-37) + 8.1(29-36)$

$Q_c + 361.3 = - 167.2 - 56.7$

$Q_c = - 585.2$W

The difference between this situation and the one without cooling load is 11.4K, which is achieved by 585.2W of cooling. Both night and day cooling loads are now approximately halved compared with the uninsulated construction.

Thus, with the improved construction the nocturnal range of 6.7 and diurnal range of 11.4K is the target for a passive cooling solution.

If we now examine the situation on the psychrometric chart in fig.(5.35), we can see that :-

with T_{D1} = 40 °C , Rh_1 = 20 %

Specific Enthalapy = 68 kJ/kg

The moisture content of this air =.010 kg/kg(dry air). Moving on the same enthalapy line and increasing the amount of (Rh_1) to (Rh_2) = 55 %, we notice a drop of (T_{D1}) to (T_{D2}) =29°C. To do this, theoretically an increase in the moisture content is required up to = .015 kg/kg (dry air), i.e. an increase of .005 kg/kg dry air. It should by noted that 70% is recognised as a maximum suitable value for dwellings[8].

For the simple model dimension 3x3x3 m, the quantity of air required for good ventilation,[9] with the assumption of three people present for 6hours is as follows :

Air space per person	= Volume/No. of people	
	= 27 / 3 = 9	m^3
Minimum air supply per person	=.0052	m^3/s
Total fresh air supply	= 3 x .0052 = .0156	m^3/s
Air supply per hour	= 3600 x .0156 = 56.16	m^3/h
Amount of dry air over 6h	= 6 x 56.16 x 1.2	kg/m^3
	= 404 kg dry air	

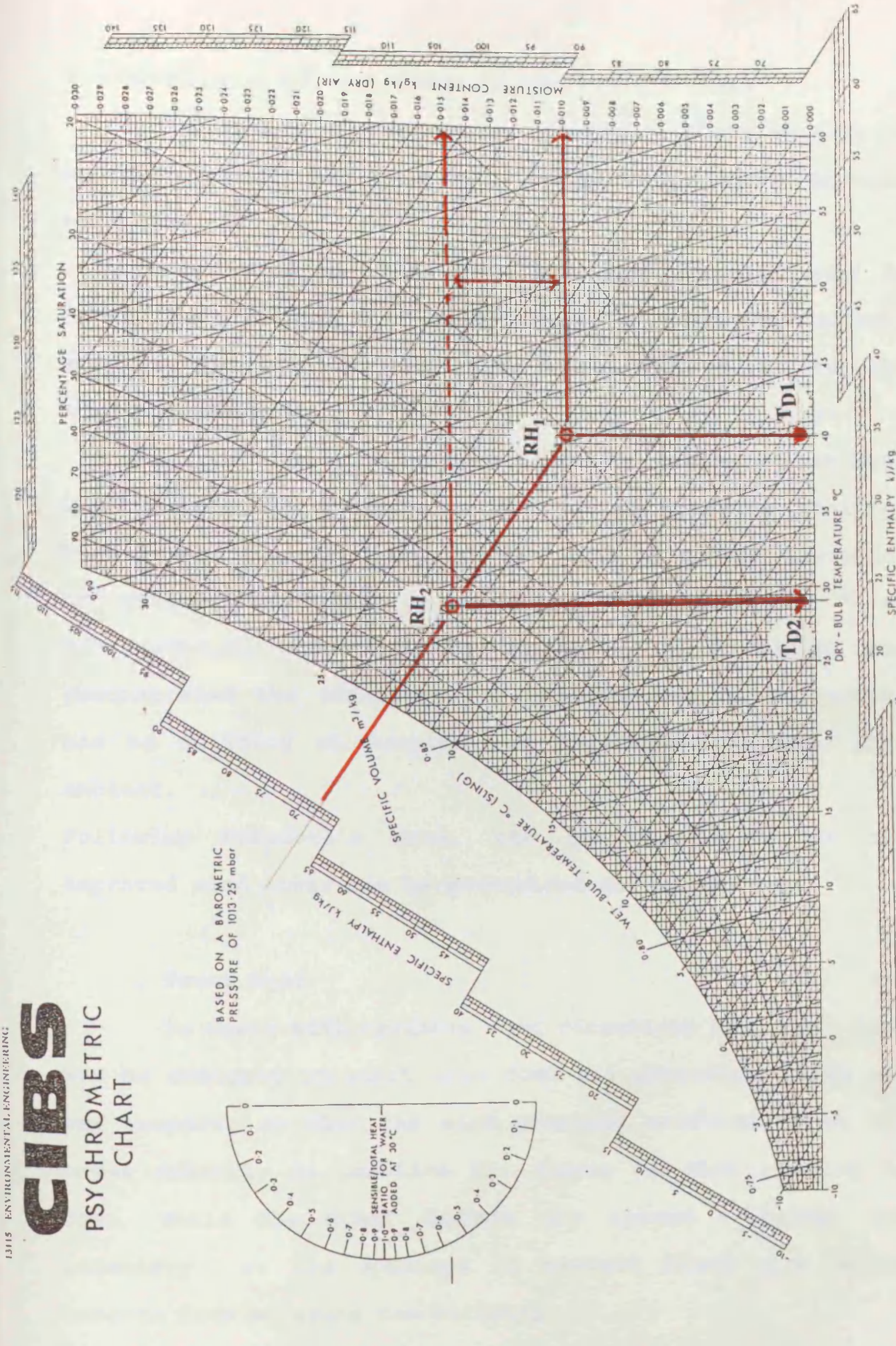

CIBS
PSYCHROMETRIC CHART
BASED ON A BAROMETRIC PRESSURE OF 1013·25 mbar
PERCENTAGE SATURATION
MOISTURE CONTENT kg/kg (DRY AIR)
DRY - BULB TEMPERATURE °C
SPECIFIC ENTHALPY kJ/kg
SPECIFIC VOLUME m³/kg
WET - BULB TEMPERATURE °C (SLING)
SENSIBLE/TOTAL HEAT RATIO FOR WATER ADDED AT 30 °C
RH1
RH2
TD1
TD2

Fig. 5.35

V.8 Analysis of the Humidification Process

To introduce an evaporative cooling strategy we have to humidify the dry air by adding 5g of water vapour to each kg of dry air.

Since we have 404 kg of dry air averaged over 24 hours, then we need 2.02 kg of water to give the coolness effects for the incoming air before taking it to the conditioned space.

Architecturally, wind towers or wind catchers have been used widely for natural ventilation and passive cooling, wind towers designed to catch the wind at higher elevation and direct it into the living space. Mehdi Bahadori,(10) in his work of improving the design of wind towers has demonstrated the efficiency of this element in delivering air to building at temperatures significantly lower than ambient.

Following Bahadori's work, the characteristics of the improved wind tower can be summarized as follows :-

. Tower Head

In areas with variable wind directions the tower head may be designed to admit wind from all direction, with one way dampers, so when the wind pressure coefficient at the tower openings is positive the damper at that opening is open, while the other dampers are closed . Screen are necessary at the openings to prevent birds and larger insects from entering the building.

. Thermal Energy Storage Section

The convective heat transfer coefficient of air blowing over energy storing materials is generally low, thus, for a given quantity of heat to be transferred to the material, the surface area must be large.

A large surface area is selected to avoid excessive pressure losses of air as it flows over them. The material is baked clay made in form of long conduits, the conduits may have circular, rectangular, or square cross section. Wind tower cross section, normal to air-flow, is $1m^2$.

. Evaporative Cooling of Air

The clay conduits are wetted uniformly by spraying or pouring water over them at the top of the column. Water uniformly spread over conduits will not run off the wall quickly, rather it keeps the clay conduits uniformly moist as it flows down.

Returning to the previous theoretical calculation, the amount of moisture to be added to dry air, can simply be achieved using this concept. Figs.(5.36), shows the results of the computations held by Bahadori. From the relationships of the height of the evaporation column, and dry-bulb temperature, we can see the following explanation:-

with T_o = 45 °C

R.H. = 12 %

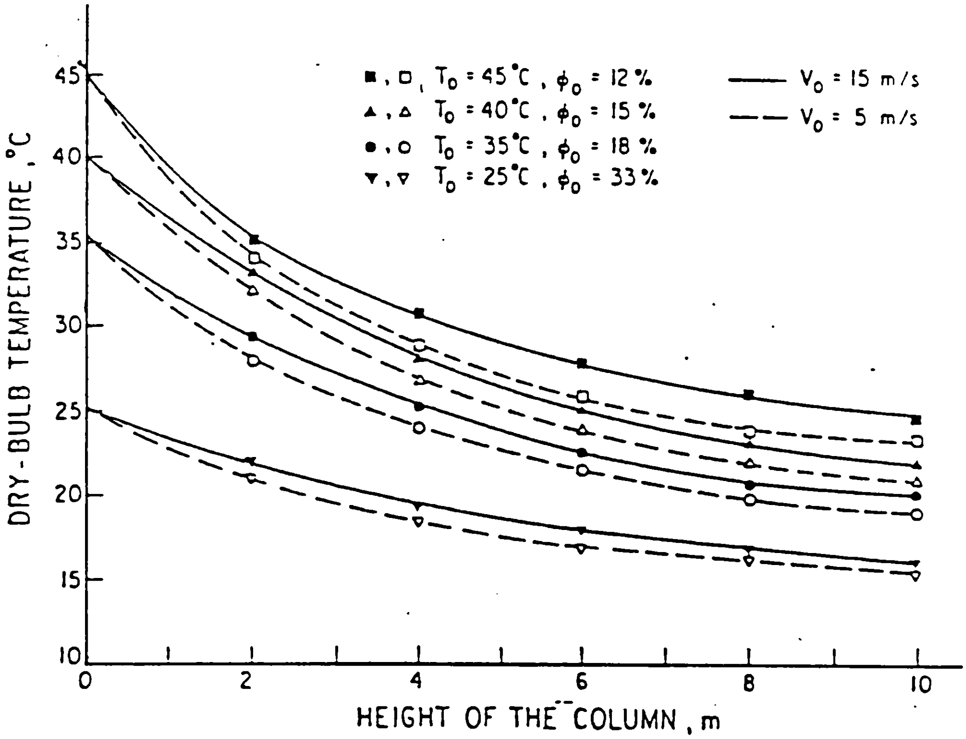
V = 5 m/s

moderate height of the tower of = 5 m .

The air leaving the evaporative tower is found to be at 28°C. At night time, when T_o =25°C, R.H.= 33 %, and for the same height, the resultant air is found to be under 20°C. Exploiting the evaporative cooling potential of the tower at night, air at such low temperatures can be used to cool the building structure at night. This process offers considerable potential in the passive cooling of building in hot arid regions. Figs.(5.37&5.38), shows the relationships of height, dry-bulb temperature, and relative humidity, when wind velocity =5m/s, and 15m/s respectively.

Air leaving the tower and reaching the occupants at the points (A_1, B_1, and C_1) on curves (A, B, &C) can maintain thermal comfort. The height of the evaporative cooling tower corresponding with points (A,B,C) represent the minimum values. heights lower than these cannot deliver air to the space in a suitable thermal condition. A passive cooling strategy utilizing an evaporative cooling tower is then considered a suitable approach for building design in the Al-Riyadh physical environment.

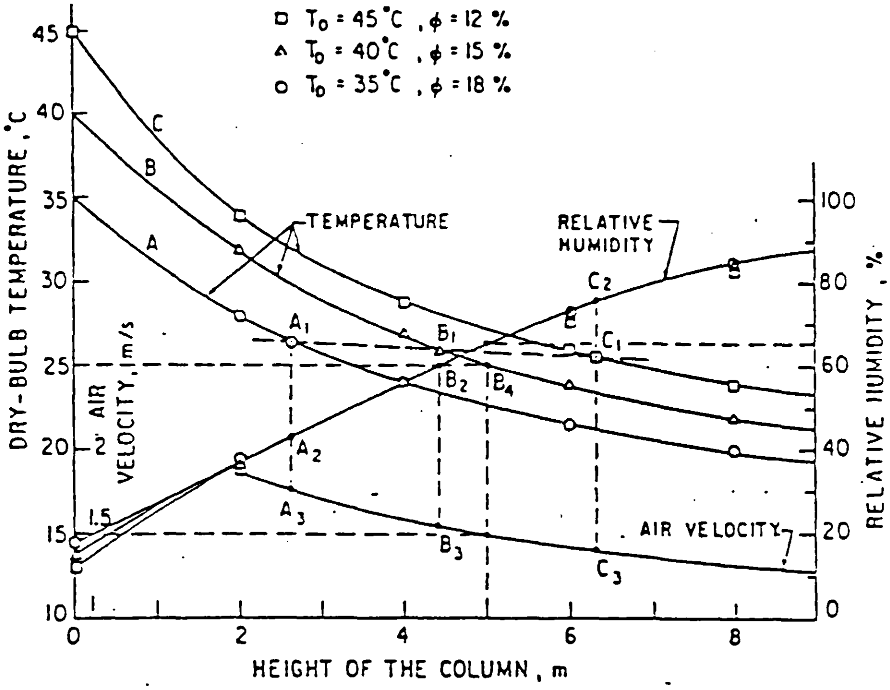
The system may be designed to meet peak cooling demands, as well as partial loads. It allows a flexible control of the evaporation, by reducing the wetted area of the conduit surfaces, and by controlling the rate of water sprayed on the conduit walls. Air flow may also be controlled by partially closing the openings admitting air into, from, the tower or out of the buildings when no cooling is required.



Dry-bulb temperature of air leaving the evaporative cooling column.

Fig. 5.36 **EVAPORATION PROCESS CHART**

Source : M.N.Bahadori, An Improved Design of Wind Towers for Natural Ventilation and Passive Cooling, Solar Energy, Vol.35,

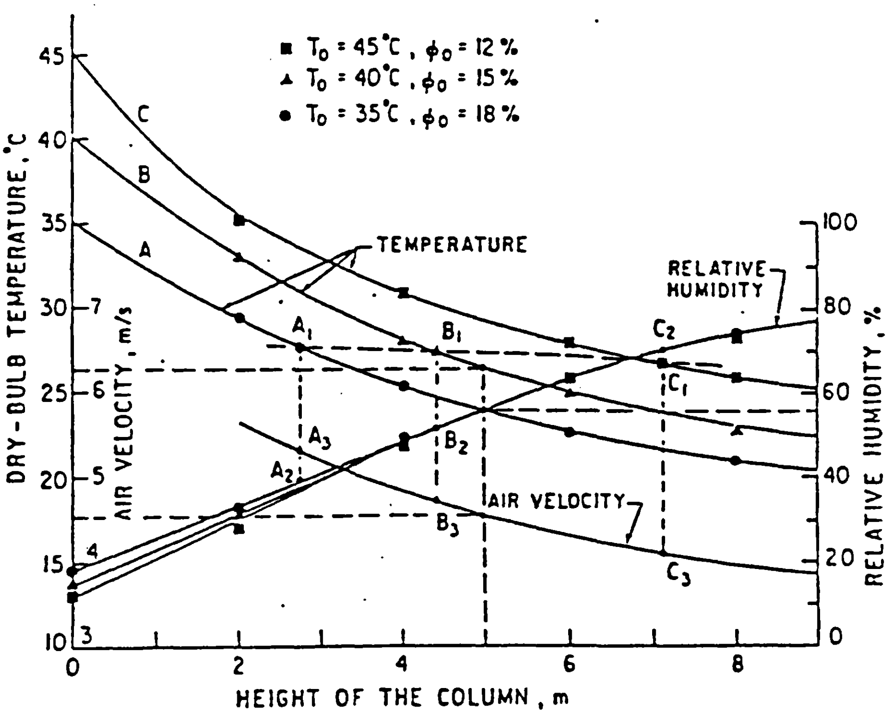


Condition of air leaving the evaporative cooling column for a wind velocity of 5 m/s.

EVAPORATION PROCESS CHART

Fig. 5.37

Source : M.N.Bahadori, An Improved Design of Wind Towers for Natural Ventilation and Passive Cooling, Solar Energy, Vol.35,



Condition of air leaving the evaporative cooling column for a wind velocity of 15 m/s.

EVAPORATION PROCESS CHART

Fig. 5.38

Source : M.N.Bahadori, An Improved Design of Wind Towers for Natural Ventilation and Passive Cooling, Solar Energy, Vol.35,

V.9 Design Criteria for Building in a Hot Arid Climate

Based on the previous observations of the thermal behavior of the buildings under many climatic factors the following criteria are established :-

. A compact building close to square in shape is found to be the most appropriate for this climate, since it minimizes the exposed surfaces.

. With respect to windows, the south and north direction are more appropriate for the openings.

. East and West direction is not recommended for openings without controlling solar radiation, i.e. by shading.

. Orientation has slight effect on the amount of the solar insolation, with the best alignment being when the long sides face north and south.

. Subsequent exchange of heat between outside and inside by night ventilation is a desirable natural cooling process of building mass.

. Humidifying the dry air using passive evaporative means can offset the amount of heat gain, hence reaching a satisfactory thermal balance.

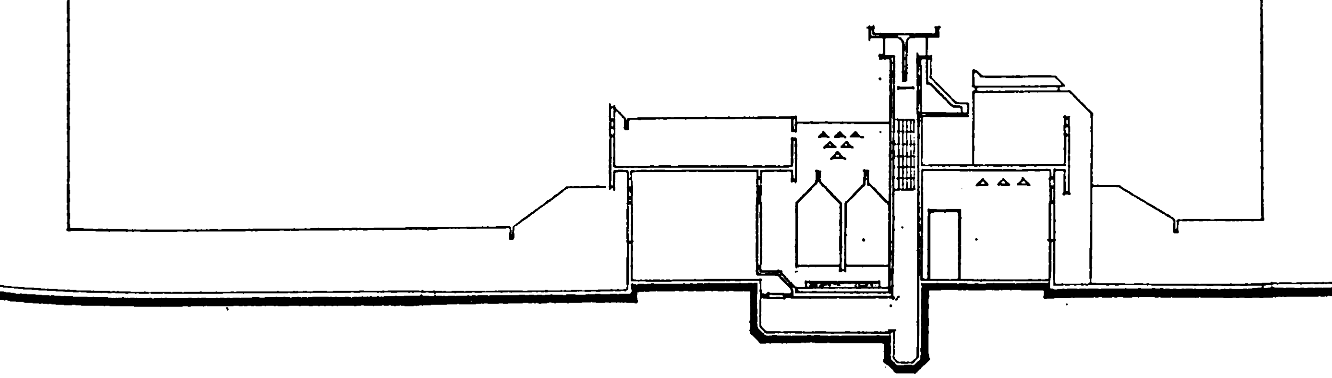
. Careful selection of building materials is essential.

. Materials with the thermophysical characteristic of being able store and release energy in a reasonable amount of time are advantageous.

. Insulation is beneficial to the night ventilation process, but implies the need for detailed dynamic modelling during the day/evening period, in conjunction with a window shading/shutter strategy.

. Application of insulation on the outside of the building envelope is beneficial with respect to time-lag and thermal damping; protecting the daytime activity space by heavy weight with a long time-lag and low decrement factor structure.

CHAPTER VI



CHAPTER VI

DESIGN PROPOSAL

VI.1 Overview :-

This chapter illustrates an architectural approach to building design which is relevant to Al-Riyadh environment, based on the previous thermal analysis, and which has integrity with social traditions of Saudi families, and the local characteristics of architectural identity.

It is not intended as a specific solution, but rather a vehicle to illustrate the potential of principles described in previous sections.

The passive solar techniques proposed are thus assigned to a dwelling unit of a typical average income family, and which consists of :-

. 2 Bed-rooms

. 2 Guest rooms

. Kitchen and two baths

The flexibility of future vertical expansion is considered as a basic design demand. The following points briefly highlight the design proposal :-

VI.2 Urban Setting and Building Form

As stated above in chapter two, the urban land - form subdivision policy of development plans has fixed square lots to be the shape of any future urban settlement. So, there are few constraints on the designer to build within that boundary, including construction systems.

The objective is to determine an appropriate house layout in planning terms which positively contributes to the thermal strategy and at the same time can perform as an individual unit or part of an attached series of housing units, i.e. cluster or neighbourhoods. An almost square building shape, which has been concluded from the previous analysis to be the optimum thermal layout of buildings in hot arid areas, is chosen as a basic plan.

It is not the research aim to provide a detailed design for a large scale settlement or housing compound, but to show the tendency of the design proposal in a realistic context.

The diagram in fig.(6.1), shows possible grouping of clusters, and the site plan in fig.(6.2), illustrates the possible arrangement of the dwelling units inside the cluster, as a part of a schematic neighbourhood.

All dwellings are fundamentally oriented to face north and south. East and west are fully protected from direct exposure by the attached units system and no openings are located on these sides.

The linear shaded urban centre penetrates all the way through the site, acting as a potential strength in connecting different clusters, and thus encouraging pedestrian movement. Shaded pools, and shaded parking lots with natural tree plantations are a strong part of the design landscape due to their significant potential to change the micro climate.

VI.3 House Organisation and Interior Circulation

Three main zones define the house interior and represent the hierarchy of spaces, considering the social nature of an Islamic family. These are :-

. Semi public zone

. Semi private

. Private

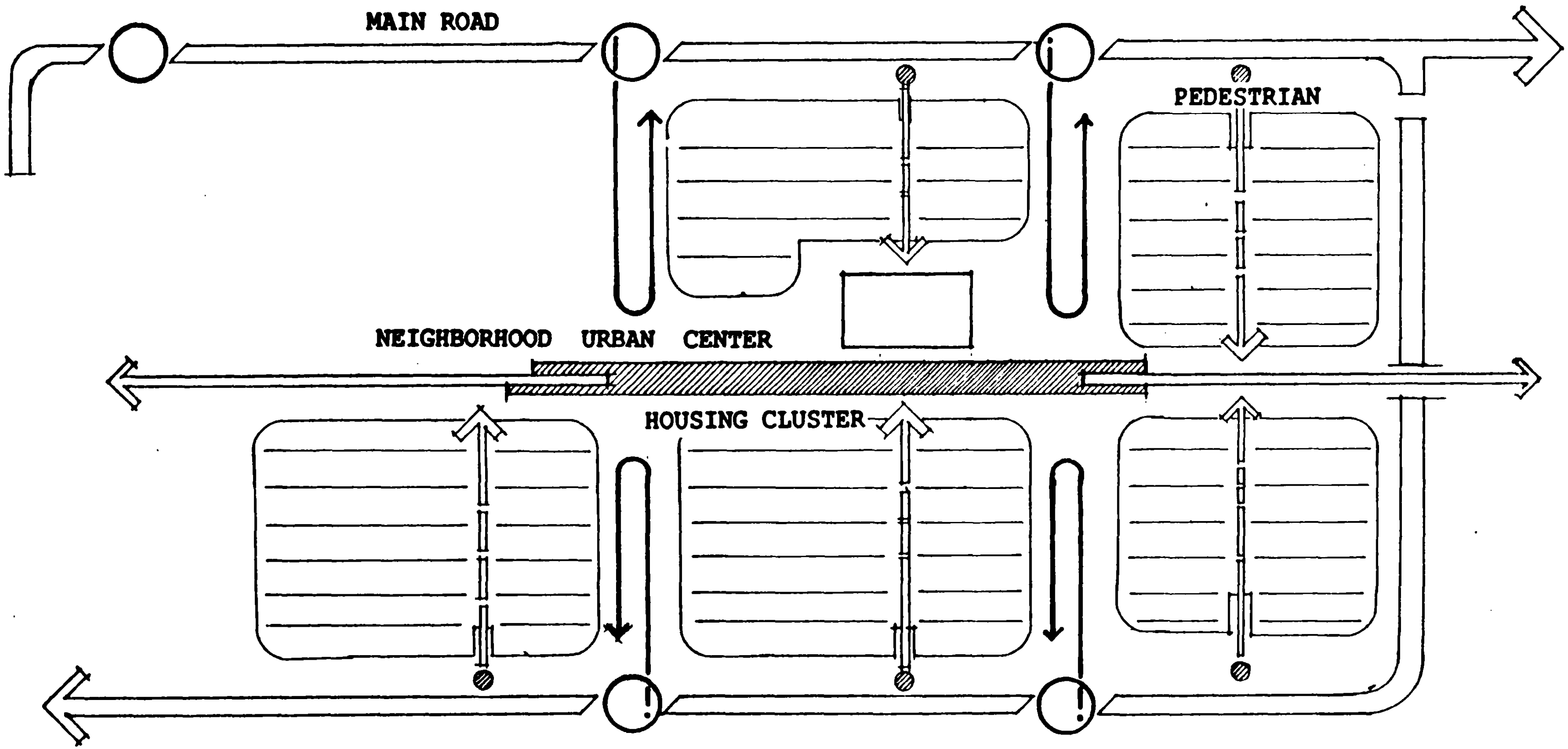
According to the recommendation on chapter V, concerning the proper distribution of house activities in relation to time lag and facade exposure, the house design took the following arrangement :-

. The living room and the bed-rooms lie to the north

. Guest rooms are on the south

. The kitchen, which is a heat generator space inside the house, is centred with no sharing walls with other primary functions, and is surrounded by two courtyards for better dispatching and exhausting of accumulated heat.

Figs.(6.3,6.4,6.5,&6.6)

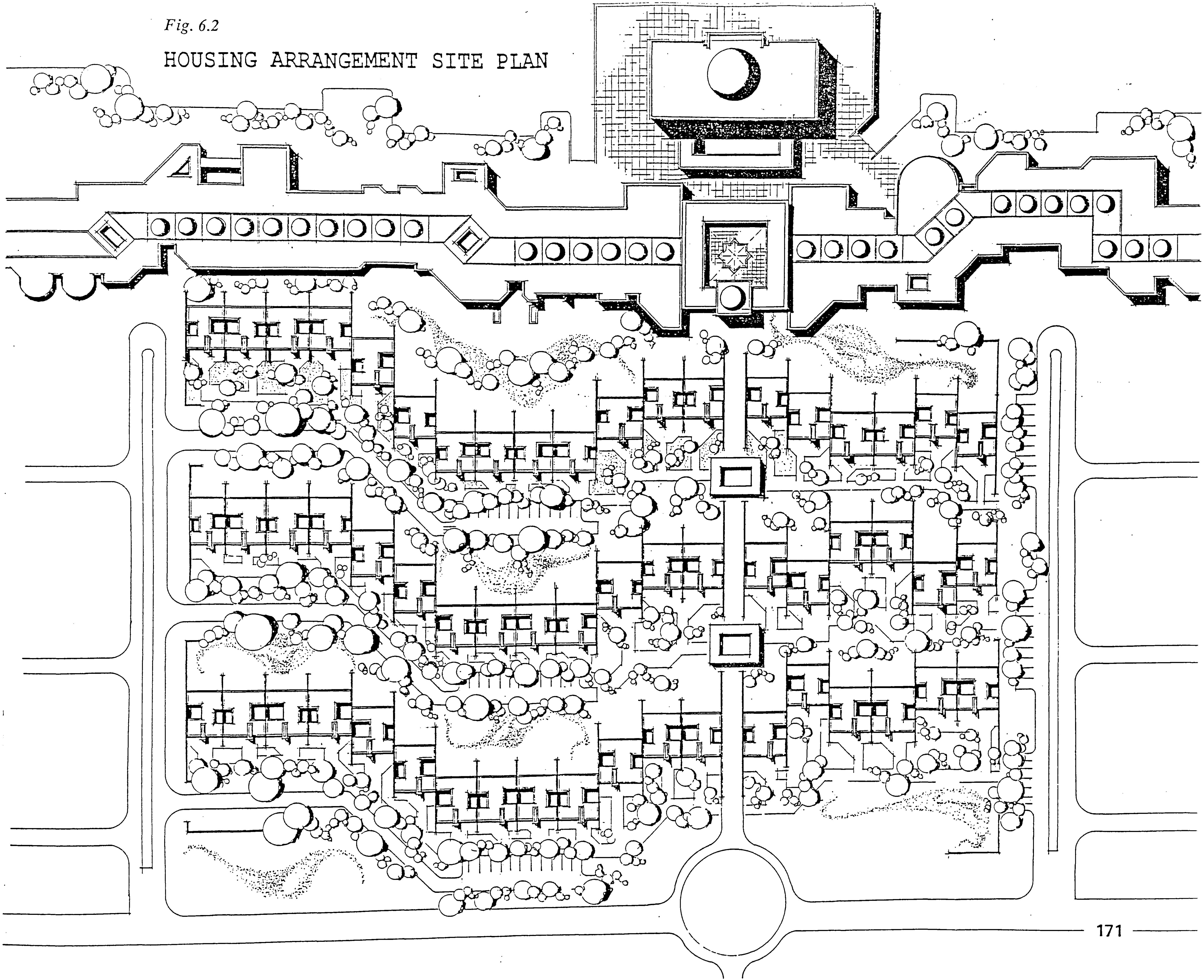


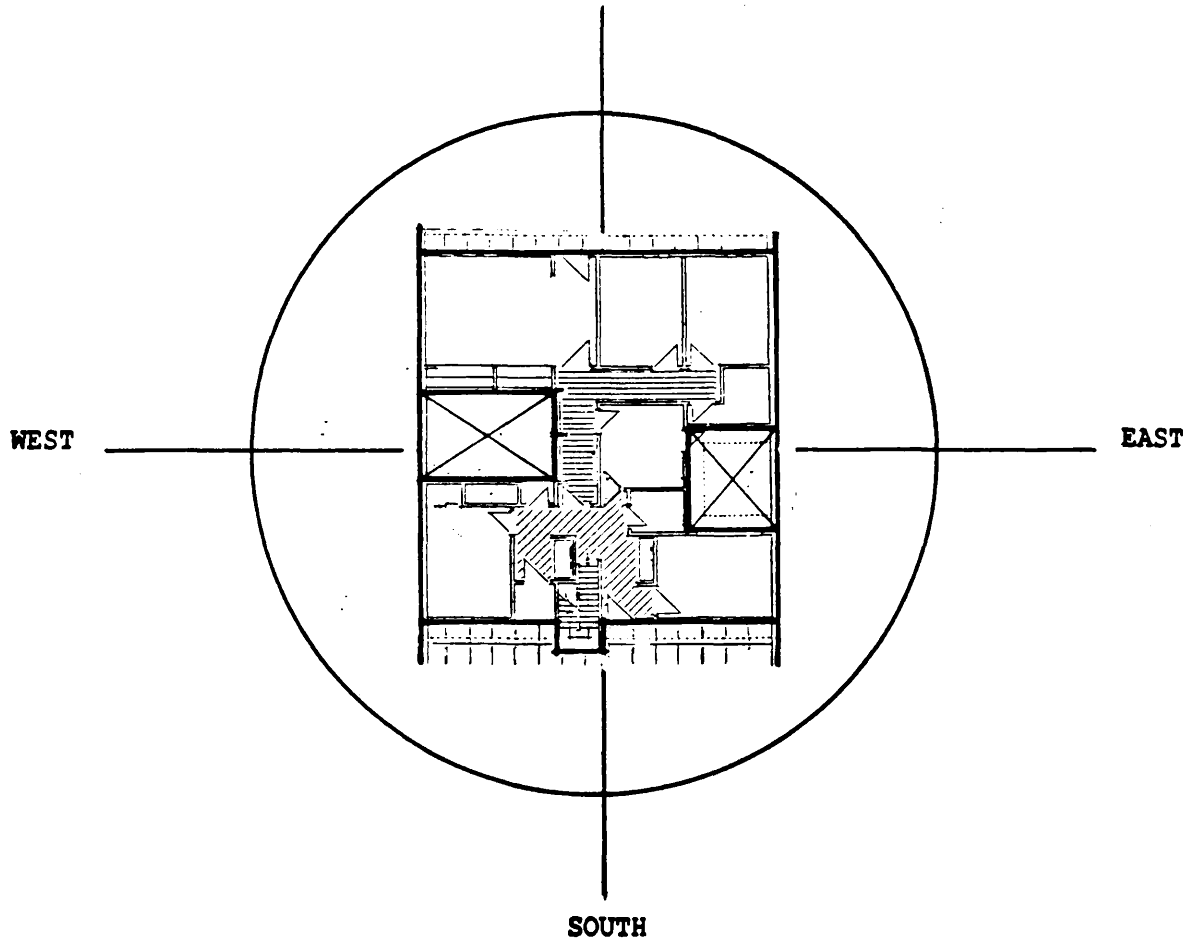
SCEMETIC GROUPING OF HOUSING CLUSTERS

Fig. 6.1

Fig. 6.2

HOUSING ARRANGEMENT SITE PLAN





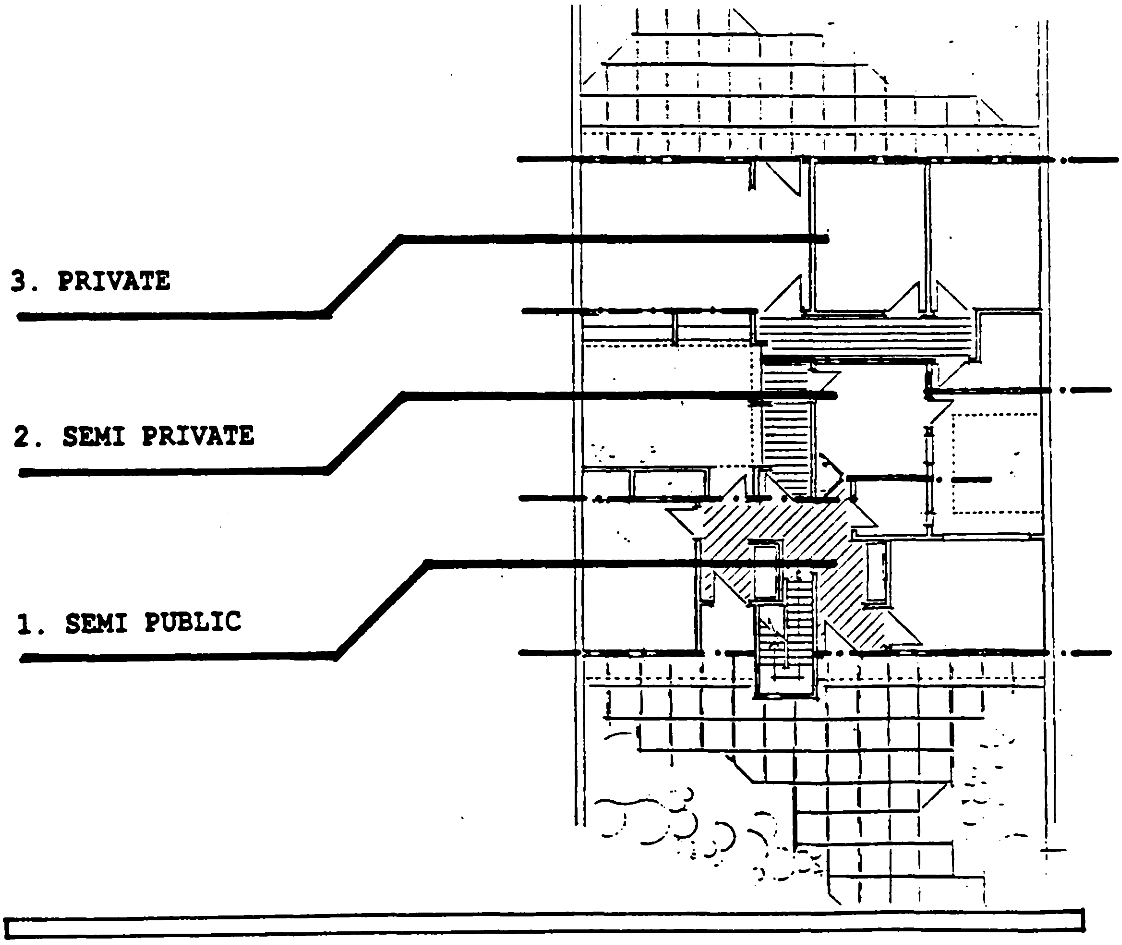
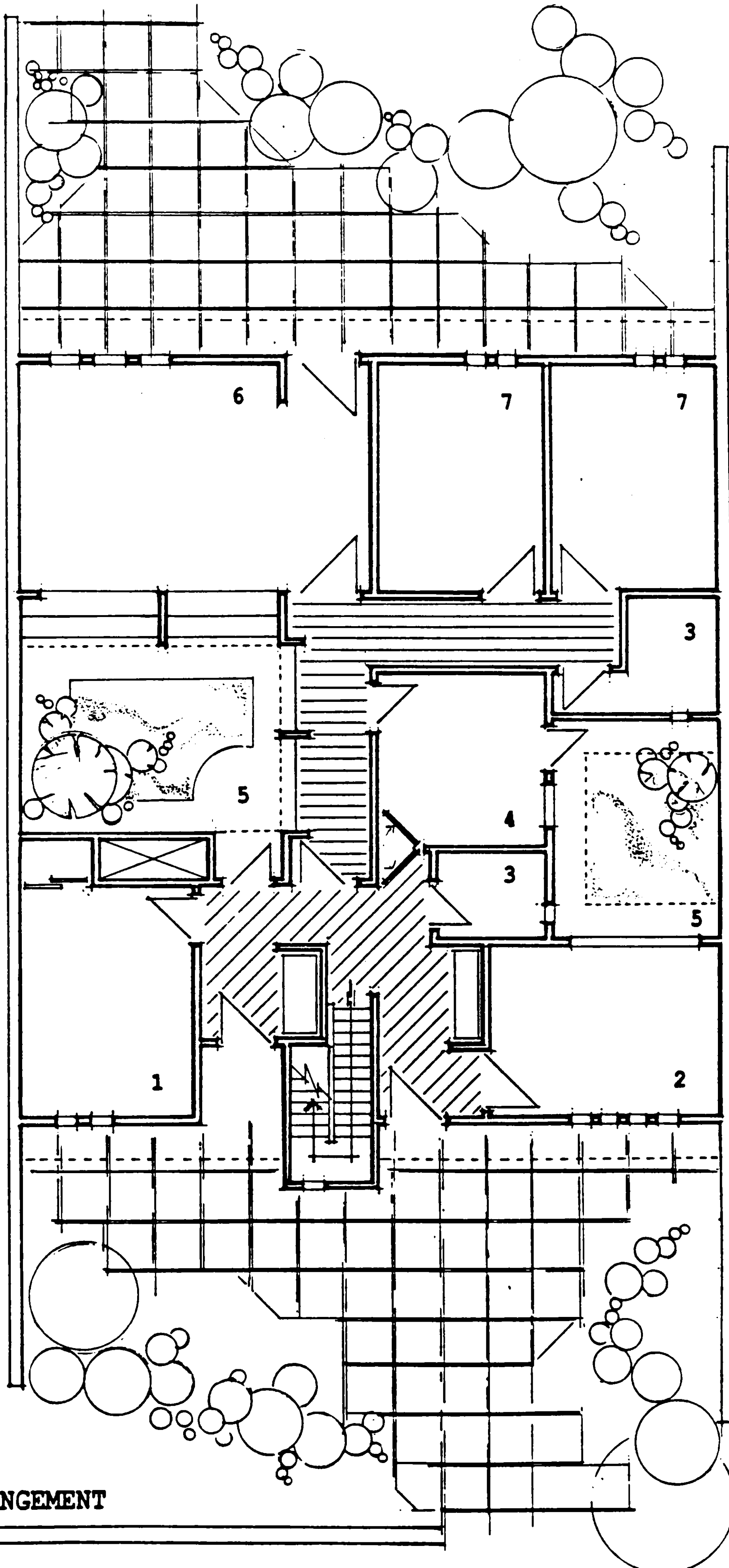


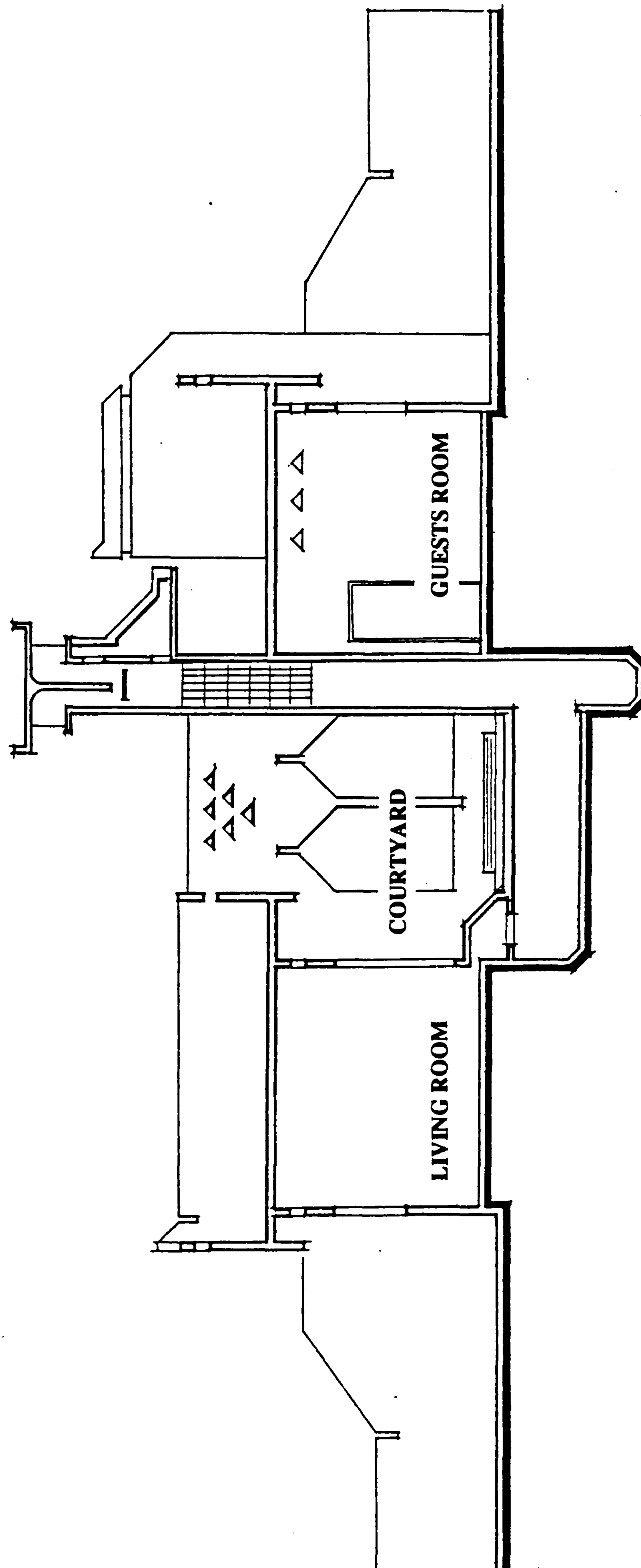
Fig. 6.3

1. FEMALE GUEST-ROOM
2. MALE GUEST-ROOM
3. BATH
4. KITCHEN
5. COURT-YARD
6. LIVING-ROOM
7. BED-ROOM



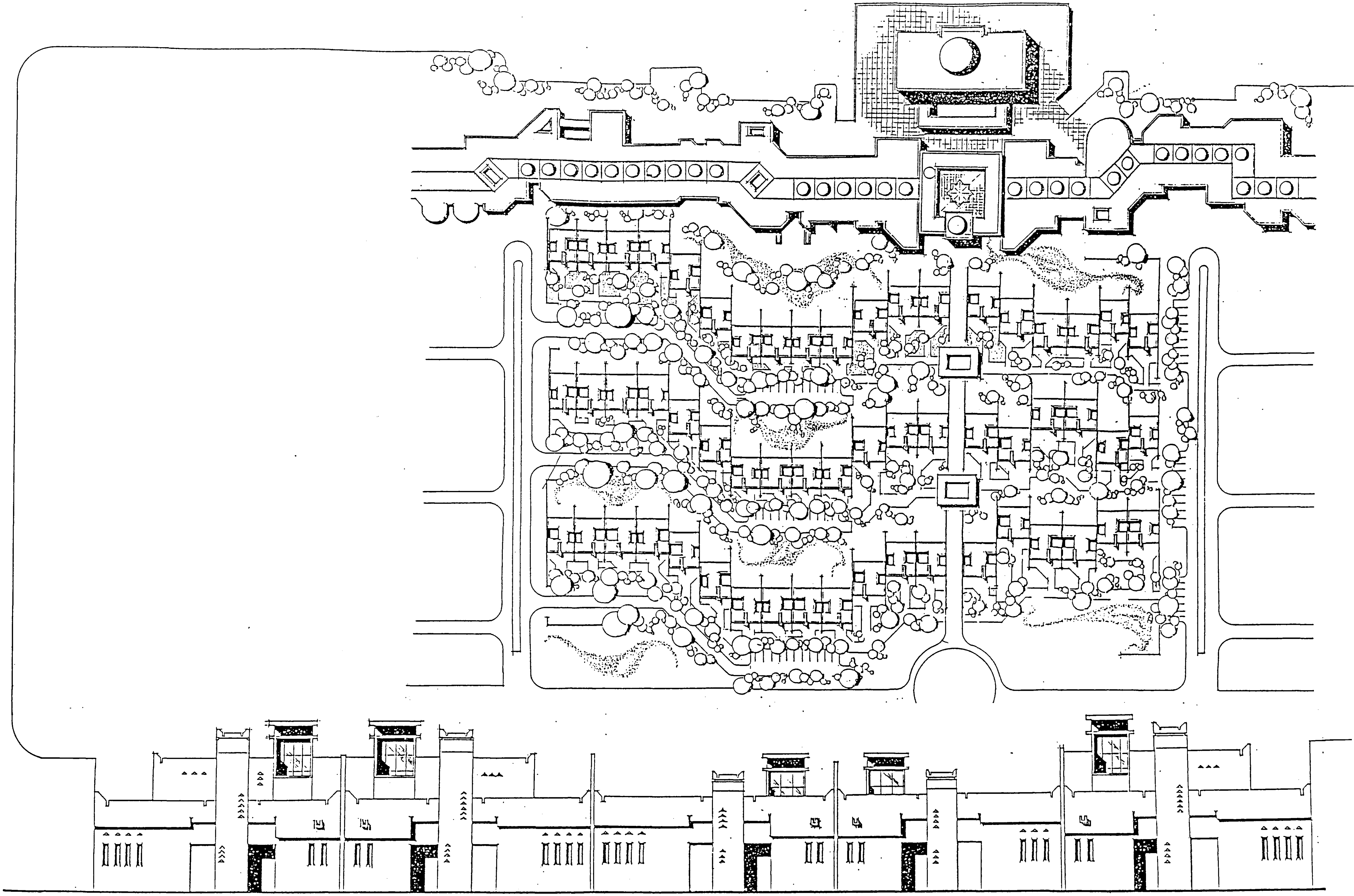
HOUSE ARRANGEMENT

Fig. 6.4



SECTION

Fig. 6.5



ELEVATION

Fig. 6.6

VI.4 Application of Thermal Strategy Application

The design concept of thermal comfort in the dwelling relies substantially upon the following approaches:-

- Passive evaporative cooling and passive solar heating
- Ventilated building envelope
- Modifying interior micro-climate

To execute these strategies architecturally, the following devices are established :-

VI.4.1 Modified wind tower

As illustrate in Fig.(6.7), a passive treatment of hot dry air is achieved by the wind tower. The tower is 2mx1m in cross section, and 5m in height, the minimum that can give the desired cooling effect as concluded from the analysis in chapter V.

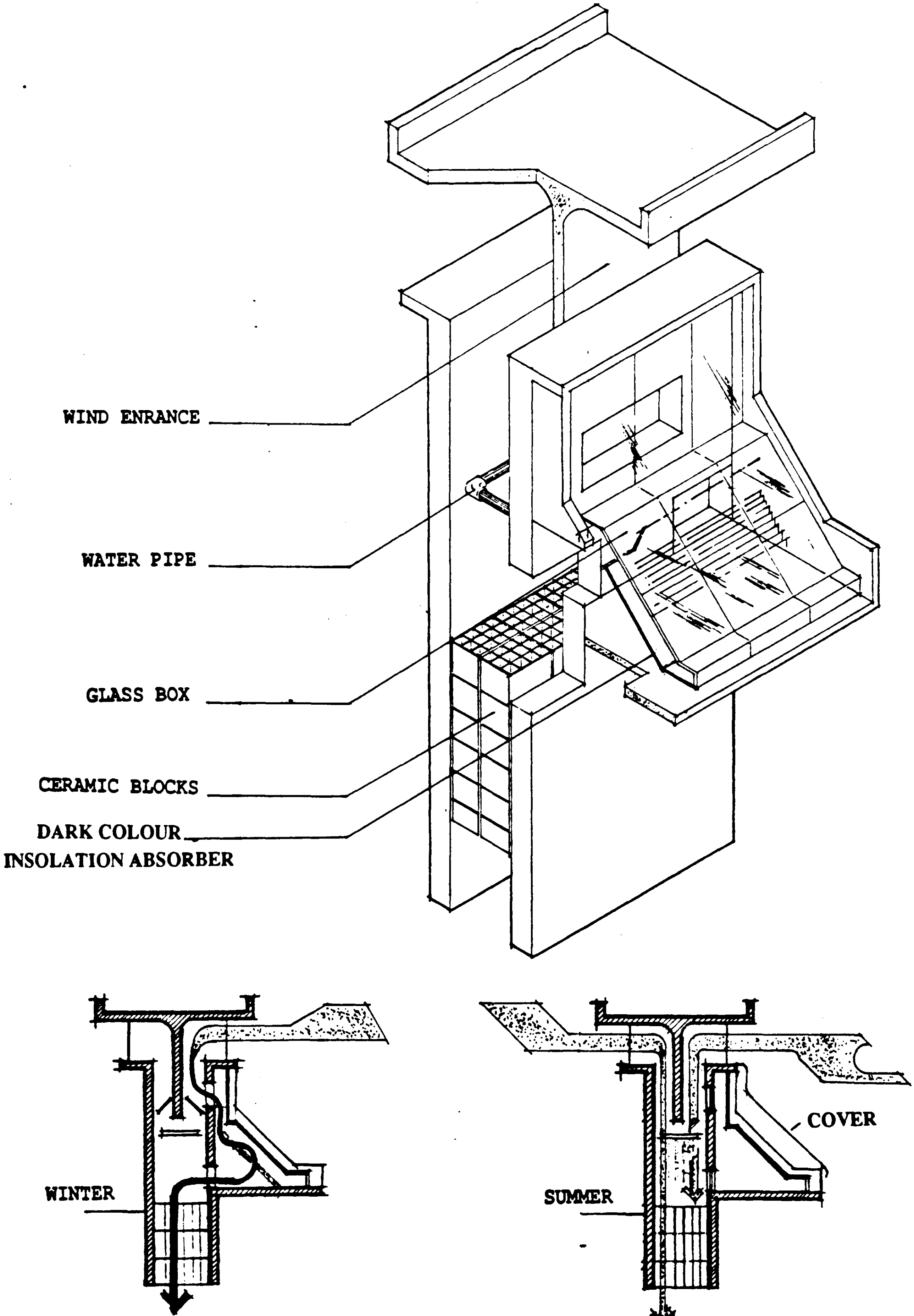
The tower collects wind from the four sides, with the main air entrance is facing south, to the prevailing wind. The tower is primarily a cooling device, but can also be a heating device.

For cooling, the dry air pass through long, vertical, and wet ceramic channels, releasing some of its heat as it comes into contact with wet surfaces.

Then it flows downward to a damp underground subfloor space, and then to rooms through low level ducts, fig.(6.8,&6.9). A small opening near roof level of each room helps to increase the air circulation by natural thermo-circulation or stack effect.

In winter, the tower can temper incoming ventilation air upwards instead of cooling it. The green-house approach is utilised through a glass box on the south face of the tower head. In winter low angle incident radiation would penetrate this air collector and elevate the temperature inside, assisted by a dark coloured absorber and insulated lining. The absorber material could be an open-weave material such as hessian[1] or expanded metal, or simply rigid, blackened insulation of a type that can withstand temperature up to 150°C.

The normal air passage is blocked at the tower head, and then the incoming air forced to go through the solar air collector by a small fan, possibly solar-powered, at lower opening level, and blown down inside the tower shaft for delivery. In summer collector glass would be screened from the outside.



TOWER HEAD DETAIL

Fig. 6.7

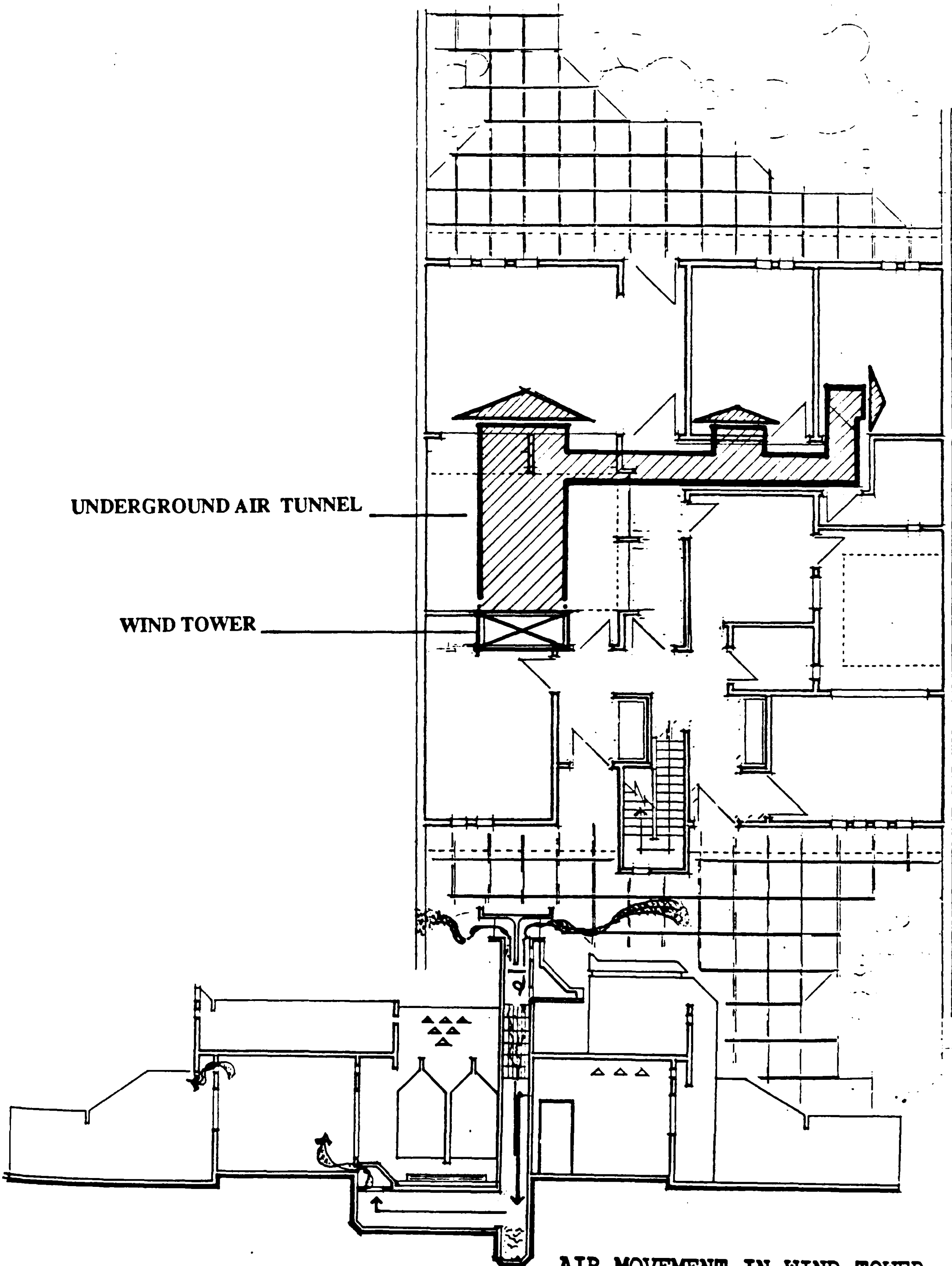
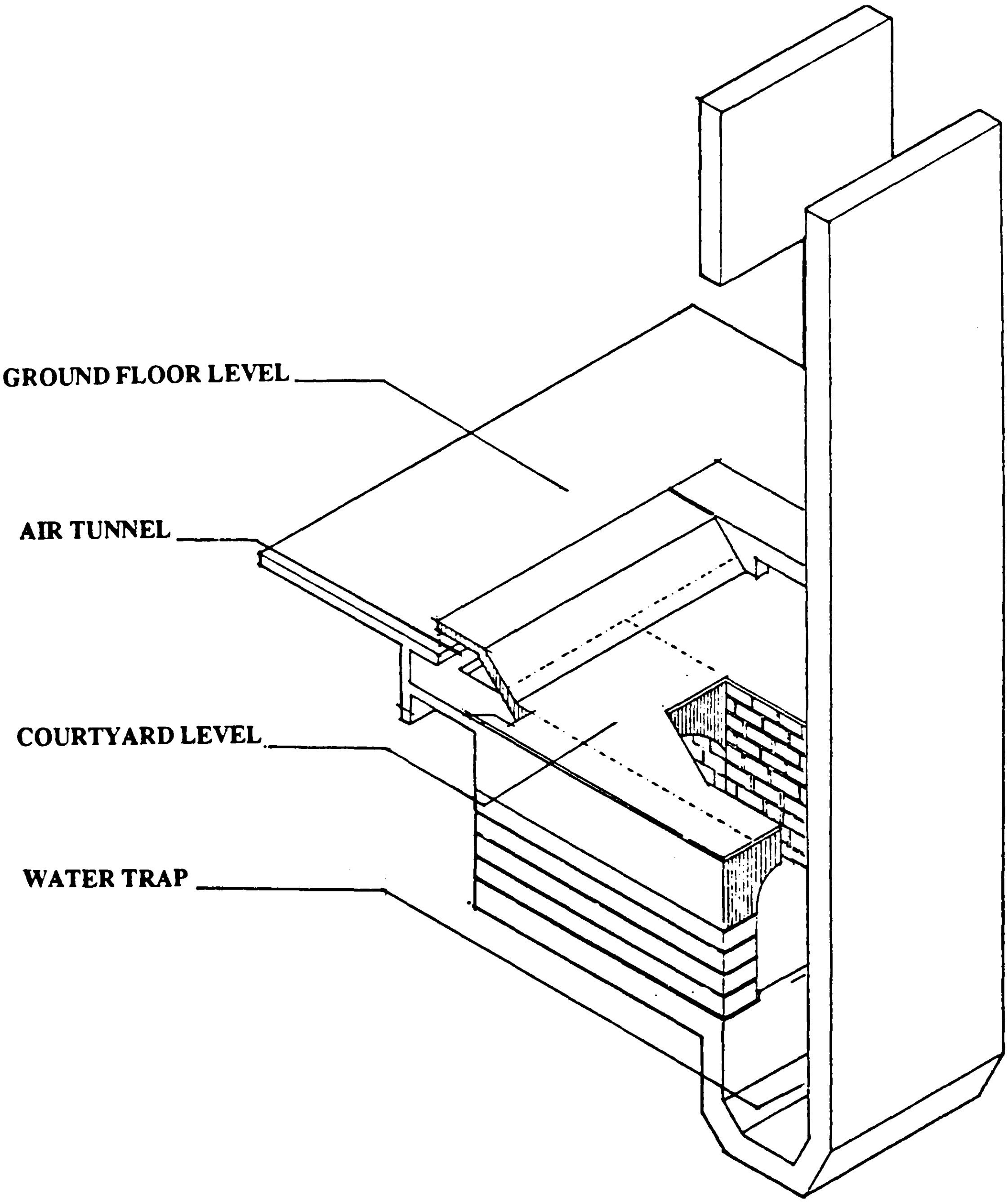

UNDERGROUND AIR TUNNEL
WIND TOWER
AIR MOVEMENT IN WIND TOWER

Fig. 6.8



UNDER-GROUND BASMENT

Fig. 6.9

VI.4.2 Ventilated building envelope

The reduction of the solar radiation effect on the building surfaces, is one of the passive thermal strategies to modify the interior environment. Since roof, east,and west surfaces receive the highest amount of insolation, the design provides a complete blockage of sun radiation on east and west sides.

For the roof, a critical surface, two technique are proposed. Firstly the traditional approach of a high wall parapet surrounding the roof boundary provides some morning and afternoon shading on the roof surface.

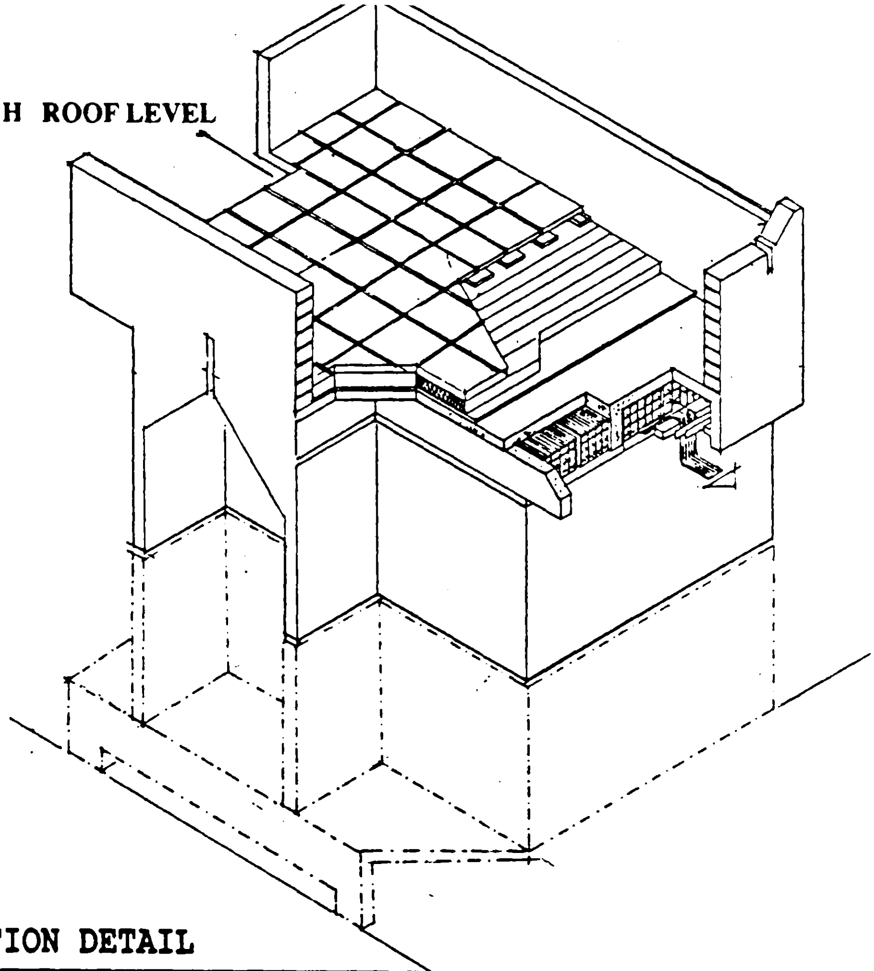
A second technique is using heavy construction which will give form 12-15 hours time-lag, construction no.3 found to be appropriate, (see section V.5.4). This is also enhanced by ventilated edges of the roof, for frequent exhaustion of any transferred heat through the hollow clay pots. Fig.(6.10).

VI.4.3 Modified micro-climate

Again, recognising the traditional feature which proves its efficiency socially as well as climatically, two courtyards are located centrally in the house, on each side of the kitchen.

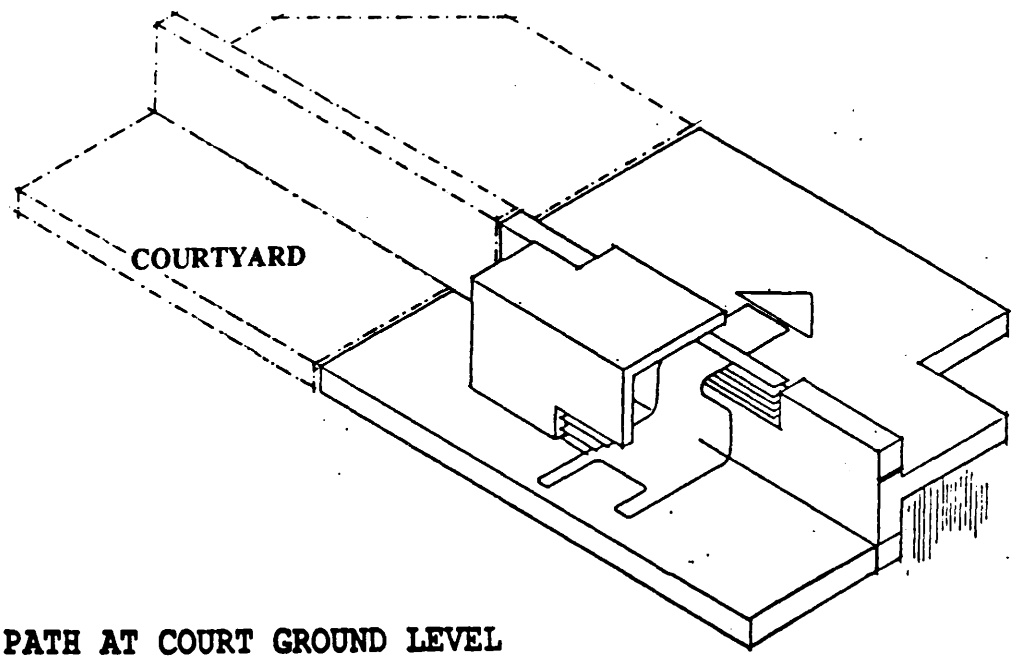
Fig.(6.11), illustrate the flow of the cool air near ground level to the house. The high wall parapet at the courtyard roof, and the overhang, create a good fence to keep the ground level of the court in shade for much of the day, and this would be very significant in altering the temperature of the court and hence the surrounding spaces.

The process of cool night air falling into the court and thence to the interior has been described above in section IV.2.1.



ROOF VENTILATION DETAIL

Fig. 6.10



AIR PATH AT COURT GROUND LEVEL

Fig. 6.11

CONCLUSIONS

This research indicates that a passive approach to summer cooling of new housing in the hot,arid climate of Al-Riyadh is feasible. To achieve this design guidelines and/or constraints are as follows :-

. appropriate disposition of living zones within a nominally square plan type; a technique found in traditional architecture, where the spaces are used multi-functionally and daily movement through the house occurs to suit ambient conditions.

.Use of the traditional courtyard as both a planning and thermal asset that can modify the micro-climate, provide a cool sink of air at night and help to improve flow of air circulation through living/sleeping accommodation.

.Careful selection of materials and appropriate multi -layer construction, including use of twin skins and ventilated air cavities, particularly for the roof, to engender adequate damping and time-lag to protect indoor spaces from excessive diurnal heat transmission.

.Insulation and night ventilation are on their own inadequate as cooling strategies for achieving an upper tolerable level of comfort, but their use significantly reduces the required residual cooling loads.

.Hence with appropriate planning and construction, summer cooling loads can be met using a passive method of evaporative cooling - e.g. a wind tower in conjunction with a courtyard to enhance the stack effect and make air flow less wind dependent.

The above design principales are presented in awareness of the deficiencies that exist in Al-Riyadh in terms of the building construction industry, such as the lack of precise supervision and poor workmanship.

Use of the system by occupants is also recognised as influential, although as far as posible passive strategy is self - regulating.

The contribution of this research is a very limited addition to a delicate and important subject, that of improving thermal performance of human shelters while preserving non - renewable energy resources.

More detalailed dynamic modelling, cross referenced to monitored case studies is recommended to extend this thesis.

REFERENCES

CHAPTER I

1- Saudi Consolidated Electric Company, Central Region. Annual Report, 1986.

2- Electricity Department, Saudi Government. Report on energy consumption, 1980.

3- Balwant S.Saini, Building in Hot Dry Climate, John Wiley & Sons Ltd., 1980.

4- Richard F. Nyrop, Saudi Arabia, a country study, Foreign area studies, The American University, U.S. Government printing Office, 1984.

CHAPTER II

1- Dr. Abdul-Majeed Ismail Daghistani, Al-Riyadh, Urban development and planing, Ministry of Information, Interior Information, 1985

2- S.Al-Hathloul,M.Al-Hussayen,A.Shuabi, Urban Land Utilisation, Case Study, Riyadh, Saudi Arabia. Urban Settlement Design Program, M.I.T.,1975

3- Kingdom of Saudi Arabia, Ministry of Municipal and Rural Affairs,Deputy Ministry for Physical Planning, Riyadh, Action Master Plan, Technical Report No.6, SCET International/SEDES, 1978

4- Ministry of Housing and Public Work, Design Criteria for Rural and Desert Housing in Saudi Arabia, 1984

5- Dr.Saleh Al-Hathloul,Development of the Contemporary Physical Environment in Al-Riyadh, Al-Benaa,Vol.5, 1986.

CHAPTER III

1- B.Givoni,Man Climate and Architecture,Architectural Science Series, 1976. Chapter 7, pp. 342-347.

2- Victor Olgyay, Design with Climate, Bioclimatic Approach to Architectural Regionalism, 1968.

3- Ministry of Defence and Aviation, Daily meteorological data, Al-Riyadh Station, 1986.

4- W.V.Macfarlane, Thermal Comfort Studies Since 1958, Architectural Science Review, Vol 21, 1978.

5- Humphreys M., A field study of thermal comfort compared and applied, Building Services Engineer, Vol.44, 1962.

6- E.Kamon, Physiological and behavioural responses to the stress of desert climate, Urban Planning for Arid Zones, Editor,Gideon Golany, 1978.

7- Stevens, J.C.,Marks,L.E. and Gagge,A.P., The quantitive assessment of thermal discomfort. Environmental Research, Vol. 20, 1969.

8- T.A.Markus and E.N.Morris, Building Climate and Energy, 1980. Chapter 3, pp. 70-73.

9- Giles,En. Australia twice traversed, Low, Marston, and Rivington, London, 1889.

10- Edmund A. Parkes. A manual of practical hygiene,1878

11- D. Waston, Faia, and K.Labs, Energy efficient building principles and practices, Climate Design, 1983. Part I, pp.21-37.

CHAPTER IV

1- P.Oliver, Dwellings the House a Cross the World, 1987. Chapter 6, pp.113-123.

2- D.Dunham,The Courtyard House as a Temperature Regulator, The New Scientist,1960.

3- G.Golany, Earth Sheltered Habitat, History, Architecture, and Urban Design, 1983.

4- R.Stromberg, Test Data from Passive Solar Houses, Desert Housing, Balance experience and technology for dwellings in hot arid zones,Kenneth,Clark,and P.Paylor, Editors, 1980.

5- Hay Harold. The California solarchitecture house. Hay's new roofs for hot dry regions.Ekistics, No.183, 1971.

6- Sodha Etal,Solar Passive Building,Science and Design International Series on Building Environmental Engiеering, Vol.2, 1985 .

7- Abdulhameid A.Albis, An Energy Urban Centre in the Egyptian Desert,Ph.D. Theses, Catholic University, 1984.

CHAPTER V

1- Barkeley Solar Group, CALPAS3 Manual, Clifornia, 1982.

2- ASHRAE, Handbook, Fundamentals. American Society of Heating, Refrigerating and Air Conditioning Engineering, INC. Atlanta,Gorgia,1981.

3- Martin Evans, Housing, Climate and Comfort. The Architectural Press, 1980. Chapter 8, pp.78-87.

4- E.L.Harkness and M.L.Mehta, Solar Radiation Control in Buildings, Architectural Science Series, 1978.

5- B. Givoni, Man Climate and Architecture, Architectural Science Series, 1976.

6- Olgay and Olgyay, Solar control and shading devices, Princeton University Press, 1957.

7- Hassan Fathy. Natural Energy and Vernacular Architecture Principles and Example with Reference to Hot arid Climate, 1986.

8- Building Research Establishment Digest (B.R.E.), no.2279, AIVC. Surface condensation and mould growth in traditionally built dwellings, BRE publication, 1985.

9- L. Miller. Student Textbook of Heating Ventilating and Air Conditioning. Ipswich, 1976.Chaptr XV, pp. 150-163.

10- M.N.Bahadori, An improved design of wind towers for natural ventilation and passive cooling, Solar Energy, Vol. 35, 1985. No.2, pp. 119-129.

CHAPTER VI

1- S. Ostergaard Jensen and V.Korgaad, Roof space collector, Proceeding of NorthSun 2, Denmark, 1986.

APPENDIX

DAILY METEOROLOGICAL DATA FOR FEB. 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEPM. (C)			GROUND TEMP. (C)			DEW POINT TEMP.(C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS.(mm-Hg)			RAIN FALL (MM)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	4	13	0	S	15	19	11	16	18	13	-2	5	-8	66	100	32	696	697	694	0.3
2	2	6	0	SW	13	18	7	13	17	10	-5	-0	-9	54	76	40	698	700	697	0.0
3	3	7	0	E	14	19	6	13	17	9	-6	-2	-9	52	75	39	699	701	696	0.0
4	4	10	1	SE	17	22	10	14	18	10	-3	-1	-8	40	63	39	696	698	694	0.0
5	4	10	1	E	19	24	12	16	20	12	-4	-1	-7	41	57	32	695	697	692	0.0
6	5	14	1	SE	23	27	16	18	22	15	-2	2	-8	36	39	34	694	696	691	1.0
7	6	11	2	W	·15	19	12	17	20	15	-3	0	-7	67	100	40	696	698	695	0.2
8	3	6	0	E	16	20	7	16	20	12	-5	1	-8	49	80	35	697	699	695	0.3
9	6	13	0	SE	20	26	13	17	20	14	-3	2	-8	43	50	6	694	696	656	0.0
10	6	12	0	SW	15	19	10	17	20	14	-8	-6	-10	42	50	34	699	701	698	0.0
11	2	6	0	W	15	19	7	15	20	11	-6	-3	-9	46	65	33	699	702	697	0.0
12	2	6	0	NW	16	22	8	15	20	11	-6	-3	-11	42	54	33	698	700	695	0.0
13	6	11	2	NW	17	21	11	16	20	12	-6	-4	-10	42	51	34	696	698	694	0.0
14	5	13	0	S	20	25	14	17	21	14	-5	-3	-9	34	42	20	694	696	692	0.0
15	5	10	0	SW	16	20	10	17	21	13	-8	-5	-12	39	46	6	696	698	656	0.2
16	2	6	0	W	15	19	9	16	20	12	-8	-5	-13	38	42	35	697	699	695	0.0
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18	7	15	0	S	18	21	14	17	20	14	-7	-6	-9	35	43	31	695	696	693	0.0
19	6	12	2	SW	12	17	6	15	19	12	-8	-7	-10	55	72	41	701	702	699	0.0
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28	4	11	0	NW	19	22	13	19	21	16	-3	1	-8	51	60	41	696	698	694	0.2
29																				
30																				
31																				
AVG.	4	10	0	S	17	22	10	17	20	13	-5	-2	-9	45	59	32	697	699	692	0.7

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR JAN. 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEMP. (C)			GROUND TEMP. (C)			DEW POINT TEMP. (C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS. (mm-Hg)			RAIN FALL (MM)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	2	6	0	S	12	17	3	10	14	6	-10	-6	-14	37	65	28	703	705	702	0.0
2	2	5	0	S	14	21	4	11	15	7	-9	-6	-16	35	58	26	702	704	700	0.0
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4	3	6	0	SW	17	22	8	12	16	8	-9	-6	-15	29	39	21	700	701	699	0.0
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11	2	6	0	S	18	25	9	14	18	11	-5	-2	-12	38	48	31	699	701	696	0.0
12	5	14	1	SE	20	24	13	15	19	11	-5	-2	-9	36	42	33	694	696	692	0.0
13	4	11	1	SW	14	17	9	15	18	12	-7	-6	-18	48	61	38	699	701	697	0.0
14	2	6	0	E	15	21	5	13	17	10	-6	-2	-12	47	59	37	700	702	698	0.0
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22	3	7	0	SE	13	19	1	11	15	7	-18	-6	-19	38	45	35	700	702	697	0.0
23	4	18	0	S	15	28	9	13	16	9	-9	-6	-13	39	43	35	699	701	697	0.0
24	4	9	1	E	11	16	4	12	16	9	-9	-7	-14	49	61	37	701	702	698	0.0
25	5	9	2	E	15	28	8	14	17	10	-8	-5	-14	43	47	40	700	702	697	0.0
26	3	9	0	E	15	28	11	14	17	12	-3	2	-7	56	68	45	698	700	696	1.5
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30	4	8	1	NW	14	18	11	15	17	12	1	18	-3	88	100	77	696	697	694	0.0
31	3	5	0	W	15	18	12	16	18	14	1	3	-1	89	100	69	696	698	694	1.0
AVG.	3	9	0	S	15	28	8	13	17	10	-6	-2	-18	58	62	41	699	701	697	0.5

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR DEC 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEMP. (C)			GROUND TEMP. (C)			DEW POINT TEMP.(C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS.(mm-Hg)			RAIN FALL (mm)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	2	6	0	NW	19	24	14	21	22	19	3	6	0	87	100	70	694	695	691	6.5
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7	2	4	0	S	10	17	1	9	11	6	-10	-7	-15	58	89	42	701	703	699	1.8
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15	5	8	2	NW	13	16	9	14	16	13	-4	-3	-6	84	100	69	700	702	698	10.8
16	4	9	1	W	9	12	7	13	14	12	-6	-2	-18	90	100	76	701	702	699	12.9
17	3	8	0	NW	13	16	7	13	15	10	-7	1	-10	62	100	48	701	703	699	7.3
18	4	11	1	SE	17	22	9	14	16	11	-6	-3	-12	53	62	48	699	701	696	7.8
19	5	11	0	SE	21	24	16	16	18	13	-2	0	-6	54	61	49	697	699	694	14.0
20	8	15	2	SW	17	21	14	17	18	16	-6	-1	-10	59	84	51	698	699	694	6.1
21	2	6	0	E	13	17	3	14	16	8	-9	-4	-15	57	88	38	702	703	692	6.4
22	2	7	0	E	18	23	8	14	17	11	-6	-3	-12	50	63	43	702	704	699	9.0
23	2	5	0	S	17	24	9	15	17	12	-6	-2	-12	52	67	44	702	704	700	6.6
24	2	6	0	E	17	23	7	14	17	11	-7	-4	-12	51	68	42	701	702	698	2.5
25	2	6	0	E	18	23	9	14	17	11	-8	-4	-15	43	54	35	700	702	697	1.5
26	2	6	0	SE	19	24	9	15	17	12	-6	-3	-14	44	55	34	697	700	687	5.5
27	5	12	0	SE	22	26	16	16	19	14	-4	-2	-9	45	51	42	696	698	693	8.9
28	5	12	2	W	16	20	12	17	18	15	-8	-6	-11	53	60	46	699	701	697	11.5
29	4	10	1	SE	19	25	11	16	18	13	-5	-1	-11	53	61	47	698	700	696	10.6
30	4	12	1	S	21	25	14	18	23	13	-4	-1	-8	53	66	39	693	698	681	6.3
31	4	8	0	SW	11	14	6	15	16	9	-12	-11	-10	52	61	44	702	703	692	15.6
AVG.	4	9	1	S	15	19	9	14	16	11	-7	-3	-11	61	76	51	699	701	695	6.7

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR MAR. 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEPM. (C)			GROUND TEMP. (C)			DEW POINT TEMP. (C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS. (mm-Hg)			RAIN FALL (MM)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	5	17	0	S	21	27	14	20	24	16	1	4	-3	61	89	44	695	698	693	1.3
2	3	7	0	W	16	19	13	18	20	16	2	7	-8	89	100	75	697	698	695	0.1
3	4	8	0	W	16	19	11	17	20	14	1	2	-2	83	100	65	699	701	698	0.0
4	3	8	0	E	17	22	12	18	21	14	1	6	-2	78	96	56	699	701	697	0.0
5	4	14	0	SE	15	18	12	16	17	15	1	6	-2	98	100	88	696	699	694	13.1
6	3	11	0	SE	17	19	15	16	18	14	2	5	-1	85	92	78	695	697	693	0.7
7	7	15	0	SW	17	22	14	18	20	14	-1	4	-5	73	95	51	692	693	690	1.3
8	3	8	0	S	17	21	9	18	22	12	-3	0	-5	56	94	48	696	698	694	0.0
9	4	18	0	SE	22	28	18	19	23	13	-1	2	-5	58	86	38	695	698	692	0.0
10	5	13	1	S	26	29	21	23	27	17	-1	1	-5	38	43	33	693	694	690	0.0
11	5	12	1	SW	19	23	12	22	25	16	-5	-3	-7	46	63	38	695	697	693	0.0
12	2	8	0	W	20	26	12	21	26	16	-3	0	-6	48	78	38	695	697	692	0.0
13	3	9	0	E	22	27	14	22	26	16	-3	2	-8	42	58	39	695	696	692	0.0
14	6	14	1	SE	25	38	15	23	27	17	-2	2	-7	41	51	36	693	695	690	0.0
15	6	11	1	S	27	38	21	25	29	19	-1	2	-5	39	45	35	691	692	689	0.0
16	5	18	0	SW	20	24	14	24	27	19	-4	-1	-6	47	68	41	696	698	694	0.0
17	2	8	0	W	18	22	11	22	26	16	-6	-3	-9	45	55	40	697	699	694	0.0
18	6	12	2	SE	25	29	17	23	26	17	-2	1	-8	39	42	38	692	695	688	0.0
19	5	11	1	SW	20	24	13	23	27	18	-7	-5	-11	36	45	32	694	695	692	0.0
20	3	18	0	SW	20	24	11	23	27	16	-5	-1	-10	42	56	37	696	698	693	0.0
21	3	7	0	W	21	25	12	23	27	17	-4	-1	-10	41	51	37	697	699	694	0.0
22	4	9	0	E	22	27	13	23	28	17	-3	1	-8	45	54	39	697	699	695	0.0
23	5	11	1	SE	26	31	15	24	28	19	-1	2	-7	41	58	37	695	698	692	0.0
24	6	16	1	S	26	33	19	24	31	18	0	4	-5	40	45	32	690	695	679	16.5
25	6	14	0	E	26	38	19	27	38	22	-2	1	-7	38	41	33	692	700	685	0.2
26	8	16	3	SW	17	22	12	24	27	20	-4	-2	-7	68	94	48	697	698	695	0.0
27	3	8	0	SW	19	25	18	24	28	17	-4	-1	-7	48	75	36	700	701	697	0.0
28	2	7	0	W	23	38	13	25	29	18	-2	2	-10	48	51	36	699	700	695	0.0
29	4	11	0	E	25	38	16	25	38	20	-2	1	-8	39	44	37	696	699	693	0.0
30	5	12	1	SE	29	34	21	27	31	22	1	4	-5	38	41	36	694	696	690	0.0
31	6	13	1	SE	31	35	24	29	33	24	3	5	-3	41	46	37	693	695	690	0.0
AVG.	4	11	0	S	21	26	14	22	26	17	-2	1	-6	51	65	43	695	697	692	1.3

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR JUN. 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEPM. (C)			GROUND TEMP. (C)			DEW POINT TEMP.(C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS.(mm-Hg)			RAIN FALL (MM)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	4	11	0	E	34	40	24	36	40	29	4	9	-4	43	45	36	694	695	684	0.0
2	4	10	0	E	38	44	30	37	41	32	7	11	-8	44	45	42	695	696	692	0.0
3	4	10	0	S	37	44	27	37	41	32	7	12	-1	45	47	42	694	696	691	0.0
4	5	15	0	E	36	42	27	37	40	33	6	10	-2	43	45	42	691	694	689	0.0
5	4	17	0	E	38	43	31	38	41	33	6	12	-1	43	45	40	691	693	689	0.0
6	5	12	0	SE	38	43	30	38	41	33	7	12	-1	43	45	40	692	693	689	0.0
7	3	10	0	SW	36	41	28	38	41	33	6	10	-8	46	50	43	692	694	689	0.0
8	3	8	0	W	35	40	26	38	41	31	6	9	-4	49	57	38	691	693	682	0.0
9	3	11	0	S	35	40	25	38	42	31	6	9	-4	47	56	34	692	694	682	0.0
10	4	15	0	SW	35	39	24	37	41	32	4	7	-5	42	43	40	692	694	689	0.0
11	7	14	1	SW	34	38	27	37	40	32	4	7	-3	44	45	42	691	693	688	0.0
12	5	14	0	W	35	40	23	37	40	31	5	8	-4	44	47	42	690	691	689	0.0
13	3	12	0	W	36	41	18	37	41	18	6	9	-6	43	45	35	690	692	678	0.0
14	4	10	0	W	34	39	25	37	40	32	4	8	-2	46	48	44	691	692	689	0.0
15	4	11	0	SW	33	38	24	37	40	31	4	7	-3	46	48	45	691	693	689	0.0
16	3	10	0	SW	34	39	23	37	41	31	4	8	-4	45	48	43	690	692	688	0.0
17	4	11	0	SW	35	39	27	37	41	31	4	8	-4	43	44	41	690	692	688	0.0
18	4	11	0	SW	34	40	24	37	41	31	5	8	-5	44	46	42	690	692	688	0.0
19	2	7	0	W	36	42	19	37	41	19	6	11	-4	43	45	34	689	691	678	0.0
20	3	9	0	W	35	41	26	37	41	32	5	10	-2	45	46	43	689	690	687	0.0
21	4	11	0	SW	34	40	25	37	41	32	4	9	-3	44	46	42	689	691	688	0.0
22	5	15	0	SW	33	38	25	37	41	32	3	6	-5	42	43	40	691	692	689	0.0
23	7	15	1	SW	33	38	24	36	39	31	2	5	-6	40	41	39	691	693	688	0.0
24	6	14	0	SW	34	39	23	36	39	30	3	7	-7	40	42	37	690	702	688	0.0
25	3	10	0	SW	35	41	28	36	40	23	4	9	-9	42	43	34	690	713	658	0.0
26	5	12	0	SW	35	40	25	37	40	31	5	9	-4	43	44	41	690	690	688	0.0
27	4	11	0	SW	35	40	25	37	40	32	5	9	-3	43	44	41	690	691	687	0.0
28	6	14	1	SW	35	40	26	37	40	32	4	7	-3	43	44	41	690	692	688	0.0
29	7	17	0	SW	34	39	26	37	40	32	3	6	-3	43	44	41	690	692	688	0.0
30	10	17	4	SW	33	38	26	36	39	32	2	5	-2	43	46	40	691	692	689	0.0
31																				
AVG.	4	12	0	SW	35	40	25	37	40	30	5	9	-3	44	46	40	691	694	686	0.0

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR AUG. 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEPM. (C)			GROUND TEMP. (C)			DEW POINT TEMP. (C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS. (mm-Hg)			RAIN FALL (MM)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	2	9	8	S	38	45	28	38	42	34	8	13	1	46	58	43	691	693	689	8.8
2	6	21	1	SW	39	44	28	39	42	34	7	11	-2	44	46	41	698	692	687	8.8
3	8	15	3	SW	38	43	32	39	42	36	6	18	1	44	45	43	698	692	688	8.8
4	7	15	8	SW	38	42	38	39	42	34	6	9	-1	43	45	3	698	694	658	8.8
5	4	13	8	SW	37	43	26	39	42	34	7	18	-3	44	45	41	689	691	687	8.8
6	4	14	8	SW	36	42	25	38	42	33	5	18	-5	43	44	3	689	691	653	8.6
7	3	9	8	SW	36	43	25	38	42	33	6	11	-4	43	45	48	698	691	688	8.8
8	4	13	8	SW	36	43	26	38	41	33	5	18	-3	43	44	42	691	698	689	8.8
9	5	14	8	SW	36	41	26	37	41	33	5	9	-4	44	46	48	698	692	688	8.8
18	6	15	1	SW	36	41	29	37	41	33	5	8	-1	45	46	43	698	692	688	8.8
11	6	15	2	SW	36	42	28	37	48	33	5	9	-2	44	45	42	698	691	688	8.4
12	5	12	1	W	36	41	28	37	48	33	5	9	-2	43	43	41	698	692	688	4.8
13	4	18	8	SW	36	42	24	37	48	32	5	18	-5	41	43	39	698	692	688	3.8
14	4	14	8	SW	36	42	24	37	48	32	5	18	-5	42	44	39	689	691	688	7.1
15	6	16	2	W	38	42	38	37	48	32	6	9	-1	43	44	48	698	692	688	8.9
16	5	17	8	W	36	42	25	37	48	32	5	9	-3	45	47	42	692	694	698	8.8
17	5	12	8	W	36	42	25	37	48	32	5	9	-3	44	46	41	693	695	691	2.2
18	6	16	8	W	37	43	26	37	48	32	6	9	-3	44	45	3	692	694	658	3.4
19	5	15	8	W	37	44	26	37	48	33	6	18	-3	45	47	3	691	694	658	1.1
28	6	16	8	W	38	44	27	37	48	33	6	18	-3	44	45	3	691	694	658	2.2
21	6	19	8	W	38	44	26	37	48	33	6	18	-3	43	45	3	698	697	658	15.2
22	4	15	1	W	38	43	26	37	41	32	7	11	-3	44	45	42	689	691	658	2.7
23	2	8	8	SE	38	44	28	38	41	33	8	12	-8	46	48	44	692	693	689	2.8
24	4	14	8	W	38	44	27	38	41	33	7	11	-1	46	47	3	692	694	658	4.8
25	4	14	8	W	38	44	28	38	41	34	8	12	1	47	52	43	692	694	689	3.6
26	3	9	8	E	39	45	28	38	42	33	8	13	-2	45	46	3	691	693	658	1.9
27	3	12	8	SW	39	45	29	38	42	34	8	13	-1	45	47	3	691	693	658	8.8
28	4	12	8	NW	37	42	28	38	41	34	6	18	-1	45	46	43	691	693	689	8.8
29	3	15	8	SE	37	43	27	38	41	33	7	12	8	47	49	44	693	695	691	8.8
38	4	14	8	S	37	44	27	37	41	33	6	12	-2	45	46	43	692	695	698	8.8
31	4	13	8	S	36	41	26	37	48	33	5	8	-4	43	48	3	691	693	658	8.8
AVG.	5	14	8	SW	37	43	27	38	41	33	6	18	-2	44	46	29	691	693	675	1.8

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR SEP 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEMP. (C)			GROUND TEMP. (C)			DEW POINT TEMP.(C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS.(mm-Hg)			RAIN FALL (mm)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	4	11	0	W	35	40	25	37	40	33	6	9	1	51	62	46	692	694	690	0.0
2	3	9	0	S	35	41	25	37	40	32	8	12	3	54	72	46	694	696	691	0.0
3	4	12	0	SW	36	41	25	37	40	32	6	9	-2	49	53	3	693	695	653	0.0
4	4	10	0	SW	35	41	25	37	40	32	6	9	0	52	68	3	693	695	650	0.0
5	3	11	0	S	35	41	24	36	39	31	5	10	-5	45	47	42	692	694	690	0.0
6	2	10	0	S	37	43	28	36	40	32	6	11	-3	44	46	42	691	693	689	0.0
7	3	8	0	SE	37	43	28	36	40	32	6	11	-3	42	44	39	693	694	691	0.0
8	3	10	-0	S	36	41	26	36	39	32	5	9	-4	41	43	40	693	695	691	0.0
9	5	15	0	SW	35	41	23	35	38	24	4	9	-8	41	43	3	692	694	650	0.0
10	6	16	0	SW	34	39	18	35	38	15	3	6	-6	42	44	32	692	694	685	0.0
11	2	11	0	W	34	41	24	35	38	30	5	9	-2	47	54	42	693	695	691	0.0
12	3	14	0	S	33	39	24	34	38	30	3	9	-7	42	44	40	694	695	692	0.0
13	3	8	0	W	32	38	22	34	37	29	2	7	-7	41	43	40	694	696	692	0.0
14	3	8	0	SW	32	38	21	33	37	29	2	8	-8	41	42	39	693	694	691	0.0
15	3	9	0	S	31	39	23	33	37	29	1	7	-4	45	49	41	693	695	691	0.0
16	3	10	0	NW	32	38	19	33	36	19	3	8	-5	48	58	36	694	696	682	0.0
17	5	13	0	E	33	38	27	34	37	31	4	6	0	50	57	45	696	697	694	0.0
18	3	12	0	S	33	39	24	34	37	30	3	7	-5	46	48	44	696	698	694	0.0
19	3	10	0	S	33	39	22	34	37	29	3	8	-7	43	44	41	695	697	693	0.0
20	3	10	0	W	32	39	22	33	36	29	2	7	-7	43	45	0	695	696	650	0.0
21	3	12	0	NW	32	38	21	33	36	28	2	7	-6	46	58	42	695	697	693	0.0
22	3	8	0	W	33	39	22	33	36	28	3	8	-6	45	47	44	697	699	695	0.0
23	5	15	0	W	31	36	22	33	35	28	2	6	-6	49	53	46	697	714	695	0.0
24	3	11	0	W	32	39	21	32	36	28	3	7	-5	48	52	45	696	699	694	0.0
25	4	10	0	W	33	39	21	33	36	28	3	8	-7	45	46	42	695	697	693	0.0
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0
27	3	9	0	E	37	40	27	34	36	26	6	8	-9	43	44	35	696	698	686	0.0
28	3	12	0	S	33	40	21	32	36	28	3	8	-8	44	45	41	697	700	695	0.0
29	4	10	0	S	33	40	22	32	36	28	3	8	-7	44	46	42	696	698	694	0.0
30	3	10	0	E	34	40	23	32	35	28	3	8	-6	44	45	42	695	697	692	0.0
31																				
AVG.	3	11	0	SW	34	40	23	34	37	29	4	8	-5	45	49	36	694	697	686	0.0

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR OCT 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEMP. (C)			GROUND TEMP. (C)			DEW POINT TEMP. (C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS. (mm-Hg)			RAIN FALL (mm)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	4	12	0	SE	34	39	24	32	35	28	3	7	-5	43	44	35	694	696	684	0.0
2	4	11	0	SE	35	38	25	32	35	28	4	7	-5	44	45	42	696	713	694	0.0
3	3	12	0	SE	34	39	26	32	35	28	4	8	-5	44	45	42	697	699	695	0.0
4	3	10	0	SE	34	39	24	32	35	28	3	8	-6	44	46	43	697	699	695	0.0
5	3	10	0	S	33	40	23	32	35	28	4	8	-6	44	46	42	697	699	695	0.0
6	3	7	0	NW	32	39	21	32	34	28	4	8	-3	52	61	45	697	699	695	0.0
7	3	13	0	SW	32	38	21	31	34	27	3	7	-6	48	58	45	696	698	694	0.0
8	2	8	0	W	32	38	21	31	34	27	4	7	-3	58	59	46	696	697	694	0.0
9	2	7	0	S	32	39	21	31	34	23	3	7	-7	47	58	37	696	697	666	0.0
10	2	7	0	S	32	39	20	31	34	27	3	8	-7	46	49	45	696	697	694	0.0
11	3	9	0	SE	33	38	19	31	34	19	3	8	-5	46	48	33	696	699	683	0.0
12	3	12	0	NW	32	38	22	31	33	27	3	7	-7	45	47	44	697	699	695	0.0
13	3	13	0	NW	32	38	21	30	33	19	3	5	-6	45	47	37	698	700	687	0.0
14	4	10	0	NW	31	36	20	30	33	26	2	5	-8	47	49	45	699	701	697	0.0
15	3	9	0	E	30	35	20	30	32	26	2	5	-3	52	59	48	700	702	698	0.0
16	3	11	0	S	30	35	19	29	32	26	2	5	-6	50	54	47	699	701	697	0.0
17	3	8	0	W	30	36	19	29	32	25	1	5	-7	47	52	44	698	700	696	0.0
18	3	7	0	E	30	35	19	28	31	25	1	5	-9	45	48	43	697	699	695	0.0
19	3	9	0	E	30	36	18	28	31	25	0	6	-10	45	46	42	699	700	697	0.0
20	4	11	1	E	30	34	19	28	30	25	0	3	-8	44	46	42	699	701	698	0.0
21	4	9	0	E	30	35	22	27	30	24	1	4	-7	45	46	44	699	701	697	0.0
22	4	11	0	SE	30	34	23	27	30	24	0	4	-6	45	46	44	698	700	696	0.0
23	3	10	0	SE	29	34	20	27	30	24	0	4	-7	47	48	46	698	699	696	0.0
24	2	6	0	S	28	37	18	27	30	24	1	7	-7	50	54	46	698	700	692	0.0
25	3	7	0	E	27	32	20	28	30	25	3	5	0	63	82	54	699	701	698	0.0
26	3	8	0	E	27	32	19	27	30	24	3	6	-2	68	78	55	700	702	698	0.0
27	2	5	0	W	26	32	18	27	29	24	1	5	-5	56	65	52	700	701	697	0.0
28	3	8	0	SW	26	31	17	26	29	23	0	4	-5	54	61	48	698	700	693	0.0
29	2	8	0	SW	25	30	14	25	28	22	-3	2	-11	47	53	43	698	700	694	0.0
30	3	8	0	SW	23	28	14	24	27	21	-4	-1	-12	49	52	46	698	700	696	0.0
31	3	11	0	W	23	28	15	24	26	21	-3	-1	-9	51	57	47	698	700	696	0.0
AVG.	3	9	0	S	30	35	20	29	32	25	2	5	-6	48	52	44	698	700	694	0.0

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR NOV 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEMP. (C)			GROUND TEMP. (C)			DEW POINT TEMP. (C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS. (mm-Hg)			RAIN FALL (mm)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	2	7	0	W	24	29	13	23	26	20	-3	1	-12	50	53	47	697	699	695	0.0
2	2	6	0	E	25	33	14	23	26	20	-2	3	-10	48	55	44	696	698	694	0.0
3	5	13	1	SE	20	32	10	24	26	21	-1	1	-8	47	49	46	695	697	693	0.0
4	4	8	0	SW	24	28	18	25	27	22	0	2	-4	61	66	56	696	698	695	0.0
5	3	9	0	W	22	26	15	24	26	21	-2	0	-6	59	60	54	699	701	697	0.0
6	3	8	0	SE	22	26	15	23	25	20	-2	0	-7	58	65	55	698	700	695	0.0
7	6	15	2	SE	26	30	20	24	26	22	-1	1	-5	55	61	51	694	696	692	0.0
8	5	13	1	SE	28	31	22	25	27	22	-1	2	-7	50	54	47	693	695	691	0.0
9	4	11	0	S	28	31	23	26	28	23	0	2	-5	51	53	48	695	696	693	0.0
10	5	12	1	SW	23	26	18	25	26	23	-2	0	-6	58	60	55	698	699	695	0.0
11	4	8	1	W	16	20	9	21	23	19	-8	-6	-12	56	63	51	701	703	699	0.0
12	4	9	1	E	17	22	11	20	22	18	-8	-5	-13	53	57	51	699	701	697	0.0
13	4	10	1	SE	22	28	12	21	23	18	-4	1	-12	57	61	53	696	699	694	0.0
14	6	10	3	SW	15	18	9	19	21	17	-9	-8	-12	57	72	47	702	704	700	0.0
15	3	7	0	SW	16	21	9	18	20	15	-9	-6	-14	52	59	46	703	704	701	0.0
16	3	8	0	E	18	22	10	18	20	15	-9	-5	-16	48	58	46	700	702	698	7.0
17	4	12	0	SE	23	27	15	20	23	18	-4	1	-12	52	55	50	696	699	694	5.2
18	3	9	0	W	21	24	17	22	24	20	0	4	-3	72	82	65	696	698	695	4.3
19	5	11	1	NW	19	23	13	21	22	19	-2	0	-5	72	81	64	699	701	697	4.7
20	6	10	2	NW	20	24	16	21	23	19	2	3	-1	79	100	64	699	701	698	2.0
21	6	10	2	NW	20	23	15	21	23	19	1	2	-1	70	100	63	699	701	697	0.9
22	4	10	1	SE	23	27	15	21	24	19	1	2	-1	62	80	49	697	699	695	2.2
23	5	8	1	W	18	21	14	21	23	19	0	2	-2	81	100	69	697	699	695	1.4
24	3	8	0	W	17	20	12	20	22	19	-2	0	-5	73	89	62	697	699	696	3.0
25	3	7	0	W	16	20	12	19	21	17	-8	-5	-11	47	56	43	699	701	697	2.9
26	3	7	1	NW	17	22	11	18	20	16	-7	-4	-12	46	52	43	698	700	697	2.7
27	5	9	1	E	19	24	12	19	21	16	-6	-3	-11	44	51	48	699	701	697	7.4
28	5	10	1	E	23	27	16	20	22	18	0	1	-4	56	67	47	698	700	696	7.9
29	6	14	2	SE	24	28	16	21	23	19	-1	1	-6	52	61	46	695	698	693	4.0
30	4	11	0	SE	25	29	19	22	24	20	0	2	-3	51	58	46	695	697	692	4.7
31																				
AVG.	4	10	1	S	21	25	15	22	24	19	-3	-0	-8	57	66	52	698	699	696	2.1

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR APR. 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIRECTION	AMBIENT TEMP. (C)			GROUND TEMP. (C)			DEW POINT TEMP. (C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS. (mm-Hg)			RAIN FALL (MM)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	4	9	1	NW	26	31	10	20	32	22	-0	2	-5	43	53	30	694	696	691	0.0
2	3	14	0	S	20	34	20	29	33	23	3	8	-3	47	53	42	691	693	689	0.0
3	4	12	0	W	25	30	20	20	30	24	1	3	-3	52	54	47	693	695	691	0.0
4	5	15	0	NW	21	24	17	23	24	22	0	4	-3	64	76	56	695	697	692	5.7
5	3	9	0	S	22	26	17	23	26	18	3	6	0	64	82	49	696	698	694	1.5
6	3	8	0	SW	22	27	16	24	27	19	4	7	1	68	92	52	696	698	692	3.5
7	5	13	0	E	21	25	18	21	24	18	3	5	1	68	84	55	693	696	690	6.6
8	4	12	0	SE	26	30	16	23	28	18	3	5	0	53	83	41	692	694	688	0.0
9	3	12	0	S	25	30	17	26	31	20	3	8	-1	59	99	37	690	692	688	0.2
10	3	10	0	S	23	27	16	26	31	20	1	6	-2	56	91	42	693	694	690	0.0
11	2	8	0	SW	24	30	16	27	32	20	1	4	-3	52	71	42	696	698	694	0.0
12	3	9	0	E	26	31	18	28	33	22	2	5	-2	58	63	43	697	699	694	0.0
13	3	9	0	SE	23	29	18	25	29	22	2	5	-2	61	83	47	697	699	695	1.3
14	2	7	0	S	26	31	18	27	32	21	2	5	-1	53	71	44	698	700	695	0.0
15	2	7	0	SE	27	32	19	28	33	22	3	6	-0	58	66	43	698	700	695	0.0
16	3	9	0	S	28	32	20	28	32	23	4	6	-1	52	61	47	697	699	695	0.0
17	2	7	0	S	26	34	18	26	33	19	4	7	0	51	60	37	691	697	678	11.0
18	4	12	0	SE	27	33	20	28	33	24	4	6	1	58	74	46	693	696	690	0.2
19	4	20	0	S	23	28	17	25	28	22	4	9	-0	66	92	46	692	694	690	11.1
20	3	9	0	S	17	20	15	21	22	19	3	10	0	93	100	78	694	696	691	10.3
21	5	12	1	SW	19	22	15	21	24	17	3	5	-0	85	98	71	692	693	690	1.5
22	4	10	0	SW	24	28	16	23	27	18	2	4	0	57	87	44	693	695	691	0.0
23	2	6	0	S	26	32	16	26	31	19	4	7	-0	57	93	41	695	697	692	0.0
24	4	17	0	W	25	30	19	25	27	21	2	7	-0	57	80	47	693	695	689	14.2
25	3	11	0	S	22	28	17	23	25	19	6	11	2	71	88	53	692	693	690	7.5
26	4	16	0	S	24	29	18	22	26	18	5	11	-0	65	85	55	691	693	688	4.5
27	3	18	0	SE	26	30	17	24	28	19	5	8	1	64	98	47	692	693	689	0.0
28	3	8	0	S	22	31	18	22	28	17	1	4	-2	58	77	30	687	694	678	13.5
29	3	8	0	S	23	32	17	23	31	18	4	9	2	56	98	8	689	695	653	13.5
30	3	9	0	S	20	32	15	20	33	21	-	-	-	99	100	99	694	696	691	0.0
31																				
AVG.	3	11	0	S	24	29	17	25	29	20	3	6	-1	61	81	47	694	696	688	3.6

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR MAY. 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEPM. (C)			GROUND TEMP. (C)			DEW POINT TEMP. (C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS. (mm-Hg)			RAIN FALL (MM)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	4	12	0	S	26	35	10	25	33	10	-	-	-	81	100	31	691	696	679	13.5
2	4	12	0	SE	33	37	23	30	35	24	-	-	-	99	100	99	692	694	683	0.0
3	7	10	0	SE	34	37	27	31	34	27	-	-	-	99	100	99	689	691	685	0.3
4	5	11	1	S	27	32	23	30	35	25	0	3	-2	73	100	30	690	691	689	0.0
5	5	12	1	W	25	29	19	30	34	25	-1	1	-4	48	57	44	695	696	693	0.0
6	4	10	1	W	26	31	10	29	34	24	-0	3	-4	46	57	42	696	698	694	0.0
7	5	12	1	NW	28	33	20	29	33	24	0	4	-4	47	54	43	695	698	692	0.0
8	3	9	0	SE	32	38	23	31	36	25	5	9	1	49	64	44	695	697	692	0.5
9	3	9	0	S	32	37	24	31	35	26	5	9	1	51	60	47	694	696	692	1.5
10	4	11	0	S	30	35	23	30	34	24	4	7	0	40	67	30	693	694	691	0.0
11	3	12	0	S	31	36	23	31	35	26	3	7	-4	45	50	40	690	692	680	0.0
12	2	8	0	S	31	36	23	32	37	26	2	6	-3	39	57	32	691	693	689	0.0
13	4	10	1	S	30	35	20	32	37	26	1	5	-4	40	51	35	693	694	690	0.0
14	4	10	0	E	30	37	20	32	36	26	1	7	-6	43	48	39	694	696	692	0.0
15	4	14	0	S	32	37	25	33	37	27	3	5	-2	42	49	37	693	694	691	0.0
16	5	14	1	W	29	34	22	32	36	27	0	4	-7	42	44	40	695	697	693	0.0
17	5	12	1	NW	30	36	21	32	36	27	1	5	-5	44	48	42	695	697	693	0.0
18	5	11	1	E	33	39	24	33	37	27	2	8	-6	40	42	37	695	696	692	0.0
19	3	10	0	NW	33	41	22	34	38	20	5	11	-3	46	51	43	695	697	693	0.0
20	5	13	0	E	36	42	26	35	39	29	5	11	-1	43	47	41	695	697	693	0.0
21	3	9	0	SE	37	43	29	36	40	30	6	11	-1	42	44	40	695	696	692	0.0
22	4	11	0	SE	36	42	26	36	40	31	7	10	1	46	56	41	695	697	692	0.0
23	5	10	1	NW	33	38	25	35	39	31	4	8	-3	46	48	44	695	697	693	0.0
24	5	11	0	SE	37	43	20	36	40	31	6	11	-1	44	47	41	694	695	691	0.0
25	4	10	0	E	37	43	26	36	40	30	6	10	-3	41	45	39	694	695	692	0.0
26	3	12	0	E	37	44	24	36	40	31	7	11	1	46	57	41	693	695	690	0.0
27	4	13	0	SE	39	43	30	37	41	32	7	12	-1	42	45	40	692	693	690	0.0
28	6	15	1	SE	39	44	32	37	41	32	7	11	1	42	44	39	692	693	690	0.0
29	3	10	0	S	38	43	31	38	42	33	7	11	-0	41	44	30	692	694	690	0.0
30	5	11	1	W	35	40	27	37	41	32	4	9	-3	43	44	40	693	695	691	0.0
31	5	11	1	NW	35	39	27	37	40	32	4	8	-2	43	45	41	692	694	691	0.0
AVG.	4	11	0	S	33	38	24	33	37	20	4	8	-2	50	57	44	693	695	691	0.5

A : AVERAGE
H : HIGHEST
L : LOWEST

DAILY METEOROLOGICAL DATA FOR JUL. 1986

DAY OF MONTH	WIND SPEED (M/SEC)			WIND DIREC-TION	AMBIENT TEPM. (C)			GROUND TEMP. (C)			DEW POINT TEMP.(C)			RELATIVE HUMIDITY (%)			BAROMETRIC PRESS.(mm-Hg)			RAIN FALL (MM)
	A	H	L		A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	
1	10	10	4	SW	33	38	26	36	39	30	2	6	-4	42	44	40	690	692	658	0.0
2	7	13	2	SW	34	39	26	36	39	31	3	6	-4	41	41	40	691	711	658	0.0
3	6	13	1	SW	35	40	26	36	39	31	4	8	-4	40	41	38	691	693	676	0.0
4	6	14	2	SW	36	41	27	36	40	31	5	9	-4	41	43	39	692	693	658	0.0
5	5	11	1	SW	37	42	27	37	40	32	6	10	-4	43	45	39	691	693	690	0.0
6	4	10	0	SW	37	43	26	37	41	32	6	10	-3	42	43	39	691	693	658	0.0
7	6	14	1	SW	37	41	28	37	40	32	5	8	-4	39	41	37	690	692	688	0.0
8	5	14	1	SW	36	42	25	37	40	32	5	9	-5	41	42	38	690	691	688	0.0
9	4	10	0	SW	38	44	26	37	41	32	7	12	-4	43	46	39	690	692	688	0.0
10	3	9	0	W	37	44	28	38	41	33	6	12	-2	43	45	40	691	692	689	0.0
11	3	9	0	S	37	43	26	38	42	33	6	11	-3	42	45	39	691	693	689	0.0
12	4	11	0	W	37	42	28	38	42	33	6	11	-2	42	44	39	690	692	689	0.0
13	3	10	0	SW	37	43	26	38	42	33	6	11	-3	41	43	38	691	693	689	0.0
14	4	14	0	SW	37	43	28	38	42	33	6	10	-2	43	44	40	691	692	689	0.0
15	6	15	0	SW	37	42	27	38	41	33	5	9	-3	42	43	41	691	693	689	0.0
16	6	17	0	SW	37	42	29	38	41	33	6	9	-2	43	44	3	692	693	658	0.0
17	6	14	1	SW	38	43	31	38	41	34	6	10	-1	42	44	40	690	703	658	32.0
18	6	15	1	SW	39	43	31	38	42	34	7	10	-1	42	44	39	689	691	687	0.0
19	3	13	0	SW	39	44	21	39	42	19	8	12	-1	43	45	32	688	690	688	0.0
20	4	11	0	SW	39	44	30	38	42	34	7	12	-1	43	45	40	689	690	687	0.0
21	3	10	0	SW	37	44	28	38	42	34	6	12	-2	42	45	3	690	709	658	32.7
22	6	17	0	SW	37	42	28	38	41	34	6	9	-3	41	44	38	689	692	687	0.0
23	7	15	1	SW	38	42	33	38	41	34	6	10	0	43	45	40	688	689	687	0.0
24	5	12	1	W	38	44	29	38	41	34	7	11	-1	44	47	41	689	691	687	0.0
25	3	11	0	NW	39	45	29	39	43	34	8	12	-1	44	47	41	689	691	687	0.0
26	4	11	0	E	39	44	31	39	42	34	7	12	-8	44	47	3	689	710	658	0.0
27	2	8	0	S	39	46	29	39	42	34	8	14	-1	45	48	3	691	694	658	0.0
28	7	15	2	SW	37	41	30	39	42	35	5	9	-1	43	45	41	692	694	689	0.0
29	5	13	0	SW	36	41	28	38	42	34	5	9	-2	41	42	39	689	692	688	0.0
30	3	9	0	SW	37	44	24	38	42	33	6	11	-5	42	44	39	689	691	687	0.0
31	3	13	0	S	37	45	25	38	41	33	8	13	-5	42	45	38	690	692	688	0.0
AVG.	5	12	1	SW	37	43	28	38	41	32	6	10	-3	42	44	34	690	694	676	2.1

A : AVERAGE
H : HIGHEST
L : LOWEST

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TITLE CONSTRUCTION 3
HOUT 2.5
*HOUSE FLRAREA=100  VOL=1000
ROOF AREA=100  TILT=0   UVAL=.07  ABSRP=.3  INSIDE=AIR
WALL NAME=NORTH  AREA=100  AZM=180  ABSRP=.3  UVAL=.07
WALL NAME=SOUTH  AREA=90   AZM=0    ABSRP=.3  UVAL=.07
WALL NAME=EAST   AREA=100  AZM=-90  ABSRP=.3  UVAL=.07
WALL NAME=WEST   AREA=100  AZM=90   ABSRP=.3  UVAL=.07
SLAB *AREA=100   *THKNS=1.5  *MATERIAL=CONC80  HTAHS=1.5  RSURF=0 &
UDB=.147
GLASS NAME=SOUTH  AREA=10  AZM=0  NGLZ=2
INTGAIN  INTGAIN=0
VENT  *TYPE=NONE
TSTATSWNTR   THEAT=0    TDSRD=68  TCOOL=150
TSTATSSMR    THEAT=0    TDSRD=85  TCOOL=150
PRINTHOURLY  *FIRSTDAY=JUL-17   LASTDAY=JUL-17
END

*** No input errors.

*** Beginning simulation    26-AUG-89    02:15:36
se energy imbalance for JUL Net=0.108 kBtu (0.0123)

*** Run complete.
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Weather: PHOENIX.AZ (Phoenix AZ TMY)

MMARY

Run period: JUL-17 - JUL-17 Conditioned floor area: 100 sf

CE CONDITIONING LOADS

	Run totals kBtu	Run totals kBtu/sf	Peaks kBtuh
House			
Cooling	0	0	
Heating	0	0	

RGY CONSUMPTION

	Run totals kWh; kBtu	Prop line kBtu/sf	Source kBtu/sf	Peaks kW; kBtuh
Electricity				
House cooling	0	0	0	
Total	0	0	0	
Fuel				
House heating	0	0	0	
Building total		0	0	

THLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES						TRANSFERS			
	COND	SHCND	INFIL	SLR	INT	STRG	RB+SS	VENT	COOL	HEAT
	-0.500		-1.424	4.454	0	-2.42			0	0
	-0.500		-1.424	4.454	0	-2.42			0	0

THLY CONDITIONS (Units as shown)

EMPERATURES (F)						WTHR (F; Btu/sf)				PEAKS (kBtuh)			
THL	THH	THM	TSL	TSH	TSM	DBL	DBH	DBM	SGL	HSCL/DY	HSHT/DY	SSCL/DY	SSHT/DY
96	102	99				86	104	95	2436	0	0		
96	102	99				86	104	95	2436	0	0		

RLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES				STORAGE						TRANSFERS		
HS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
99	-0.41	-0.10	0	0	0.38		0.10					0	-
98	-0.44	-0.11	0	0	0.42		0.10					0	-
98	-0.47	-0.12	0	0	0.46		0.10					0	-
97	-0.50	-0.13	0	0	0.49		0.11					0	-
97	-0.53	-0.13	0	0	0.52		0.11					0	-
96	-0.56	-0.14	0.00	0	0.54		0.12					0	-
96	-0.35	-0.11	0.09	0	0.29		0.06					0	-
96	-0.11	-0.10	0.23	0	-0.04		0.02					0	-
96	0.09	-0.07	0.23	0	-0.22		-0.03					0	-
97	0.26	-0.05	0.34	0	-0.44		-0.08					0	-
97	0.43	-0.02	0.45	0	-0.69		-0.13					0	-
98	0.51	-0.00	0.55	0	-0.84		-0.16					0	-
99	0.56	0.01	0.59	0	-0.93		-0.19					0	-
100.	0.62	0.02	0.57	0	-0.96		-0.19					0	-
101	0.69	0.03	0.47	0	-0.94		-0.20					0	-
101	0.59	0.02	0.30	0	-0.71		-0.16					0	-
102	0.53	0.03	0.25	0	-0.62		-0.15					0	-
102	0.39	0.02	0.25	0	-0.51		-0.12					0	-
102	0.04	-0.02	0.12	0	-0.10		-0.04					0	-
102	-0.15	-0.04	0.01	0	0.16		0.02					0	-
102	-0.32	-0.08	0	0	0.31		0.07					0	-
102	-0.41	-0.10	0	0	0.39		0.09					0	-
101	-0.44	-0.11	0	0	0.43		0.10					0	-
101	-0.52	-0.13	0	0	0.51		0.12					0	-

RLY CONDITIONS (Various units)

		WEATHER DATA							CNTRLS		FLOWS				SUPPLY TMPS		
THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
99		91	69	0	0	0	2	90	0								
98		90	69	0	0	0	2	90	0								
98		89	69	0	0	0	3	112	0								
97		88	69	0	0	0	3	112	0								
97		87	69	0	0	0	3	112	0								
96		86	69	2	1	1	3	112	0								
96		88	70	20	21	25	3	112	0								
96		89	70	108	46	88	3	135	0								
96		91	71	200	35	151	2	135	0								
97		93	71	216	49	209	3	135	0								
97		96	71	230	53	252	3	135	0								
98		98	71	244	53	284	3	112	0								
99		100	71	266	47	306	2	135	0								
100.		101	71	280	46	312	2	135	0								
101		103	71	276	46	288	1	135	0								
101		103	71	260	34	230	2	180	0								
102		104	71	210	37	162	2	225	0								
102		104	72	104	51	94	2	270	0								
102		101	72	26	26	31	3	225	0								
102		99	72	6	2	2	3	180	0								
102		96	72	0	0	0	4	135	0								
102		94	71	0	0	0	3	135	0								
101		93	71	0	0	0	3	112	0								
101		91	70	0	0	0	2	112	0								

RLY TEMPERATURES (Degrees F)

HOUSE									SUNSPACE					ROCKBED		
THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
99			98	98												
98			98	98												
98			97	97												
97			97	97												
97			96	96												
96			96	96												
96			96	95												
96			96	95												
96			96	95												
97			96	96												
97			97	97												
98			98	97												
99			98	98												
100.			99	99												
101			100	100												
101			101	101												
102			101	101												
102			102	102												
102			102	102												
102			102	102												
102			102	101												
102			101	101												
101			101	101												
101			100	100												

```
TITLE CONSTRUCTION 3
HOUT 2.5
*HOUSE FLRAREA=100  VOL=1000
ROOF AREA=100  TILT=0   UVAL=.07  ABSRP=.3  INSIDE=AIR
WALL NAME=NORTH  AREA=100  AZM=180  ABSRP=.3  UVAL=.07
WALL NAME=SOUTH  AREA=90   AZM=0    ABSRP=.3  UVAL=.07
WALL NAME=EAST   AREA=100  AZM=-90  ABSRP=.3  UVAL=.07
WALL NAME=WEST   AREA=100  AZM=90   ABSRP=.3  UVAL=.07
SLAB *AREA=100   *THKNS=1.5  *MATERIAL=CONC80  HTAHS=1.5  RSURF=0 &
UDB=.147
GLASS NAME=SOUTH  AREA=10  AZM=0  NGLZ=2
INTGAIN  INTGAIN=0
VENT  *TYPE=NONE
TSTATSWNTR   THEAT=65   TDSRD=68  TCOOL=85
TSTATSSMR    THEAT=65   TDSRD=85  TCOOL=86
PRINTHOURLY  *FIRSTDAY=JUL-17   LASTDAY=JUL-17
END
```

** No input errors.

** Beginning simulation   26-AUG-89   02:18:25

** Run complete.

RUCTION 3 CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

MARY Run period: JUL-17 - JUL-17 Conditioned floor area: 100 sf

CONDITIONING LOADS	Run totals kBtu	Run totals kBtu/sf	Peaks kBtuh
House			
Cooling	24	0.236	2.095
Heating	0	0	

Y CONSUMPTION	Run totals kWh; kBtu	Run totals Prop line kBtu/sf	Run totals Source kBtu/sf	Peaks kW; kBtuh
Electricity				
House cooling	3	0.118	0.354	0.307
Total	3	0.118	0.354	
Fuel				
House heating	0	0	0	
Building total		0.118	0.354	

RUCTION 3 CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

THLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES						TRANSFERS			
	COND	SHCND	INFIL	SLR	INT	STRG	RB+SS	VENT	COOL	HEAT
	16.214		2.849	4.454	0	0.08			-23.616	0
	16.214		2.849	4.454	0	0.08			-23.616	C

THLY CONDITIONS (Units as shown)

TEMPERATURES (F)						WTHR (F; Btu/sf)				PEAKS (kBtuh)			
THL	THH	THM	TSL	TSH	TSM	DBL	DBH	DBM	SGL	HSCL/DY	HSHT/DY	SSCL/DY	SSHT/DY
86	86	86				86	104	95	2436	-2.10 17	0		
86	86	86				86	104	95	2436	-2.10	0		

RUCTION 3 CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

RLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES				STORAGE						TRANSFERS		
HS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
86	0.26	0.07	0	0	0		0.06					-0.40	C
86	0.21	0.05	0	0	0		0.05					-0.32	C
86	0.16	0.04	0	0	0		0.04					-0.24	C
86	0.10	0.03	0	0	0		0.03					-0.17	C
86	0.05	0.01	0	0	0		0.03					-0.10	C
86	0.00	0	0.00	0	0		0.03					-0.04	C
86	0.19	0.03	0.09	0	0		-0.01					-0.30	C
86	0.44	0.04	0.23	0	0		-0.02					-0.68	C
86	0.65	0.07	0.23	0	0		-0.03					-0.91	C
86	0.83	0.09	0.34	0	0		-0.04					-1.21	C
86	1.03	0.14	0.45	0	0		-0.06					-1.54	C
86	1.14	0.16	0.55	0	0		-0.05					-1.79	C
86	1.24	0.19	0.59	0	0		-0.05					-1.95	C
86	1.33	0.20	0.57	0	0		-0.04					-2.06	C
86	1.45	0.23	0.47	0	0		-0.04					-2.10	C
86	1.38	0.23	0.30	0	0		-0.02					-1.88	C
86	1.35	0.24	0.25	0	0		-0.02					-1.82	C
86	1.24	0.24	0.25	0	0		-0.01					-1.72	C
86	0.90	0.20	0.12	0	0		0.03					-1.25	C
86	0.70	0.18	0.01	0	0		0.04					-0.93	C
86	0.53	0.14	0	0	0		0.06					-0.73	C
86	0.42	0.11	0	0	0		0.05					-0.59	C
86	0.37	0.09	0	0	0		0.04					-0.51	C
86	0.26	0.07	0	0	0		0.05					-0.38	C

RUCTION 3 CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

RLY CONDITIONS (Various units)

		WEATHER DATA							CNTRLS		FLOWS				SUPPLY TMPS		
THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
86		91	69	0	0	0	2	90	0								
86		90	69	0	0	0	2	90	0								
86		89	69	0	0	0	3	112	0								
86		88	69	0	0	0	3	112	0								
86		87	69	0	0	0	3	112	0								
86		86	69	2	1	1	3	112	0								
86		88	70	20	21	25	3	112	0								
86		89	70	108	46	88	3	135	0								
86		91	71	200	35	151	2	135	0								
86		93	71	216	49	209	3	135	0								
86		96	71	230	53	252	3	135	0								
86		98	71	244	53	284	3	112	0								
86		100	71	266	47	306	2	135	0								
86		101	71	280	46	312	2	135	0								
86		103	71	276	46	288	1	135	0								
86		103	71	260	34	230	2	180	0								
86		104	71	210	37	162	2	225	0								
86		104	72	104	51	94	2	270	0								
86		101	72	26	26	31	3	225	0								
86		99	72	6	2	2	3	180	0								
86		96	72	0	0	0	4	135	0								
86		94	71	0	0	0	3	135	0								
86		93	71	0	0	0	3	112	0								
86		91	70	0	0	0	2	112	0								

RLY TEMPERATURES (Degrees F)

HOUSE									SUNSPACE					ROCKBED		
THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
86			87	87												
86			87	87												
86			86	87												
86			86	86												
86			86	86												
86			86	86												
86			86	86												
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86			87	87												

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-----------------------------------------------------------------------------
TITLE  SIMPLEHOUSE (CONC.HOLLOW BLOCK  CONSTRUCTION)
HOUT   2.5
*HOUSE  FLRAREA=100     VOL=1000
ROOF   AREA=100      TILT=0     UVAL=.298   ABSRP=.2  INSIDE=AIR
WALL   NAME=N        AREA=99    AZM=180     ABSRP=.2  UVAL=.423
WALL   NAME=S        AREA=89    AZM=0       ABSRP=.2  UVAL=.423
WALL   NAME=E        AREA=100   AZM=-90     ABSRP=.2  UVAL=.423
WALL   NAME=W        AREA=100   AZM=90      ABSRP=.2  UVAL=.423
SLAB  AREA=100   *THKNS=4.5    MATERIAL=CONC120   HTAHS=2  RSURF=0 &
UDB=.5
GLASS  NAME=S        AREA=10    AZM=0     NGLZ=2
INTGAIN  INTGAIN=0
VENT *TYPE=NATURAL  AINLET=1  AOUTLET=1   HDIFF=6.7  STACKEFF=1 &
AZMINLET=0  DDEFF=1
TSTATSWNTR  THEAT=65  TDSRD=68   TCOOL=85
TSTATSSMR   THEAT=65  TDSRD=85   TCOOL=86
CHNGSEASON *TYPE=TEMP   TEMP=85
PRINTHOURLY *FIRSTDAY=JUN-10   LASTDAY=JUN-10
PRINTHOURLY *FIRSTDAY=JAN-01   LASTDAY=JAN-01
END

*** No input errors.

*** Beginning simulation    04-JUN-87    00:22:11

*** Run complete.
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ouse				
Cooling	6745	67.455		8.919
Heating	6957	69.572		8.916

Y CONSUMPTION	Run totals			Peaks
	kWh; kBtu	Prop line kBtu/sf	Source kBtu/sf	kW; kBtuh
lectricity				
House cooling	988	33.727	101.182	1.307
Total	988	33.727	101.182	
uel				
House heating	11595	115.953	115.953	14.860
Building total		149.681	217.135	

HOUSE (CONC.HOLLOW BLOCK CONSTRUCTION) CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

THLY HOUSE ENERGY BALANCE (kBtu; + into house)

GAINS & LOSSES						TRANSFERS			
COND	SHCND	INFIL	SLR	INT	STRG	RB+SS	VENT	COOL	HEAT
-2017.9		-138.23	336.53	0	0.12		-36.982	0	1856.5
-1540.2		-113.16	316.08	0	-16.1		-38.366	0	1392.4
-866.68		-81.247	302.29	0	-10.3		-108.99	0	765.27
-238.88		-47.706	218.33	0	-9.16		-160.59	-18.985	257.32
562.95		-5.906	173.44	0	-8.71		-205.64	-517.24	1.402
1249.9		36.084	152.64	0	-1.80		-14.983	-1421.8	0
1835.9		73.844	147.46	0	-0.71		-10.650	-2045.8	0
1414.4		49.403	183.43	0	-0.15		-13.649	-1633.4	0
763.95		13.663	266.04	0	5.69		-54.829	-994.70	0
-55.055		-30.902	346.66	0	18.8		-216.94	-113.52	50.252
-855.83		-72.770	369.42	0	19.8		-88.136	0	626.76
-2160.5		-145.21	331.74	0	5.48		-39.013	0	2007.3
-1908.0		-462.14	3144.1	0	3.02		-988.76	-6745.5	6957.2

THLY CONDITIONS (Units as shown)

TEMPERATURES (F)						WTHR (F; Btu/sf)				PEAKS (kBtuh)			
THL	THH	THM	TSL	TSH	TSM	DBL	DBH	DBM	SGL	HSCL/DY	HSHT/DY	SSCL/DY	SSHT/DY
65	69	66				41	64	52	1024	0	7.82 1		
65	70	67				42	67	54	1399	0	7.63 23		
65	76	70				47	75	61	1855	0	6.52 5		
66	80	73				54	80	68	2329	-3.25 30	5.47 22		
71	85	79				62	92	79	2709	-6.88 28	0.88 13		
81	86	85				73	101	88	2697	-7.30 10	0		
84	86	86				82	103	93	2430	-8.16 25	0		
83	86	85				79	101	90	2292	-8.92 1	0		
79	86	84				73	97	85	2030	-6.86 5	0		
68	84	76				59	87	73	1571	-4.12 1	2.54 18		
65	74	68				50	72	61	1210	0	5.91 28		
65	70	66				40	65	52	921	0	8.92 31		
72	79	75				59	84	71	1874	-8.92	8.92		

EHOUSE (CONC.HOLLOW BLOCK CONSTRUCTION) CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

RLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES				STORAGE						TRANSFERS		
HS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
86	-0.55	-0.03	0	0	0.14		0.49					-0.07	V
85	-1.32	-0.07	0	0	1.01		0.71					-0.38	V
84	-1.84	-0.10	0	0	1.05		0.83					0	-
83	-2.07	-0.11	0	0	1.21		0.90					0	-
82	-2.50	-0.13	0	0	1.51		1.04					0	-
81	-1.98	-0.12	0.05	0	1.03		0.95					0	-
81	-0.61	-0.08	0.10	0	-0.05		0.60					0	-
82	0.58	-0.04	0.18	0	-0.91		0.18					0	-
83	2.03	0.02	0.34	0	-1.97		-0.37					0	-
86	3.63	0.08	0.50	0	-3.01		-0.98					-0.11	C
86	4.74	0.14	0.59	0	0		-0.94					-4.52	C
86	5.62	0.19	0.67	0	0		-0.95					-5.49	C
86	6.46	0.24	0.71	0	0		-0.94					-6.45	C
86	6.97	0.27	0.66	0	0		-0.85					-7.01	C
86	7.17	0.28	0.55	0	0		-0.73					-7.25	C
86	7.22	0.30	0.44	0	0		-0.63					-7.30	C
86	6.97	0.30	0.36	0	0		-0.50					-7.11	C
86	6.54	0.30	0.30	0	0		-0.40					-6.71	C
86	5.57	0.28	0.16	0	0		-0.28					-5.71	C
86	4.09	0.23	0.04	0	0		-0.04					-4.30	C
86	2.74	0.16	0	0	0		0.20					-3.09	C
86	1.29	0.08	0	0	0		0.44					-1.80	C
86	0.82	0.05	0	0	0		0.45					-1.34	C
86	0.12	0.01	0	0	0		0.50					-0.64	C

LEHOUSE (CONC.HOLLOW BLOCK CONSTRUCTION) CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

URLY TEMPERATURES (Degrees F)

HOUSE									SUNSPACE					ROCKBED		
THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
86			87	88												
85			86	86												
84			86	85												
83			85	84												
82			83	83												
81			82	82												
81			82	82												
82			82	82												
83			83	82												
86			84	84												
86			84	85												
86			85	87												
86			86	88												
86			86	89												
86			87	90												
86			87	91												
86			88	91												
86			88	92												
86			88	92												
86			89	92												
86			89	91												
86			88	90												
86			88	90												
86			88	89												

EHOUSE (CONC.HOLLOW BLOCK CONSTRUCTION) CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

RLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES				STORAGE						TRANSFERS		
HS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
65	-7.42	-0.42	0	0	0		1.01					6.87	H
65	-7.40	-0.42	0	0	0		0.83					6.94	H
65	-7.34	-0.42	0	0	0		0.67					7.06	H
65	-7.32	-0.42	0	0	0		0.53					7.18	H
65	-7.53	-0.43	0	0	0		0.47					7.48	H
65	-7.52	-0.43	0	0	0		0.38					7.55	H
65	-7.74	-0.45	0	0	0		0.35					7.82	H
65	-7.69	-0.45	0.02	0	0		0.28					7.82	H
65	-7.39	-0.46	0.35	0	0		0.27					7.23	H
65	-5.46	-0.39	0.98	0	0		-0.01					4.86	H
65	-3.63	-0.31	1.50	0	0		-0.28					2.71	H
65	-2.34	-0.24	1.79	0	0		-0.46					1.26	H
65	-1.71	-0.20	1.91	0	0		-0.51					0.54	H
65	-1.19	-0.18	1.83	0	0		-0.51					0.06	H
65	-0.57	-0.14	1.58	0	-0.26		-0.58					0	-
65	-0.65	-0.12	1.09	0	0.17		-0.49					0	-
65	-1.31	-0.12	0.47	0	0.09		-0.38					1.27	H
65	-1.68	-0.11	0.06	0	0		-0.35					2.09	H
65	-2.76	-0.16	0	0	0		-0.10					3.05	H
65	-3.74	-0.22	0	0	0		0.10					3.86	H
65	-4.70	-0.27	0	0	0		0.27					4.71	H
65	-5.18	-0.30	0	0	0		0.31					5.16	H
65	-5.65	-0.32	0	0	0		0.34					5.62	H
65	-6.12	-0.35	0	0	0		0.37					6.09	H

EHOUSE (CONC.HOLLOW BLOCK CONSTRUCTION) CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

RLY CONDITIONS (Various units)

		WEATHER DATA							CNTRLS		FLOWS				SUPPLY TMPS		
THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
65		34	32	0	0	0	1	112	1.0			0			34		
65		34	32	0	0	0	1	112	1.0			0			34		
65		34	32	0	0	0	1	112	1.0			0			34		
65		34	31	0	0	0	1	112	1.0			0			34		
65		33	31	0	0	0	2	90	1.0			0			33		
65		33	31	0	0	0	2	90	1.0			0			33		
65		32	30	0	0	0	1	67	1.0			0			32		
65		32	30	4	2	2	1	67	1.0			0			32		
65		31	29	58	26	36	1	45	1.0			0			31		
65		36	32	154	41	92	1	67	1.0			0			36		
65		42	36	218	41	142	1	90	1.0			0			42		
65		47	39	242	43	176	2	112	1.0			0			47		
65		50	40	252	42	189	1	112	1.0			0			50		
65		52	42	246	42	181	1	90	1.0			0			52		
65		55	43	224	41	152	1	90	1.0			0			55		
65		56	43	168	40	103	1	67	1.0			0			56		
65		56	43	78	28	45	0	22	1.0			0			56		
65		57	43	12	4	5	0	0	1.0			0			57		
65		53	42	0	0	0	0	22	1.0			0			53		
65		49	40	0	0	0	1	22	1.0			0			49		
65		45	38	0	0	0	1	45	1.0			0			45		
65		43	38	0	0	0	1	67	1.0			0			43		
65		41	37	0	0	0	2	90	1.0			0			41		
65		39	36	0	0	0	2	112	1.0			0			39		

EHOUSE (CONC.HOLLOW BLOCK CONSTRUCTION) CALPAS3 V3.12 License: PC0188

Weather: PHOENIX.AZ (Phoenix AZ TMY)

RLY TEMPERATURES (Degrees F)

HOUSE									SUNSPACE					ROCKBED		
THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
65			63	58												
65			63	58												
65			62	57												
65			62	56												
65			61	56												
65			61	55												
65			61	55												
65			61	55												
65			60	54												
65			60	55												
65			60	55												
65			61	56												
65			61	57												
65			61	58												
65			62	59												
65			62	60												
65			62	60												
65			63	60												
65			63	60												
65			63	60												
65			63	59												
65			63	59												
65			62	58												
65			62	57												

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----------------------------------------------------------------------------------
TITLE  SIMPLEHOUSE (INSULATED MUD CONSTRUCTION)
HOUT   2.5
*HOUSE  FLRAREA=100     VOL=1000
ROOF   AREA=100     TILT=0     UVAL=.033   ABSRP=.2  INSIDE=AIR
WALL   NAME=N       AREA=99    AZM=180     ABSRP=.2  UVAL=.055
WALL   NAME=S       AREA=89    AZM=0       ABSRP=.2  UVAL=.055
WALL   NAME=E       AREA=100   AZM=-90     ABSRP=.2  UVAL=.055
WALL   NAME=W       AREA=100   AZM=90      ABSRP=.2  UVAL=.055
SLAB  AREA=100   *THKNS=4.5    MATERIAL=CONC120   HTAHS=2  RSURF=0 &
UDB=.5
GLASS  NAME=S       AREA=10    AZM=0     NGLZ=2
INTGAIN  INTGAIN=0
VENT *TYPE=NATURAL  AINLET=1  AOUTLET=1   HDIFF=6.7  STACKEFF=1 &
AZMINLET=0  DDEFF=1
TSTATSWNTR  THEAT=65  TDSRD=68   TCOOL=85
TSTATSSMR   THEAT=65  TDSRD=85   TCOOL=86
CHNGSEASON *TYPE=TEMP   TEMP=85
PRINTHOURLY *FIRSTDAY=JUN-10   LASTDAY=JUN-10
PRINTHOURLY *FIRSTDAY=JAN-01   LASTDAY=JAN-01
END

*** No input errors.

*** Beginning simulation    03-JUN-87    23:36:06
** energy imbalance for OCT Net=-0.814 kBtu (0.0011)

*** Run complete.
```

Weather: PHOENIX.AZ (Phoenix AZ TMY)

RLY TEMPERATURES (Degrees F)

HOUSE									SUNSPACE					ROCKBED		
HS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
65			63	58												
65			63	58												
65			62	57												
65			62	56												
65			61	56												
65			61	55												
65			61	55												
65			61	55												
65			60	54												
65			60	55												
65			60	55												
65			61	56												
66			61	57												
66			62	58												
66			62	59												
66			63	60												
66			63	60												
65			63	61												
65			63	61												
65			63	60												
65			63	59												
65			63	59												
65			62	58												
65			62	58												

RLY CONDITIONS

(Various units)

		WEATHER DATA							CNTRLS		FLOWS				SUPPLY TMPS		
THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
65		34	32	0	0	0	1	112	1.0			0			34		
65		34	32	0	0	0	1	112	1.0			0			34		
65		34	32	0	0	0	1	112	1.0			0			34		
65		34	31	0	0	0	1	112	1.0			0			34		
65		33	31	0	0	0	2	90	1.0			0			33		
65		33	31	0	0	0	2	90	1.0			0			33		
65		32	30	0	0	0	1	67	1.0			0			32		
65		32	30	4	2	2	1	67	1.0			0			32		
65		31	29	58	26	36	1	45	1.0			0			31		
65		36	32	154	41	92	1	67	1.0			0			36		
65		42	36	218	41	142	1	90	1.0			0			42		
65		47	39	242	43	176	2	112	1.0			0			47		
66		50	40	252	42	189	1	112	1.0			0			50		
66		52	42	246	42	181	1	90	1.0			0			52		
66		55	43	224	41	152	1	90	1.0			0			55		
66		56	43	168	40	103	1	67	1.0			0			56		
66		56	43	78	28	45	0	22	1.0			0			56		
65		57	43	12	4	5	0	0	1.0			0			57		
65		53	42	0	0	0	0	22	1.0			0			53		
65		49	40	0	0	0	1	22	1.0			0			49		
65		45	38	0	0	0	1	45	1.0			0			45		
65		43	38	0	0	0	1	67	1.0			0			43		
65		41	37	0	0	0	2	90	1.0			0			41		
65		39	36	0	0	0	2	112	1.0			0			39		

RLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES				STORAGE						TRANSFERS		
HS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
65	-2.17	-0.42	0	0	0		1.00					1.62	H
65	-2.15	-0.42	0	0	0		0.83					1.69	H
65	-2.10	-0.42	0	0	0		0.67					1.81	H
65	-2.07	-0.42	0	0	0		0.53					1.93	H
65	-2.12	-0.43	0	0	0		0.47					2.06	H
65	-2.10	-0.43	0	0	0		0.38					2.13	H
65	-2.15	-0.45	0	0	0		0.35					2.24	H
65	-2.13	-0.45	0.02	0	0		0.28					2.26	H
65	-2.12	-0.46	0.35	0	0		0.27					1.96	H
65	-1.66	-0.39	0.98	0	0		-0.01					1.06	H
65	-1.17	-0.31	1.50	0	0		-0.28					0.25	H
65	-0.81	-0.25	1.79	0	-0.23		-0.49					0	-
66	-0.63	-0.21	1.91	0	-0.44		-0.59					0	-
66	-0.52	-0.19	1.83	0	-0.47		-0.62					0	-
66	-0.34	-0.15	1.58	0	-0.37		-0.68					0	-
66	-0.34	-0.14	1.09	0	-0.01		-0.59					0	-
66	-0.43	-0.13	0.47	0	0.51		-0.41					0	-
65	-0.43	-0.11	0.06	0	0.76		-0.28					0	-
65	-0.74	-0.16	0	0	0.25		-0.02					0.70	H
65	-1.04	-0.22	0	0	0		0.17					1.11	H
65	-1.33	-0.27	0	0	0		0.32					1.28	H
65	-1.46	-0.30	0	0	0		0.35					1.40	H
65	-1.59	-0.32	0	0	0		0.38					1.53	H
65	-1.72	-0.35	0	0	0		0.39					1.67	H

URLY TEMPERATURES (Degrees F)

HOUSE									SUNSPACE					ROCKBED		
THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
86			87	88												
86			87	87												
85			86	86												
85			86	85												
85			85	83												
84			84	83												
84			84	83												
84			84	83												
85			84	84												
85			84	85												
86			85	86												
86			86	87												
86			86	89												
86			87	90												
86			87	90												
86			88	91												
86			88	92												
86			88	92												
86			89	92												
86			89	92												
86			89	91												
86			88	90												
86			88	90												
86			88	89												

RLY CONDITIONS (Various units)

		WEATHER DATA							CNTRLS		FLOWS				SUPPLY TMPS		
THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
86		84	60	0	0	0	0	0	0			0			84		
86		80	59	0	0	0	1	0	0			79.4			80		
85		77	58	0	0	0	1	90	0			75.4			77		
85		75	58	0	0	0	1	67	0			0			75		
85		72	57	0	0	0	0	0	0.0			0			72		
84		72	57	38	11	13	0	0	0.1			0			72		
84		75	57	144	17	50	1	135	0.2			0			75		
84		79	57	182	29	106	1	90	0.3			0			79		
85		85	61	184	61	173	1	90	0.3			0			85		
85		92	62	222	86	256	2	135	0.2			0			92		
86		96	64	258	85	313	2	135	0			0			96		
86		100	63	262	87	338	1	225	0			0			100		
86		104	66	262	89	346	1	90	0			0			104		
86		106	65	258	86	332	3	270	0			0			106		
86		107	66	252	81	301	2	225	0			0			107		
86		108	66	242	72	253	3	315	0			0			108		
86		108	66	214	63	189	3	292	0			0			108		
86		108	66	140	60	117	2	315	0			0			108		
86		107	66	56	34	45	2	292	0			0			107		
86		103	65	6	10	10	4	270	0			0			103		
86		98	63	0	0	0	2	270	0			0			98		
86		92	62	0	0	0	0	0	0			0			92		
86		90	61	0	0	0	0	0	0			0			90		
86		87	60	0	0	0	0	0	0			0			87		

RLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES				STORAGE						TRANSFERS		
HS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
86	-0.24	-0.03	0	0	0		0.48					-0.23	C
86	-0.50	-0.08	0	0	0.41		0.63					-0.48	V
85	-0.67	-0.11	0	0	0.67		0.72					-0.66	V
85	-0.78	-0.13	0	0	0.20		0.69					0	-
85	-0.96	-0.17	0	0	0.36		0.74					0	-
84	-0.88	-0.17	0.05	0	0.33		0.63					0	-
84	-0.55	-0.12	0.10	0	0.15		0.39					0	-
84	-0.20	-0.07	0.18	0	-0.05		0.11					0	-
85	0.28	0.01	0.34	0	-0.40		-0.24					0	-
85	0.81	0.09	0.50	0	-0.78		-0.61					0	-
86	1.08	0.14	0.59	0	-0.89		-0.78					-0.08	C
86	1.33	0.19	0.67	0	0		-0.80					-1.38	C
86	1.58	0.24	0.71	0	0		-0.83					-1.67	C
86	1.70	0.27	0.66	0	0		-0.76					-1.84	C
86	1.74	0.28	0.55	0	0		-0.66					-1.88	C
86	1.76	0.30	0.44	0	0		-0.57					-1.91	C
86	1.71	0.30	0.36	0	0		-0.46					-1.88	C
86	1.64	0.30	0.30	0	0		-0.37					-1.85	C
86	1.46	0.28	0.16	0	0		-0.25					-1.63	C
86	1.09	0.23	0.04	0	0		-0.02					-1.32	C
86	0.70	0.16	0	0	0		0.22					-1.07	C
86	0.27	0.08	0	0	0		0.45					-0.80	C
86	0.14	0.05	0	0	0		0.46					-0.67	C
86	-0.06	0.01	0	0	0		0.51					-0.48	C

Weather: PHOENIX.AZ (Phoenix AZ TMY)

ITHLY HOUSE ENERGY BALANCE (kBtu; + into house)

GAINS & LOSSES						TRANSFERS			
COND	SHCND	INFIL	SLR	INT	STRG	RB+SS	VENT	COOL	HEAT
-600.33		-138.87	336.53	0	-0.06		-27.452	0	430.19
-464.92		-111.29	316.08	0	-14.6		-23.051	0	298.30
-259.02		-70.121	302.29	0	-7.85		-93.086	0	128.05
-63.120		-29.354	218.33	0	-10.8		-161.93	0	47.313
129.04		9.763	173.44	0	-10.8		-244.67	-56.362	0
215.81		29.585	152.64	0	-1.87		-37.276	-358.83	0
404.70		71.937	147.46	0	-0.67		-20.726	-602.67	0
286.57		46.539	183.43	0	-0.15		-34.871	-481.50	0
100.01		7.428	266.04	0	4.48		-90.824	-287.27	0
-45.471		-22.171	346.66	0	22.3		-302.17	0	0
-290.33		-72.852	369.42	0	15.3		-96.480	0	74.393
-630.69		-144.54	331.74	0	7.68		-28.242	0	463.79
-1217.7		-423.94	3144.1	0	2.93		-1160.8	-1786.6	1442.0

ITHLY CONDITIONS (Units as shown)

EMPERATURES (F)						WTHR (F; Btu/sf)				PEAKS (kBtuh)			
HL	THH	THM	TSL	TSH	TSM	DBL	DBH	DBM	SGL	HSCL/DY	HSHT/DY	SSCL/DY	SSHT/DY
65	68	66				41	64	52	1024	0	2.26 1		
65	69	66				42	67	54	1399	0	2.20 23		
66	71	68				47	75	61	1855	0	1.77 5		
68	74	71				54	80	68	2329	0	1.60 22		
74	81	78				62	92	79	2709	-1.67 28	0		
84	86	85				73	101	88	2697	-1.91 10	0		
85	86	86				82	103	93	2430	-2.17 25	0		
85	86	86				79	101	90	2292	-2.66 1	0		
82	85	84				73	97	85	2030	-2.30 5	0		
70	79	75				59	87	73	1571	0	0		
66	71	68				50	72	61	1210	0	1.67 28		
65	68	66				40	65	52	921	0	2.65 31		
73	77	75				59	84	71	1874	-2.66	2.65		

	kWh; kBtu	Prop line kBtu/sf	Source kBtu/sf	kW; kBtuh
Electricity				
House cooling	262	8.933	26.800	0.389
Total	262	8.933	26.800	
Fuel				
House heating	2403	24.034	24.034	4.421
Building total		32.967	50.834	

PD0H6f

CE CONDITIONING LOADS

	Run totals kBtu	Run totals kBtu/sf	Peaks kBtuh
House			
Cooling	3317	33.170	4.455
Heating	2390	23.903	3.985

RGY CONSUMPTION

	Run totals kWh; kBtu	Run totals Prop line kBtu/sf	Run totals Source kBtu/sf	Peaks kW; kBtuh
Electricity				
House cooling	486	16.585	49.755	0.653
Total	486	16.585	49.755	
Fuel				
House heating	3984	39.839	39.839	6.642
Building total		56.424	89.594	

Weather: PHOENIX.AZ (Phoenix AZ TMY)

NTHLY HOUSE ENERGY BALANCE (kBtu; + into house)

GAINS & LOSSES						TRANSFERS			
COND	SHCND	INFIL	SLR	INT	STRG	RB+SS	VENT	COOL	HEAT
-831.70		-140.85	336.53	0	0.03		-55.831	0	691.83
-615.55		-114.70	316.08	0	-17.1		-57.819	0	489.74
-296.00		-79.896	302.29	0	-8.94		-142.20	0	225.05
-19.466		-45.430	218.33	0	-11.2		-214.18	-1.672	74.028
301.98		-7.267	173.44	0	-6.85		-281.42	-179.66	0
557.31		30.299	152.64	0	-1.84		-29.854	-708.50	0
828.80		72.194	147.46	0	-0.65		-17.620	-1030.1	0
644.91		46.849	183.43	0	-0.15		-28.718	-846.30	0
336.70		6.965	266.04	0	4.70		-85.443	-529.10	0
10.370		-34.093	346.66	0	19.7		-321.68	-21.635	0
-342.95		-76.665	369.42	0	18.2		-128.07	0	159.43
-888.50		-146.89	331.74	0	7.22		-54.082	0	750.26
-314.10		-489.49	3144.1	0	3.05		-1416.9	-3317.0	2390.3

NTHLY CONDITIONS (Units as shown)

TEMPERATURES (F)						WTHR (F; Btu/sf)				PEAKS (kBtuh)			
THL	THH	THM	TSL	TSH	TSM	DBL	DBH	DBM	SGL	HSCL/DY	HSHT/DY	SSCL/DY	SSHT/DY
65	69	66				41	64	52	1024	0	3.43 1		
65	70	67				42	67	54	1399	0	3.35 23		
66	74	69				47	75	61	1855	0	2.78 5		
67	78	73				54	80	68	2329	-0.80 30	2.40 22		
74	84	79				62	92	79	2709	-3.32 28	0		
83	86	85				73	101	88	2697	-3.50 10	0		
85	86	86				82	103	93	2430	-3.83 25	0		
85	86	86				79	101	90	2292	-4.45 1	0		
81	86	84				73	97	85	2030	-3.68 5	0		
70	82	76				59	87	73	1571	-2.32 14	0		
65	73	69				50	72	61	1210	0	2.57 28		
65	69	66				40	65	52	921	0	3.99 31		
73	79	76				59	84	71	1874	-4.45	3.99		

URLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES				STORAGE						TRANSFERS		
THS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
86	-0.31	-0.03	0	0	0		0.48					-0.16	C
86	-0.69	-0.07	0	0	0.56		0.65					-0.47	V
85	-0.96	-0.11	0	0	0.59		0.72					-0.29	V
85	-1.12	-0.13	0	0	0.47		0.73					0	-
84	-1.37	-0.16	0	0	0.68		0.80					0	-
84	-1.14	-0.16	0.05	0	0.49		0.70					0	-
84	-0.43	-0.12	0.10	0	-0.00		0.42					0	-
84	0.18	-0.07	0.18	0	-0.41		0.10					0	-
85	0.95	0.00	0.34	0	-0.96		-0.32					0	-
86	1.84	0.08	0.50	0	-1.43		-0.75					-0.20	C
86	2.32	0.14	0.59	0	0		-0.77					-2.26	C
86	2.68	0.19	0.67	0	0		-0.81					-2.71	C
86	3.02	0.24	0.71	0	0		-0.83					-3.13	C
86	3.26	0.27	0.66	0	0		-0.76					-3.39	C
86	3.35	0.28	0.55	0	0		-0.66					-3.50	C
86	3.36	0.30	0.44	0	0		-0.57					-3.50	C
86	3.23	0.30	0.36	0	0		-0.46					-3.41	C
86	3.01	0.30	0.30	0	0		-0.37					-3.22	C
86	2.49	0.28	0.16	0	0		-0.25					-2.66	C
86	1.76	0.23	0.04	0	0		-0.02					-1.99	C
86	1.13	0.16	0	0	0		0.22					-1.50	C
86	0.49	0.08	0	0	0		0.45					-1.01	C
86	0.28	0.05	0	0	0		0.46					-0.82	C
86	-0.02	0.01	0	0	0		0.51					-0.51	C

U R L Y   C O N D I T I O N S

(Various units)

			WEATHER DATA							CNTRLS		FLOWS				SUPPLY TMPS		
S	THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
S	86		84	60	0	0	0	0	0	0			0			84		
S	86		80	59	0	0	0	1	0	0			78.9			80		
S	85		77	58	0	0	0	1	90	0			33.1			77		
S	85		75	58	0	0	0	1	67	0			0			75		
S	84		72	57	0	0	0	0	0	0.1			0			72		
S	84		72	57	38	11	13	0	0	0.3			0			72		
S	84		75	57	144	17	50	1	135	0.5			0			75		
S	84		79	57	182	29	106	1	90	0.5			0			79		
S	85		85	61	184	61	173	1	90	0.4			0			85		
S	86		92	62	222	86	256	2	135	0.1			0			92		
S	86		96	64	258	85	313	2	135	0			0			96		
S	86		100	63	262	87	338	1	225	0			0			100		
S	86		104	66	262	89	346	1	90	0			0			104		
S	86		106	65	258	86	332	3	270	0			0			106		
S	86		107	66	252	81	301	2	225	0			0			107		
S	86		108	66	242	72	253	3	315	0			0			108		
S	86		108	66	214	63	189	3	292	0			0			108		
S	86		108	66	140	60	117	2	315	0			0			108		
S	86		107	66	56	34	45	2	292	0			0			107		
S	86		103	65	6	10	10	4	270	0			0			103		
S	86		98	63	0	0	0	2	270	0			0			98		
S	86		92	62	0	0	0	0	0	0			0			92		
S	86		90	61	0	0	0	0	0	0			0			90		
S	86		87	60	0	0	0	0	0	0			0			87		

URLY TEMPERATURES (Degrees F)

HOUSE									SUNSPACE					ROCKBED		
THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
86			87	88												
86			87	87												
85			86	86												
85			85	85												
84			85	83												
84			84	83												
84			84	83												
84			83	83												
85			84	83												
86			85	85												
86			85	86												
86			86	87												
86			86	89												
86			87	90												
86			87	90												
86			88	91												
86			88	92												
86			88	92												
86			89	92												
86			89	92												
86			89	91												
86			88	90												
86			88	90												
86			88	89												

URLY HOUSE ENERGY BALANCE (kBtu; + into house)

	GAINS & LOSSES				STORAGE						TRANSFERS		
THS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
65	-3.29	-0.42	0	0	0		1.03					2.72	H
65	-3.27	-0.42	0	0	0		0.85					2.79	H
65	-3.22	-0.42	0	0	0		0.69					2.92	H
65	-3.19	-0.42	0	0	0		0.54					3.04	H
65	-3.27	-0.43	0	0	0		0.48					3.20	H
65	-3.25	-0.43	0	0	0		0.39					3.28	H
65	-3.34	-0.45	0	0	0		0.35					3.42	H
65	-3.31	-0.45	0.02	0	0		0.28					3.43	H
65	-3.10	-0.46	0.35	0	0		0.27					2.93	H
65	-2.15	-0.39	0.98	0	0		-0.01					1.54	H
65	-1.29	-0.31	1.50	0	0		-0.28					0.37	H
65	-0.74	-0.25	1.79	0	-0.29		-0.50					0	-
66	-0.52	-0.21	1.91	0	-0.53		-0.61					0	-
66	-0.33	-0.19	1.83	0	-0.62		-0.65					0	-
67	-0.07	-0.16	1.58	0	-0.58		-0.73					0	-
67	-0.17	-0.15	1.09	0	-0.11		-0.64					0	-
66	-0.52	-0.14	0.47	0	0.63		-0.43					0	-
65	-0.71	-0.11	0.06	0	1.02		-0.27					0	-
65	-1.18	-0.16	0	0	0.50		0.01					0.85	H
65	-1.63	-0.22	0	0	0		0.19					1.66	H
65	-2.05	-0.27	0	0	0		0.34					1.98	H
65	-2.26	-0.30	0	0	0		0.37					2.18	H
65	-2.46	-0.32	0	0	0		0.39					2.39	H
65	-2.66	-0.35	0	0	0		0.40					2.60	H

URLY CONDITIONS (Various units)

			WEATHER DATA							CNTRLS		FLOWS				SUPPLY TMPS		
S	THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
W	65		34	32	0	0	0	1	112	1.0			0			34		
W	65		34	32	0	0	0	1	112	1.0			0			34		
W	65		34	32	0	0	0	1	112	1.0			0			34		
W	65		34	31	0	0	0	1	112	1.0			0			34		
W	65		33	31	0	0	0	2	90	1.0			0			33		
W	65		33	31	0	0	0	2	90	1.0			0			33		
W	65		32	30	0	0	0	1	67	1.0			0			32		
W	65		32	30	4	2	2	1	67	1.0			0			32		
W	65		31	29	58	26	36	1	45	1.0			0			31		
W	65		36	32	154	41	92	1	67	1.0			0			36		
W	65		42	36	218	41	142	1	90	1.0			0			42		
W	65		47	39	242	43	176	2	112	1.0			0			47		
W	66		50	40	252	42	189	1	112	1.0			0			50		
W	66		52	42	246	42	181	1	90	1.0			0			52		
W	67		55	43	224	41	152	1	90	1.0			0			55		
W	67		56	43	168	40	103	1	67	1.0			0			56		
W	66		56	43	78	28	45	0	22	1.0			0			56		
W	65		57	43	12	4	5	0	0	1.0			0			57		
W	65		53	42	0	0	0	0	22	1.0			0			53		
W	65		49	40	0	0	0	1	22	1.0			0			49		
W	65		45	38	0	0	0	1	45	1.0			0			45		
W	65		43	38	0	0	0	1	67	1.0			0			43		
W	65		41	37	0	0	0	2	90	1.0			0			41		
W	65		39	36	0	0	0	2	112	1.0			0			39		

OURLY TEMPERATURES

(Degrees F)

	HOUSE									SUNSPACE					ROCKBED		
H	THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
1	65			63	59												
2	65			63	58												
3	65			62	57												
4	65			62	57												
5	65			61	56												
6	65			61	55												
7	65			61	55												
8	65			61	55												
9	65			60	54												
0	65			60	55												
1	65			60	55												
2	65			61	56												
3	66			61	57												
4	66			62	58												
5	67			63	59												
6	67			63	60												
7	66			63	61												
8	65			63	61												
9	65			63	61												
0	65			63	60												
1	65			63	59												
2	65			63	59												
3	65			62	58												
4	65			62	58												

```
Line
---- -------------------------------------------------------------------------
     TITLE  SIMPLEHOUSE (MUD CONSTRUCTION)
     HOUT   2.5
     *HOUSE  FLRAREA=100     VOL=1000
     ROOF   AREA=100     TILT=0     UVAL=.11    ABSRP=.2  INSIDE=AIR
     WALL   NAME=N       AREA=99    AZM=180     ABSRP=.4  UVAL=.128
     WALL   NAME=S       AREA=89    AZM=0       ABSRP=.4  UVAL=.128
     WALL   NAME=E       AREA=100   AZM=-90     ABSRP=.4  UVAL=.128
     WALL   NAME=W       AREA=100   AZM=90      ABSRP=.4  UVAL=.128
     SLAB  AREA=100   *THKNS=4.5   MATERIAL=CONC120   HTAHS=2  RSURF=0 &
     UDB=.5
     GLASS  NAME=S       AREA=10    AZM=0     NGLZ=2
     INTGAIN  INTGAIN=0
     VENT *TYPE=NATURAL  AINLET=1  AOUTLET=1   HDIFF=6.7  STACKEFF=1 &
     AZMINLET=0  DDEFF=1
     TSTATSWNTR  THEAT=65  TDSRD=68   TCOOL=85
     TSTATSSMR   THEAT=65  TDSRD=85   TCOOL=86
     CHNGSEASON *TYPE=TEMP   TEMP=85
     PRINTHOURLY *FIRSTDAY=JUN-10   LASTDAY=JUN-10
     PRINTHOURLY *FIRSTDAY=JAN-01   LASTDAY=JAN-01
     END

 *** No input errors.

 *** Beginning simulation    03-JUN-87    22:55:22

 *** Run complete.
```

```
ine
---  -----------------------------------------------------------------
     TITLE CONSTRUCTION 3
     HOUT 2.5
     *HOUSE FLRAREA=100  VOL=1000
     ROOF AREA=100  TILT=0   UVAL=.27  ABSRP=.3  INSIDE=AIR
     WALL NAME=NORTH  AREA=100  AZM=180  ABSRP=.3  UVAL=.22
     WALL NAME=SOUTH  AREA=90   AZM=0    ABSRP=.3  UVAL=.22
     WALL NAME=EAST   AREA=100  AZM=-90  ABSRP=.3  UVAL=.22
     WALL NAME=WEST   AREA=100  AZM=90   ABSRP=.3  UVAL=.22
     SLAB *AREA=100   *THKNS=1.5  *MATERIAL=CONC80  HTAHS=1.5  RSURF=0 &
     UDB=.147
     GLASS NAME=SOUTH  AREA=10  AZM=0  NGLZ=2
     INTGAIN  INTGAIN=0
     VENT  *TYPE=NONE
     TSTATSWNTR   THEAT=0    TDSRD=68  TCOOL=150
     TSTATSSMR    THEAT=0    TDSRD=85  TCOOL=150
     PRINTHOURLY  *FIRSTDAY=JUL-17   LASTDAY=JUL-17
     END

  *** No input errors.

  *** Beginning simulation    26-AUG-89    02:08:36
use energy imbalance for JUL Net=0.027 kBtu (0.0031)

  *** Run complete.
```

HOURLY TEMPERATURES

(Degrees F

	HOUSE									SUNSPACE					ROCKBED		
H	THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
1	100			100	100												
2	99			99	99												
3	98			98	98												
4	97			97	97												
5	97			97	96												
6	96			96	95												
7	95			95	95												
8	95			95	95												
9	96			95	95												
10	97			96	96												
11	98			97	97												
12	100.			99	98												
13	101			100	99												
14	103			101	101												
15	104			103	102												
16	105			104	104												
17	106			105	105												
8	107			106	105												
9	106			106	106												
0	106			105	105												
1	105			105	104												
2	104			104	104												
3	103			103	103												
4	102			102	102												

Weather: PHOENIX.AZ (Phoenix AZ TMY)

OURLY CONDITIONS

(Various units)

				WEATHER DATA							CNTRLS	FLOWS					SUPPLY TMPS		
H	S	THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
1	S	100		91	69	0	0	0	2	90	0								
2	S	99		90	69	0	0	0	2	90	0								
3	S	98		89	69	0	0	0	3	112	0								
4	S	97		88	69	0	0	0	3	112	0								
~~5~~	~~S~~	~~97~~		~~87~~	~~69~~	~~0~~	~~0~~	~~0~~	~~3~~	~~112~~	~~0~~								
6	S	96		86	69	2	1	1	3	112	0								
7	S	95		88	70	20	21	25	3	112	0								
8	S	95		89	70	108	46	88	3	135	0								
9	S	96		91	71	200	35	151	2	135	0								
10	S	97		93	71	216	49	209	3	135	0								
11	S	98		96	71	230	53	252	3	135	0								
12	S	100.		98	71	244	53	284	3	112	0								
3	S	101		100	71	266	47	306	2	135	0								
4	S	103		101	71	280	46	312	2	135	0								
5	S	104		103	71	276	46	288	1	135	0								
6	S	105		103	71	260	34	230	2	180	0								
7	S	106		104	71	210	37	162	2	225	0								
8	S	107		104	72	104	51	94	2	270	0								
9	S	106		101	72	26	26	31	3	225	0								
0	S	106		99	72	6	2	2	3	180	0								
1	S	105		96	72	0	0	0	4	135	0								
2	S	104		94	71	0	0	0	3	135	0								
3	S	103		93	71	0	0	0	3	112	0								
4	S	102		91	70	0	0	0	2	112	0								

Weather: PHOENIX.AZ (Phoenix AZ TMY

HOURLY HOUSE ENERGY BALANCE (kBtu; + into house

D	H	THS	GAINS & LOSSES TCOND	INFIL	SLR	INT	STORAGE AIR	MW	SLB	IW	XW	RBSLB	TRANSFERS RB+SS	MECH	M
	1	100	-1.25	-0.13	0	0	1.10		0.21					0	-
	2	99	-1.25	-0.13	0	0	1.10		0.21					0	-
	3	98	-1.26	-0.13	0	0	1.10		0.22					0	-
	4	97	-1.26	-0.13	0	0	1.11		0.22					0	-
	5	97	-1.27	-0.13	0	0	1.11		0.22					0	-
	6	96	-1.26	-0.13	0.00	0	1.10		0.22					0	-
	7	95	-0.67	-0.10	0.09	0	0.50		0.13					0	-
	8	95	0.08	-0.09	0.23	0	-0.26		0.03					0	-
	9	96	0.63	-0.07	0.23	0	-0.71		-0.06					0	-
	10	97	1.05	-0.05	0.34	0	-1.13		-0.15					0	-
	11	98	1.43	-0.03	0.45	0	-1.53		-0.24					0	-
	12	100.	1.55	-0.02	0.55	0	-1.69		-0.29					0	-
	13	101	1.58	-0.02	0.59	0	-1.74		-0.32					0	-
	14	103	1.66	-0.02	0.57	0	-1.78		-0.33					0	-
	15	104	1.74	-0.02	0.47	0	-1.75		-0.34					0	-
	16	105	1.35	-0.03	0.30	0	-1.26		-0.28					0	-
	17	106	1.07	-0.03	0.25	0	-0.98		-0.24					0	-
	18	107	0.60	-0.04	0.25	0	-0.59		-0.18					0	-
	19	106	-0.37	-0.07	0.12	0	0.35		-0.03					0	-
	20	106	-0.85	-0.09	0.01	0	0.83		0.08					0	-
	21	105	-1.17	-0.12	0	0	1.08		0.17					0	-
	22	104	-1.31	-0.13	0	0	1.17		0.21					0	-
	23	103	-1.31	-0.13	0	0	1.16		0.22					0	-
	24	102	-1.43	-0.14	0	0	1.26		0.24					0	-

O N T H L Y   H O U S E   E N E R G Y   B A L A N C E   (kBtu; + into house)

	GAINS & LOSSES						TRANSFERS			
	COND	SHCND	INFIL	SLR	INT	STRG	RB+SS	VENT	COOL	HEAT
	-1.902		-1.978	4.454	0	-0.55			0	0
	-1.902		-1.978	4.454	0	-0.55			0	0

O N T H L Y   C O N D I T I O N S   (Units as shown)

	TEMPERATURES (F)						WTHR (F; Btu/sf)				PEAKS (kBtuh)			
	THL	THH	THM	TSL	TSH	TSM	DBL	DBH	DBM	SGL	HSCL/DY	HSHT/DY	SSCL/DY	SSHT/DY
	95	107	101				86	104	95	2436	0	0		
	95	107	101				86	104	95	2436	0	0		

Weather: PHOENIX.AZ (Phoenix AZ TMY)

UMMARY Run period: JUL-17 - JUL-17 Conditioned floor area: 100 sf

PACE CONDITIONING LOADS	Run totals		Peaks
	kBtu	kBtu/sf	kBtuh
House			
Cooling	0	0	
Heating	0	0	

ERGY CONSUMPTION	Run totals			Peaks
	kWh; kBtu	Prop line kBtu/sf	Source kBtu/sf	kW; kBtuh
Electricity				
House cooling	0	0	0	
Total	0	0	0	
Fuel				
House heating	0	0	0	
Building total		0	0	