The Architectural Implications of Passive Solar Cooling Systems in Hot-Arid Climates

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ABSTRACT :

Residential architectural design should fulfill both the comfort and the social requirements of the occupants. Khartoum, the capital of the Sudan was chosen for this study because of two reasons; The first is its unusually hot-arid climate (thus cooling interior spaces becomes a crucial design consideration). and the second is its multi-dimensional urban identity. The city is a mixture of African, Arab, and European influences and resembles at the same time an oasis in the middle of the desert. The research follows two distinct but closely related paths. The first is the study and analysis of the passive and hybrid cooling systems and strategies under which the climatic conditions of Khartoum determines the type and size of each approach. The second stage of the research will focus on the architectural implications of these systems. Both directions lead to better understanding of the built environment and its interactions with man.

Two moves were taken into account, when considering the cooling potentials in this climate. First, the solar control strategies which were found to be most appropriate in Khartoum climatic conditions. These include the use of eggcrate shading devices on all openings except for southern exposures which can be shaded effectively by vertical fins to reduce the solar transmission through glazed surfaces. The study showed also that reducing the glazed area reduces the total heat gain but this affects negatively both daylighting and the freedom of design to incorporate the exterior spaces. This can be solved by using the Low-E glass which has better thermal properties in terms of reducing both solar transmission and heat conduction. The results of the study showed that using single Light-Green Low-E glass allows one and half times larger glass area with the same amount of heat gain. For the same area, the Double Low-E glass can reduce heat gain form these surfaces by a factor of two. Economically, their use is hard to justify because of their projected high prices as compared to the DS single-pane clear glass. Another effective way of controlling the heat gain through buildingskin is to use thermal insulation on the walls and roof. Roof insulation which is commonly specified in Khartoum was found to be thermally satisfactory and additional insulation will not reduce heat gain appreciably since the roof share is already reduced with basic insulation. The wall insulation strategy proved to be economically feasible and does not require skilled labor to install or to maintain since it is protected from the weather. Landscaping is another move that will improve the environmental quality through shading and evaporatively cooling the surrounding spaces and at the same time add to the visual quality of the space, but it is not cost effective.

The second move was to promote heat losses through ventilation, convection, radiation, and evaporation. Because of the environmental condition of Khartoum, the first three moves are restricted to certain parts of the day or the year. Nevertheless, combination of either one with evaporative cooling increases the thermal comfort. The desert-type evaporative coolers reduce the indoor temperature and increase the relative humidity which is required in the dry periods of the year. Two-stage coolers which combines both evaporative (adiabatic) and sensible cooling concepts increases the rate of heat removal and thus reduces obtained indoor temperature. The air scoops or wind catchers are convective and evaporative cooling systems that admit high winds at high elevations to be circulated inside living spaces for ventilation. This air can be further cooled be passing the air stream over wet Clay jars or through wetted pads. Although they represent a reasonable alternative for mechanical evaporative coolers, these systems suffer from their limited applications in terms of air circulation and small rate of heat transfer.

In this thesis, a new air scoop is developed to overcome the above mentioned limitations. Basically, it is a combination of an air scoop and a chimney. This configuration generates suction pressure at the tower head because of the wind acceleration at a nozzle. When there is no wind, the tower acts as a solar chimney that creates a stack effect between the inlet stack (air scoop) and the the outlet vent. The advantages of this system is summarized in the following : First, the suction pressure is more effective than positive pressure in dragging the air between the two stacks. Also this system performs in the absence of any wind which detracts from the performance of other conventional air scoops. Because of the specific relation between inlet and outlet stacks, the higher the height difference the better. This means that an inlet air scoops as low as the window sill level gives better result. This in fact may lead to the use of small inlet scoops opening to the windward side and a central chimney to exhaust the hot room air and replace it with fresh outdoor air. Such configuration facilitates a better and controlled indoor air circulation without the need to use windows for natural ventilation. Economic analysis examining a number of scenarios that include the air scoop/ chimney scheme with other strategies such as wall insulation and Light-Green Low-E glazing has shown the tradeoffs between improving the indoor thermal comfort and the payback period or the economic feasibility of each of these scenarios.

Finally, architectural designs were proposed to show how some of the systems discussed in this study will be expressed architecturally and to what extend the regional identity can express itself through addressing the environmental aspects of the area.

Thesis Supervisor: Timothy Johnson
Title: Principal Research Associate

To my parents and Laiz

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When the words are gathered to express my gratitude to my thesis advisor Timothy Johnson, I find it extremely difficult to list in a single paragraph or even the whole page, the help and encouragement I got from him throughout the two years I spent at M.I.T. His enthusiasm and interest in my work made this thesis a reality even beyond my wildest dreams.

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A. M. K.

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CHAPTER ONE

INTRODUCTION

1.1 THE ISSUE :

Man and environment have always affected each other. The human race survived only because it has adapted to and shaped the environment. Looking for a shelter meant seeking protection against the weather extremes, rain, sun, and cold. Throughout history, house design has evolved to satisfy the needs of its occupants. Thermal comfort was one of the main issues tackled by builders through the trial-and-error process. Traditional architecture has come up with forms and designs that are responsive to the climatic, social, technological, economical, and even the political structure of these societies.

Building materials have also developed in this course of progress. New building materials promise to make architecture to perform up to present day aspirations. Nevertheless, for a long time modern architecture has neglected environmental design criteria since technology facilitates the creation of artificial indoor environments. The energy conservation criteria we inherited from the 70's have no longer become crucial design criteria since the oil prices have dropped dramatically in this decade. Thermal comfort on the other hand, has never lost its importance. Architecture seems to move along two different paths; the first is to revive indigenous solutions, and the second is to discover potential solutions that may be generated through applying new building materials.

In this thesis, both approaches are combined to maintain the balance between modernization and preservation without sacrificing regional or national identity. In section 1.5, the research methodology covers the issues of accommodating the local elements of design with the functional morphology of urbanism.

1.2 THE REGION :

The world's Arid region covers a large part of the subtropical areas of Africa, Central and Western Asia, North-Western and Southern America, and Central and Western Australia (Fig.1.1). This area is characterized by high diurnal temperature range, low relative humidity, cloudless skies, and frequent haze and dust storms. In Africa aridity is caused by the trade winds blowing south-west and north-west towards the equator[1]. The wind loses most of its water vapor content by passing over the vast land of the African continent.

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[1] Givoni, B. "*Man, Climate and Architecture*". Van Nostrand Reinhold. New York, 1981.,

For thermal comfort, buildings in these areas should be designed to satisfy different summer conditions. Psychologically, thermal comfort requirements in winter will be satisfied when summer conditions are taken into account. Solar *rejective* forms, thick adobe walls, small openings, domed and flat roofs, became part of the indigenous architecture of these regions. Compact urban layouts, narrow alleys, internal courtyards, and different life patterns are examples of the social interaction manifestation dedicated by the climate (photographs 1 and 2)[2].

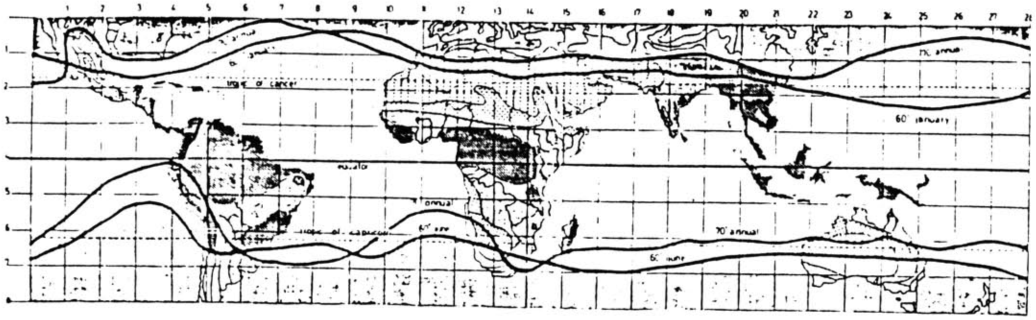

Fig. 1.1. Climatic Regions.

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[2] Norberg-Schulz, Christian. "*Genius Loci, Towards a Phenomenology of Architecture*". Rizzoli International Publications, Inc., New York, 1980, pp. 125-126.

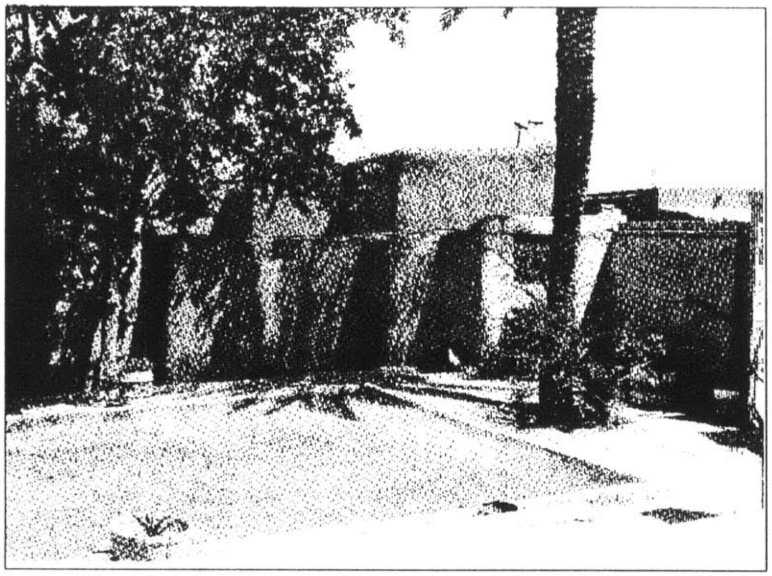

Photo. 1. Front Yard.
(Source : Norberg, ref. 2).

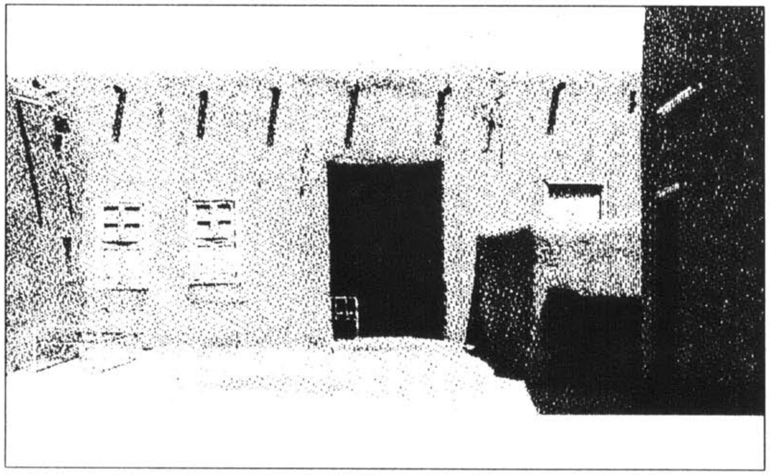

Photo. 2. Backyard of a house in Omdurman.
(Source : Norberg, ref. 2).

1.3 THE CITY :

Khartoum is a unique mixture of African, Arab, and European influences. It is in fact a conurbation formed by the *Three Towns* (Khartoum, Khartoum North, and Omdurman). They differ in their historical background, social structure, political influence, and the formal spatial organization of their urban fabric and architectural phenomenology. Sharing almost all the characteristics of the Hot-Arid regions, Khartoum is distinguished by its location in the apex of the peninsula formed by the Blue and the White Niles, (Fig.1.2 and 1.3). The urban mosaic as described by Norberg[3] :

> *"Two basic types of urban structure are found in the three towns : the labyrinthine world of the desert settlement, and the geometrical pattern of "Baroque" derivation which symbolizes a general ideological system. Of these, the labyrinthine pattern represents the original, vernacular solution". "The labyrinthine parts of the Three Towns were generated by a gradual clustering of units, leaving the streets as secondary "intervals". This approach to urban "design" is still used in the squatter settlements along the periphery, which thus repeat the constitu-*

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[3] Ibid pp. 118.

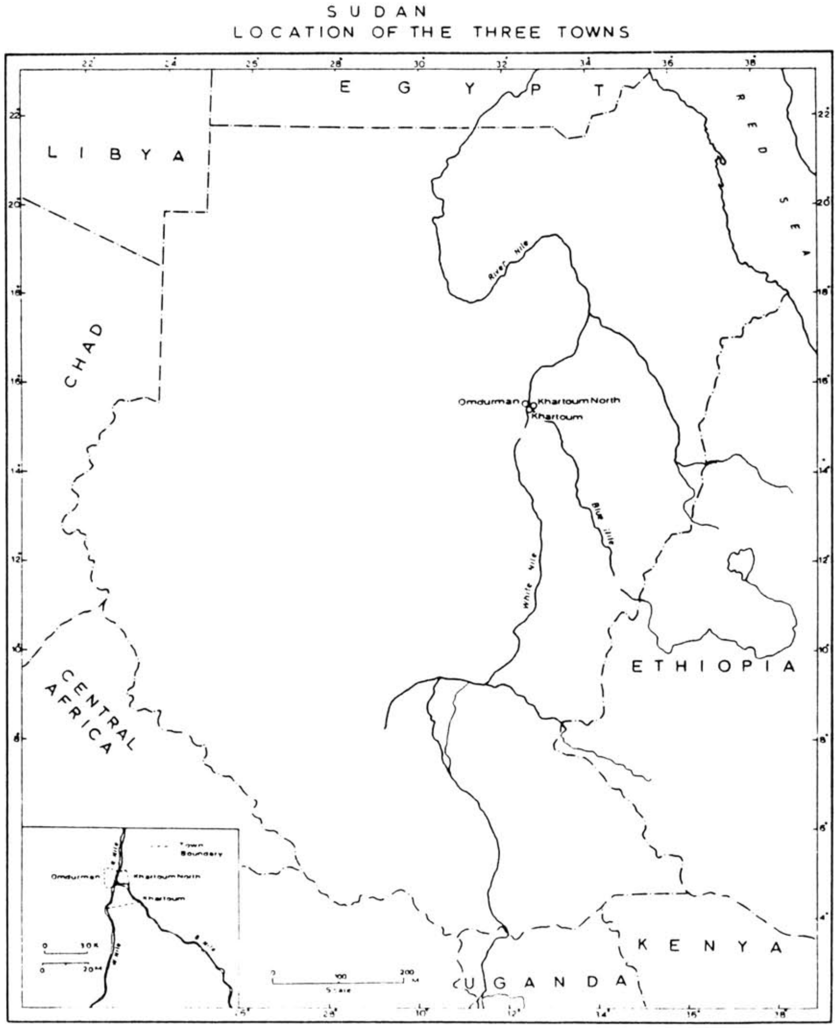

Fig. 1.2. Map of Sudan.

> *ent principle of Arabic towns. The spaces formed in this way have an eminently human quality, changing shape and size according to the needs. Only in the new city-extensions north of Omdurman and south of Khartoum, carried out after the second world war according to the master-plan by Doxiadis, the street is taken as the point of departure, where the urban spaces lose their traditional quality.*

Taking the external environmental conditions into account when designing the building envelope is not a new trend or a fashion, but a necessary endeavor to meet the psychological and physiological comfort requirements. This research explores new approaches to the climatic responsive architecture in the context of the sub-saharan Hot-Arid Sudan and utilizes the new terminology brought by new glazing.

1.4 THE SCOPE :

This thesis deals primarily with the architectural implications of Passive Cooling Systems in Hot-Arid Climates. Its scope covers the performance of different *classic* individual urban house designs and building materials. It also covers the applications of some passive/ active cooling systems as well as the utilization of the new energy conserving materials such as the the different types of Low-E glazing and thermal insulation in terms of the effect on the reduction of cooling loads within the building envelope. The study deals with the individual-

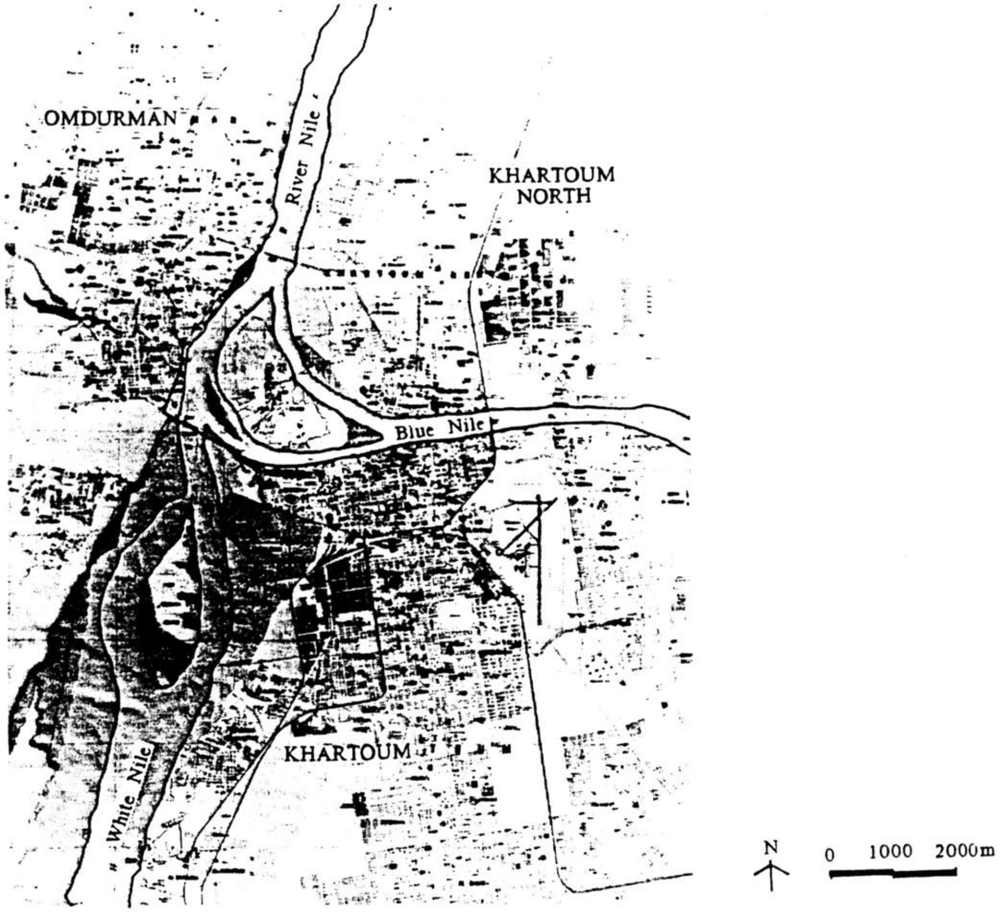

Fig. 1.3. Khartoum Conurbation.

house scale which overweighs other building types both in size and energy consumption in Khartoum, (Fig.1.4). The aim is to outline an environmental responsive architecture using new and classic materials in innovative ways to satisfy the requirements of modern society in arid climates. Providing thermal comfort through natural environmental control techniques will add another dimension to the role of architects and architecture. In terms of reducing the energy consumption in the residential sector, the *country* (Sudan) will be able to re-allocate its energy resources for the productive sectors. For the *users* of the proposed cooling systems, the motivation for using these ideas will be : 1) reduction of the energy bill with minimum initial cost (economical) and, 2) obtaining thermal comfort (physiological and psychological) through more reliable sources (eliminate risk of power-cuts). *Architects* represent the third party which will be affected by this climatic-design impact. They will have more opportunities for dealing with new architectural terminology introduced in this thesis and better understanding of new building materials such as Low-E glazing and the development of conventional cooling techniques such as the Air Scoop-Solar Chimney Scheme proposed in chapter five.

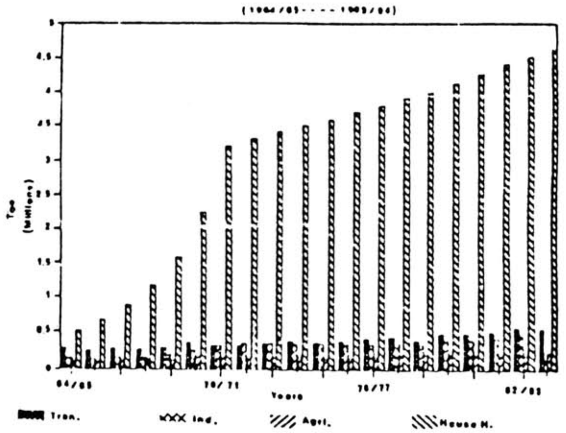

Fig. 1.4. Energy Consumption by Sector in Sudan. (Source : NEA "Sudan Energy Handbook" Ministry of Energy and Mining, Khartoum, 1981).

1.5 RESEARCH METHODOLOGY :

It is the interest of the author in this thesis to stress the research methodology that enables architects in the Hot-Arid climates to manipulate the various climatic elements in the early stages of the design process. Environmental design concepts provide a systematic approach towards solving the architectural design problem-solving process with the comprehension of the urban context, social needs, psychological and physiological comfort. Nevertheless, these efforts should not stop at this level, but also should be manifested and dealt with as aesthetic elements that add to the richness of design and at the same time satisfy the functional, structural, and physical requirements of a building.

The research is structured as follows : Environmental problems will be discussed first, then a number of cooling techniques will be suggested. These techniques will be analyzed in order to see which is appropriate to the Sudan and how it may affect the architecture or the occupants' life patterns. The research will cover both traditional and modern cooling strategies and study different possibilities of combining both approaches. Low-E glass is a new building material which will be considered in the thermal analysis of a typical house in Khartoum to investigate its impact on cooling loads and how it affects the facade design. Improving thermal properties of building elements such as roofs and walls will also be studied to improve the thermal performance of existing buildings. The effect of these movements will further be persuaded to determine both the physical and social implications of passive and hybrid cooling systems on the built form.

1.6 THESIS PREMISES:

The thesis is divided into two parts. The first part is concerned with studying and analyzing different cooling techniques (passive and hybrid) under Khartoum's climatic conditions. The second part is devoted to the architectural implications of these systems.

The first part is structured as follows : In the first chapter, the environmental problems in Khartoum will be identified within the regional integrity of its urban context. Then different cooling strategies that are most applicable in Khartoum in terms of thermal performance and economical feasibility are outlined. The second chapter deals with environmental responsive design criteria. This chapter is based on understanding the indigenous solutions and how traditional building forms, materials, and social behavior have responded to the climate. Chapter Three concentrates on the transformation of the climatic data and other design tools and shows how these guidelines can be transferred to physical design requirements. In the fourth chapter, cooling load minimization strategies will be discussed as to what extent they affect the thermal behavior of a typical house in Khartoum. The effect of adding thermal insulation on walls and roof, using cavity walls, building orientation and form, different types of Low-E glazing, and changing window areas will be compared to the thermal performance of the typical house with DS clear single-pane glass and common construction techniques. Other climatic control strategies such as exterior shading devices and landscaping will also be analyzed. Chapter Five is mainly devoted to analyzing passive and hybrid cooling systems that are most appropriate to Khartoum. Convective, radiative, and evaporative cooling systems will be discussed on a theoretical basis, followed by an analysis of the most promising ones for the hot-arid climate of Khartoum. These were found to be the evaporative cooling systems (passive and hybrid) such as roof ponds, roof sprinklers and evaporative air coolers will be analyzed under the climatic conditions of Khartoum. Traditional and newly developed air scoops (convective and evaporative) will be analyzed in terms of their thermal performance and wind catching characteristics. A new air scoop configuration will be introduced as a combination of an inlet air scoop and a suction stack which acts at the time as a solar chimney. Comparison between this cooling system and conventional air scoops and evaporative air coolers will be made.

In the second part, Chapter Six will deal with the architectural implications of cooling systems as design elements that affect the architectural expression (physical) and occupants' interactions with buildings (social). However, the architectural quality is a function of the architects integrity and technical knowledge. In this chapter, an example of how some of the analyzed cooling systems can be formulated in architectural form without sacrificing the intended architectural expression is given.

Finally, the conclusions and design guidelines will be presented in the form of a message to the architects proposing a check list of some environmental design criteria that have to be considered in the early design stages. Hence, designers are given the chance to explore new forms which are coherent with nature. Understanding the economic tradeoffs associated with the thermal benefits of different cooling strategies adds another dimension to the assessment of each system proposed.

1.7 IDENTIFICATION OF THE PROBLEM :

According to existing housing standards, a number of problems can be identified. One is the problem of high thermal loads within the building envelope which is due to insufficient thermal insulation on the house perimeter and poor thermal performance of the single-pane DS clear glass used in Sudan. In addition, letting in more heat raises the inner surface temperature and thus increases the radiational heat transfer to the occupants. The other problem is the high cost of provision, installation, and operation of conventional air conditioning systems available in the country.

1.7.1 Symptoms of the Problem :

The symptoms of the environmental problems are related to the following :

A. Roofs :

Roofs usually do not receive careful thermal consideration in building designs mainly because of their high cost (41%[4] of total cost on average)[5]

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[4] This percentage is for a single-storey building, for two and three storeys the percentage is 17% and 14% respectively.

[5] Mukhtar, Y. A. “Roofs in Hot Dry Climates, with Special Reference to Northern Sudan". Building in Hot Climates. Overseas Division of the Building Reasearch Establishment. London, 1980, pp.411

- Roofs generally receive about 31-58% of annual solar radiation (Fig.1.5).

High sol-air temperature which is the combined effect of solar and ambient outdoor temperatures can reach 82° C (180° F) on a bare concrete roof slab in June, can cause softening of the insulation material which usually cracks and rapidly deteriorates. As the result of a high diurnal temperature difference of 14.4° C (58° F)[6], almost all of the roof materials are subjected to considerable thermal movements which also cause cracks and consequently the deterioration of the building materials.

B. Walls :

As seen from figure 1.5, the wall facing east receives almost the same amount of solar radiation in summer (June) as the roof. This should draw our attention to the fact that although the roof represents a major element in the heat gain, the total gain through all the walls outnumbers the effect of the roof. Since the walls represent another interface between the inside and the outside, their consideration as a major source of trouble has to take place in the early design stages. In addition, the walls are not solid surfaces enclosing a completely protected interior. In fact the openings (fenestrations, and access points) are likely to weaken

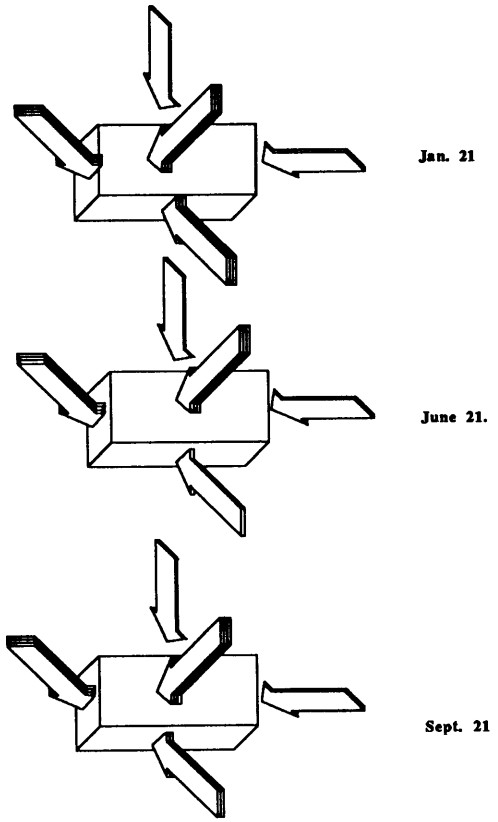

Fig. 1.5. Solar Intensities Recieved on the roof and walls. (Source : Stien. et. al. "Mechanical and Electrical Equipments for Buildings". 7th. ed. Wiley and Sons, New York, 1986

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[6] Meteorological Station- Khartoum.

the wall's prospective function of protection against the harsh outside conditions.

The exterior walls experience a change in temperature in day-and-night cycles. This variation depends primarily on the color, texture, and the orientation of the surface. Only part of the heat that is absorbed in the external surfaces reaches the internal spaces[7]. The remainder goes into raising the surface temperature of the external wall and thus increase the temperature differential between the two surfaces of the wall. This also increases the amount of heat flowing through the skin fabric.

At night, the outer surface loses part of the stored heat gradually to the outside air through convection , and radiation (nocturnal radiation), to the clear sky, the other part is being conducted to the interior spaces. This loss rate depends also on the heat capacity of the wall which is a factor of the density and the specific heat of the material . The lesser the density of the wall material, the faster it loses the heat and vice versa. Thus, we can say that this thermal inertia moderates the flow of heat through the building skin and at the same time, delays the timing for heating and cooling periods in in the thermal cycles (time lag).

This time lag can only be utilized if the mean temperature is in the comfort zone. When the daily mean is above the mentioned conditions (which is

[7] Givoni op. cit. pp. 132.

normal during the hot summer nights of Khartoum), this time lag will increase the indoor air temperature which is already high and add to the psychological discomfort by radiation to the occupants and the internal masses.

C. Windows :

Windows in Khartoum are usually single-pane 1/8" clear glazing (DS Glass) with timber, steel, or aluminum frames. In response to modern architecture movements, architects tend to use the glass and fenestrations as design elements, which provide more opportunities in dealing with the facade treatment. Large areas of glazed surfaces generate extensive heat loads through solar transmission and conduction (which represents a considerable portion of the heat flow through the DS glass due to the large temperature differential between the two sides of the glass). Although shading devices can reduce the amount of heat flow appreciably, providing sufficient shading has always been a major design burden because no other function can justify the provision of projected horizontal canopies or vertical fins in the east and west sides of a building. Having a window is not only a thermal problem, but also an inlet through which dust and insects can get into the interior spaces. The solution is not simply the design decision of decreasing the window areas, because the transparent nature of the glass provides the advantageous visual link between the inside and the outside without the physical contact. Another important factor is the daylighting which is pleasant to possess, control, and play with in the interior design. Such a trade-off always results in larger glazing areas and consequently the use of air coolers/ conditioners units to maintain the required indoor conditions.

D. Thermal Comfort :

Thermal comfort is defined as[8] "that condition of mind which expresses satisfaction with the thermal environment". There are several factors of which different combinations and permutations can provide the psychological feeling of comfort :

(A) Uncontrolable Factors :

activity level,
thermal resistance of clothing,
air temperature,

(B) Controllable Factors :

mean radiant temperature,
relative air velocity, and
water vapor pressure in the ambient air.

As far as the building design is concerned, the last three factors can

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[8] Fanger, P O. "Thermal comfort". McGraw Hill book Co., New York, 1970, pp. 15.

be controlled through different mechanical and natural cooling processes. Among these, the selection of materials, orientation, shading devices, detailing, and low exterior surfaces to living volume ratios can be utilized whenever the design conditions permit.

Human skin is exceptionally sensitive to far infra-red radiation. Its absorptivity ratio is approximately .99 (the highest in existence)[9] · High boundary wall interior surface temperatures are generally translated into discomfort as the surfaces radiate to the body. This forces the occupants to open the windows (in case of shedding or power distribution failure), which brings in even more cooling load as hot outdoor air flows inside the building envelope and consequently raises the degree of discomfort. The remedy of this exogenous problem can be fully diagnosed when the weak points or areas of the building can be identified.

1.7.2 The Strategies :

Heat gain can be reduced through numerous ways which affect both the selection of construction materials and the awareness of the occupants. Ideally, the energy conservation or the minimization of the cooling loads should be decided upon at the very beginning of the design process (Fig.1.6)[10], rather than solving

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[9] Hall, E. T. "Architectural Implications of the Thermal Qualities of Human Skin". Ekistics No. 198, May 1972. pp. 352-354.

[10] Watson and Labs. "Climatic Design". McGraw Hill Book Co., New York, 1983, pp. 33.

CONTROL STRATEGIES

SUMMER

	CONDUCTION	CONVECTION	RADIATION	EVAPORATION
RESIST GAIN	Minimize Conductive Heat Flow	Minimize infiltration	Minimize Solar Gain	
PROMOTE LOSS	Promote Earth Cooling	Promote Ventilation	Promote Radiant Cooling	Promote Evaporative Cooling
HEAT SOURCES		Atmosphere	Sun	
HEAT SINKS	Atmosphere	Earth	Sky	Atmosphere

Fig. 1.6. Identification of hypothetical andPractical Cooling Strategies for Climate Control. (Source : Watson and Labs. Ref. 10)

those problems after the design reaches a stage beyond which major alterations are either very difficult or unfeasible. Among the several strategies that can be used as a primary design check list[11], only the four major ones are going to be discussed in this section :

a) Reduction of thermal loads through major building elements; walls, floor, and roof.
b) Reduction of direct solar gains through windows by using external or internal shading devices and/ or selection of glass types which have better thermal properties.
c) Reduction of loads caused by infiltration.
d) Reduction of negative effects of ventilation on the overall thermal performance of the building envelope.

Each of these elements will be discussed separately in terms of its impact on heat gain based upon the predefined measures of thermal comfort standards.

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[11] Dubin, F S. "Energy Conservation Standards, for Building Design and Construction". McGraw Hill Book Co., New York, 1978, pp. 161.

(A) Roofs :

Generally, the roof receives more energy during summer than in the winter (Fig.1.5), because of the sun's low incidence angle in the winter. The roof suffers most because it is subjected to the highest temperature fluctuations. During daytime, its temperature is raised high above the ambient temperature, depending on the absorptivity (color) and emissivity of the exposed surface of the roof. At night, the surface cools down because of the effect of nocturnal radiation to the atmosphere. Again, this process depends on the selective characteristics of the roof surface.

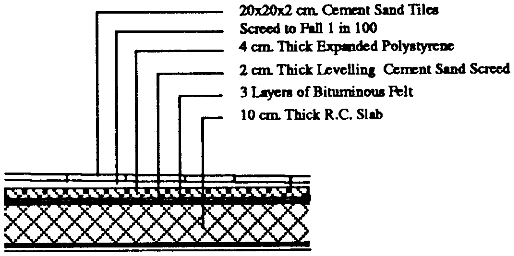

Fig. 1.7. Conventional Roof Construction Detail Specifications.

Load Reduction:

Since the roof receives more energy than any other individual surface of the building, it is, necessary to use a thermal insulation membrane, especially in a low-rise building or any building which has a high roof to floor ratio. In addition, reducing the absorption coefficient of the roof will add to the energy saving by decreasing the heat flow through the roof fabric.

Utilization of light-colored paints and reflective roof finishes must be taken into account when applied to an existing roof in order to avoid wearing out the roof materials and to ensure a reasonable durability. Other materials can be added to increase the solar reflectance of the roof, e.g. gravel, white pebbles, white wash, and light colored tiles, without contradicting the structural requirements (increasing the dead loads). Rain water must be drained when using gravels or pebbles to prevent stagnant water from accumulating in the middle of the roof. Another way of decreasing the transmittance of heat energy through the roof, is to spray water on the roof (discussed in details in Chapter Five). These suggestions though appropriate form the thermal point of view, might prevent occupants from using an accessible roof, especially in low-rise residential buildings, (this is not true when using light-colored tiles as roof finish)[12].

(B) Walls :

Since exterior walls also receive a significant amount of solar radiation, certain measures have to be taken into account when designing the building envelope.

Chapter one

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[12] Sharag-Eldin, A. "Total Building Performance". A paper represented for a class at M.I.T. Fall 1987. (Unpublished).

Load Reduction:

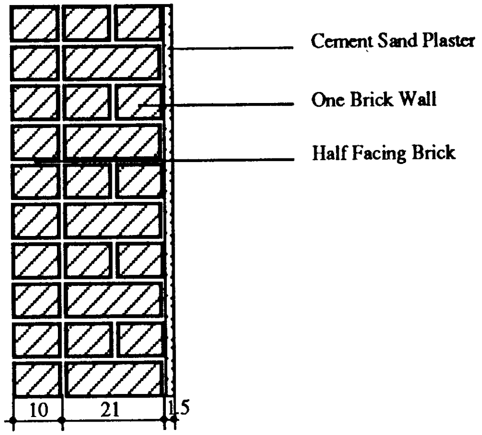

Fig. 1.8. Conventional Wall Construction.

Heat gain is dictated primarily by the orientation, location, wind velocity, and absorption coefficient of the wall surface. The wall insulation is again a major means of decreasing the cooling loads as it decreases the heat flow through the building skin. Lower U-values for the walls doe the same and also increase the time lag. Light colors are preferred for the same reasons, but for practical purposes, a wall of a very low absorption coefficient (high reflectivity) is not recommended because it creates glare (visual discomfort). Also, white surfaces lose their reflectivity coefficient faster (dirt, smoke, and rain). This decreases the surface temperature and consequently the temperature differential between the outdoor and indoor surfaces. High thermal mass retards the heat flow and reduces the heat gain. For areas with long cooling seasons, a sufficient time lag has to be determined according to the activity of the occupants, their number, the time of the day, and duration of the work or activity, and the special thermal requirements of the space.

(C) Floors :

Floors are not as exposed to the outside as the other surfaces of the building envelope. They can either be on the ground (slab-on-grade floor), or above a basement which is usually left thermally uncontrolled (lower temperature of the soil temperature). In both cases, heat flow through floors has to be tackled in a slightly different way.

Load Reduction:

Floors usually do not need insulation against heat gain, especially when the indoor air temperature is kept at 29.4° C (85° F) because the temperature difference yields to zero when the soil temperature is equal to 29.4° C (85° F). If the temperature of the soil goes above that, heat will be expected to flow through one of the two following ways. The first will be through the floor slab directly to the ground or to the basement . The second way is through the perimeter of the floor and foundation. In all cases, insulating the edge of the slab will be sufficient since the flow in both cases occur in this area.

(D) Windows :

Windows are usually the weakest points of the building envelope in terms of thermal behavior. Their U-values are higher than those of the rest of the uninsulated walls, therefore special precautions have to be taken in order to avoid overloading of the cooling system required for the space. The thermal characteristics of the window depend on the area of glazing, type (single or double, fixed or operable), orientation, geographic location of the building, type of shading devices (attached to or associated with), glass thermal properties (shading coefficient emissivity, absorptivity, and thermal transmittance), precision of construction, and the level and quality of maintenance.

Load Reduction :

Replacing single glazing with double glazing to reduce conduction heat gain through the window is less likely because of the relatively small portion that conduction shares in the overall heat gain through the window. Heat gain through a window is mainly a factor of direct and diffused radiation striking the glass surface. Therefore, the remedy should concentrate on either protecting the glass surface from the sun and/ or minimize the amount of energy gained through the window.

The first strategy is based upon the use of shading devices. These can be either external, e.g. horizontal eye-brows or vertical fins, located on the southern/ northern exposures and east/ west sides respectively. The horizontal shading devices can be supplemented with vertical fins to protect the window from late-day sun rays (the energy of the sun does not create uncomfortable conditions in early morning). Movable vertical fins are preferred, because it is impossible to protect against the sun throughout the year with the same position of the fins. Horizontal shading devices are usually designed to block the high angle of the sun in the summer and allow it to enter in the winter. This practice usually causes winter time overheating of the interior spaces. Although interior shading devices are cheaper than the exterior (horizontal canopies and vertical fins), the latter works more efficiently in terms of the climatic controls.

As a second alternative, different types of glazing should be considered. Reflective and absorptive glazing or the addition of reflective polyester film might not provide a good solution for the heat gain problem. The latter suffers from its relatively short durability and the need for more care from the occupants. The absorptive glazing radiates heat (far infra-red radiation) to the inside because it gets heated (with fractional reflection) and causes uncomfortable conditions in the indoor environment. Reflective glazing, though a slightly more effective, reflects both the heat and the visible radiation to the surroundings causing discomfort in terms of glare and additional heat on the neighboring surfaces that intercept the reflections. Single glazed low-E glazing can provide a very low U-value and Shading coefficients without sacrificing the daylight transmission and without getting hot, (properties of Low-E glazing will be discussed fully in Chapter Four).

(E) Infiltration :

Infiltration usually occurs through cracks and joints in the building skin, through leaky window sash, and faulty dampers[13]. Air leakage also results in the entry of dirt, odors, and drafts. The control strategy can be implemented at

Chapter one

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[13] Dubin. op. cit. pp. 167.

all stages of the design process, beginning with careful site selection and ending with protective landscaping. The building itself can be shaped and oriented (including underground placement) to minimize the exposure to winds. Air tightness is achieved by careful detailing and construction of the building, and in selection of window type and quality, as well in security-closing dampers for other ventilation devices[14].

(F) Ventilation :

Ventilation serves three ends in the environmental control in buildings ; it is used 1) to satisfy the fresh air requirement of the occupants (health ventilation), 2) to increase the rate of evaporation and sensible heat loss from the body (comfort ventilation), and 3) to cool the building interior by exchanging warm indoor air for each outdoor air (structural ventilation)[15]. Generally, any action taken to reduce ventilation rate (without sacrificing the health and indoor air quality requirements), will decrease the amount of energy consumed.

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[14] Watson and Labs. op. cit. pp. 46.

[15] Ibid. pp. 53.

CHAPTER TWO

ENVIRONMENTAL RESPONSIVE DESIGN

The case of Khartoum

2.1 GENERAL CONCEPTS :

Regionalism in architectural expression does not only imply the formal manifestation of a certain culture or region, but also a reflection of the climatic impacts on building forms and interior designs. Unfortunately, because of many factors, the regional styles could not cope with today's requirements. Among these factors, is the discouragement of old life styles which were associated with a rapid replacement of foreign values that changed the way things were used to be seen by people during and after the colonial period. This is not in totality an evil thing to happen, but the new generation of architects have drifted beyond the limits where the basic thermal requirements should not be overridden. In fact many aspects of traditional architecture are worth preserving or at least studying to be adopted and used in the modern architecture[1] . If these aspects are fully understood and implemented with respect to the climatic influences on the structures, micro-climate, and landscaping, the result will then be an architectural design which will best suit the geographical location and at the same time give the architecture some sort of a formal identity.

Architectural identity is to a great extent a response to environmental prerequisites. A building can be described in three unique but related ways ; 1) in terms of the spatial organization, 2) formal lay-out (juxtaposition or interlocking of blocks and solids), and 3) facade treatment (the relationship between solids and voids in 2-D distribution patterns). This issue of architectural expression will be discussed and analyzed in detail in Chapter Six. Environmental responsive architectural design is the coadunation of the three mentioned elements of design with the climatic variables for a specific location.

Chapter Two

[1] Write, David. "Natural Solar Architecture". 3ed. Van Nostrand Reinhold Co., New York, York, 1984.pp.54.

2.2 INDIGENOUS SOLUTIONS :

2.2.1 General Practices :

People who lived in Hot-Arid regions have learned to cope with and make use of these severe environmental contrasts and to create comfortable dwellings for themselves. They have also adopted a way of life highly influenced by the climate. for example, in the Hot-Arid areas, people have acclimated their dwellings to the climate in the following ways[2] :

(1) Reduction of the exposed surfaces of the building to reduce the extensive heat gain during the day. This led to more cubical building forms (minimum surface with maximum floor area), 2) introduction of the *Verandah* (porch or a shaded terrace around the building), and 3) using cluster form (habitat-like) lay-outs to make as much use of the shared walls as possible.

(2) Increasing the thickness of the adobe walls beyond the structural requirements in order to maximize the thermal time lag. This, as mentioned earlier, is not very effective because it only delays the heating of the interior to the night time (which is usually hot in summer). But the social behavior has adapted to this situation and developed a whole spectrum of outdoor

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[2] Mamazian, Ali "direct Use of Solar Radiation for Heating and Cooling for Residential Buildings in Hot Arid Climates". Ph.D. Dissertation, University of Michigan, 1981 .pp .72.

activities, games, and social interactions ending with sleeping in the open or on the roofs. By using thicker walls, the people also reduced the energy exchange with the outside air as well as the infiltration and collection of the dust inside the building.

(3) Utilizing the radiational heat loss to the night sky (nocturnal radiation) is also one of the reasons why people prefer to sleep under the sky dome rather under a roof.

(4) Creating interior shaded spaces to satisfy the cooling requirements of the building complexity (in terms of plan and block lay-outs) which is necessitated by the natural growth of the family with the need for cross ventilation. The latter being passed across shaded (cooler) areas, loses part of its energy through a sensible cooling process. These courtyards are planted with trees and shrubs to increase the shading effect and to trap the cool air for longer periods in the day time. Another asset of having trees in these spaces is the cooling effect through evaporation from the plant itself and from the water sprayed in the soil for irrigation.

(5) Making use of the dry summer winds through wind towers for better air circulation within the living spaces and cooling down the ambient air temperature through evaporation (adiabatic cooling process). This issue will be tackled thoroughly in chapter five when dealing with the evaporative and convective cooling characteristics of wind towers.

(6) Living in underground compartments in the hot hours of the day is common in places where the water Table is deep and there is no need for expensive moisture insulation. This practice is not common in the tradi-

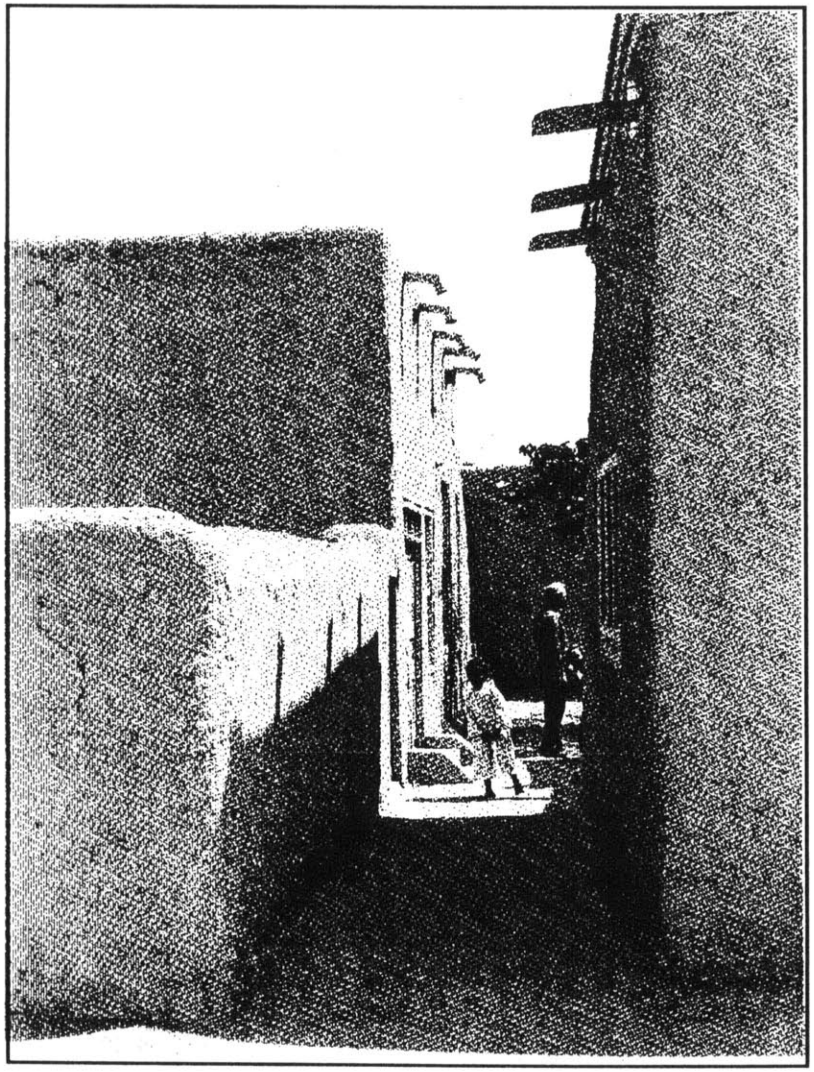

Photo 3. Self Shading Alley Ways Create Cool Pockets that Reduce Heat Gain to the Building

tional architecture of Khartoum or the Northern Sudan because of the high water Table and the flat nature of the topography.

2.2.2 The Traditional House Design :

The Plan Morphology

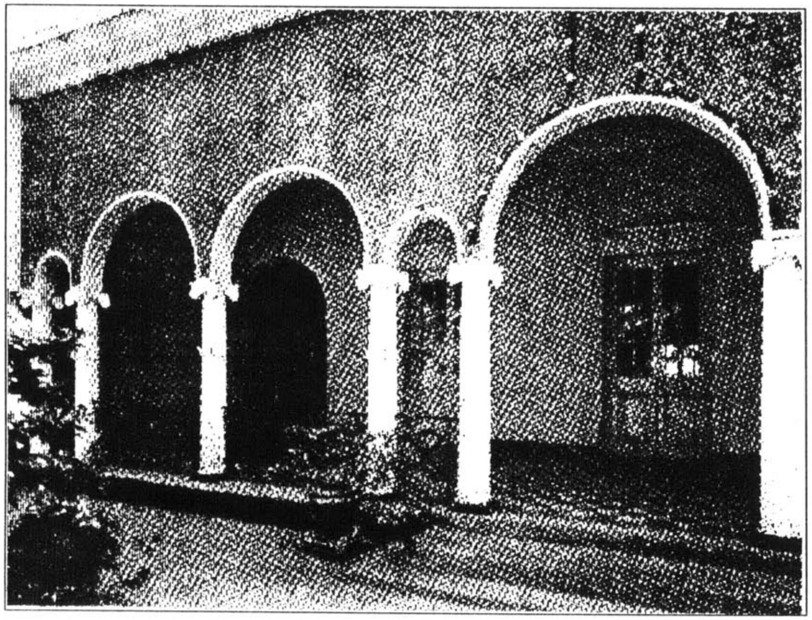

Photo 4. A Colonial house in Khartoum with Shaded Portico and Ionic Prefabricated Columns. (Source: Norberg, Ref. 2).

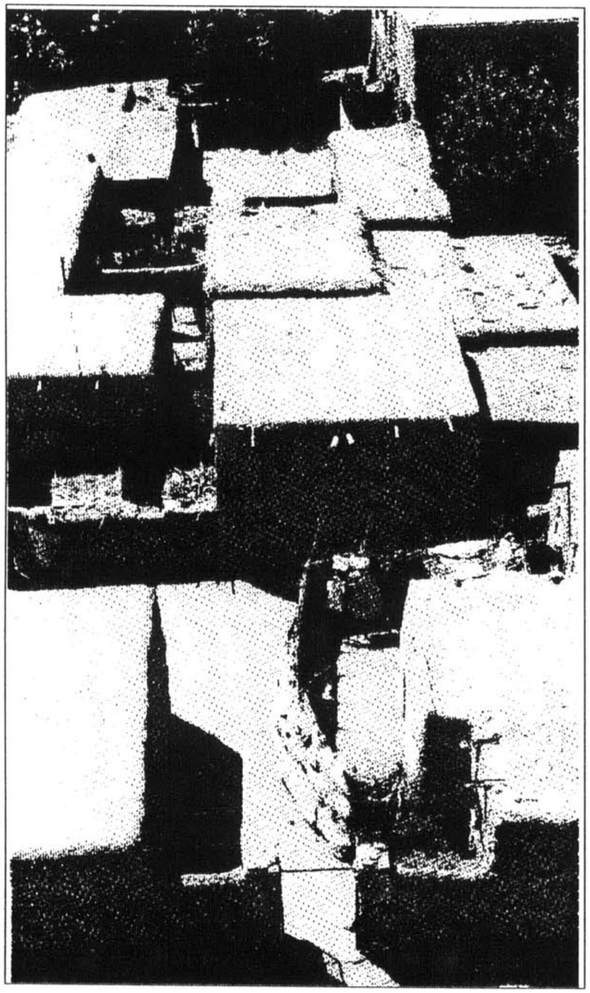

Photo. 5. Compact grouping of houses provides maximum shading on exterior walls.
(Ref. Norberg, 2)

The traditional house in greater Khartoum is basically a synthesis of the Arab and African characters. The presence of a courtyard embodies the two styles and yet gives a unique character that distinguish it from both. An exterior court rather than an interior court functions the same way both thermally and socially but emphasizes a more communal and neighborhood interactions. This was generated originally because of the natural growth of the extended family which then necessitated the need for some sort of privacy and at the same time a strong link with the rest of the family (photograph 2). Doors between the neighbors in the separating walls -if any- is a feature hardly found in the Arabic house. This space sometimes opens into a back narrow alley which links a large number of houses and acts as a waste water drainage channel. Depending on the size of the plot, a provision for a front yard is maintained to receive strangrs. This space represents the reception front of the house and usually ornamented with trees (evergreens or deciduous), paved or ramped (photograph 1), and serves as an evening gathering place.

In order to understand how traditional architecture responded to climate, it is necessary to know that the ultimate goal is the thermal comfort of the occupants. Indigenous building materials are not efficient in terms of R values and their thermal transmission properties. Also the structural limitations of the adobe walls prevent either having projections above the window openings or larger fenestrations. That is why the windows are small and always kept closed during the day. The other reason is that the occupant want to preserve the coolth stored as long as possible[3]. People have adapted their life patterns to the climate in the following ways ; 1) shaded areas in the courtyard and cool rooms (night sky cooling) are used during the hours of the day till their temperature rises gradually to reach the outside temperature through the ventilation, infiltration, and conduction 2) some rooms are kept locked and dark throughout the day for afternoon use (specially for men coming from work), 3) after 5:00 pm. (tea time), the outdoor solar intensity starts to fall rapidly and at the same time the indoor air temperature reaches its maximum. The front and back yard (which is referred to here as the courtyard) is sprayed with water, and by sun-set the beds are done and let to cool under the clear sky. Thus, as we see here the traditional house was a part in the chain of the life pattern. It provided a shelter against the hottest hours of the day and the night flashy storm rains in the short fall season. On the other hand, the houses in colonial Khartoum were built on a completely different typology[4]. The dwelling is outward looking (opens to the outside environment). Instead of the amorphous typological walls, ionic prefabricated columns (photograph 3) support a shaded portico and reflect the image of authority of the occupants (government officials). These house are generally made of green or red bricks 50-70 cm thick walls, with larger window openings to the porch. Although the windows are shaded in this case, they are also kept closed because of the dust and insects as well as the hot air as mentioned in the traditional house earlier.

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[3] The notion here means keeping the interior masses as cool as possible by making use of theirthermal inertia and capabilities of absorbing the energy till they reach the equilibrium state.

[4] Norberg-Schulz. "Genius Loci". Rizzoli International Publications, Inc. New York, 1981. pp.131.

2.3 THE MODERN HOUSE :

After independence in 1956, the house in modern Khartoum borrowed the typology that characterized new trends of architecture in other parts of the world. Cubical lay-outs, straight lines, large window openings, and a clear bias towards outward looking themes became the prevailing practise in Khartoum. The life cycle of the families has consequently changed. The people spend more time in their houses, therefore they are subject to more heat-generated stresses unless mechanical cooling systems are used.

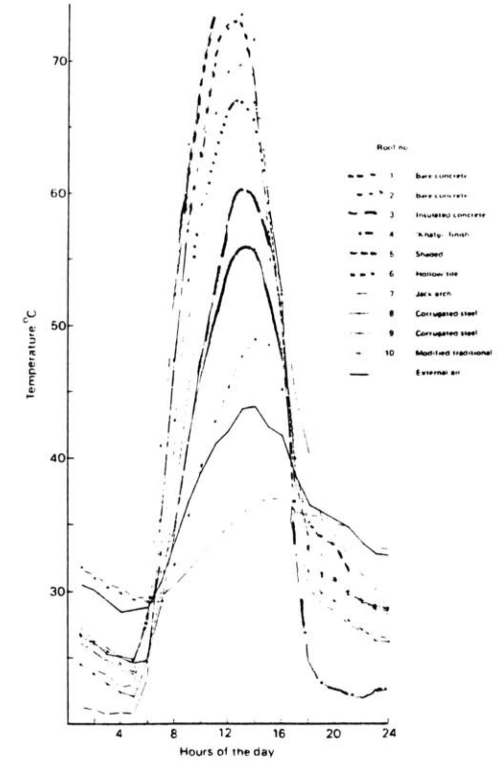

Fig. 2.1. Surface Temperature Swings for Different Materials in Khartoum. (Source: Mukhtar. Ref. 6).

2.4 THE PHYSICAL CHARACTERISTICS :

A Comparison between the Thermal Behavior of Each House

2.4.1 The Roofs :

In an experimental study in the University of Khartoum on the thermal behavior of different roof types and construction, a number of half-scale models were constructed and tested[5]. The findings were in favour of the reinforced concrete slab with 50 mm (2") expanded polystyrene and two layers of roofing felt

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[5] Mukhtar, Y A. op. cit. pp. 414.

in terms of reducing the maximum slab temperature and moderating the diurnal range of the indoor air temperature. Meanwhile, the traditional roof suffers from the highest diurnal range and roof exterior surface (sol-air temperature), (Fig. 2.1).

The study also showed the positive effects of the surface treatment (light colors). White wash and white cement sand tiles have the same thermal properties, but the latter is more durable and allows for roof utilization, without scratching the white wash which also gets dirty and needs seasonal maintenance.

The effect of ventilation is found to be most prominent when used during the night only. It increases the diurnal range, but reduces the maximum indoor air temperature and delays the time of its occurrence. This is more effective in the case of heavy roof construction[6]. This scenario cannot always be used because of insects and dust which will get through the windows during the calm and windy days respectively.

2.4.2 The Walls :

Table 2-1 shows some thermal characteristics of both burnt clay brick and adobe[7].

Chapter Two

[6] Mukhtar, Y A. op. cit. pp. 419.

[8] Rush, R. "Uses of Energy in Buildings" 1987, from a class note at M.I.T.

Property	Brick	Adobe
* Density (lb/sq ft.)	112	120
* Specific Heat (Btu/lb/sq ft.)	0.22	0.20
* Conductivity k (Btu/sq ft.)	0.40	0.332
* Energy Stored Daily Surface temp. Change (Btu/sq ft. def F)	6.1	5.5
* Energy Stored Daily Air temp. Change (Btu/sq ft. def F)	3.5	3.3

Table 2-1 The Thermal Properties of Brick and Adobe

From the Table, the thermal characteristics of brick and adobe are very much similar. Therefore, the evaluation of their characteristics can hardly be based upon their thermal performance (note that the thickness of the adobe wall covers its relatively smaller conductivity). Nevertheless, brick construction allows for the addition of insulation which adds to its thermal resistance. Common brick is also durable and sustains structural stability without the need to use very thick sections which in itself is a design burden because it consumes more usable interior spaces. Above all, building regulations and bylaws restrict the use of mud construction to the third class (low income) areas and forbid it completely in the upper classes.

2.5 Conclusion :

Dealing with the urban tissue in the contextual design is subject to different variables that influence the final product of any architectural activity. Among these variables, the climatic conditions shape the built environment and its relation with the occupants. Modern building materials, although often misused, yet they offer a greater opportunity for thermal control and architectural design. Special attention should be given to detailing and construction to get the maximum benefit from these materials. The critical question is then, how to satisfy all the occupants' needs and at the same time express a unique architectural identity. The environmental responsive design offers these two aspects and sustains the living relationship between man and his environment.

CHAPTER THREE

TRANSFORMATION OF THE CLIMATIC DATA

3.1 DESIGN PRIORITIES :

Architectural design is the process through which a final product is reached. This final product in this thesis is primarily the practical application of environmental responsive design in building forms which satisfy a number of requirements, namely these are ;

clients' needs,
society needs, and
architects' satisfaction,

A second level of design constraints must also be taken into consideration in this process. Being a shelter, the house design in particular, should comply with the occupants' comfort requirements. Thermal comfort is a major component to be fulfilled, and at the same time should should satisfy the following design aspects ;

functional,
economical,
social, and
aesthetical.

In this chapter, the environmental aspects of design are manipulated in the design process as one of the design criteria that have to be considered in the early design stages.

3.2 THE CLIMATIC DATA AS DESIGN TOOLS :

The climatic variables of any region can determine the choice of materials, application of construction techniques, detailing, plan lay-outs, and ceiling heights. This gives the designer an opportunity to work on a preset design criterion which has to be dealt with in accordance with the design aspects mentioned above.

There are two goals associated with the implementation of environmental responsive design[1] ;

(1) Thermal comfort for building occupants,
(2) Protection of building occupants and contents during extreme weather conditions.

In order to achieve the first goal, the dry-bulb, wet-bulb, relative humidity, mean radiant temperature, and interior wind velocities are controlled by modern architectural practices and intelligent choice of materials.

The climatic data is dealt with in the chapter as independent elements, although they are really influencing each other. The objective is to simplify the analysis of each variable and then, overlapping them will give clearer picture of the degree, type and extend of this influence. The data is classified under three categories; 1) solar components : which includes solar radiation,cloud cover data, sun shine duration, dust storms frequency, and sun path analysis, 2) air components : this includes the dry-bulb, wet-bulb temperatures and wind velocities, and 3) ground components : which are mainly the soil temperatures and landscaping.

Chapter Three

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[1] Cowan, H.J. "Solar Energy Application in the Design of Buildings". Applied Science Publishers Ltd. London. 1980, pp.6.

3.3 ELEMENTS OF THE CLIMATE :

3.3.1 Solar Components :

The amount of solar radiation (insolation) reaching a surface is divided into three components; (I_D) direct from the sun, (I_d) diffused from the sky, and (I_R) reflected radiation from the ground or nearby buildings[2].

$$I = I_D + I_d + I_R$$

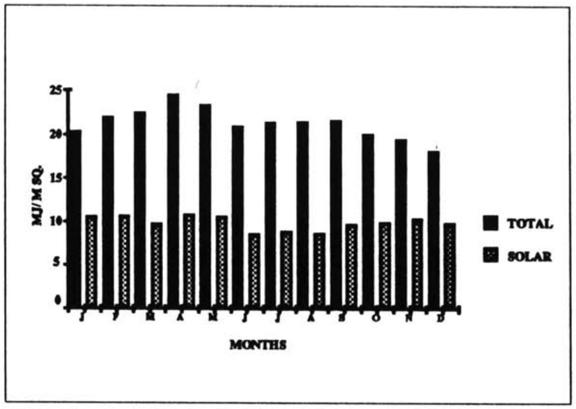

Fig. 3.1.Daily Average Solar Radiation, Khrtoum.

In Khartoum, the yearly average solar insolation reaches its highest in March, April, and May. A horizontal surface in these months receives a daily average total radiation of 25.5, 26.9, and 25.9 MJ/m^2 respectively (Fig. 3.1). The rest of the year except for December and January levels out to an average total radiation of 23 MJ/m^2. In winter, the amount of global solar radiation averages between 19.8-20.8 MJ/m^2 because of the small angle of incidence[3].

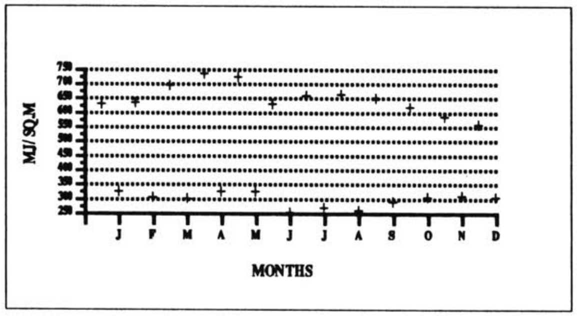

Fig. 3.2. Monthly Total Solar Radiation Average, Khartoum

The diffused component of the solar insolation follows a different

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[2] Givoni, B.op. cit. pp. 70.

[3] Posorski and Ahmed. "Evaluation of the Meteorological Data of Soba (Khartoum)". Khartoum, 1984, pp. 21.

distribution pattern which is related to the cloud cover and bright sunshine duration (Fig. 3.3 and 3.4). It reaches a maximum of 7.8-7.9 MJ/m^2, which represents about 33% of the total amount of solar radiation received on a flat surface in Khartoum. In January, the amount of diffused solar radiation reaches its minimum of 2.6 MJ/m^2 (13% of total solar insolation). In the rest of the year, the average is 5 MJ/m^2 (21% of the total average insolation in these months). The annual distribution pattern is similar to that of total insolation with the exception of its relative uniformity over the year .

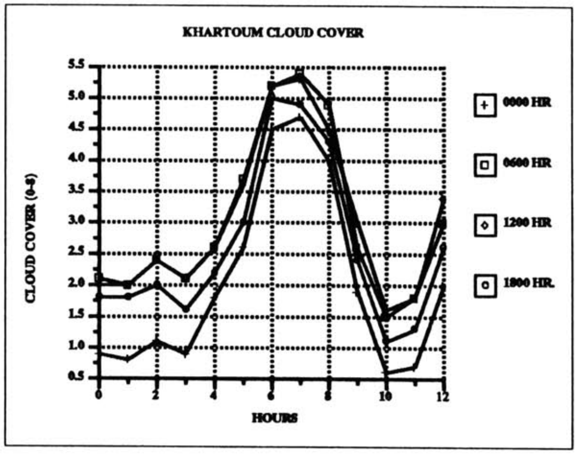

Fig. 3.3. Cloud Cover in Khartoum

Following the same pattern, the monthly bright sun duration (Fig. 3.3) is dependant on the cloud cover and the daytime hours which does not vary much throughout the year -10.5-13 hours- (Fig. 3.4). While the cloud cover pattern is a function of the south-east trade winds which bring some moisture in the short rainy season from July to mid September (Fig. 3.5). The maximum rain fall occurs in August reaching an average monthly maximum of 78 mm. (3 1/8 ").

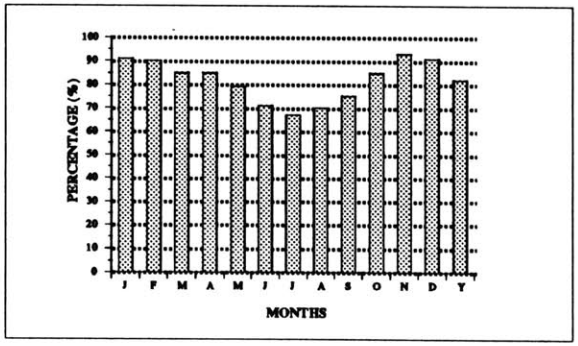

Fig. 3.4. Sun Shine Duration, Khartoum

For solar control, the designer needs to consider the position of the sun at any time of the day, in any month of the year. He/ she will also need to match this information with the annual, monthly, and hourly solar intensity values to decide upon the orientation, shading devices, and the proportion of the building block.

Khartoum lies in the tropical zone at latitude 15°-33' north. In terms of building design, this means that the sun *sees* all sides of the building throughout the year, thus the use of shading devices (horizontal and vertical) and optimizing the exposed surfaces with respect to floor area become major design strategies.

Figure 3.6 represents the solar chart corresponding to the sun path at 17° north[4] .

The time (hours) of the day represented in this chart is the solar time which is defined as[5] "the hours based on the position of the sun". Solar noon is the instant the sun reaches its maximum altitude for that day. The bearing of the sun at this moment is the "True South". It can be calculated from the following formula[6] :

$$\mathbf{SuT = StT + ET + 4\ (SM - L)}$$

Where ;

SuT - Sun Time (hours and minutes),
StT - Standard Time (hours and minutes),
ET - Equation of Time, (the factor for the non-uniformity of sun time (minutes),
- SeeFigure 3.7,

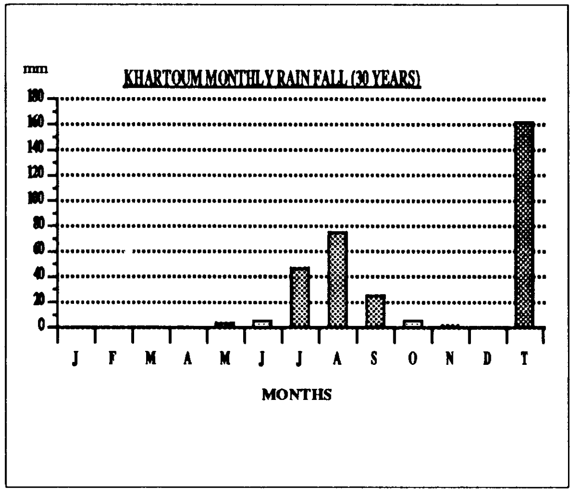

Fig. 3.5. Average Monthly Rain Fall, Khartoum.

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[4] Kukreja, C.P. "Tropical Architecture". TATA McGraw Hill Publishing Co. Ltd. New Delhi, 1975, pp. 25.

[5] Libbey-Owens-Ford Co. "Sun Angle Calculator". Manual, 1975, pp.4.

[6] Ibid. pp. 23.

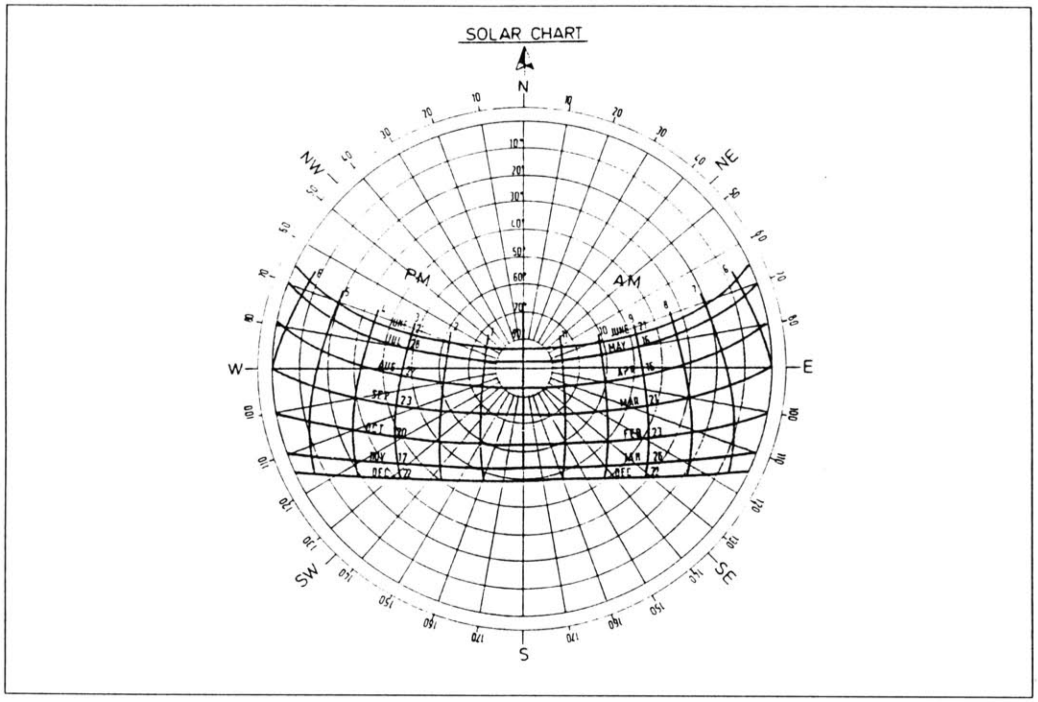

Fig. 3.6. Solar Chart, 17°N

4 - Number of minutes required for the sun to pass over one degree of longitude,
SM - Standard Meridian (longitude) for the local time zone,
L - Longitude of location.

3.3.2 Air Component :

Dry heat exchange to and from the body through convection and radiation is a function of the dry-bulb and mean radiant temperature as it depends on the air velocities and level of clothing[7]. Dry-bulb temperature is defined as the "temperature as measured by a standard thermometer"[8] and the mean radiant temperature is the "weighted average of all surface temperatures"[9]. Together with the relative humidity and wind velocity, they form the basic components of the thermal comfort measures.

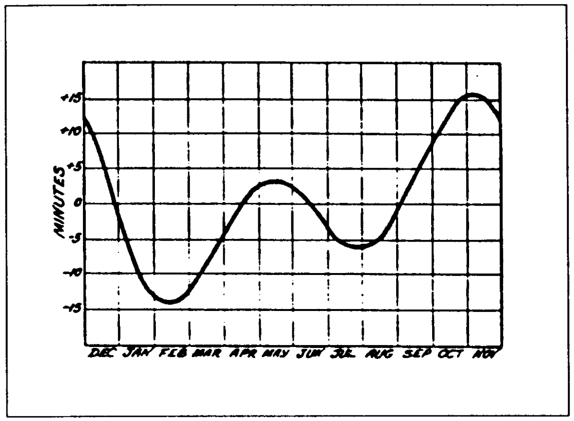

Fig. 3.7. Time Equation. (Source: LOF, Ref. 5).

The mean maximum and minimum dry-bulb temperature in Khartoum are 43° C (109.4° F) and 18° C (64.4° F) respectively in summer; and 37° C (98.6° F) and 10° C (50° F) in winter (Fig. 3.8)[10]. The relative humidity which is defined as "the percentage of the amount of moisture in the air to the maximum amount that it could carry for the same temperature" is dependant upon the dry-bulb temperature and the amount of moisture in the air. The higher the air temperature, the more

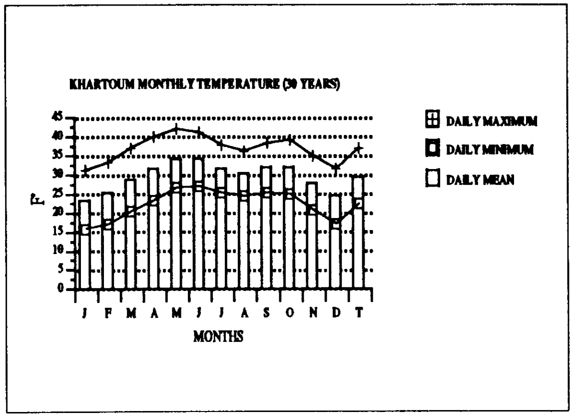

Fig. 3.8. Khartoum Monthly Dry Bulb Temperature.

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[7] Givoni. op. cit. pp. 64.

[8] Tang, Joseph. "A Passive Cooling Design for Multifamily Residences in Hot, Humid Cli[7] mates". S.M.Arch.S Thesis, M.I.T. 1983. pp.36.

[9] Johnson, Timothy. "Solar Architecture. The Direct Gain Approach". McGraw Hill Book Co. New York, 1981, pp. 40.

[10] Meteorological Station -Khartoum.

moisture it can take and consequently the smaller the relative humidity and vise verse. Overlapping the dry-bulb temperature and the rain fall graphs, one sees the mean relative humidity can be predicted (Fig. 3.9). In this graph, the relative humidity reaches its mean maximum approximately of 50% in July corresponding to the rain fall which peaks at the same time. The minimum values of RH occur in March, April, and May at the periods of maximum outdoor dry-bulb temperature and solar insolation intensities.

The horizontal transport of air mass is a consequence of large-scale difference in air pressure, ie. of the horizontal pressure gradient[11]. The wind then is a *gradient wind*; and as such can be observed in its undisturbed state only at higher levels from 275-500 ms (900-1500 ft.) depending on the urban typography or the roughness of the terrain.

The general pattern of the annual distribution of the monthly wind speed reaches three highest levels over the year. The first peak is in April the southerly hot trade wind blows at a speed of 4.3 m/s (9.7 mph) and is usually associated with dust storms. The second peak occurs between June and August at almost the same speed -4.2 m/s (9.4 mph) and carries less dust. This wind is highly appreciated especially in the afternoons when the solar intensity starts to fall off and air temperature cools down (Fig. 3.13). The third peak occurs in December when the

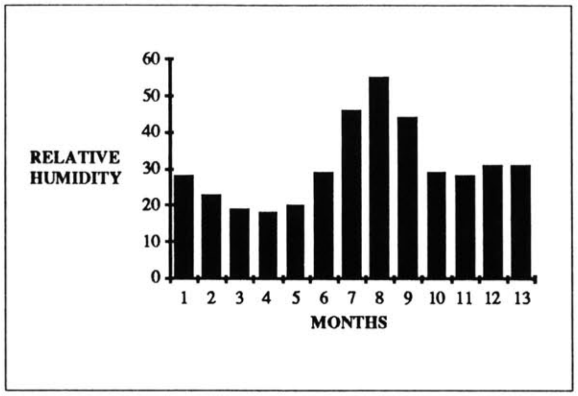

Fig. 3.9. Average Monthly Relative Humidity.

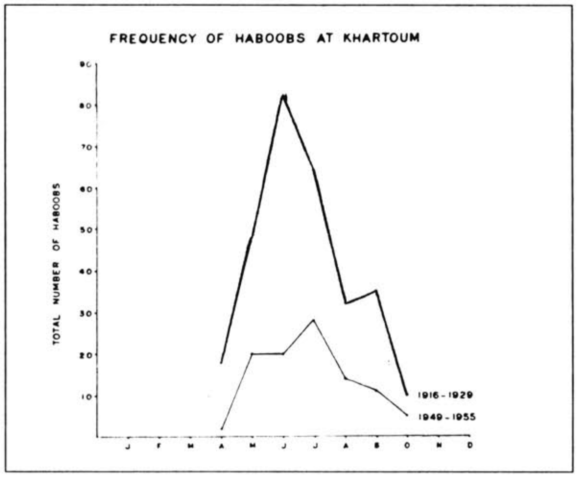

Fig. 3.10. Frequency of Wind Sorms (haboob), Khartoum. (Source: Elbushra, Ref. 12).

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[11] Geiger, R. "The Climate Near the Ground". 7th. ed. Harvard University Press. Cambridge,Massachusetts, 1975, pp. 68.

northern dry and cooler wind blows across the Sahara Desert and moderates the air temperature during the daytime.

The data reveals a typical daily shift of wind speed with a maximum value during daytime at around 10 am. and a minimum around nighttime except for the stormy nights which often blows in summer season. Figure 3.14 shows the daily course of the relative wind speed which is referred to the daily wind speed ;

$$\textbf{Relative Wind Speed} = V/\ V_D$$

The extreme values of wind speed appear to depend on the prevailing wind direction. The peak values occur while northern winds (winter) are blowing, whereas the southern winds (summer) are more moderate.

In summary, the climatology of Khartoum in the problematic season (summer) is hot and dry except for the few rainy days during the period between July and September. The intensive heating occurs between 10 am. and 5 pm. and the dry-bulb temperature in the shade can easily reach 45° C (113° F). At the beginning of summer season in March and April, the relative humidity is very low, not exceeding 13% at 2 pm.standard time[12]. This overheating of the lower layers of the atmosphere destablizes the prevailing wind patterns. This creates a low-pressure

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[12] El Bushra, E. "An Atlas of Khartoum Conurbation". University of Khartoum Press. Khartoum, 1976, pp. 22.

zone which pulls the air from zones of higher pressures, henceforth, the dust storms *haboob* become a widespread phenomenon in this season (Fig. 3.10).

3.3.3 Ground Component :

The underlying geological structure within the Three Towns area is a Nubian sandstone, which is a water bearing sedimentary formation, probably deposited during the cretaceous age. In Khartoum and Khartoum North, the Nubian series is covered by a thick layer of dark, heavy Gezira clay which has been layed down by the Blue Nile during the Pleistocene. The clay which may reach 30 meters in thickness expand when moist and contracts when dry, thereby causing constructional hazards. This might have a limiting effect on the heights of buildings.

Depth cm. (in)	**Temperature °C (°F)**
5 (2)	35.2 (95.4)
10 (4)	33.1 (91.6)
20 (8)	32.6 (90.7)
50 (20)	33.6 (52.5)
100 (39)	33.6 (92.5)

Table 3-1. Annual Mean Soil Temperature in Khartoum.

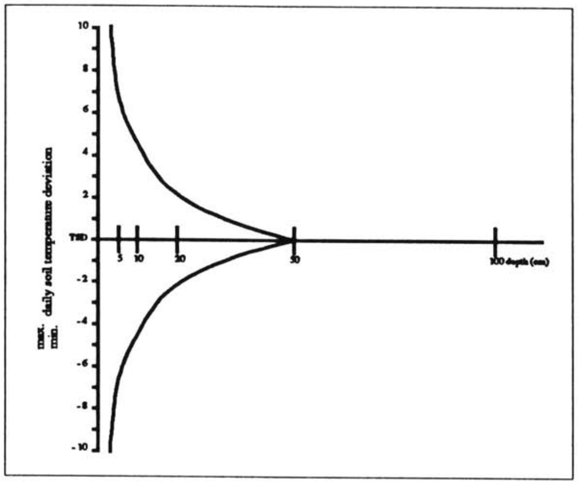

Fig. 3.11Daily soil Temperature Deviation from the Daily Mean Value.

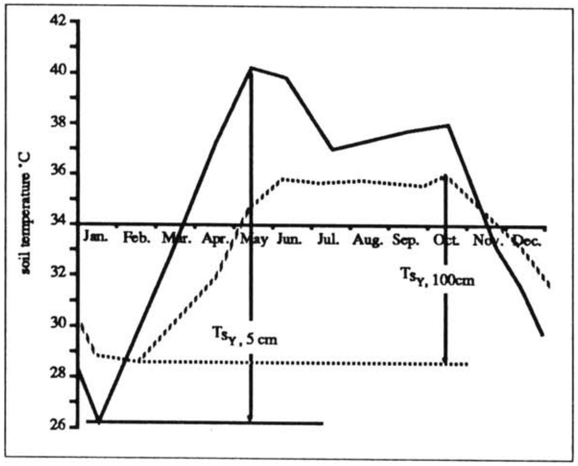

Fig. 3.12. Annual Pattern of Monthly Mean Soil Temperature for 5 and 100 cm. Depth.

On the other hand, Omdurman rests on the Nubian sandstone which suits construction and other building purposes. Most of the Town, however, has been built on a thin layer of decomposed parts of the Nubian series[13].

The flat nature of Khartoum has created serious drainage problems especially in in the peripheries of the Three Towns. Another microclimatic factor which is affected by the flatness of the the land and scarcity of vegetation, is the soil temperature. The temperature near the ground is controlled by the temperature of its soil which is entirely dependent upon the prevailing climatic conditions[14]. For clear day conditions, which are most common in Khartoum region, the earth is the major recipient of solar radiation and hence has a great impact on the lower boundary energy balance of the atmosphere. The daily temperature shift of the surface follows equal or even greater shift patterns of the ambient air temperature because of the seasonal annual shift overlay of the soil temperature which is added to the daily oscillation[15].

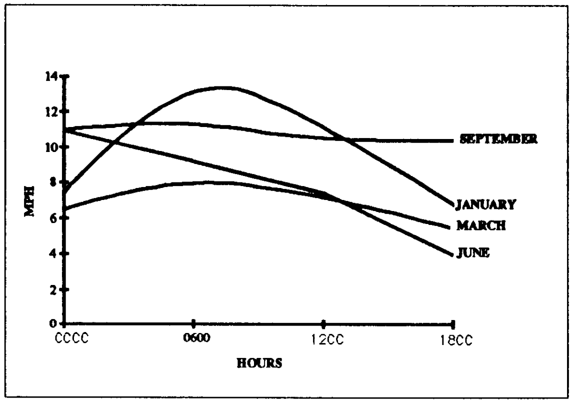

Fig. 3.13. Hourly Wind Pattern.

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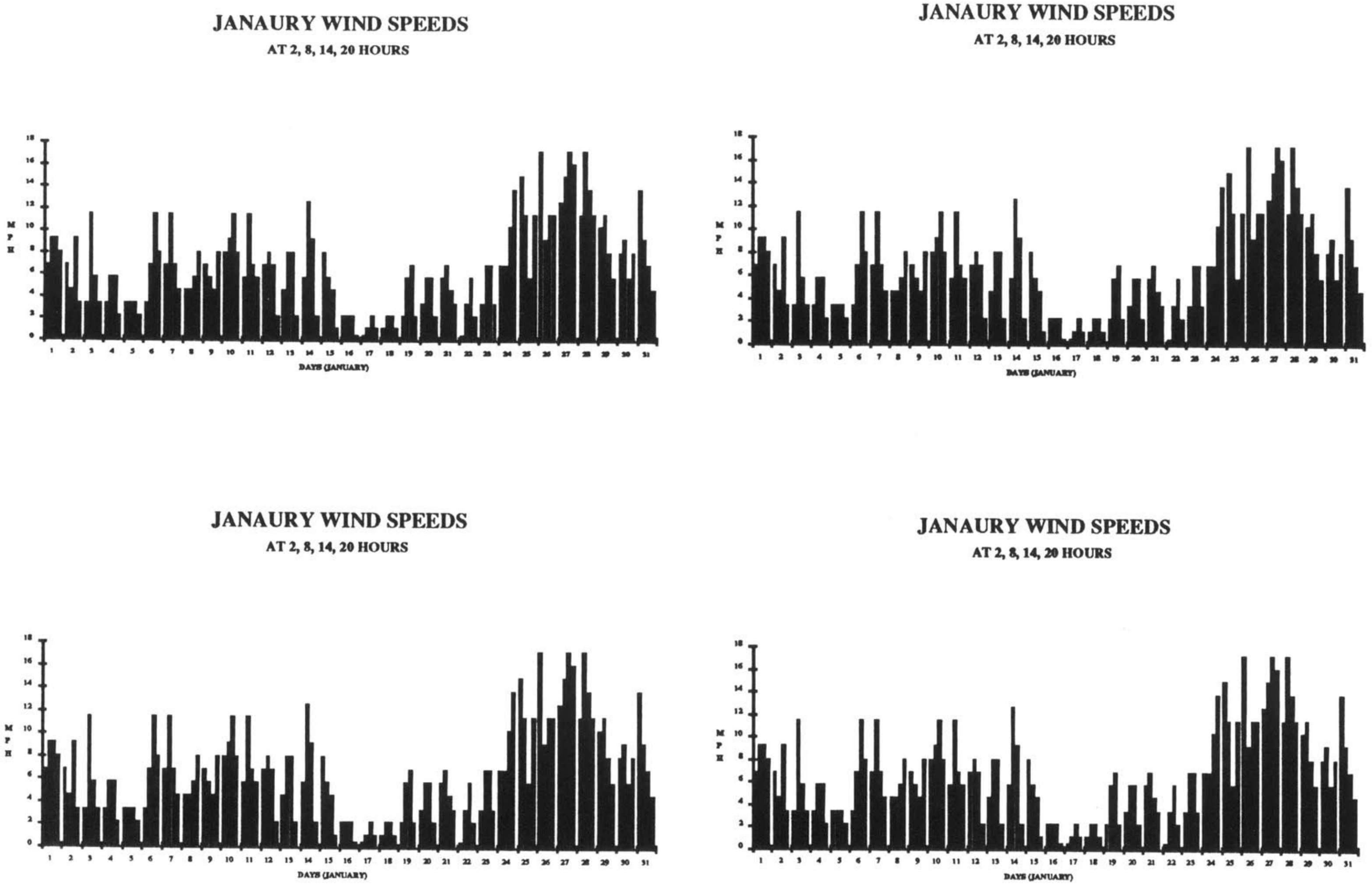
[14] Geiger. op. cit. pp. 55.

[15] Posorski and Ahmed. op. cit. pp. 31.



JANAURY WIND SPEEDS
AT 2, 8, 14, 20 HOURS

JANAURY WIND SPEEDS
AT 2, 8, 14, 20 HOURS

JANAURY WIND SPEEDS
AT 2, 8, 14, 20 HOURS

JANAURY WIND SPEEDS
AT 2, 8, 14, 20 HOURS

Fig. 3.14. Daily Wind Pattern, Khartoum.

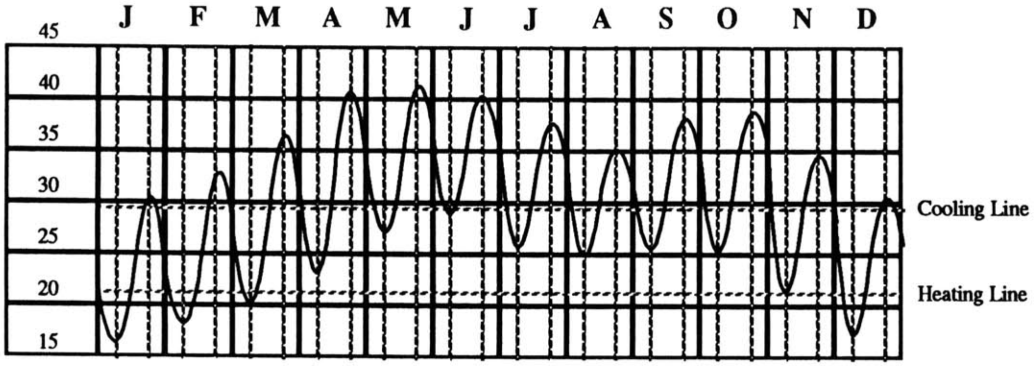


Fig. 3.15. Average Daily Temperature Profile in Khartoum (30 Years). (Source: Meteorological Station-Khartoum).

Due to the transient phenomena of ground insulation, there is a damping effect as well as a time lag of the minimum and maximum temperature between the surface layer and the deep layers. At 6 am. and 2 pm. the surface layers are likely to reach the minimum and maximum vicinity of top soil temperature respectively, (Fig. 3.11). The annual pattern of the monthly mean soil temperatures is shown in figure 3.12 for depths of 5 cm (2") and 100 cm (39")[16].

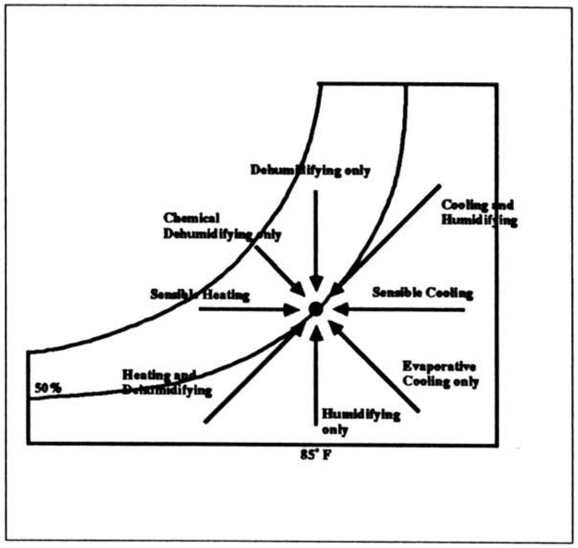


Figure 3.16 Psychrometric Strategies.

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[16] Posorski and Ahmed.Ibid. pp. 33.

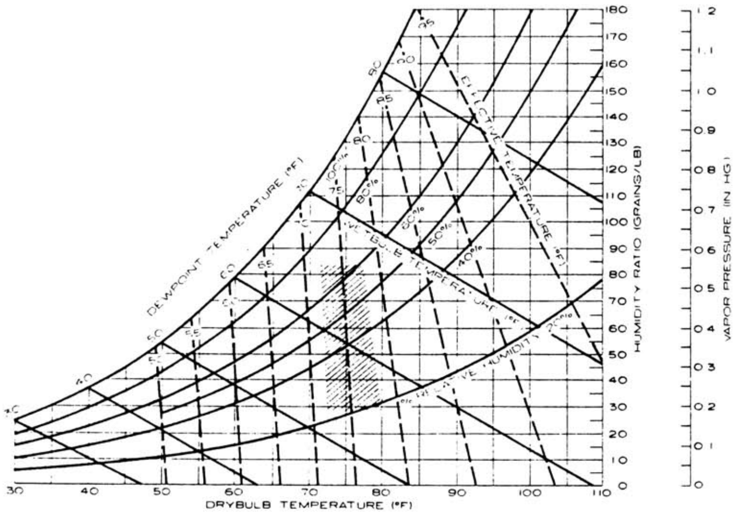

Fig. 3.17. Psychrometric Chart.

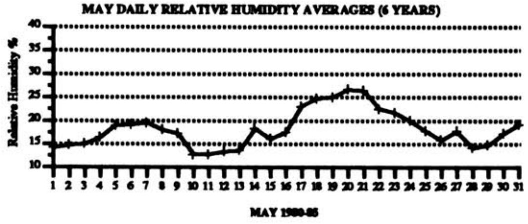

Fig. 3.18 (a). Relative Humidity in May, Khartoum.

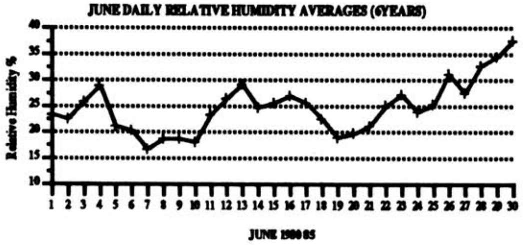

Fig. 3.18 (b). Relative Humidity in June, Khartoum.

Another important aspect to be dealt with when considering the climatic variables, is the effect of vegetation on the micro and macroclimates of Hot-Arid regions. Because of the low rain fall rate in summer, the amount of moisture in the

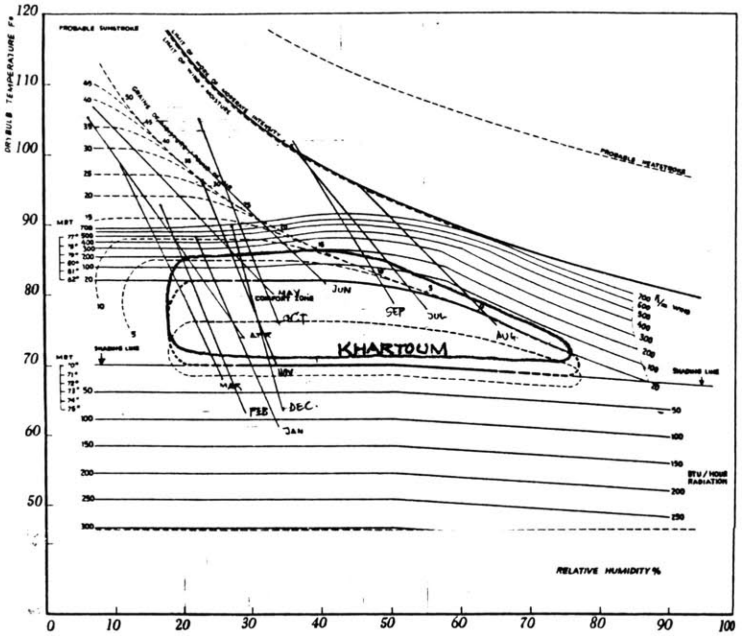

Fig. 3.19. Kharoum Climatic Conditions Plotted on Olgay's Bioclimatic Chart.

soil is sufficient only for the growth of quick maturing grasses and some desert shrubs. Therefore, trees are grown in Khartoum mainly by irrigation especially in the early stages of tree development and till roots have access to the permanent water Table. Some of these trees are indigenous while the others are exotic[17]. A number of deciduous and evergreen trees grown in Khartoum and potential vegetation schemes for energy conservation in the Hot-Arid climates are shown in (Appendix B).

Chapter Three

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[17] El Nady A.H. "Notes on the Important Shade Trees Grown in Khartoum". Research Paper; Dept. of Forestry and Dept. of Agronomy, Faculty of Agriculture, University of Khartoum. Khartoum, 1987.

3.4 Graphical Presentation of Data :

Weather data as provided by meteorological stations (air ports), weather bureaus, or any other source cannot be used directly. As a matter of fact, as any other sort of raw materials, it needs processing. In this section, the climatic data in appendix A is represented in a way to facilitate its utilization by architects and designers.

3.4.1 Air Temperature :

Plotting the average daily temperature swing diagram creates a clear understanding of periods which need cooling (above cooling line in Fig. 3.15) and the periods when heating the indoor air temperature is important. From figure 3.15, the shaded areas above the cooling line covers most of the year in Khartoum (from March to October). This figure also shows that the only periods when overheating does not represent a problem is between December and February.

3.4.2 Psychrometry :

Knowing the air temperatures component is not enough, as it represents one of the four elements of thermal comfort, hence, it is necessary to understand the interaction between moisture heat and air. The psychrometric chart can be utilized to indicate the different strategies and processes that can be taken to bring the climatic conditions to the comfort zone[18] .

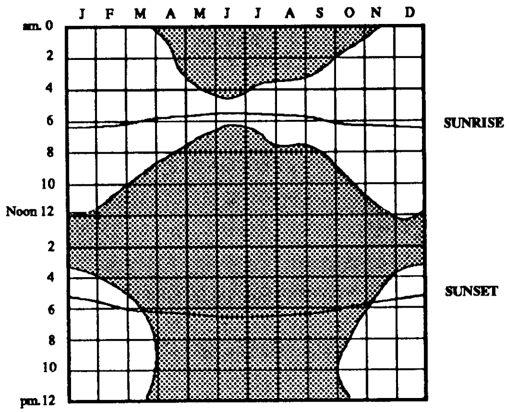

Fig. 3.20 Overheated-Periods Chart, Khartoum 17° N.

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[18] Stein et. al. "Mechanical and Electrical Equipments for Buildings". 7th. ed. John Wiley and

On comparing these climatic strategies with the psychrometric overlays of Khartoum (Fig. 3.17), the following can be depicted :

1) During fall (between July and September), the strategy is to use cooling and humidifying processes for the indoor living spaces. But, because this graph is based on monthly averages, it doesn't take into consideration the, fact that in Khartoum, it rains heavily only three or four times during this season. The rest of the season is usually hot and dry (Fig. 3.18).
2) In winter (December and January), evaporative cooling may be needed from 2-5 pm., while in the early morning hours the temperature drops below the thermal comfort level at a relatively high relative humidity.
3) The rest of the year suffers from high outdoor dry bulb temperature with varying relative humidity rates depending on the time of the day (RH is usually higher before sunrise). The climatic conditioning process to be used is evaporative (adiabatic) and sensible cooling depending on the water content of the air.
4) The hours between 1-6 am. throughout the year enjoy pleasant weather conditions.

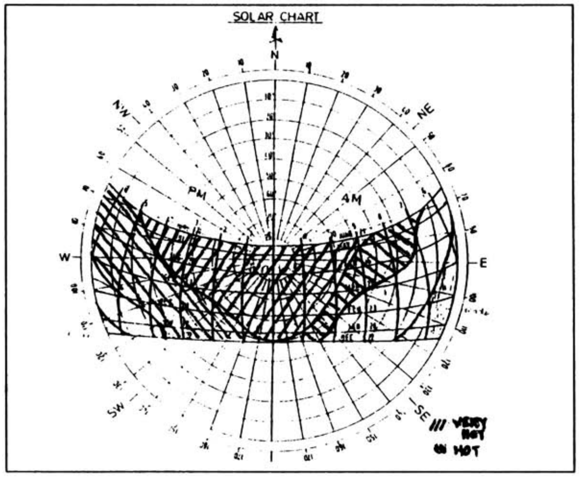

Fig. 3.21. Overheated Periods in Khartoum Plotted of the Solar Chart.

Although the psychrometric overlay gives a clear picture of the climatic-conditioning processes than using dry-bulb temperature graphs (Fig. 3.15), it does not take into account the other components of the thermal comfort. Olgay's and Aren's bioclimatic charts try to add the other climatic variables (MRT, WBT and DBT).

3.4.3 The Boiclimatic Charts :

Figure 3.19 represents Khartoum climatic conditions plotted on Olgay's bioclimatic chart. The straight lines indicate the monthly average DBT and RH for the whole year. From this chart, the following strategies can be extracted;

1) From February to November the cooling strategy can be maintained through evaporizative cooling during the daytime while during the nighttime, natural indoor ventilation of speeds up to 3.6 m/s (7.9 mph) at the cill level is required. This is in fact hard to maintain in Khartoum during the summer time.

2) Lowering the MRT by cooling the internal masses can reduce the heat impact on the occupants, but still this is limited to the midday and late afternoon hours. Making use of the thermal inertia of the structure could be effective when complemented with evaporative and/ or sensible cooling processes, because it permits storing the coolth for longer periods and thus reduces the cooling loads on the mechanical or natural systems used.

3) The use of direct solar radiation is not needed since the short periods when outdoor conditions (January, February and December) lie under

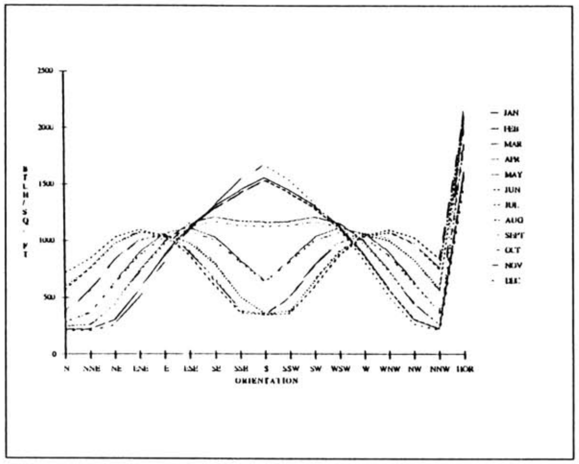

Fig. 3.22 a. Solar Insolation on Different Wall Orientations and Roof for all Months of the Year.

the comfort conditions, occur before sunrise. During these periods interior spaces can be heated by letting afternoon sun warm up the interior masses and thus delay the cooling of interior spaces to the morning.

3.4.4 Overheated Periods Charts :

As seen from the previous analysis, the solar intensity represents the major element in the environmental problem in Khartoum. Since the external shading devices can be utilized to prevent the sun rays from striking the vulnerable areas of the walls (which are usually the glazed surfaces), their form must be carefully designed in terms of orientation, position, size, and geometry.

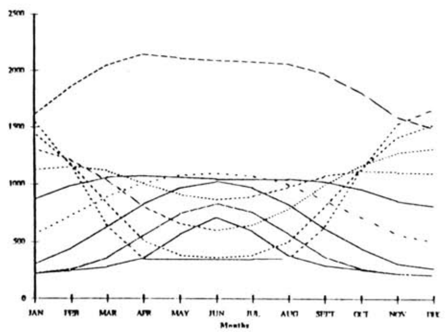

Fig. 3.22 b. Solar Insolation on Different Wall Orientations and Roof Throughout the Year.

In order to determine the time when shading is needed, a yearly chart is plotted and the overheated periods are outlined on it[19]. Figure 3.20 shows that for most of the year, shading devices are required from 9 am. to 5pm. Despite the fact that in summer the overheated periods start earlier and continue to sunset, providing large exterior shading devices against the low sun angles is impractical because

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[19] Olgay and Olgay. "Solar Control and Shading Devices". Princeton University Press, Princeton, New Jersey, 1976. pp.23.

most of the solar intensity is received from 9 am. to 5 pm. (about 77% for June on direct normal surface)[20]. Plotting this data on a sun path diagram (Fig. 3.21) will be utilized to design the shading devices that satisfy the environmental requirements throughout the year (this will be discussed in more details in Chapter Four).

3.5 CONCLUSIONS AND RECOMMENDATIONS :

Extracting from the data presented in this chapter, one can conclude that cooling the indoor represents the major criterion to be considered while designing in the Hot-Arid climates. This takes place in two ways :

3.5.1 Strategies of Minimizing Heat Gain (pp. 66), and
3.5.2 Strategies of Promoting Heat Loss (pp. 67).

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[20] Stein, et. al. pp. 1342.

3.5.1 Heat Gain Minimization :

	STRATEGY	REMARKS ON UTILIZATION
1	*SOLAR CONTROL*	
	(A) USE SHADING DEVICES	* From 9 am. to 5 pm. Standard Time (summer). * From 10:30 am. to 3 pm. Standard Time (winter-Dec.-Feb.)
	(B) MINIMIZE WINDOW AREA	* Avoid windows on east and west sides, (they receive solar energy almost in the same intensity throughout the year-figs. 3.22a and b.). * On the north and south orientations, windows should have minimum aperture to avoid overheating of indoor spaces, (analysis of this aspect is discussed in detail in Chapter Four).
	(C) USE LOW-E GLASS	* Instead of optimizing on window size, Low-E glazing reduces both solar transmission and heat conduction through glass surface, (chapter 4).
	(D) OPTIMIZING EXPOSED SURFACE-FLOOR RATIO.	* Since solar insolation is received on all sides of the building block, the house should be more cubical in form to obtain the maximum indoor living space with minimum of exposed surfaces.
	(E) LANDSCAPING	* Evergreens should be utilized to obstruct solar radiation on walls and windows. They should be grown in such a way that they shade the summer sun (north facade) and at noon in winter (south side) and at the same time allow low sun angle in winter afternoons to be permitted to interior spaces. * Use light colored materials to increase the reflectance value of surfaces.
2	*THERMAL INSULATION*	
	(A) ROOF	* Evaluate the roof insulation practices to minimize heat flow through various roof components.
	(B) WALLS	* Reconsider wall construction in terms of R-values and thickness.
3	*MINIMIZING INFILTRATION*	* Estimate the heating loads introduced through infiltration and consider minimizing its rates by better detailing, reducing window areas, or minimizing the use of operable windows

3.5.2 Heat Loss Promotion :

	STRATEGY	REMARKS ON UTILIZATION
1	*VENTILATION*	* From fig. 3.19, ventilation can be a good solution in the heating periods of winter (11 am. to 3 pm.) and in summer early day and later afternoon hours (from 6 pm. to 8 am.), provided that outdoor temperature is not higher than comfort conditions. Otherwise another cooling strategy is required. * Since wind speed at sill level does not always satisfy the comfort requirements, methods of natural ventialtion that can reach the 8 mph wind speed should be promoted. * Night ventilation should also be considered to cool down the interiors, (see Radiant Cooling). * Use wind inducing elements.
2	*EVAPORATIVE COOLING*	* For most of the year, (except in the rainy, humid days), evaporative cooling represents an obvious solution in the hot, dry periods. * Different mechanical and natural systems of evaporative cooling should be considered.
3	*RADIANT COOLING*	* The night coolth can be stored in the thermal masses to stablize the indoor air temperature during parts of the daytime. This is most suitable from January to April and parts of October.
4	*EARTH COOLING*	* Ground temperatures reaches stable conditions of 34° C (93.2° F) at a depth of about 3 ms (9.87 ft). In addition to its relatively high temperature, the water table of Khartoum is high (almost reaches 3 ms in depth in the flood season). Therefore, earth cooling strategy is not effective since there will be heat gain from the ground. * Raising the structure above ground level and filling the gap with hardcore and sand provides an insulation layer as far as the structure is insulated from the outdoors temperature swings.

CHAPTER FOUR

LOAD MINIMIZATION

4.1 BASIC PRINCIPLES :

The most important step in reaching the comfort zone indoors in hot and dry climates is minimizing the heat gain flow through building skin. Instantaneous rate of heat gain is "the rate at which heat enters or is generated within a space at a given instant of time"[1]. Heat builds up in the building through various ways. These are ;

1) Solar radiation through glass surfaces.
2) Heat conduction through floors, walls, and roof.
3) Heat generated inside the building envelope by people, appliances, and lights.
5) Loads added through ventilation and infiltration.

Chapter Four

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[1] ASHRAE. "Cooling and Heating Load Calculation Manual". Atlanta, GA 1980, pp. 1.1.

Heat gain is divided into two components. The first is the sensible heat which is defined as the heat that is associated with a change of temperature of a material. The second is the latent heat and defined as the type of heat energy that is involved in a change of state of material, ie. from liquid to vapor or from liquid to solid. Both these types constitute the total heat content of the air (enthalpy), and are used to determine the ventilation rate required to remove heat from the living space. Sensible cooling is the term used to denote the rate of heat that has to be removed from a space to maintain the indoor air temperature at the comfort level. The portion of the heat gain which is radiated to the space is not an instantaneous gain since it is delayed and partially absorbed depending on the absorptivity, emissivity, and the temperature of the surface, and the mass and conductivity of the material itself.

The heat extraction rate is the rate at which heat is removed from the space[2]. Usually an air-conditioning equipment is designed to satisfy the thermal requirements during peak conditions. The heat extraction rate can be used to determine the excess cooling loads that can be stored in the interior masses in times when the cooling loads are less than the maximum capacity of the cooling system (air-conditioning scheduling).

Chapter Four

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[2] ASHRAE. Ibid. pp. 1.2.

4.2 PEAK LOAD CALCULATIONS :

Among the methods available to calculate the peak cooling loads, the CLTD (Cooling Load Temperature Difference) and the CLF (Cooling Load Factor) method is used to take into account the sol-air temperature and the effect of the mass which retards and dampens the heat flow through the building material. The conduction loads for external walls, and the heat conduction through glass are determined by the use of the CLTD factors, while other sensible heat gains through glass or from appliances are computed using the CLF to modify the instantaneous heat flow. Both the CLTD and CLF procedures include the time lag effect between the sensible heat gain and the cooling loads due to temporary storage of the radiation components in the internal thermal masses of the building[3]. Table 4-1 shows the different calculation steps and equations of calculating the peak cooling loads using the CLTD and CLF method.

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[3] ASHRAE. Ibid. pp. 1.4.

4.3 COOLING LOADS :
The Case of Khartoum

In order to determine the thermal performance of a typical house in Khartoum, a two-storey, single-family, south-facing residence is selected[4] . This house has a reinforced concrete frame structure with common red brick infill. The built area is 200 ms sq. (2000 ft. sq.) divided between the two floors, and the ceiling height is 3.15 ms (10.36 ft.). External walls are partially farefaced and partially rendered with cement sand plaster, and are 30 cm (11.8") to 25 cm (9.8") thick respectively. The house has an overall glass area of 69.5 ms sq. (695 ft. sq.) of which 71% is on the north side, 19% on the south, and 10% on the east side (Appendix F). The most commonly used glass in Khartoum is the clear DS single-pane. This house has no exterior insulation except on the roof where typically 5 cm (2") thick Expanded Polystyrene Extruded membrane is used under a layer of cement sand screed-to-fall, and 2 cm (.79") thick white cement sand tiles of low absorptivity. This roof is chosen among the two types of roof construction commonly used in Khartoum. The other roof is a light-weight construction composed of 5% inclined Galvanized Corrugated Iron sheets (GCI) on timber boarding supported by a timber frame of joists and purlins. This roof construction (with the plywood ceiling) costs almost the same as the concrete roof, but it has five main disadvantages ;

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[4] This house was designed in Khartoum by the author in 1984.

DETAILED HOURLY HEAT GAIN CALCULATIONS (CLTD)

LOAD SOURCE	EQUATION	REMARKS
External Roof	$q = U\ x\ A\ x\ CLTD$	U = Design heat transfer coefficients A = Area calculated from architectural plans CLTD = Cooling load temperature difference at base conditions for roofs Note : Correction for color of exterior surfaces Correction for outside dry-bulb temperature and daily range Correction for inside dry-bulb temperature Application for latitutde and month
Walls	$q = U\ x\ A\ x\ CLTD$	U = Design heat transfer coefficients A = Area calculated from architectural plans (wall construction description) CLTD = Cooling load temperature difference at base conditions for walls Note : Convection for color of exterior surfaces Correction for outside dry-bulb temperature and daily range Correction for inside dry-bulb temperature Application for latitutde and month
Glass Conduction	$q = U\ x\ A\ x\ CLTD$	U for type of glass and interior shading if used Area, Net glass area calculated from architectural plans CLTD, Cooling load temperature difference for conduction load thru glass Note : Correction for outside dry-bulb temperature and daily range Correction for inside dry-bulb temperature
Solar	$q = A\ x\ SC\ x\ SHGF\ x\ CLF$	A = Net glass area calculated from plans SC = Shading coefficients for combination of type of glass and type of shading SHGF = Maximum solar heat gain factor for specific orientation of surface, latitude, and month CLF = Cooling load factor with/ without interior shading

Table 4-1. Space Cooling Loads Using the CLTD and CLF Method *(From ASHRAE 1981 Handbook of Fundamentals).*

Partitions, Ceilings, Floors	$q = U \text{ x } A \text{ x } TD$	U = Design heat transmission coefficients A = Area calculated from architectural plans TD = Design temperature difference
Internal Lights	$q = Input \text{ x } CLF$	Input rating from electrical plans or lighting fixture data CLF = Cooling load factor based on total hours of operation and time Note : Correction for schedule of operation of cooling system
People Sensible Latent	$qs = No. \text{ x } Sens.\ H.\ G. \text{ x } CLF$ $ql = No. \text{ x } Lat.\ H.\ G.$	No. = Number of people in space Sens. H. G. = Sensible heat gain from occupants CLF = Cooling load factor for people, based on duration of occupancy and time from entry Note : Correction for density of occupants and/ or space temperature Lat. H. G. = Latent heat gain from occupants
Appliances Sensible Latent	$qs = Heat\ Gain \text{ x } CLF$ $ql = Heat\ Gain$	Heat gain = recommended rate of sensible heat gain CLF, for use with hood Latent Heat Gain = is recommended rate of heat gain
Power	$q = Heat\ Gain \text{ x } CLF$	Heat Gain provided from the manufacturer's data CLF = 1.0 if cooling system is not operated continuously
Ventilation and infiltration Sensible Latent Total	$qs = 1.08 \text{ x } cfm \text{ x } \Delta T$ $ql = 4840 \text{ x } cfm \text{ x } \Delta W$ $qs = 4.5 \text{ x } cfm \text{ x } \Delta H$	Cfm = Ventilation and infiltration air standards ΔT = Inside-outside air temperature difference ΔW = Inside-outside air humidity ratio difference ΔH = Inside-outside air enthalpy difference

Table 4-1. Space Cooling Loads Using the CLTD and CLF Method. Ibid.

		Month	Roof		Walls		Glass Windows		People		Ventilation		Infiltration		Total	
			Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%
1	Closed Windows (S1)	Jan.	2593	8.2	8644	27.3	17122	54.2	1269	4	-	-	1980	6.3	31608	100
		Jun.	7347	9.9	20527	27.7	33879	45.6	1269	1.7	-	-	11220	15.1	74241	100
		Sept.	7995	14.5	13277	24	25465	46.1	1269	2.3	-	-	7260	13.1	55266	100
2	Open Windows (S2)	Jan.	2593	6.7	8644	22.4	17122	44.5	1269	3.3	8910	23.1	-	-	38538	100
		Jun.	7347	9.9	20527	27.7	33879	22.2	1269	0.8	89760	58.8	-	-	152781	100
		Sept.	7995	8.4	13277	14	25465	26.7	1269	1.3	47190	49.6	-	-	95196	100

Table 4-2. Summary of Peak Loads at 3:00 pm. for A Typical House in Khartoum.

		Month	Roof		Walls		Glass Windows		People		Ventilation		Infiltration		Total	
			Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%
1	Closed Windows (S1)	Jan.	2593	7.2	9038	25.2	21101	58.6	1269	3.5	-	-	1980	5.5	35981	100
		Jun.	7347	10.1	20194	27.6	33083	45.3	1269	1.7	-	-	11220	15.3	73112	100
		Sept.	7995	13.6	13249	22.6	28764	49.2	1269	2.2	-	-	7260	12.4	58536	100
2	Open Windows (S2)	Jan.	2593	6	9038	21.1	21101	49.1	1269	3	8910	20.8	-	-	42911	100
		Jun.	7347	4.8	20194	13.3	33083	21.9	1269	0.8	89760	54.2	-	-	151652	100
		Sept.	7995	8.1	13249	13.5	28764	29.2	1269	1.3	47190	47.9	-	-	98466	100

Table 4-3. Summary of Peak Loads at 3:00 pm. for A Flipped Orientation of the Same House.

Glass Type	Visible Transmission	Thickness (inches)	U-vlaue	SC.
1 Low-E Coating on Green Covered Plate	64%	1	0.32	0.47
2 Low-E Coating on Bronze Cover Plate	43%	1	0.32	0.49
3 HM-55 with Clear Cover Plate	49%	1.25	0.23	0.42
4 HM-55 with Green Cover Plate	40%	1.25	0.22	0.28

Table 4-4. Cool Daylight Glass with 1/2" Air Space, (Source: Johnson, Ref. 11).

Glass Type	Visible Transmission	Solar Rejection	U-value (winter)	U-value (summer)
1 Clear Single Glazed	0.86	0.16	1.11	1.04
2 Clear Double Glazed	0.81	0.23	0.58	0.61
3 Reflective Glazed	0.20	0.64	1.02	1.02
4 Reflective Double Glazed	0.18	0.73	0.46	0.52
5 Retrofit Film on Single Glazed	0.61	0.56	0.43	0.42
6 Low-E Coated Double Glazed Green Cover Plate	0.65	0.60	0.32	0.32
7 South Wall Heat Mirror 88 Triple Glazed	0.68	0.48	0.25	0.28
8 South Wall Heat Mirror 55 Triple Glazed	0.49	0.66	0.32	0.32

Table 4-5. Thermal and Optical Properties of Eight Glazing Options (Source: Johnson, Ref. 11).

		Month	Roof		Walls		Glass Windows		People		Ventilation		Infiltration		Total	
			Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%
1	Closed Windows (S1)	Jan.	2593	21.8	1979	16.6	4091	34.3	1269	10.7	-	-	1980	16.6	11912	100
		Jun.	7347	22.2	4699	14.2	8966	27	1269	3.8	-	-	11220	33.8	33193	100
		Sept.	7995	30.8	3039	11.7	6417	24.7	1269	4.9	-	-	7260	27	25980	100
2	Open Windows (S2)	Jan.	2593	13.8	1979	10.5	4091	21.7	1269	6.7	8910	47.3	-	-	18842	100
		Jun.	7347	6.6	4699	4.2	8966	8	1269	1.1	89760	80.3	-	-	111733	100
		Sept.	7995	12.2	3039	4.6	6417	9.7	1269	1.9	47190	71.6	-	-	65910	100

Table 4-6. Peak Load Summary at 3:00 pm. for Double Low-E Glazing, (U= .32, SC= .23).

		Month	Roof		Walls		Glass Windows		People		Ventilation		Infiltration		Total	
			Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%
1	Closed Windows (S1)	Jan.	2593	11.9	1979	9.1	11146	51.1	1269	5.8	-	-	1980	6.3	21833	100
		Jun.	7347	14.5	4699	9.2	26304	51.7	1269	2.5	-	-	11220	22.1	50839	100
		Sept.	7995	20.2	3039	7.7	20000	50.5	1269	3.2	-	-	7260	18.4	39563	100
2	Open Windows (S2)	Jan.	2593	9	1979	6.9	11146	38.8	1269	4.4	8910	31	-	-	28763	100
		Jun.	7347	5.7	4699	3.6	26304	20.3	1269	1	89760	69.4	-	-	129379	100
		Sept.	7995	10.1	3039	3.7	20000	25.2	1269	1.6	47190	59.4	-	-	79493	100

Table 4-7. Peak Load Summary at 3:00 pm. for Clear Single Low-E Glazing, (U= .69 SC= .84).

		Month	Roof		Walls		Glass Windows		People		Ventilation		Infiltration		Total	
			Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%	Btuh	%
1	Closed Windows (S1)	Jan.	2593	15	1979	11.5	9425	54.6	1269	7.4	-	-	1980	11.5	17245	100
		Jun.	7347	16.6	4699	10.6	19680	44.5	1269	2.9	-	-	11220	25.4	44214	100
		Sept.	7995	23.4	3039	8.9	14626	42.8	1269	3.7	-	-	7260	21.2	7260	100
2	Open Windows (S2)	Jan.	2593	10	1979	7.9	9425	31.6	1269	5	8910	35.5	-	-	25075	100
		Jun.	7347	6	4699	3.9	19680	16	1269	1	89760	73.1	-	-	122754	100
		Sept.	7995	10.8	3039	4.1	14626	19.7	1269	1.7	47190	63.7	-	-	74120	100

Table 4-8. Peak Load Summary at 3:00 pm. for Light-Green Single Low-E Glazing, (U= .69, SC= .53).

1) The light weight roof does not delay or dampen the heat flow through the different components of the construction, thus the sol-air temperature (which is very high during summer days) is the driving force of heat flow.
2) Expansion and contraction of the GCI sheets damages the joints.
3) Water leakage of rain water through the joints which damages the plywood ceiling fabric.
4) The percentage of the imported materials in this type is much higher than the reinforced concrete construction.
5) The roof is structurally weak and cannot be used for sleeping or any other night activity.

The calculation of the peak sensible cooling loads in June of this house is summarized in Table 4-2[5].

Design Potentials :

In order to determine the amount of heat that has to be removed by the cooling system and to compare it with the situation when there is no electricity (mechanical systems), two scenarios were set up. The first was to

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[5] In the calculations, lighting and equipments are neglected, (refer to Appendix C for the calculation procedure).

assume the windows were open and the second when they were closed at 3:00 pm. Table 4-2 shows that the peak load in the first scenario (S1) doubles that of the second scenario (S2) in June, hence, the first design consideration should ignore the use of window for ventilation during the summer days. On the other hand, even in the (S2), the total heat gain is still problematic and this is due to the large amount of heat transferred through the walls and windows or glazed surfaces (27.7% and 45.6% respectively). It also shows the effectiveness of roof insulation which reduces its share in the total amount of heat transfer to 8.2, 9.9, and 14.5% in January, June, and September respectively. In the second scenario, the roof transmits slightly more heat in September than in June because of the effect of clouds. This in fact does not reflect on the vertical walls and windows because of the effect of the larger area of walls in the first case, and the solar transmission entering through the glazed surfaces in the second case. Therefore, a number of design procedures should be studied to reduce the heat gains through the walls and windows.

1) Using cavity walls on east and west sides of the house.
2) Using Expanded Polystyrene thermal insulation on the walls[6].
3) Changing the orientation of the building.
4) Although roof insulation seems satisfactory in terms of its thermal performance in both scenarios, the effect of changing the thickness should be tested.

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[6] The Expanded Polystyrene is manufactured locally from imported materials. Mukhtar. op. cit. pp. 412.

5) Testing and evaluating the thermal performance of different types of Low-E glass.

6) Changing the size of the window opening should be considered when the rate of heat transfer through the glass exceeds the point beyond which any type of glazing material cannot reduce the total share of the window openings.

4.4 CAVITY WALLS :

The addition of non-reflective air space (cavity) on the east and south walls has increased the total R-value from 3.125 to 4.255 hr.°F.ft sq./ Btu (35% increase) see appendix B. The reduction only changes the total share of the walls in (S2) from 27.7% to 22% (15,075 Btuh). Thus, it is not economically justified since the construction and skilled labors' cost is high.

4.5 WALL INSULATION :

Since the use of cavity walls does not give the required reduction of the heat transfer through building skin, direct insulation of the wall is then tested. A 5 cm (2") thick layer of Expanded Polystyrene is fixed on the outer side of the brick wall and then protected from weather by a 15 cm thick facing brick (fig. 4.1).

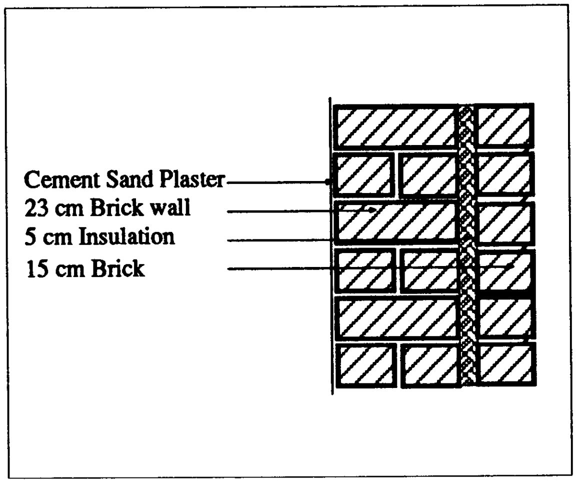

Fig. 4.1. Proposed Wall Construction.

The R-value of this wall equals 13.65 hr.°F.ft sq./ Btu and the total wall conduction load in June is 4699 Btuh (9.2% of total heat gain in S2) refer to table 4-6. The conduction in January, June and September after using the wall insulation represents 23% of the heat conduction through the wall before adding the insulation layer. Therefore, using insulation on the wall is more effective than using cavity wall construction in damping the heating effect of solar radiation absorbed in the outer surface. The other advantage of wall insulation is that it cuts the radiated heat transfer between the two leaves of the brick wall, consequently reduceing the total heat flow. The location of the insulation layer is an important design consideration, as the external placement is more effective in damping the heat effect of solar radiation and diurnal temperature swings. Therefore the maximum internal air temperature is lower and the minimum higher with external rather than internal insulation[7].

In addition to the damping effect of heat, wall insulation affect the psychological comfort of the occupants. Reducing the internal surface temperature minimizes the heat radiated from the walls and even when the surface temperature goes below the body temperature (37° C - 98° F), the occupants lose heat through radiation to the cooler surfaces. The cool interior masses absorbs the additional heat which enters through infiltration or door use, thus a total

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[7] Givoni, B. op. cit. pp. 128.

feeling of comfort is maintained during a large part of the daytime (from 8 am. to 1 pm.).

4.6 ROOF INSULATION :

Doubling the roof insulation by the use of a 4" Expanded Polystyrene layer has increased the R-value of the roof to 22.2 Hr. Ft Sq. °F/ Btu. This has reduced the amount of heat conducted through the roof 7347 to 4040 Btuh. this reduction represents only 7.5% of the total heat gain in June using insulated walls and single Light Green Low-E glass (Table 4.7). When comparing the reduction in heat gain, adding only 2" of insulation on the roof reduces gains from 40432 (uninsulated roof) to 7347 Btuh. Therefore, doubling the roof insulation which is in fact doubling the cost does only result in reducing heat gain by a factor of 45% in the roof share which is already reduced when 2" of insulation is added.

4.7 ORIENTATION AND FORM :

4.7.1 Orientation :

Because of the specific site requirements, the house is facing the north (71% of glazing area). For comparison, the house is flipped around its east-west axis and the same calculation procedure is conducted Table 4-3).

The analysis shows that in June the glass orientation does not create a large difference because of the relative position of the sun (which is almost vertical) during the hottest hours of the day. This can only be true if the windows are properly shaded taking into account the azimuth angle (bearing from the south) as well as the sun's altitute of the afternoon hours (2:00-5:00 pm.). From December to March/ September, the southern exposure receives more energy, but because of the relatively comfortable conditions during most of the day, only afternoon sun should be shaded.

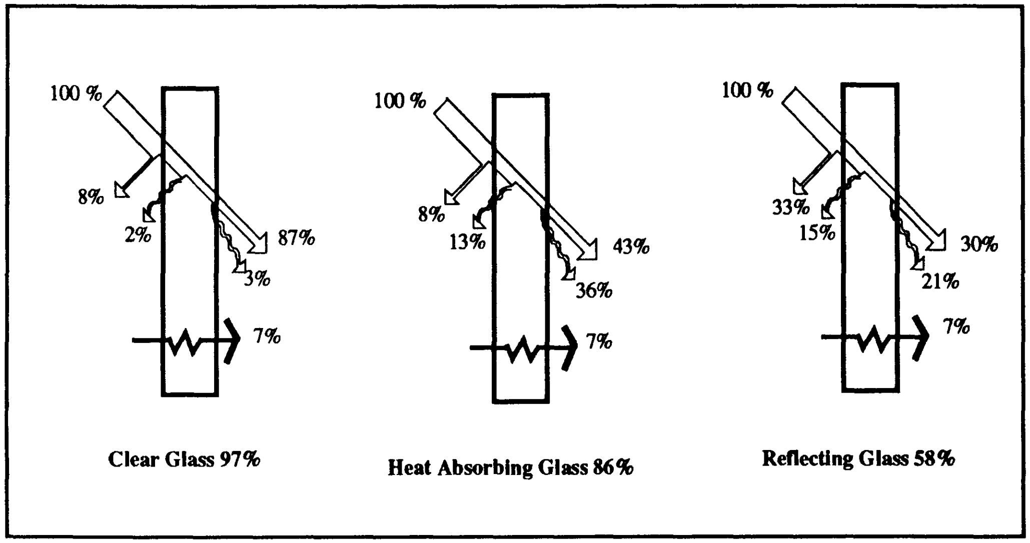
4.7.2 Building Form :

In order to satisfy the building regulations, only 38% of the plot area is occupied by the building (40% maximum), and because of the site configuration, the house proportion is 1.25:1. This ratio is not the optimum for the hot, dry climates, which is 1:1.3 to 1:1.6[8]. Thus, for Hot-Dry climates, compact building forms and closed spaces are recommended to provide shelter from the hot wind and to minimize the solar exposure[9].

Chapter Four

[8] Olgay and Olgay. "Design with Climate". Princeton University Press. Princeton, New Jersey, 1973, pp. 88.

[9] Cook, Jeffery. "Cooling as the Absence of Heat: Strategies for Prevention of Thermal Gain". Passive and Hybrid Cooling Conference Proceedings. Bowen et. al. ed. Miami Beach, 1981, pp. 618.



Clear Glass 97% **Heat Absorbing Glass 86%** **Reflecting Glass 58%**

Fig. 4.2. Solar Heat Gain Through Different Types of Glass,
(Source : Anderson and Riordan, the Solar Home Book).

As a major design criterion, houses in Khartoum are designed in such a way that they should depend on natural cross-ventilation for comfort in the absence of electricity (mechanical systems). Such a criteria necessitated a different ratio from the recommended above according to the heat gain/ loss optimization process first suggested by B. Givoni. Therefore, air ventilation/ cooling systems that are independent of the classical concept of having two sets of windows facing each other, should be promoted. This approach is also supported by the fact that having large operable windows for ventilation purposes allows hot air, dust, and insects to enter the living spaces.

The other aspect that involves the building form is the concept of self shading. In the indigenous architecture in Khartoum, this was attained by narrow alleys, courtyards, and neighborhood clustering. This is no longer the

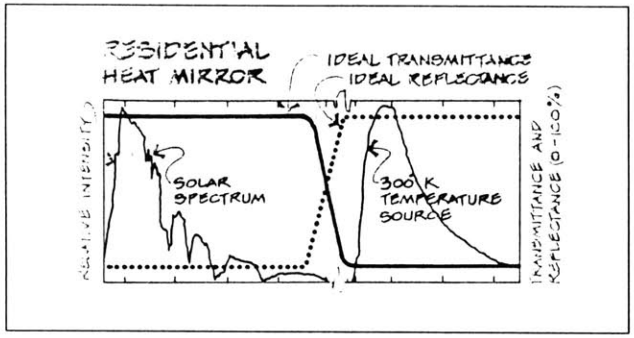


Fig. 4.3. Selective transmitting Windows for Residences (Johnson, Ref. 11).

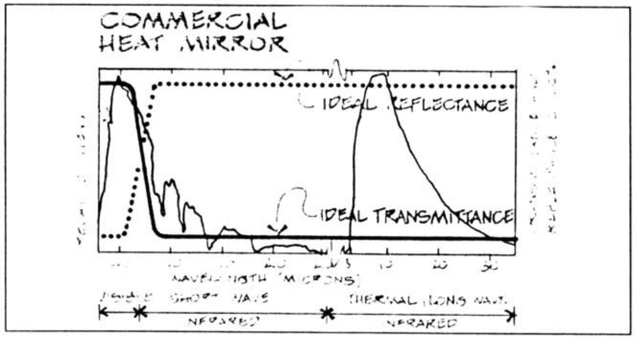


Fig. 4.4. Selective Transmitting Windows for Offices (Johnson, Ibid).

case since the grid-iron road pattern has been adopted, and consequently the building envelope has been more subjected to the external weather extremes. Proper shading design, cantilevering upper levels, and landscaping can provide this self shading without sacrificing architectural and aesthetical freedom.

4.8 WINDOWS :

As seen fromTables 4-1 and 4-2, the amount of heat entering the space through a glazed surface constitutes the largest share of heat transfer when considering the infiltration scenarios. In order to translate the dynamics of heat flow through transparent materials one should identify the components of the solar spectrum and the optical and thermal characteristics of different types of glass. The DS single-pane flat glass admits 97% of the heat that strikes its outer surface, where other types e.g. heat absorbing and reflecting glass permit 86% and 58% of the total energy respectively (Fig. 4.2)[10].

From the heat gain point of view, the reflective glass is more appealing since only 58% of the total solar energy is admitted. The drawback of this glass is its very low daylight transmission value (20%) plus the large amount of energy reflected or rejected through conduction, convection, and

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[10] These values are determined assuming 32° C and 24°C outdoor, indoor temperature respectively. In Khartoum, the heat gain is higher due to the high dt design conditions.

radiation, which affects the neighboring buildings and surfaces.

4.8.1 Low-E Glazing :

There are two types of selective transmitters : the first is used for solar heat gain and the second type is used to minimize the gains through the glass (Fig. 4.3 and 4.4). The second type or the cool daylight is commonly used in offices and commercial buildings (of higher internal loads) in temperate climates[11], but also its selective transmittance properties can be used for overheated climates in the residential (skin loads) scale.

The single Light-Green Low-E glass coated with a selective transmitter, has a shading coefficient of .53, permits 65% of the visible (daylight) transmission, and a U-value of .68, while ordinary DS clear single-pane glazing transmits 86% of the daylight and only rejects 16% of the solar heat gain and a U-value of 1.18 (Tables 4-4 and 4-5).

The surface location of the coating affects the thermal performance of double glazed windows. For cooling purposes, locating the film on surface 2 (Fig. 4.5) is best to ensure that the absorbed heat will be washed away by the

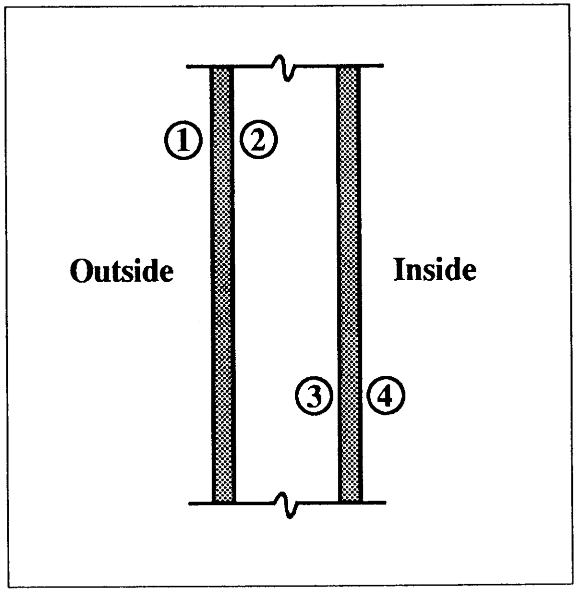

Fig. 4.5. Possible Location for Coating, (Source: Johnson, Ref. 11).

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[11] Johnson, Timothy. "Cool Windows". Solar Age. Vol. 9, August 1984, pp. 28-31.

external winds. Another advantage of this location is that the internal leaf of the glass remains cooler than the outside, thus reducing the mean radiant temperature of the living spaces.

The ability of the Low-E glass to reflect most of the infra-red (IR) portion of the solar spectrum without sacrificing much of the visible transmission together with its significantly low U-value[12] gives it a commercial appeal necessitating its consideration in this thesis.

4.8.2 Analysis of Thermal Performance in Khartoum :

The same peak heat load calculations (section 4.3) are conducted using three types of Low-E glass : Double glass, Single Clear, and Single Light Green glazing. The house is assumed to be insulated on both the roof and walls using 5 cm. thick Expanded Polystyrene boards. The output of this study is summarized in Tables 4-6, 4-7, and 4-8.

Comparing the heat gain when using different types of Low-E glass with the ordinary DS clear glass shows a considerable reduction in total heat gain through the windows (solar transmission and conduction). When using double Low-E glazing (Table 4-5), the reduction factor is 73.5% of the heat gain through

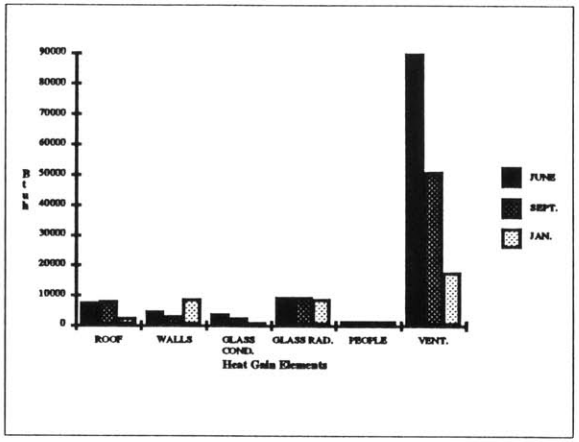

Fig. 4.6 a. Redesigned Building Elements Performance, Including the Ventilation effect (Original Orientation).

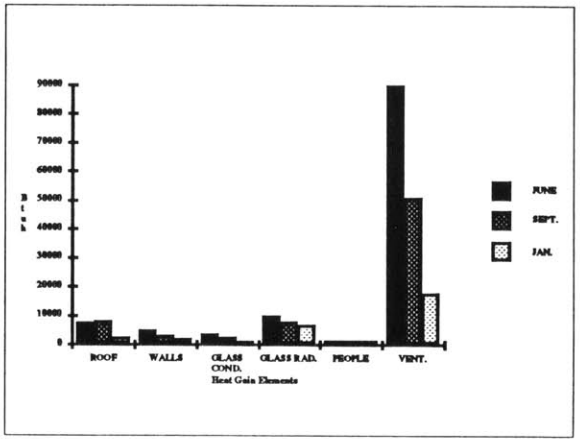

Fig. 4.6b. Redesigned Building Elements Performance, Including the Ventilation Effect (Flipped Orientation).

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[12] Bartovics, W.A. "The Thermal Performance of Fixed and Variable Selective Transmitters in Commercial Architecture".S.M.Arch.S Thesis, Dept. of Arch. M.I.T. 1984.

the windows. This translates to about 43.2% reduction in the total peak cooling load in June. This reduction is even higher in January, when the window share is reduced by 88.4% and the total load is reduced by 52.2%. In September, the reduction is 74.8% and 42.3% for the heat gain through glass and the total heat gain respectively. In case of Single Light Green (SLG) Low-E glass (Table 4-7), the heat gain through windows has been reduced by 42% while the total load is 24.3% less when SLG glass is used in June. These percentages hold in January and September when the share of windows is reduced by a factor of 45% and 42.6% respectively. The total heat gain in January is reduced by a factor of 30.9% while in September the reduction is about 24.1%.

In summary, this analysis shows the benefits of using Low-E glazing throughout the year. Double Low-E glass reduces the total cooling loads by an average of 46% while the Light Green Low-E glass cuts the heat gain by an average of 26.4%. This means that the choice of selective transmitters reduces cooling loads and allows the designers to use larger window areas when wall and roof insulation are used (Fig. 4.6 a, b, 4.7 a, and b).

4.9 EFFECT OF CHANGING THE WINDOW AREAS :

Window openings are important elements in the architectural design. These, with the solids and masses gives the building an identity. Nevertheless, these fenestrations represent the weakest thermal points in the building skin, thus not only the glass material should be questioned, but also the effect of changing

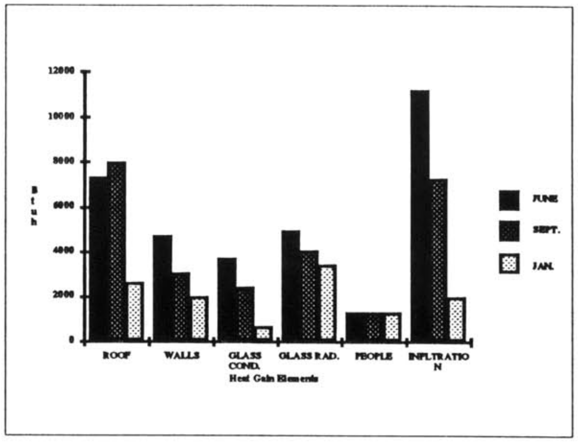

Fig. 4.7 a. Redesigned Building Elements Performance, Including the Infiltration effect (Original Orientation).

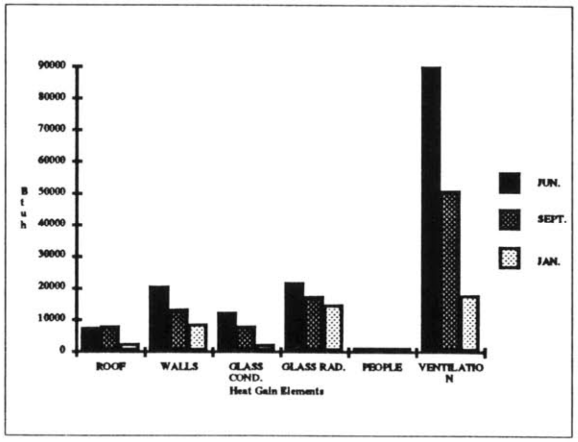

Fig. 4.7 a. Origninal Building Elements Performance, Including the Ventilation effect.

the area of glazed surfaces. The architectural impact of such change will be be discussed in chapter six. In this section, the main concern is the thermal impact.

The same model house was analyzed with the insulated ceilings and walls and for different window-to-wall ratios (12, 22, 38, and 47%) for two Low-E glass types were analyzed (Fig. 4.8 and 4.9). Obviously, the higher the ratio, the more heat enters the house. By comparing these figures with the window-to-wall ratios commonly implemented in Khartoum (22 to 30%), one can conclude the following :

1) Maintaining the same window-to-wall ratio using Single-Light Green withLow-E and Double Low-E glass, reduces the heat gain through the window by a factor of 42 and 74% respectively over the year.

2) The possibility of using a larger ratio (38%) and still maintain the same percentage of window share to total cooling loads in the case of the SLG glass and up to 64% ratio of window-to-wall when using Double Low-E glass.

The second conclusion allows the architect to investigate new relationships between solids and voids and at the same time reduce total heat gain. The choice of the selective transmitter becomes mainly an architectural as well as economical

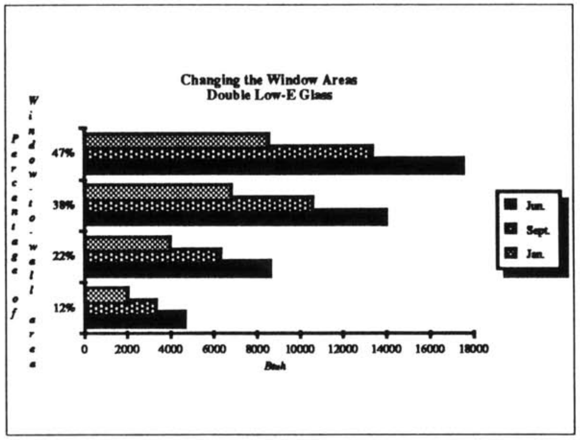

Fig. 4.8 a. Effect of Changing Window Area on Cooling Loads When Using Double Low-E Glass.

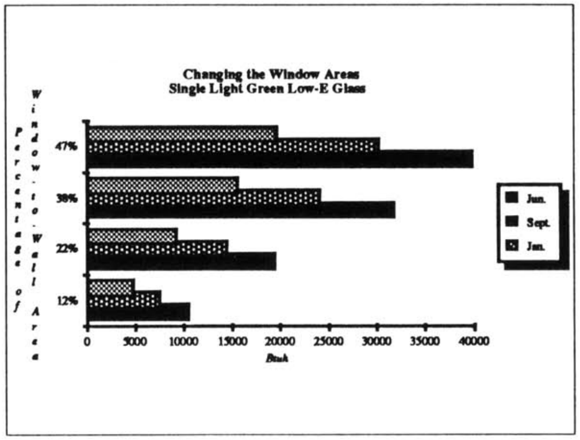

Fig. 4.8 b. Effect of Changing Window Area on Cooling Loads When Using Single Light-Green Low-E Glass.

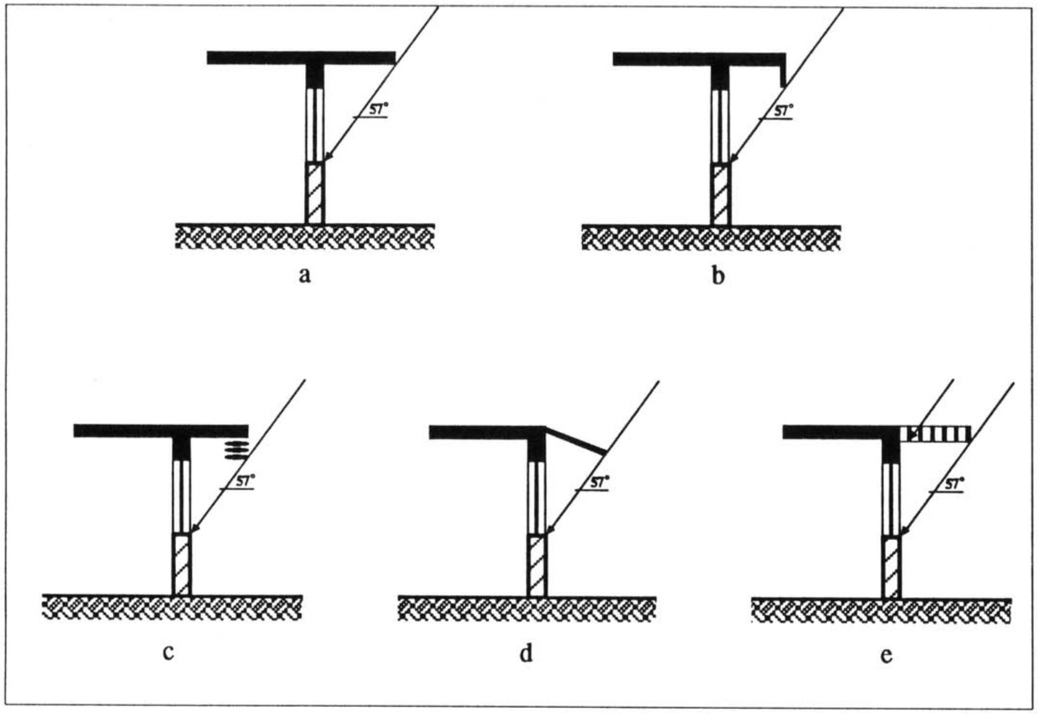

Fig. 4.10. Different Configurations of Horizontal Shading Devices on the Southern Exposures.

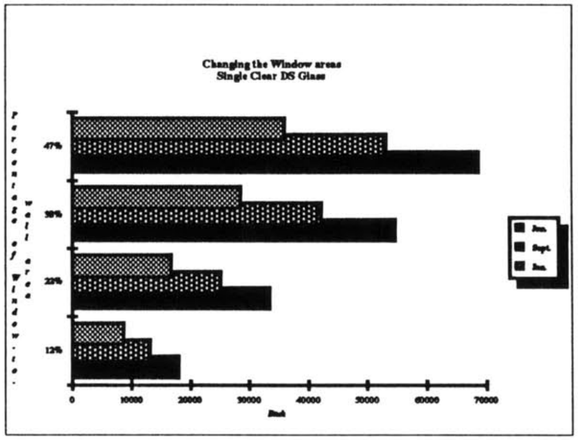

Fig. 4.9. Effect of Changing Window Area on Cooling Loads When Using Single Cear DS Glass.

consideration (the economic appraisal of these types of glass is discussed in Chapter Six). The other important aspect in increasing the window size is to promote the use of daylighting in the living spaces without sacrificing thermal comfort. With more or less square plans as suggested in the analysis of the impact of the building form on the thermal performance, Low Emissivity glass becomes a necessity once daylighting is required. Light shelves and skylights are devices to bring light to the deep interiors, with the latter only be feasible when low-E glazing is used.

4.10 SHADING :

From the previous analysis of the thermal performance of different glass types, the share of the windows in the total heat gain remained substantial in all cases. The choice of the shading device criteria is dependant on the overall shading performance ratio of the window[13]. In section 3.5.1, the recommended shading strategy is from 9 am. to 5 pm.in summer and from 10:30 am to 3 pm. in winter. In Fig. 3.21, two overheated zones were outlined ; the "Very hot" and "hot" periods.

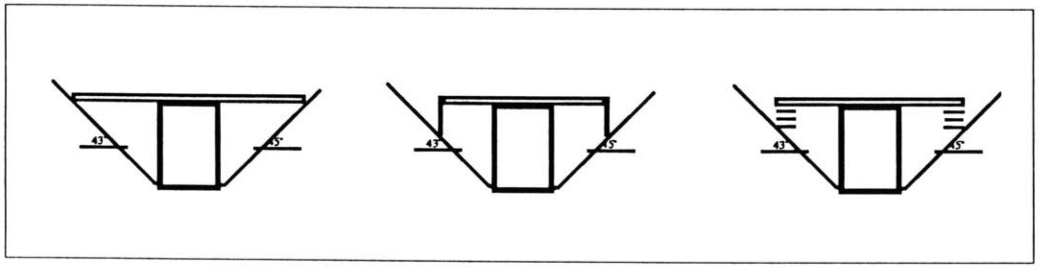

Fig. 4.11. Side Projection Possibilities.

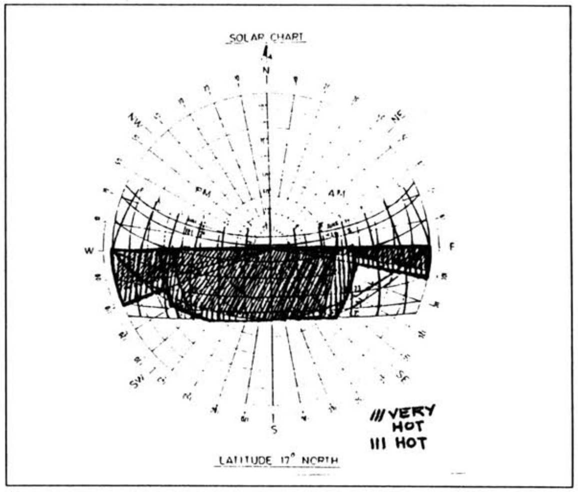

Fig. 4.12. Shading Mask for South Windows.

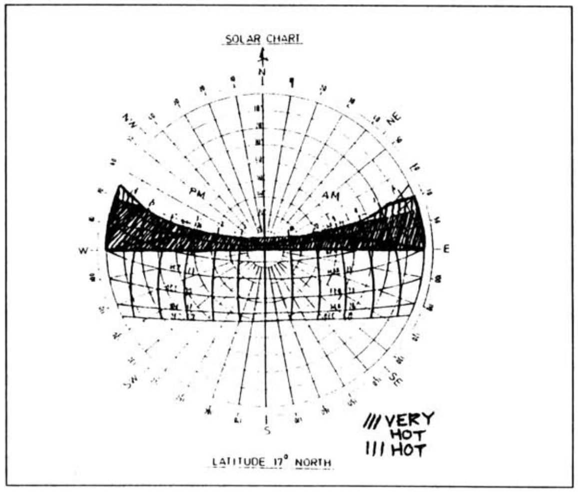

Fig. 4.13. Shading Mask for Nort Windows.

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[13] Summer Shading Performance $S_p=(S_o/R_o) \times 100\%$. Where S_o is the intercepted Btu value during overheated periods and R_o is the total amount of Btu's which strike the surface during the overheatedperiod. Olgay and Olgay, op. cit. pp. 64.

In order to minimize the solar heat gain through the glazed surfaces, the shading performance ratio (percentage of shaded area to the total area of a window) should be 100% in the first zone "very hot" and 75% in the second zone "hot". This will be translated into physical terms as follows :

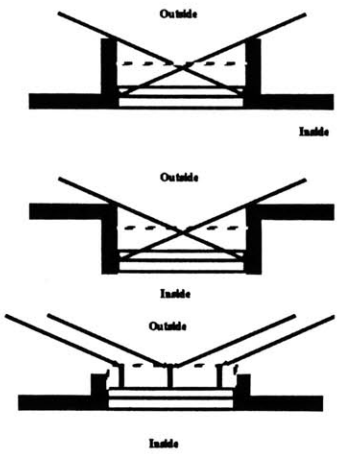

Fig. 4.14. South window shading proposed configuration

4.10.1 South Windows :

Because Khartoum lies in the tropics, the southern exposures receive direct solar insolation only during part of the year (from August to April). Following the outline of the "very hot" zone, the design angle will coincide with the profile angle in December 22 at noon which is approximately 51° south for the 100% design criteria. The side projections of the windows should obstruct the sun's profile angle at 43° and 45° on the west and east sides respectively. Although this consideration covers a large portion of the 75% design criterion, it requires supplementary vertical elements to shade against the afternoon hours from August to October, and early daytime sun. The latter being of less significance, since before 9 am. the solar intensity is relatively weak and also the fact that the azimuth angle is 70° WSW and 80° ESE on the west and east sides respectively, permits the use of deep recessed windows instead of separate vertical shading elements. Fig. 4.12 shows how the design considerations respond to the overheated periods throughout the year.

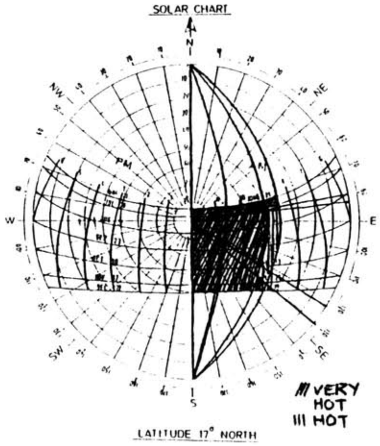

Fig. 4.15. Shading Mask for East Windows.

4.10.2 North Windows :

Because of Khartoum's location on latitude 16° north, the sun faces the north walls from May to June. This necessitates shading provision in these months when the overheated periods covers all the day hours except for 1-1 1/2 hours in the early morning (Fig. 3.21). In order to design a shading device which will obstruct the sun at high noon and at the same time the low afternoon and morning sun, two approaches can be followed ; 1) Use very long horizontal canopy to shade the 5 pm. sun with the help of small vertical fins on the sides, or 2) provide larger fins and use the canopy to cast shadows only at noon. The second approach is adopted in this study because of the following advantages and disadvantages of the first approach ;

1) The horizontal eye brows can be roof projections or separate fixed structures and in both cases cost more than merely extending the walls beside the window.
2) In addition to the shading effect, the projected wall functions as a wind inducing element which increases the ventilation (internal wind speed) rates inside the building.

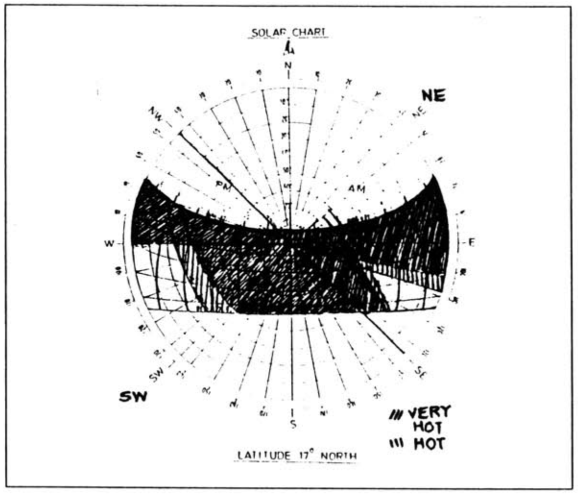

Fig. 4.16 a. Shading Mask for North-East and South-West Windows.

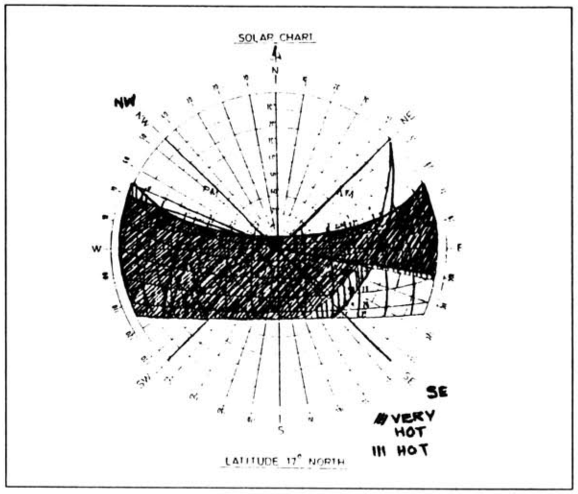

Fig. 4.16 b. Shading Mask for South-East and North-West Windows.

3) Less shade is wasted in the second approach while the first scheme cast shadows on the ground from 7 am. to 5 pm. in addition to the window itself.

Therefore, the proposed configuration (Fig. 4.13) is based on a small canopy to shade against the noon's sun altitute (85° north) and vertical fins or wall projections to cast shadows on the windows from east and west (105° ENE and 110° WNW Respectively).

4.10.3 East and West Windows :

On the east side, fixed vertical fins are not efficient since the sun move from the North to the South over the year. Therefore, either movable vertical fins or eggcrate (combination of vertical and horizontal shading elements) can be used (Fig. 4.15). But still the horizontal elements cannot shade March and April's 9 am. sun. This also applies to the west sides except for the more apparent limitations of the eggcrate shading devices when the high intensity afternoon sun cannot be obstructed.

4.10.4 North-East, South-East, North-west, and South-West Windows:

North-East facing windows need a combination of horizontal and vertical (eggcrate) shading devices to obstruct the low-altitude sun angles in summer mornings (the vertical elements) and the higher angles before noon (the horizontal elements) Fig. 4.16a. In this orientation, both the horizontal and vertical shading elements have the same significance, therefore architecturally, one would expect a non-biased treatment to be used on the North-Eastern facade.

In case of having South-West window orientation, the shading design criteria is more biased towards using more horizontal than vertical elements. This is true because the objective is to shade against the high-altitude afternoon hours from August to April. The afternoon low sun's altitute is best obstructed only from June to August by the use of vertical fins or wall projections Fig. 4.16a. The shading on this orientation is very critical since the solar intensity is at its maximum when it is facing these windows. Architecturally, this may be solved either by staggering the building or using small horizontal shading elements repeated vertically in front of the glazed surfaces rather than using a single element with a large projection to obstruct the sun.

If the window faces the South-East orientation, the vertical fins from February to June shade against the low-altitute morning sun ie. from sunrise to 9 am. (up to an azimuth angle of 80° ESE), while the horizontal elements obstruct the higher sun's altitude from 9 am. to 3:30 pm. from December to June. The chosen profile angle should be 60° to cast shadows in the overheated periods in the south-East exposures and allow the winter early morning sun to heat up the interior spaces.

The North-west exposure is the worst orientation to have windows on. Nevertheless, if the design constraints necessitate such an orientation, the action then is to use vertical shading devices to obstruct the sun up to 110° WNW azimuth angle. Horizontal shading elements are not efficient since they can only shade against the sun from 3 to 4 pm. throughout the year and leave the window in summer (April to September) from 4 t 6:30 pm. exposed to the sun at its highest intensity.

4.10.5 Conclusion on Shading :

This study has shown that the ongoing shading design practices do not fully satisfy the above discussed design criteria. There is a common belief saying that "on the north and south exposures use horizontal shading devices, on east and west exposures use vertical shading devices and on other exposures use eggcrate configuration". This is only true in case of North-East, South-East, and South-West orientations, otherwise the shading design criteria should follow the recommendations mentioned in this section.

4.11 LANDSCAPING :

The effect of landscaping on temperature, humidity, visibility, dust control, and other environmental variables must be taken into account when designing for thermal comfort within specific environmental conditions[14]. The effect of vegetation on microclimate is an essential element of the design even when well-insulated structures (as proposed in this thesis) are dealt with. This is

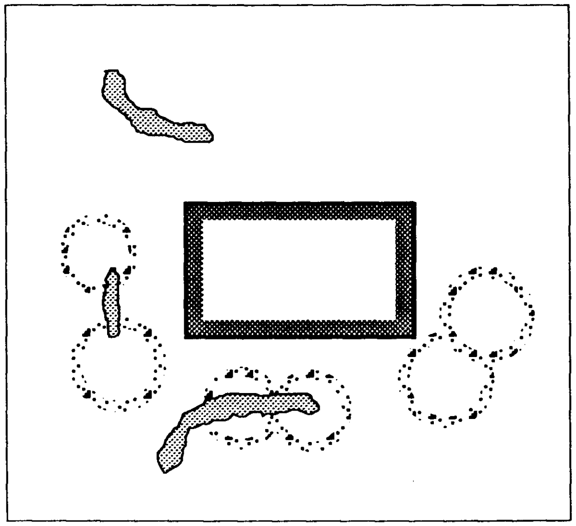

Fig. 4.17. Trees and Shrubs Orientations in Relation to the Building.

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[14] Rizvi, and Talib. "Landscape as Energy and Environmental Conservator in the Arid Regions-Saudi Arabia". Bowen. et. al. op. cit. pp. 355.

inherently so because of the relatively low insulating values of the windows (section 4.8 and 4.9)[15]. Selection of vegetation types depend on whether they are evergreen or deciduous (leaf appearance and fall patterns), mature height and crown, permeability (density of leaves), and rate of growth. Evaporative cooling from the trees isvery difficult to evaluate for a tree or shrub type selection because of their inherent characteristics in hot-arid zones which tend to preserve as much moisture in the leaves and minimize evaporation. Therefore, exotic trees which accelerate the convective air currents by combining the sunny and shaded areas, and also assist cooling by evaporation should be selected[16]. The water which is evaporated from the vegetation has an air-conditioning effect as it absorbs the heat from the air and stores it as water vapor. This only happens when there are enough trees to make a large canopy.

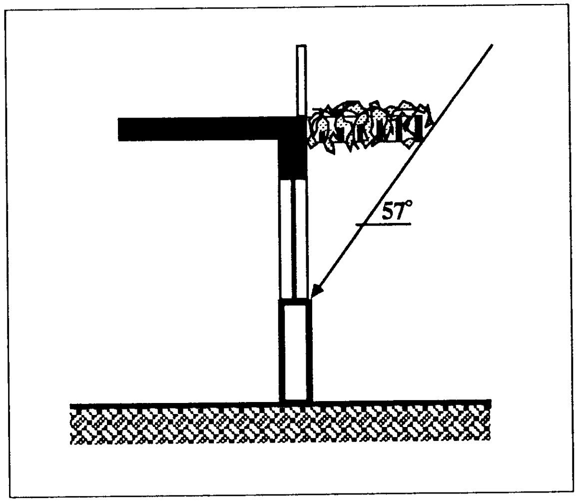

Fig. 4.18. Use of Plants for Shading.

For shading purposes, trees should be located on the southern portion of the site as well as the four corners of the building if the site permits fig 4.17. Overhanging trellises are horizontal solar screens which perform as horizontal shading devices and obstruct the high-altitude midday sun Fig. 4.18. The use of plant solar screens is in fact better than opaque canopies since the diffused light is allowed to enter the interiors, thus improving the daylight quality in the living spaces. Trees with branch heights that allow the low-altitude sun in winter in the

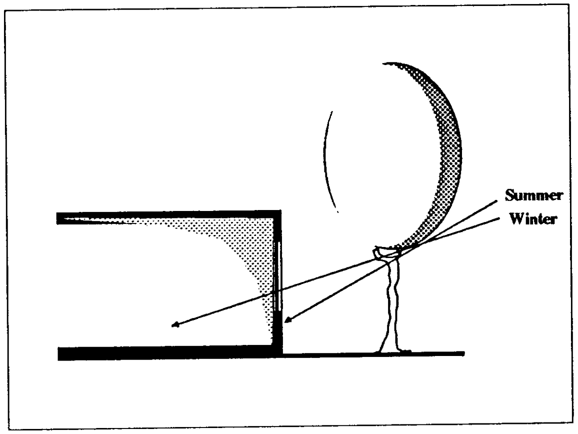

Fig. 4.19. Selection of the right type and height of a tree to shade against summer sun and allow part of winter sun into the building.

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[15] Johnson, Timothy. op. cit. pp. 55.

[16] Montgomry, D. "Landscaping for Passive Solar Cooling". et. al. op. cit. pp. 362.

early morning and before sunset should be located in front of the South-East and South-West exposures Fig. 4.19. Another environmental use of landscaping is the funnelling effect of the cool afternoon wind from October to February to modify the building skin temperature. The wind breaking value of the trees cannot not be perceived or even obtained on this scale because of the thick wind barrier requirements, which by no means fits the Khartoum sub-urban houses limited sites. On the other hand, the filtering of dust underneath the crown reduces the effect of dust storms within the house premises.

CHAPTER FIVE

COOLING SOLUTIONS AND APPROACHES

5.1 GENERAL COOLING CRITERIA :

Passive cooling with natural resources can be attained through several ways[1] :

1) The ambient air (convective cooling).
2) The ambient water vapor (evaporative cooling).
3) The upper atmosphere (radiant cooling).
4) The subsurface earth (direct and indirect cooling).

The combination of these sources is possible, such as combining convective and evaporative nocturnal cooling or combining initial nocturnal

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[1] Givoni, B. "Options and Applications of Passive Cooling". Energy and Buildings Vol.7 No.4, Dec.

longwave radiant cooling of air with subsequent additional cooling by evaporation[2].

5.2 CONVECTIVE COOLING :

Air masses move by virtue of the differences in pressure gradient across a space. This pressure differential builds up by one of two main categories : 1) temperature difference between outdoor and indoor (thermal force or thermal buoyancy) and, 2) external wind flow (wind force or dynamic draft)[3].

5.2.1 Convective Heat Transfer :

The rate of heat transport by convection is a function of the air heat capacity and the rate of flow (unit volume per unit time), and the temperature difference between inlet and outlet air. The convective heat transmission rate for air exchange between outdoor and indoor (q_{conv}) can be expressed in the following formula[4] :

$$q_{conv} = CFM \times 60 \times p \times c \times (T_o - T_i)$$

Chapter Five

[3] Watson and Labs. “Climatic Design”. McGraw Hill Book Co. New York. 1983, pp. 53.

[4] Ibid.

Where : CFM = air flow rate (ft^3 / min),
60 = minutes per hour conversion,
p = air density ,
= 0.075 (lb/ ft^3),
c = specific heat of air ,
= .24 (Btu/ lb °F),
To = outdoor air temperature (°F),
Ti = indoor air temperature (°F).

From this formula, convective heat transfer is proportional to the difference between indoor and outdoor temperature. Therefore, natural ventilation can be an ideal mean of passive cooling if outdoor temperature is below or equals indoor temperature (in the comfort zone). In Khartoum, these conditions occur only in a small part of the daytime over the year. In an experiment conducted in the University of Khartoum[5], it was found that ventilation during the daytime hours has increased the total heat gain within the living spaces because of the high tempera-

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[5] Mukhtar. op. cit. pp. 419.

Room No.	All openings closed			Windows opened from 1800 to 0600 (Night)			Windows opened from 0600 to 1800 (Day)			Windows opened 24 hours		
	Difference in Temperature * Deg.C	Temp. Range Deg.C	Time of Peak	Difference in Temperature * Deg. C	Temp. Range Deg.C	Time of Peak	Difference in Temperature * Deg.C	Temp. Range Deg.C	Time of Peak	Difference in Temperature * Deg.C	Temp. Range Deg.C	Time of Peak
1	8.1	25.3	1500	5.8	25.2	1500	9.5	26.0	1500	5.3	20.4	1530
2	3.1	20.3	1500	1.9	21.0	1500	3.9	21.6	1500	4.3	19.6	1500
3	-8.1	3.6	1900	-10.5	3.9	1830	-6.3	4.6	1700	-8.1	4.1	1730
4	-4.3	8.9	1830	-6.8	8.6	1730	-5.2	6.9	1630	-6.0	7.3	1600
5	-7.1	7.1	1830	-8.3	8.1	1730	-5.2	7.8	1730	-6.7	6.2	1800
6	-1.7	12.8	1700	-3.5	14.0	1700	-0.5	13.5	1700	-2.2	11.4	1800
7	-1..3	12.6	1800	-3.8	12.6	1700	-0.2	13.0	1600	-1.2	11.7	1700
8	-6.3	6.8	1500	-8.2	8.6	1500	-4.5	8.3	1500	-5.4	6.9	1500
9	-6.0	6.4	1530	-8.2	8.3	1600	-3.9	8.0	1600	-5.1	7.0	1600
10	1.1	9.7	1500	No recording						2	16.2	1500

Table 5-1. Effect of Nighttime Ventilation on Maximum Internal Temperature (Mukhtar, Ref. 5)

Month	Mean Min Temp. (F°)	Qconv. Btuh	3000 cfm Evaporative Cooler Equivalent	Time Constant	Surface Temp. (F°)
April	73.3	60653	2	5 hr.	-1
May	79.9	26438	1	"	-0.5
June	80.8	21773	1	"	-0.5
July	77.9	36806	1	"	-0.7
August	76.5	44064	2	"	-1
September	77.9	36806	1	"	-0.7
October	77.4	39398	1	"	-0.7

Table 5-2. Night Ventilation Heat Removal (Summer Conditions).

ture difference (T_o - T_i). On the other hand, the nighttime ventilation has reduced the total heat gain and consequently the maximum internal temperature is delayed and reduced in magnitude (Table 5-1). Natural ventilation is best used during the daytime in the winter season and the night and early daytime periods throughout the summer (from March to mid-October). This time also coincides with the period on which the dust storms (haboob) frequency is at its minimum (Fig.3.7). Table 5-2 shows the cooling effect of the pre-sunrise ventilation from April to October.

Although the cooling effect on this period is equivalent to one to two desert-type air coolers, the reduction in the interior surface temperature is marginal and cannot be used to store the coolness in the interior masses.

In winter pre-sunrise hours from December to February (Table 5-3), the heat removal from the interior is equivalent to four evaporative (desert-type) air coolers. In addition to the high rate of heat transmission air exchange, the relatively longer duration of cool and uncomforTable condition period facilitates storing coolness in the interior masses unless fans are usaed to blow air through channels in the mass.

Month	Mean Min Temp. (F°)	Qconv. Btuh	3000 cfm Evaporative Cooler Equivalent	Time Constant	Surface Temp. (F°)
December	62.6	116121	4	5 hr.	-2.2
January	60.3	128045	4	"	-2.5
February	62.8	115085	4	"	-2.2

Table 5-3. Night Ventilation Heat Removal (Winter Conditions).

5.2.2 Stack Effect :

When the inlet and outlet windows are not on the same height, the thermal force that moves the air is called the stack effect. It depends on the the cooler air replacement at the bottom of the stack. This is a function of the difference in inlet and outlet aperture, the height, and temperature of the air in each case. The driving pressure difference is the different unit forces exerted by the columns of indoor and outdoor air over the height (h)[6]. The larger the distance between the intake and outlet vent the greater the air flow as given by the following relation where V is the air velocity in feet per minute[7],

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[6] Watson and Labs. op. cit. pp. 54.

[7] Johnson, Timothy. "Solar Energy". op. cit. pp. 94-95.

$$V = k\sqrt{h \times (T_u - T_d)}$$

Where

k = constant,
= 9.4 (in British units),
h = the distance between intake vent and exhaust vent, in feet.
T_u = the average air temperature at the exhaust vent, in °F.
T_d = the average air temperature at the intake vent, in °F.

The cfm (amount of air flow in cubic feet per minute) equals free area of opening multiplied by air velocity, ie.

$$cfm = A \times V$$

Where A = free area of opening, in square feet.

Therefore, the amount of air flow in the stack can be computed from the following relation ,

$$A\,k\sqrt{h \times (T_u - T_d)}$$

This phenomena can only be used in the absence of wind force effect which washes away the thermal pressure differential effect. Architecturally, this may lead the designer to consider (in multi-storey houses) an open plan layout through which the first floor opens to the second through a void in the floor. The staircase can also be used to create this buoyant draft and drains out the hot air from the entire structure.

As for the natural ventilation, the possibility of using the draft effect is primarily dependant on the time of the year and and the period of the day (section 5.2.1).

5.2.3 Cross Ventilation (Wind force Ventilation) :

When outdoor wind is obstructed by a solid barrier (e.g. a non-permeable wall construction), the air stream is disturbed and deflected around the building. This obstruction raises the air pressure (Kinetic energy transformation), in the windward side (positive pressure), and at the same time creates negative pressure pockets on the leeward sides. This is more apparent when the obstacle is perpendicular to the wind direction. In case of oblique wind direction this pressure is reduced and distorted according to the direction and speed of the wind (Fig.5.1)[8].

The stagnant pressure (P_{stag})is a function of the wind velocity (V) -wind speed and direction- and the density of the outdoor air. This can be expressed

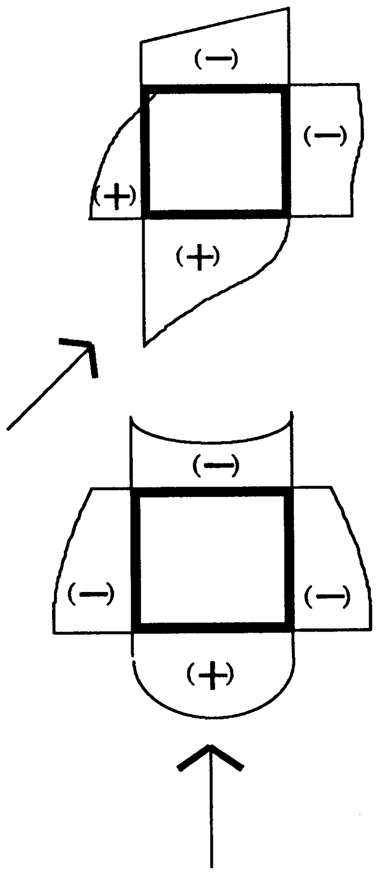

Fig.5.1. Effect of Wind Direction on the PressurePockets (Source: Givoni, Ref. 8).

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[8] Givoni, B. "Man, Climate, and Architecture". op. cit. pp. 283.

as follows :

$$P_{Stag} = 1/2\ p\ V^2$$

Where : P_{stag} = static wind pressure (psf)
p = density of outdoor air (pcf)
V = wind velocity (fps)

Considering the air density as constant, the only variable by which the rate of internal air movement and speed is determined is the wind velocity. Together with this, the window openings in terms of number, position, size, and whether the windows have baffles (wind inducing elements) or not, affect both the amount and speed of the inlet air. These relations are shown in figures 5.2 to 5.7[9]. In Khartoum, the vertical shading devices are required in the four cardinal sides which can also be used as baffles (section 4.10) during the early summer mornings (fig 5.8).

The position of the outlet and inlet window aperture at various heights affect the efficiency of ventilation (Fig.5.9). In temperate climates, the best combination is to have the inlet window below the ceiling and the outlet near the

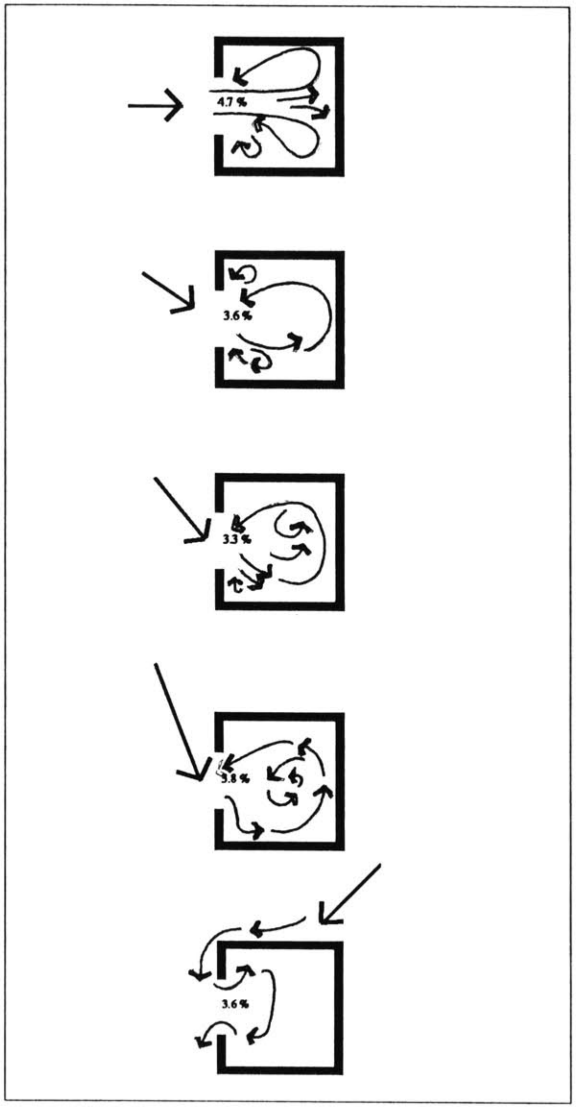

Fig. 5.2. Average air velocity for varous wind directions (Melarago, Ref. 9).

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[9] Melarago, M. "Wind in Architectural and Environmental Design". Van Nostrand Reinhold Publishing, New York, 1982, pp. 322-337.

floor on the opposite side[10]. But in overheated climates, the ceilings are usually high to allow the stratified hot air to remain suspended above the body level. Using the above mentioned window layout forces the hot air back to the usable volume of the space and thus increases its ambient temperature. A better layout is to have the inlet at the floor level and the outlet approximately at the human height (six feet maximum). Thus the inlet air is contained within the usable space without mixing with the hot air which is trapped under the ceiling. As this hot air cushion gets thicker, it seeps out with the outlet air without reaching the working height level.

5.2.4 Mechanically Forced Ventilation :

In Khartoum there are two ways to ventilate the space using mechanical means. The most common is the ceiling fan and the second way is to operate the evaporative cooler only with the fan without wetting the pad. These methods are very energy efficient since the fan is the only part which requires to be operated and their energy consumption is about 20% of the total energy consumed by the most efficient air-conditioning system[11]. The major disadvantage of electrical fans in the Sudan is that they can only provide cooling effect during the rainy season (high relative humidity) otherwise, they increase the hot air speed and consequently increase the conductive and convective heat gain to the occupants. The other

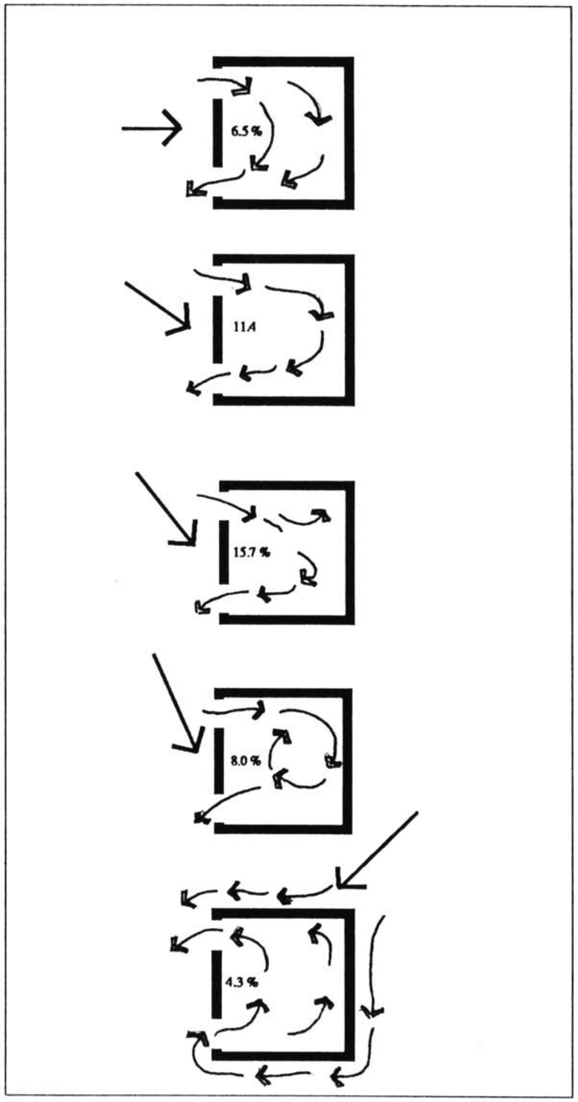

Fig. 5.3. Ventilation with two apertures on the same wall (Melarago. Ibid).

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[10] Ibid. pp. 331.

[11] Tang, J. op. cit. pp. 29.

disadvantage of the ceiling fan is that it pushes the stratified hot air from below the ceiling and mix it with the relatively cooler air at the body level. Because of the frequent power failures and programmed shedding, depending on electricity should not be the prime consideration when designing for thermal comfort in the hot arid Khartoum. On the other hand, increasing the indoor air speed increases the rate of evaporation from the skin and thus creating a cooling effect on the the occupants.

5.3 NOCTURNAL RADIANT COOLING :

5.3.1 Basic Principles :

Radiant heat flow between two surfaces is an electromagnetic heat transfer that depends on the temperature difference of the surfaces. Outer space is considered as an imaginary dome at a very low temperature. The degree of radiation to the night sky depends on the moisture (water vapor or clouds) and dust (or impurities) content of the atmosphere. Since these are opaque to IR in large quantities, increasing any of the obstacles in the atmosphere will decrease the efficiency of the nocturnal radiation cooling effect regardless of the radiator. This

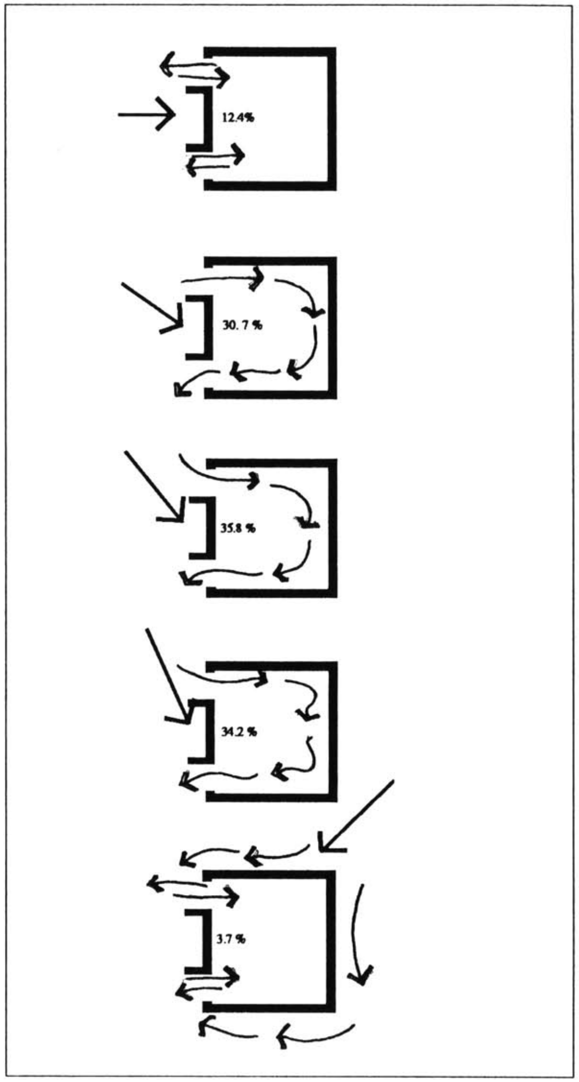

Fig. 5.4. Ventilation through a spasce with two apertures with baffles (Melarago, Ibid).

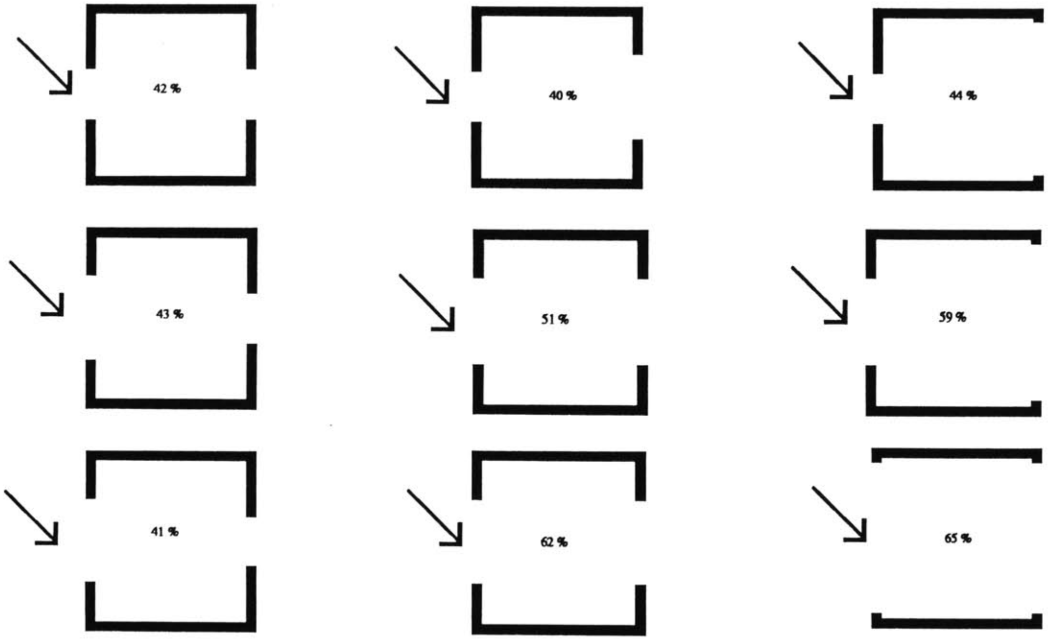

Fig. 5.5. Openings on opposite walls; wind oblique to inlet (Melarago, Ibid).

can be summarized in the following[12] :

1) Except under very dry and clear sky, the radiant temperature rarely drops by more than 18° C (32° F).
2) The temperature differential between the ambient air and sky

[12] Watson and labs. op. cit. pp. 64.

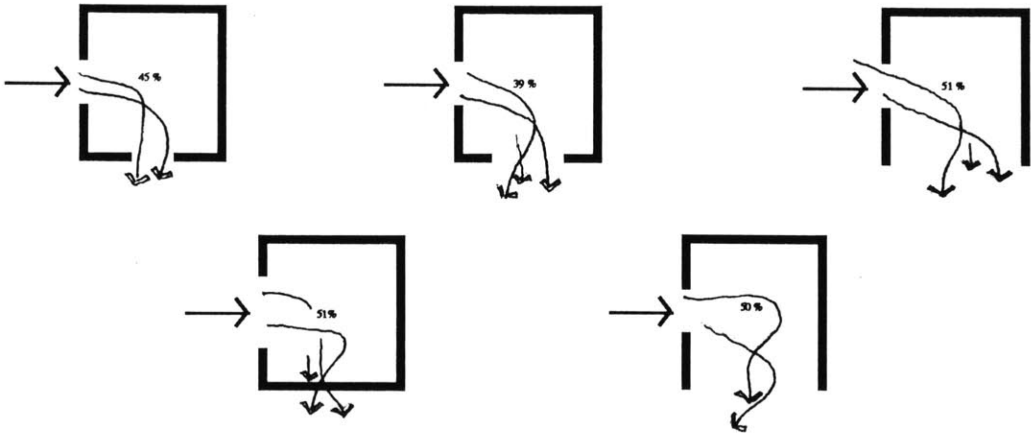

Fig. 5.6. Effect of inlet and outlet sizes in cross-ventilated spaces (Melarago, Ibid).

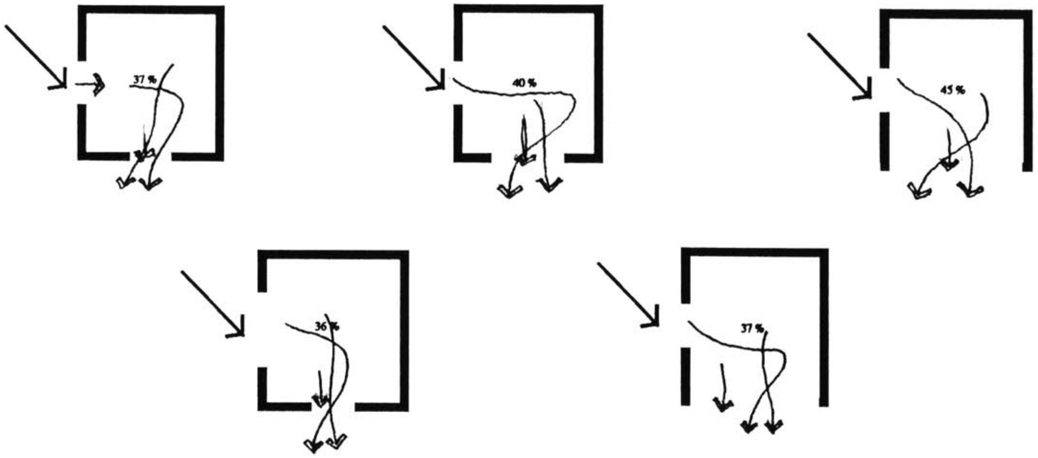

Fig. 5.7. Openings on adjacent walls; wind oblique to inlet (Melarago, Ibid).

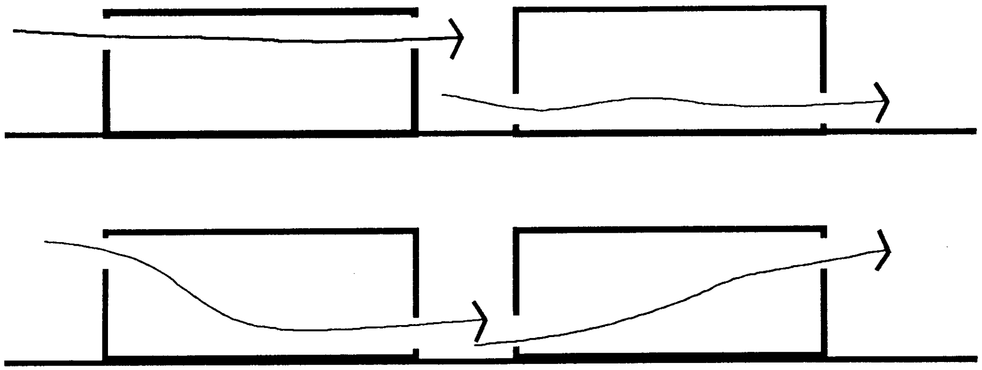

Fig. 5.9. The effect of positioning the aperture at varoius heights (Melarago, Ibid).

temperature is determined by moisture content of the atmosphere which in case of overcast night conditions may slightly reduce the nocturnal radiation cooling process (the clouds are usually 20° F cooler than the ground).

3) Convective heat exchange can also erase the radiant temperature depression by a factor of 50% to 85% when the warm air blows at speeds of 3 to 7.5 mph respectively.

There are two approaches to utilize the night sky radiation losses to cool down buildings[13] :

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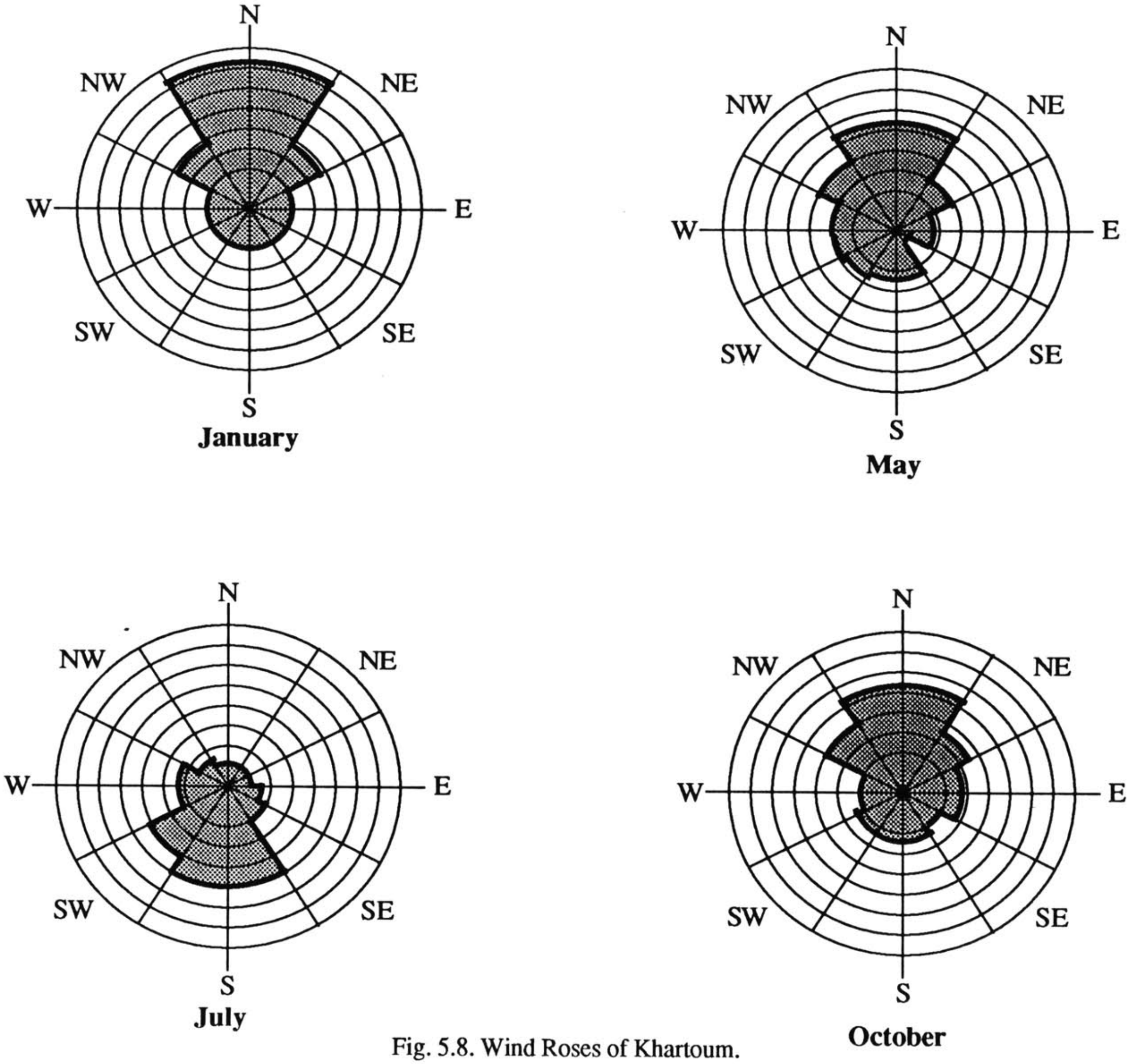
[13] Givoni, B. "Options and Applications of Passive Cooling". op. cit. pp. 298.



January

May

July

October

Fig. 5.8. Wind Roses of Khartoum.

Temperature in F°	Btu/ lb	Btu/ gallon
32	1075.1	8961
40	1070.6	8924.5
50	1065	8875.5
60	1059.3	8822.1
70	1053.7	8766.7
80	1048	8706.5
90	1042.2	8646.7
100	1036.7	8575.6
110	1030.9	8510.1
120	1025.2	8444.6
130	1019.4	8376.4
140	1013.6	8308.1
150	1007.7	8237.4
160	1001.8	8166.1
170	995.8	8092.9
180	989.8	8018.9
190	983.7	7916.2
200	977.5	7838.5
212	970	7749.7

Table 5-4. Latent Heat of Vaporization of Water at Atmospheric Pressure. (Source : Watson and Labs. Climatic Design, Ref. 11).

(A) DIRECT NOCTURNAL COOLING (SKYTHERM) :

This approach depends on cooling a storage mass (e.g. roof) and protecting it during the daytime from solar radiation and ambient outdoor air (Fig.5.10). The problem of this approach is summarized in the following :

1) High dead loads on the roof which necessitates special structural

considerations.

2) Utilizing most of the roof area which might be used for sleeping or any other social activity.

3) Proper installation requires relatively high labor skill.

4) Unless the daily mounting and dismounting of the insulation covering panels is operated mechanically, manual operation makes this systems unattractive.

(B) ISOLATED LOSS SYSTEM (LIGHTWEIGHT ROOF RADIATION) :

In this type, a lightweight radiator is used to cool down the ambient air or water and store it in the building mass or any special thermal storage within or near the building itself (e.g. rockbed).

The major problem with this approach is its high conductance, since the low mass enables the roof to respond instantaneously to the outdoor temperature. This is generally considered unacceptable because of its poor performance during the daytime overheated periods.

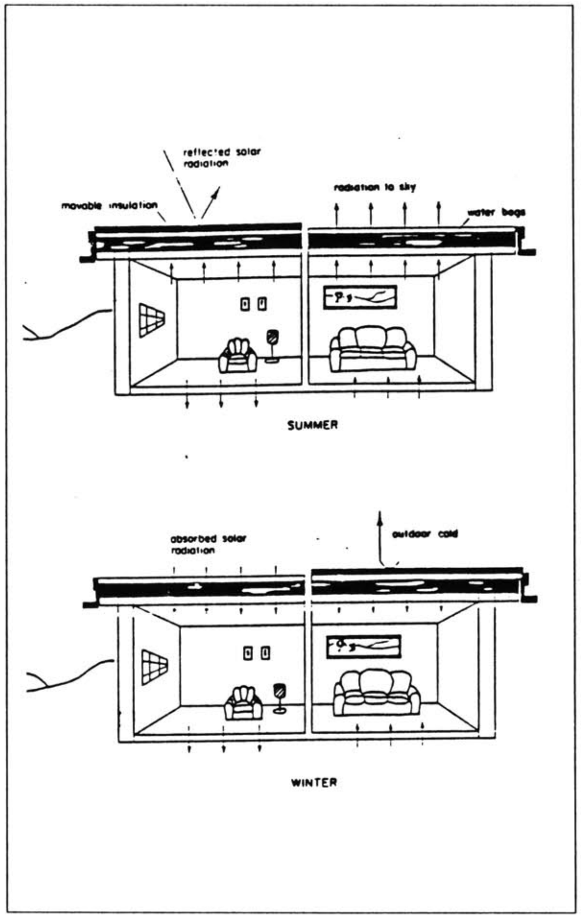


Fig. 5.10. Night Sky Radiation (Mamazian, Ref. 19).

Month	Mean Max Temp. (F°)	Btu/ lb
January	88	1046.1
February	92.1	1041
March	98.6	1037.5
April	104.2	1034.3
May	107.6	1032.3
June	106.5	1032.9
July	100.6	1036.4
August	97.5	1038.1
September	101.3	1036
October	102.6	1035.2
Novemeber	95.4	1039.2
December	89.2	1042.7

Table 5-5. Latent Heat of Vaporization in Khartoum over the Year.

5.3.2 Transparent Wind Screens :

In order to overcome the effect of the convective heat exchange mentioned in section 5.3.1, the efficiency of the radiant cooling process can be increased by using a transparent Polthene film (Polypropelyne and Teflon are also used) which is 60% to 80% transparent to longwave radiation. The idea is not to interfere with the emisision of the IR to the atmosphere, while creating an insulating air space (by spacing the film away from the IR emitter). That insulates the cool emitter from the warm atmosphere and the heat adding effects of the wind that normally would brush the emitter with warm air. Any condensation that forms on the film stops the IR transmission through the plastic film becuause liquid water is opaque to IR. Also another problem is that the film must be thin enough to maintain IR transparency, but this seriously reduces the film's strength (resistance to erosion, falling branches, etc.), and UV degredation is a problem with Polypropelyne[14].

However, the dew point is often reached on both the film and the radiant surface, hence obstructing the cooling process. This is because the emissivity of the of the water is the same as that of the ordinary surface (90%) and thus eliminating the temperature difference between the two radiators[15].

5.3.3 Selective Radiators :

In order to maximize the net radiant heat loss, special reflective radiators have been developed. Their basic characteristics concentrate on their ability to admit the longwave radiation of the atmospheric window (8-13 microns) while reflecting most of the other atmospheric radiation. But when these selective radiators were tested, no superior thermal performance was proven. Basically this is because of the dew that is collected on the supercool surfaces intrfering with solar transmission, and thus nullifying their selective properties[16]. White paint is a good example of selective transmitters.

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[15] Johnson, Timothy. From Class Notes M.I.T. 1988.

[16] Givoni. op. cit.

5.4 EVAPORATIVE COOLING :

5.4.1 General Approaches :

Cooling the interior of a building using the evaporation of water can be accomplished by two approaches. The first is the direct cooling (Adiabatic) where air is passed by evaporating water and consequently loses its heat which is consumed to change the state of water to vapor. Thus, the air is humidified (increases its relative humidity or the moisture content of the air) without changing its total heat content (enthalpy). The second approach is to cool the building by evaporating the water in an isolated space or building element (indirect evaporative cooling). This element acts as a heat sink which in turn absorbs heat from adjacent spaces without increasing the water content of the air (sensible cooling).

Because of the dry conditions, evaporative cooling systems are most suitable in the abundance of water resources in Khartoum. Evaporative cooling effect is calculated from the latent heat of evaporization (Tables 5-4 and 5-5)

Increasing the wind speed increases the rate of evaporation by whisking away the highly humidified air that clings on the water surface (section 5.4.4). On the other hand, the air may either supply or extract heat depending on whether the air temperature is higher or lower than the water surface temperature respectively. The net heat exchange balance between the combined effect of the convective and evaporative cooling depends primarily on which dominates of the media involved in the energy transaction (temperature vs. humidity)[17].

5.4.2 Roof Ponds :

Roof ponds consist of a heat conducting roof overlayed with thin transparent bags filled with water which collect, store, and distribute heat where it is exposed to solar radiation, cool night air, and night sky radiation[18]. During overheated periods, the heat moves upwards to the ceiling and to the water filled thermoponds, thus cooling the interior spaces. During the nights, the building interior is cooled by exposing the water surface or bags to the night sky . Movable insulation is used to control the thermal behavior of this system for either heating or cooling the building on diurnal and seasonal overlays (Fig.5.11). When using water instead of concrete, the energy stored per unit weight is higher, but at the same time, the isothermal effect tends to nullify the time-lag. However, this disadvantage which eliminates the diurnal cycling, can be overridden by the use of movable insulation though its day long efficiency will not exceed 45%.

The main advantages of this approach are crystalized in four points :

Chapter Five

[17] Watson and Labs. op. cit. pp. 66.

[18] Total Environmental Action Inc., Los Almos Scientific Labs., and Los Almos National Lab. "Passive Solar Design Handbook". Nostrand Reinhold Co. Los Almos, 1984, pp. 52.

1) Provision of both heating and cooling with the same configuration and operational modes.
2) Uniformity of cooling and heating distribution within single-storey living spaces.
3) Reduction of temperature swings in the buildings.
4) Requiring only a supply pipe and an adjustable drain.

Additional advantages are mentioned in section 5.3.1. The main disavantage of this system is its weight which requires special structural considerations. The system also has the following disadvantages if the water is uncovered to make use of the evaporative cooling[19] :

1) The still water is generally apt to become a breeding place for mosquitos and algae.
2) Soot, dust, and oil (for preventing mosquitos from breeding) on the water would tend to reduce the reflectivity and hinder evaporation of water.
3) This would also cause the water to heat up and to a higher temperature.

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[19] Mamazian, A. op. cit. pp. 133.

5.4.3 Roof Sprinkler Systems :

Another evaporative, convective, and conductive cooling method that is installed on roofs is the roof sprinkler (spray) cooling system. It functions mainly as a prevention measure of the adverse effect of solar radiation. This system is used during the daytime hours (10-12 hrs.)in the summer (refer to the overheated periods diagram Fig.3.20)[20].

In this system, nozzles are placed so that the spray covers the entire roof surface. The spray pipes can be laid on the roof surface since the water temperature has little effect on the cooling process of the system (Table 5-4). This method can provide the greatest possible range of damping spray with the least amount of water. This does not only save water, but also gives the greatest cooling effect since it produces the highest degree of evaporation. With properly adjusted spray, the sprinkler installation can reduce the transmission of the solar heat by 80%.

The amount of water used by the sprinkler system depends on the number of hours in which the system is in operation. However, in order to reduce water consumption, a central device can be added to the system on automatically for certain intervals during the day in summer. If the sprays were operated for 41

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[20] Ibid. pp. 128.

seconds out of each five minutes cycle, or slightly less than 14% of the total time, the flow rate will be 0.29 lb/hr Ft^3. In this way, water can be considered as a most economical refrigerant, since one gallon represents about 8530 Btu (Table 5-4) of cooling capability. Comparing the potential cooling of this system with the cooling loads (in June) of the model house studied in Chapter Four, the total heat gain when using single Low-E Glazing and wall and roof insulation, can be balanced theoretically when a little more than five gallons of water are evaporated on the roof.

The advantages of this system are :

1) No time-lag between maximum solar heat and maximum heat penetration into the building.
2) Under the same climatic conditions, the sparyed roof is 18 times as effective as a dry roof in terms of excluding solar radiation.
3) It is thermally more efficient than the roof pond cooling system.
4) It is an effective passive cooling system for both flat and pitched roofs.

The disadvantages are :

1) The roof sprinkler cooling system needs special structural considerations and moisture insulation which represent additional costs in areas where such insulation measures are not needed (low precipitation rates during the short rainy season).

2) The most obvious argument against these systems is the occupants' preference to use the accessible roofs as sleeping areas.

3) Installation and maintenance costs are usually higher than most of the other cooling systems which can provide the same thermal benefits within the building envelope.

5.4.4 Thermal Characteristics Determination :

The thermal analysis of the above evaporative cooling systems is based on ; convection, radiation to the night sky, and evaporation. As expressed by the following relationship[21]:

(A) CONVECTION :

$$Q_c = (1.0 + .33 \times V) \times (t_w - t_a)$$

Where : Q_c = rate of heat flow in Btuh to or from the pond by convection.
t_w , t_a = temperature of the water and air respectively in F°.
V = Velocity of Air in mph.

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[21] Mamazian, A. op. cit. pp. 134-135.

(B) RADIATION :

$$Q_v = (0.95 \times R_{pw} - C_a \times R_{pa})$$

Where : Q_c = radiant energy exchange in Btuh.

R_{pw}, R_{pa} = radiation powers of black bodies at the temperature of the water and the air respectively (Btu/ ft^2).

C_a = Emittance of the atmosphere (ratio).

(C) EVAPORATION :

$$Q_e = 0.093 \times hfq \times (1.0 + 0.38 \times V) \times \Delta P_v$$

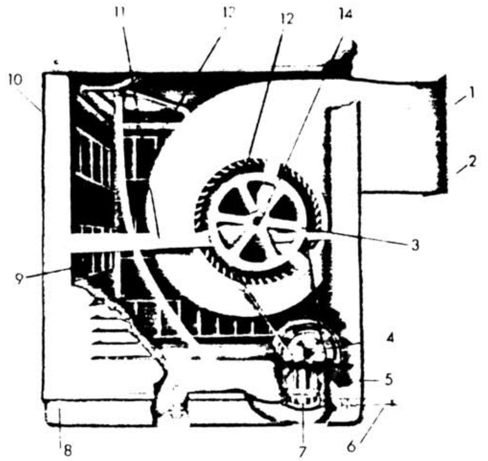
Where : Q_e = rate of heat loss by evaporation in Btuh.

hfq = latent heat of water at pond temperature (Btu/ ib).

ΔP_v = Difference between vapor pressure of the pond and the atmosphere (hg).

V = wind speed (mph).

Evaporative heat loss of an open pool is a function of the wind velocity and the difference between the vapor pressure of the pond water (P_w) and of the ambient air (P_a). The vapor pressure of the water depends entirely on its temperature while the dew point temperature determines the vapor pressure of the atmosphere.



1	Control for air volume	8	Bolts
2	Switches	9	Snap--shut type pad frames
3	Blower pulley (quiet action)	10	Blower mount support
4	Motor	11	Blower wheel
5	Weather resistant exterior finish	12	Even-drip water trough
6	Supports	13	Bronze bearings
7	Water pump, plastic impeller	14	Blower shaft

Fig.5.13. Evaporative Cooler Desert-Type (Source : Stein et. al. Ref 3-20).

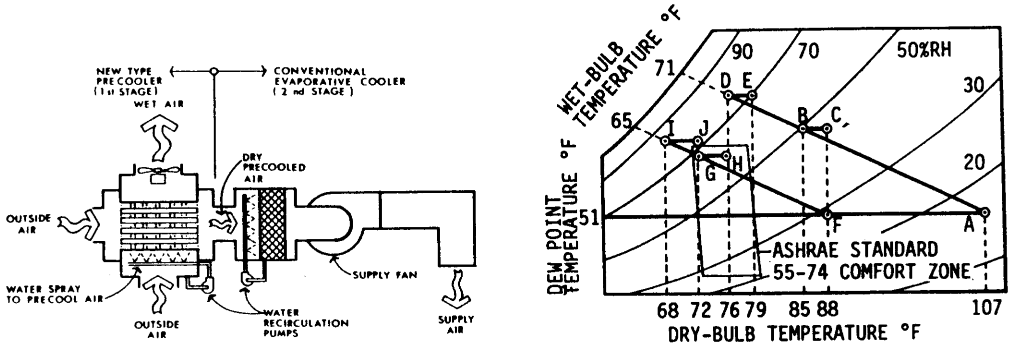


Fig. 5.14. The Cooling Effect of the Two-Stage Evaporative Cooler (sherman and Evans, Ref. 23).

5.5 EVAPORATIVE COOLERS :

Although these are hybrid systems (with electrical driven motors), they are worth consideration as cooling alternatives since the energy is required only to operate the electrical fan.

The evaporative cooling process can be obtained through evaporating water at ambient temperature into the air stream. So, the dry-bulb temperature (DBT) is reduced along a line of constant wet-bulb temperature (WBT) with a consequent increase of latent heat and moisture content of the air in the conditioned spaces[22].

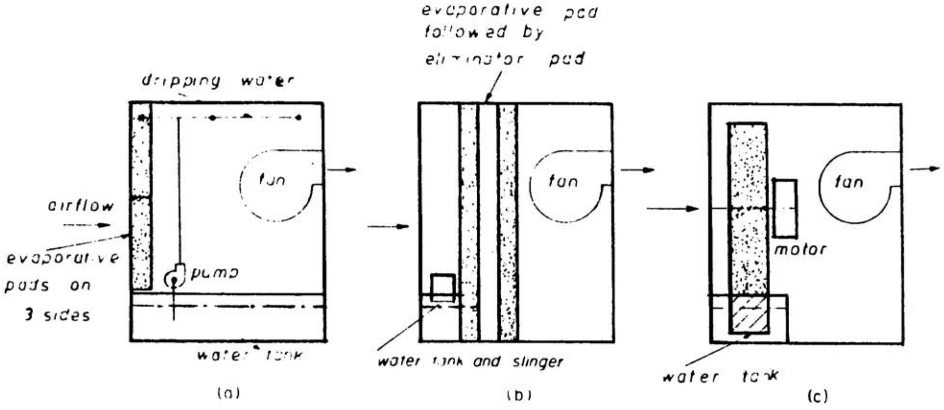


Fig.5.12. Evaporative Air Coolers : (a) Drip type, (b) spray type, and (c) rotary type. (Source : Sayigh. Ref. 22).

There are many types of evaporative coolers types classified by spraying water system or evaporation cooling process. Among these the drip or desert-type will be discussed in this section. This type is manufactured and used in the Sudan because of its simplicity and relatively low cost. It is a fan unit with evaporative pads over which water passes through a small circulating pump (fig 5.13). The pads are usually made of saw-dust or aspen wood. The cooling process may be idealized as an adiabatic saturation, with the exception that complete

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[22] Sayigh. "Passive Cooling of Buildings". Solar Energy Applications in Buildings. Sayigh ed. op. cit. pp. 152.

saturation may not necessarily be achieved or even desired. The cooling process of these coolers is directly proportional to the change in the amount of water in the air.

The dry-bulb temperature of the air leaving the cooler is determined by the dry-bulb (T_{DBL}) and wet-bulb temperature of air entering a space as well as the efficiency of the pad (n). This relation can be expressed in the following formula[23]:

$$T_{DBL} = T_{DBE} - n\,(T_{DBE} - T_{WBE})$$

Where : T_{DBL} = dry-bulb temperature of air leaving the cooler (F°).
T_{DBE} = dry-bulb temperature of air entering the cooler (F°).
T_{WBE} = wet-bulb temperature of air entering the cooler (F°).
n = pad coefficient.

Figure 5.13 shows the performance of a desert-type evaporative cooler with pad efficiency of 75% under the summer design conditions of Khartoum (line ABC)[24]. From this figure, evaporative coolers decrease the dry-bulb temperature from 41.6° C (107° F) to 29° C (84° F) which is represented by line AB. But the relative humidity jumps from 23% to 70% which is higher than the thermal comfort

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[23] Sherman and Evans. "System Simulation of Six Conventional And Hybrid Evaporative Cooling Alternatives for Residential Applications in Hot desert Climates". Passive Cooling. Bowen Ed. op. cit. pp. 232.

[24] ASHRAE. op. cit. pp. 2.21.

requirement. When the entering air mixes with the hot interior air it rises to 33° C (91° F) and reduces the feeling of comfort. This explains why the occupants arrange their furniture and working spaces keeping a small distance from the cooler outlet. This problem can be solved by increasing the pad efficiency, but still the maximum it can get is 85% which will not substantially drop the dry-bulb temperature of the leaving air or otherwise increasing the horse power of the blower (use bigger unit) which will increase the energy consumption dramatically (proportional to the cube of the fan speed FS ratio). This is explained by the following relation :

$$HP = \left[\frac{\text{New FS}}{\text{Old HP}}\right]^3 \times \text{Old FS}$$

Where : HP = horse power.

FS = fan speed.

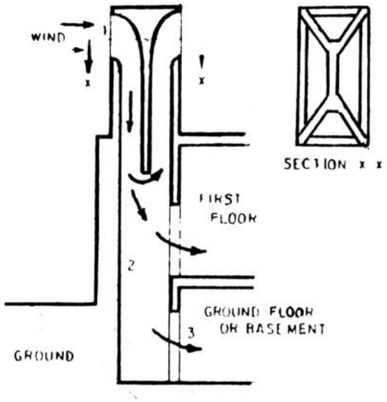

Fig.5.15. Operation of wind Tower in Summer. (Source : Bahadori,Ref. 25).

5.6 TWO-STAGE COOLING PROCESS :

The two stage evaporative cooling process combines a dry heat exchanger (sensible cooling without increasing the moisture content of the air - represented by line AD in Fig.5.13) in the first stage with a conventional evaporative cooling system in the second stage (Fig.5.14). This system allows (theoretically) to override the limitations of the conventional systems in which the cooling process is limited by the WBT of the entering air since the first stage cools down the air in the heat exchanger unit without moisture, the WBT is reduced before it enters the conventional evaporative cooling process. Because of the relatively low WBT (low relative humidity), this cooling process can bring the indoor conditions to the thermal comfort zone. But this system requires a continuous 100% outdoor air supply, otherwise, the relative humidity builds up till it reaches uncomfortable indoor conditions. Against the summer climatic design conditions, the two stage cooling process brings the indoor dry-bulb temperature to 29° C (84° F) and relative humidity to 60% after the entering air mixes with indoor air (line EF).

The advantages of these systems are ;

1) Consume much less energy than other air-conditioning systems, since the fan and the small pump are the only elements which need electricity.
2) For day conditions, these systems can provide the required humidity through natural processes.
3) These systems are relatively inexpensive (locally manufactured and installed) and at the same time easy to maintain and operate.

The disadvantages can be summarized in the following :

1) This system depends primarily on the electrical power supply which is subject to frequent failures specially in times when they are

needed most.

2) Although they are easy to maintain, these systems require continuous maintenance (painting against rust and seasonal change of pads).

3) The whole system fails during a water shortage or loss of water pressure unless a water tank (or any other water storage facility) is used.

5.7 WIND CATCHERS :

5.7.1 Conventional Configuration :

The wind catchers or air scoops are convective and evaporative cooling systems. Basically, they are masonry rooms designed and built to provide natural cooling of ambient air within the building. They admit wind at higher elevations into the living spaces (Fig.5.15).

During the night, when the cool ambient air flows through the tower, it cools the structure (masses of high thermal inertia). This process may be referred to as the storage of night air coolness into the tower mass. During the day, this stored coolness is utilized to partially cool the hot air entering the tower[25]. The air entering

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[25] Bahadori, M. "Natural Cooling of Hot Arid Regions". Solar Energy Applications in Buildings. Sayigh ed. op. cit. pp. 201.

the living space may further be cooled evaporatively in the tower if it can be made to pass over moist surfaces. These conventional air scoops have some disadvantages due to the available technology during the time in which these towers were built. Some of these disadvantages are :

1) Not all the air entering the tower is directed to the living spaces, there is always some air leaving the tower at the leeward openings.
2) The rate of heat transfer for cooling or heating for the storage material is small because the ratio of the surface area to the volume of the storage is small.
3) The rate of mass transfer or evaporative cooling in the tower is small because of the limited area which can normally be provided for the evaporative cooling in the conventional tower design.
4) Dust, insects, and birds coming down through the towers are some of the inconveniences created by this system[26].
5) Formation of mildew on walls and eposed surfaces.

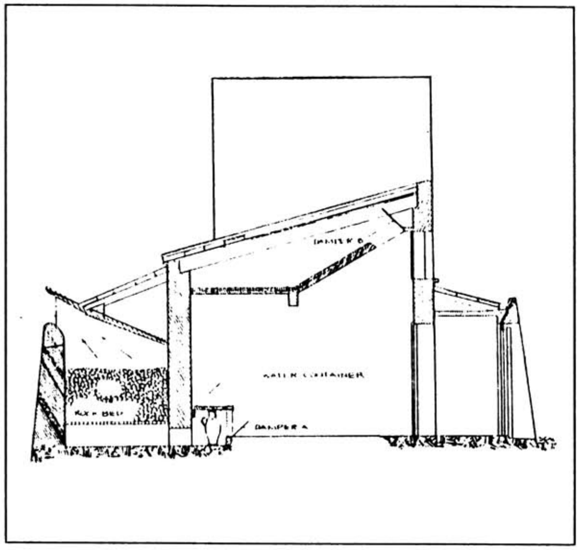

Fig.5.16. A Wind Tower Design Considered for a Settlement of Nomads in Central Algeria (Source : Bahadori,Ref. 28).

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[26] cit. pp. 208.

5.7.2 Solutions and Recommendations :

Air scoops can be very efficient cooling systems utilizing natural sources if they are designed to overcome the disadvantages mentioned in section 5.7.2. A number of recommendations and strategies are outlined for better designs[27]:

1) More and better circulated air should be admitted to the living spaces.

2) The ratio of heat transfer area to the volume of the storage mass should be increased considerably.

3) New evaporative schemes with storage mass transfer area should be introduced to the tower design. Therefore, more effective evaporative cooling can be accomplished with appreciable reduction of the ambient air temperature entering the building.

4) At night, with cool air entering the space, it should be possible to cool the structure to the lowest level. This could not be abtained in the conventional systems because of the small rate of heat transfer.

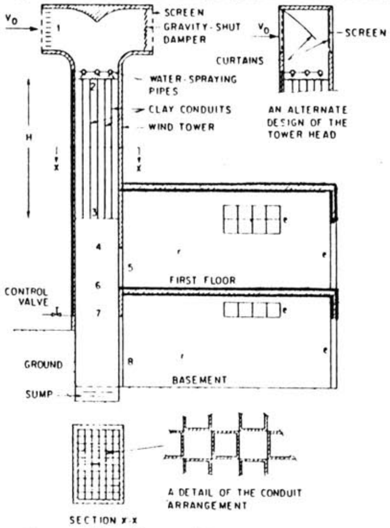

Fig.5.17 a. Cross Section of Improved Wind Tower, (Source : Bahadori, Ref. 28)

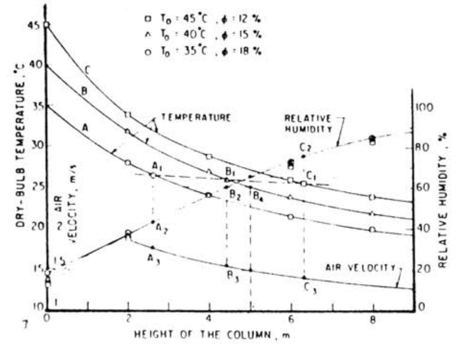

Fig.5.17 b.

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[27] Bahadori, M. "Passive and Low Energy Cooling". Solar Energy Prospects in the Arab World. Alawi. et. al. ed. Pergamon Press. Oxford, 1986, pp. 149.

5.7.3 NEW DESIGNS :

During the last few years, a number of air scoop designs were developed to make use of the natural wind flow at high altitudes in cooling the interior spaces. In this section, two new designs are described.

(A) WIND TOWERS WITH STORAGE OF COOLNESS IN ROCKBED :

A design which uses rocks for additional storage of night air coolness and water containers for evaporative cooling on air is shown in Fig.5.16[28]. During the day, wind blows normal to the opening of the wind catcher. With a wind pressure differential created between this opening and the outlet in the building envelope, air is forced through the rockbed. In passing, air is cooled because the rocks were cooled the night before. The air passed over unglazed clay water containers (jars) were further cooled by evaporation. It is then exhausted through

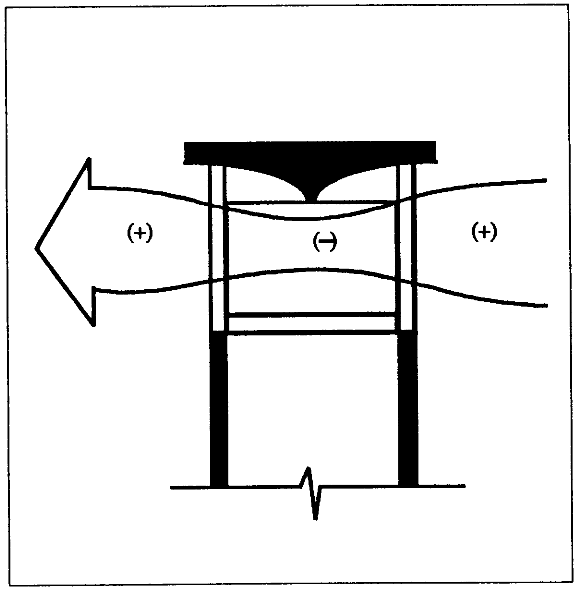

Fig.5.18. Proposed Wind Tower Head Configuration.

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[28] Bahadori, M. "Design of a Cooling System for the Settlement of Nomads in Algeria". International Seminar on Bioclimatic Design. University of Catalina, Italy, 1981.

a solar chimney, which assists in creating additional draft for air flow. During the night, the wind blows from the opposite direction and thus cools the ambient air entering the building through the door and evaporatively cools it as passes through the jars, passes through, and cools the rockbed, and is finally exhausted through the air scoop opening. The water cooled in these jars can be used for drinking[29].

(B) WIND TOWER WITH VENTILATED THERMAL STORAGE :

This scheme is designed by Bahadori[30] with improved air flow characteristics and a more effective evaporative cooling process. This air scoop is composed of a tower through which air (at ambient temperature) passes wetted clay conduits and cools evaporatively before distributed in the different living spaces (Fig.5.17 a).

The results of the above theoretical study showed that for a tower five

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[29] Ibid.

[30] Bahadori, M.N. College of Architecture and Environmental Design, Arizona State University, Tempe, AZ 85287.

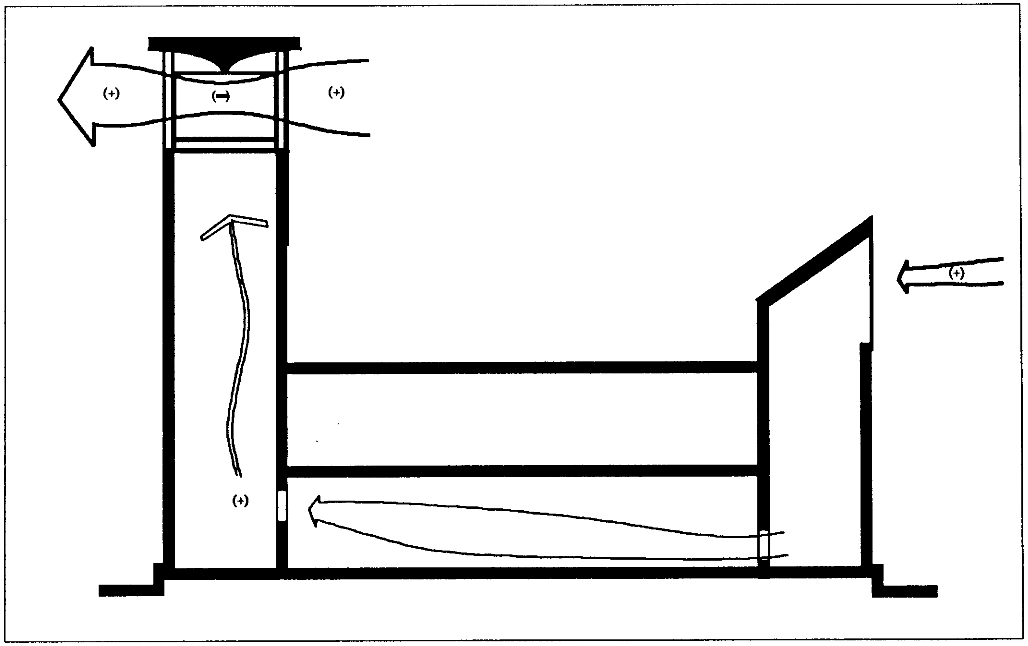

Fig.5.19. Schematic Drawing
of the proposed Scheme.

meters high located in a region with a wind velocity of 5m/ sec (11 mph) and an outdoor state of 40° C (104° F) and 15% RH respectively, the air entering the tower can be cooled down to a temperature of 25° C (77° F) and a relative humidity of 65%. The conditioned air is admitted into a living space of 300 m^3 (10600 ft^3) at a velocity of 0.1 m/ sec (20 ft/ min). Air at these conditions can maintain the thermal comfort of the building occupants (Fig.5.17 b)[31].

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[31] Bahadori, M. "Passive and Low Energy Cooling". op. cit. pp. 149.

5.8 AIR SCOOP/ SOLAR CHIMNEY SCHEME :

5.8.1 Introduction :

The need for cooling systems which are electricity independent and utilize as little as possible of imported materials necessitates the use of air scoops as an alternative system for convective and evaporative cooling. With better understanding of thermal phenomena (natural and forced air movement behavior), and improving thermal properties of building materials, air scoops can be very effective in Hot-Arid climates. In this thesis, a new air scoop design is proposed to overcome the disadvantages of the conventional designs. The new scheme depends on combination of a wind catcher and a solar chimney. The role of the chimney is two-fold : First a solar induced thermal stack effect is created by the temperature difference at aperture openings (which is also dependent on the difference in heights between inlets and outlets). The thermal stack effect is easily overpowered by any wind. The second function of the chimney occurs when air passes through the tower head and accelerates when it squeezes through a nozzle. This creates negative pressure and drags the air up the chimney. In this way, the wind force substitutes for the stack effect and at the same time maintains the same internal air flow pattern.

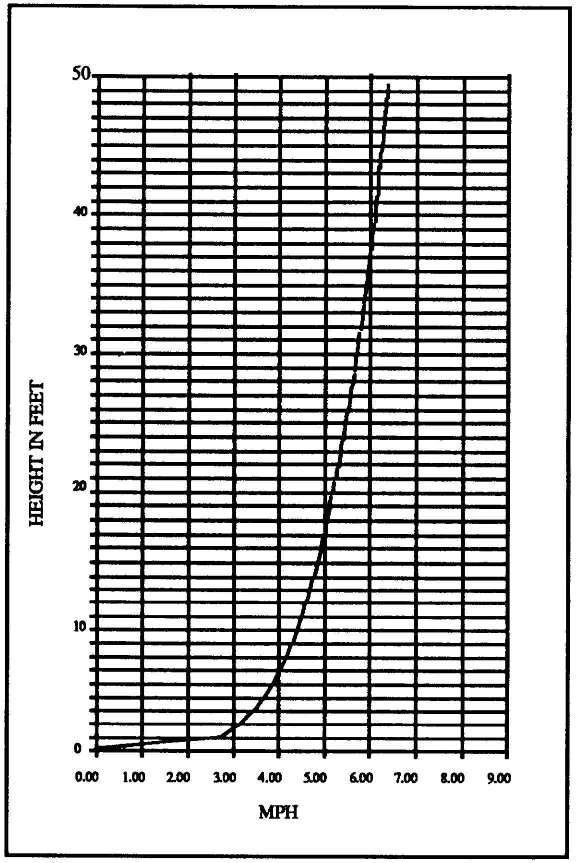

Fig.5.20. Khartoum Wind Profile.

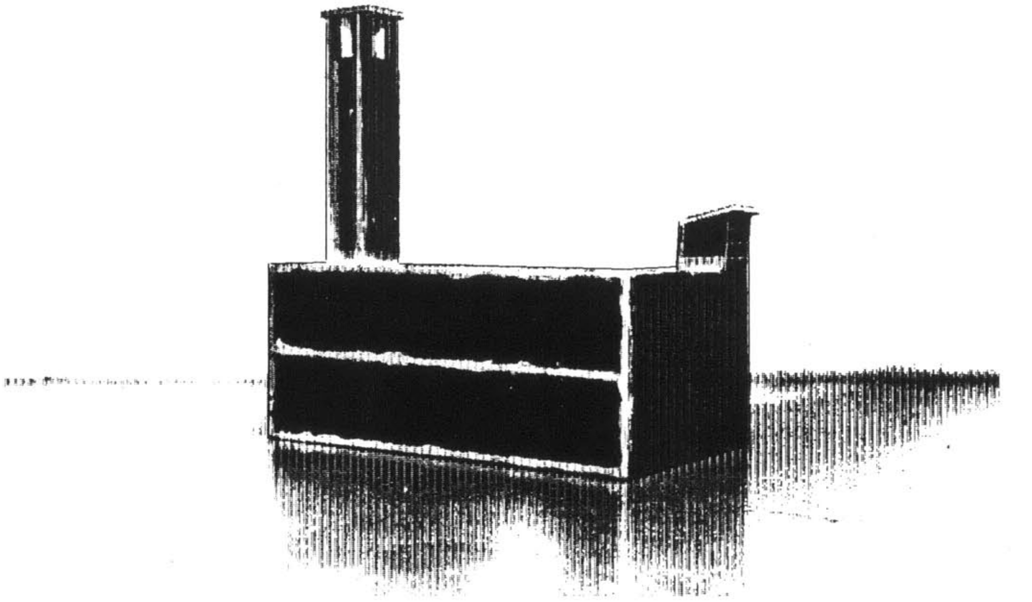

Photo. 6. The Model.

Because of the number of simultaneous functions this configuration performs, the new design can cool down the interior spaces throughout the year in either presence or absence of wind and during day and night. In winter nights (from December to February), the inlet air scoop should be closed. In summer, the cooling effect can be increased by cooling the inlet air evaporatively before it reaches the indoor living spaces.

The new features of this design is the combination of the solar chimney with the outlet stack in one tower. Basically, the difference between this scheme and other conventional and newly developed wind catchers is the nature of the pressure (suction) that forces the air to move within the spaces.

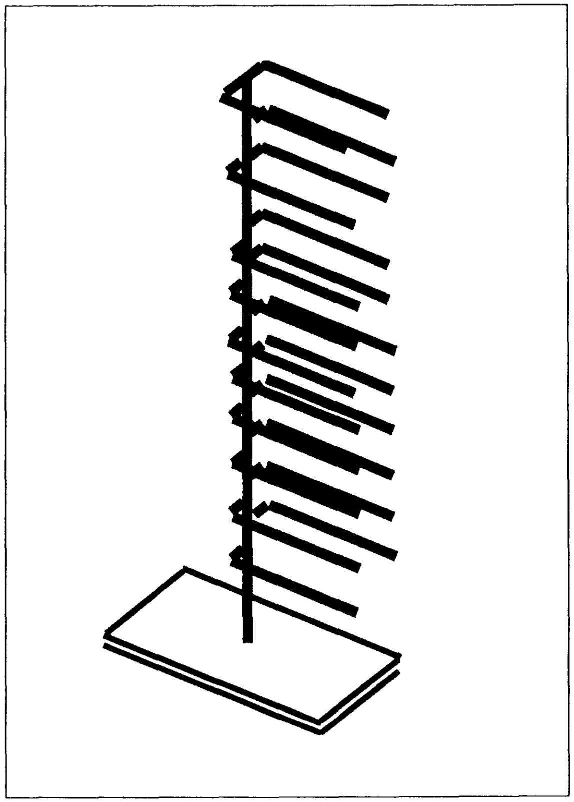

Fig.5.21 a The Pitot Tube Rake.

5.8.2 General Principles of the Proposed Design :

From section 5.2.2, the stack (chimney) effect is proportional to the difference in heights between openings and the square root of the temperature difference of each aperture. The thermal stack effect is added to a wind tower that draws out the air from the interior spaces.

The cross sectional area of the middle part of the head is 75% of each of the windward and leeward openings to increase the wind speed at the center of the outlet stack. The air suction is caused by the Venturi effect at the tower head (Fig.5.18), which creates a negative pressure at the upper part of the stack due to the acceleration of the prevailing wind. Because of this suction pressure at the tower head, indoor air is pulled through the air shaft (chimney) creating an air movement in the room. Instead of letting the replacing air to flow through open windows, the scheme suggests a provision of one or more inlet air scoops through which air is filtered, cooled and directed in the indoor spaces. In section 5.2.3, the stagnant pressure is proportional to air density (p) and the square of the wind velocity (V). Since the pressure is proportional to the square of air velocity, the suction pressure is determined by the pressure difference between the middle zone and outlet of the tower head, this relation can be expressed as follows:

$$P_{Suc} = \frac{1}{2} p \left[\left[\frac{V_H}{.75}\right]^2 - V_H^{\ 2} \right]$$

Where : P_{Suc} = suction pressure (psf)
p = air density (pcf)
V_H = air velocity at aperture height (fps)

The wind velocity increases with height till it reaches a ceratin point where the ground friction no longer affects the wind at all (gradient height Fig.5.20). The gradient height is a function of the terrain friction ie. high buildings or any other topographical feathure. The gradient velocity (velocity at gradient height) is calculated from the following formula[32] :

$$V_Z = V_G \left[\frac{Z}{Z_G}\right]^{1/\alpha}$$

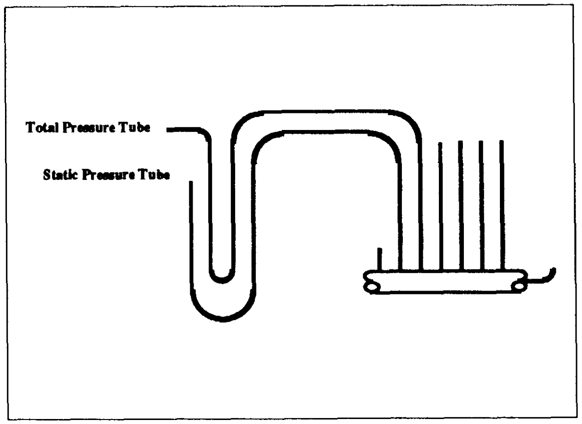

Fig.5.21 b. Schematic Diagram of Multi-tube Manometer.

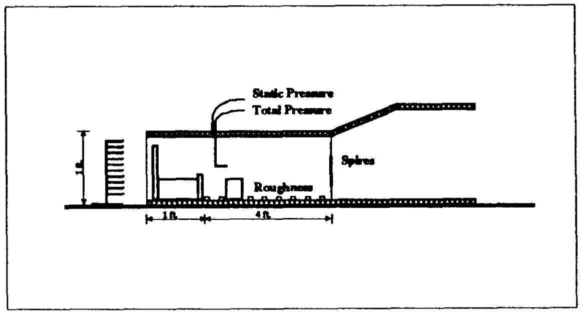

Fig.5.21 c. Section of Wind Tunnel Experiment Set-up.

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[32] Melargo, M. op. cit. pp.45.

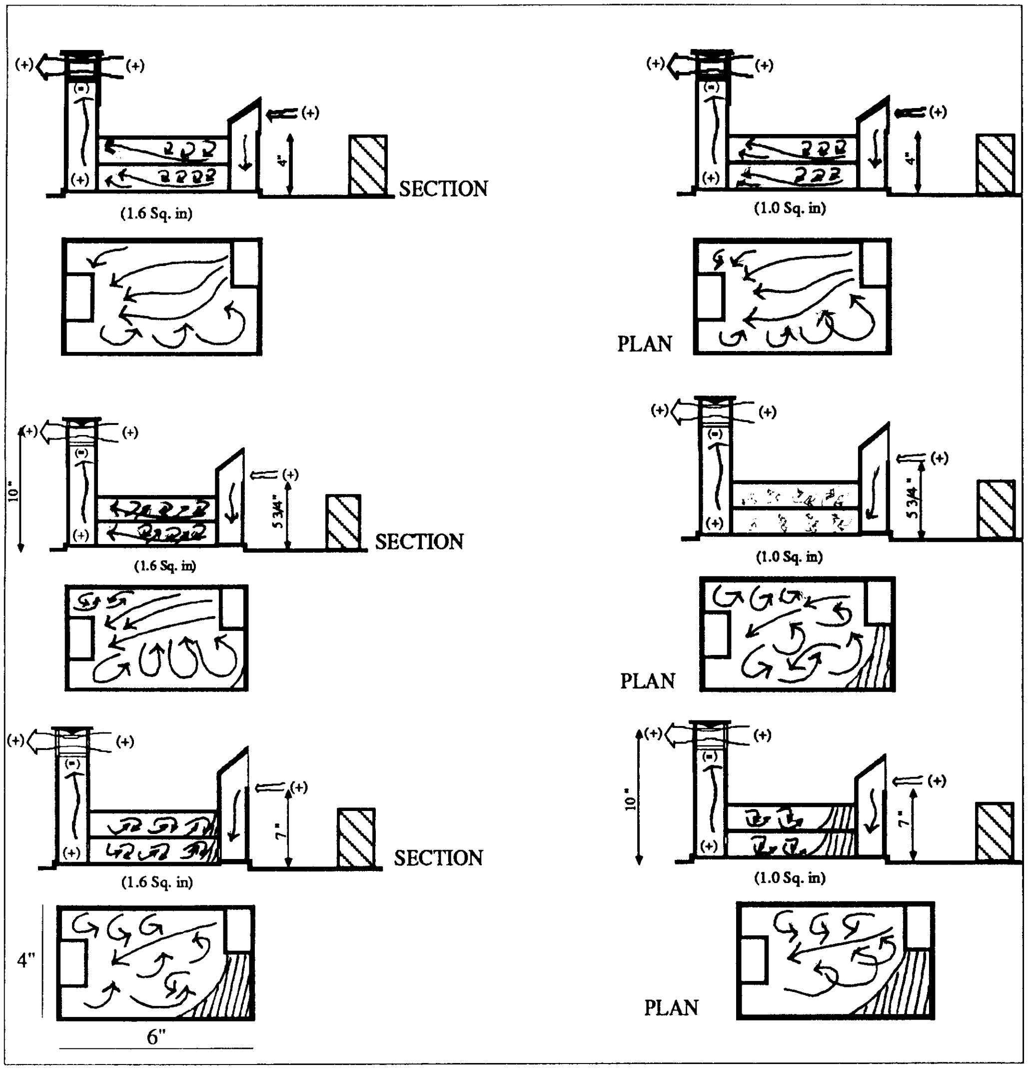
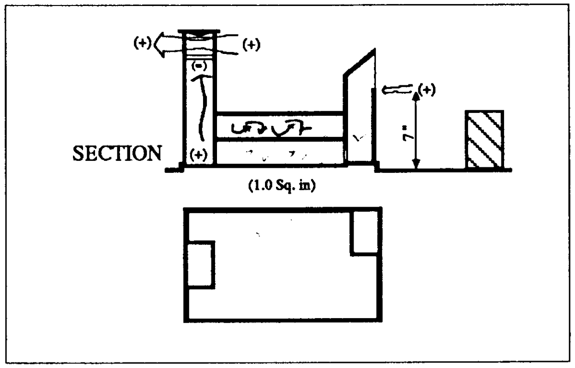


Fig.5.22 Effect of Changing Height of Inlet Air Scoop on the InternalWind Flow Pattern (heights of all Chimneys in the Model = 10").

When Inlet Air Scoop height is at the roof top, the smoke evacuation time is maximum and no stagnant air pockets formed



With Double-Stack Scheme to the top of Inlet and Outlet stacks, smoke evacuation time was slowest.

Where : V_Z = Gradient wind speed (mph)
V_Z = wind speed (mph)
Z = height above ground (ft)
Z_G = gradient height (ft)
$1/\alpha$ = exponent dependent on the terrain (Table 5-6)[33].

Type of Terrain	Z (ms.)	Z (ft.)	1/
Flat Open Country	275	900	(1/7)
Suburban Areas	366	1200	(1/4.5)
Heavy Built Area	457	1500	(1/3)

Table 5-6. Gradient Height and Terrain Exponent.

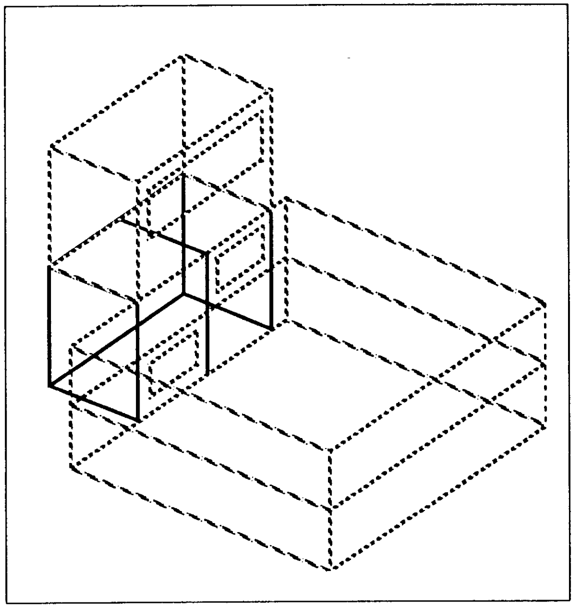


Fig.5.23. Double-Stack Chimney.

5.8.3 The Experimental Set-up :

In order to evaluate the performance of the new design, an air tight cardboard model was built and tested in one of the M.I.T. Wind Tunnels. The effect

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[33] Ibid.

of changing the height of the inlet stack and the area of the opening versus the air movement patterns in the interior was studied.

5.8.4 The Model :

The model represents a double-storey building with an independent stack outlets and inlets each of which opens at a different floor to avoid the short circuiting effect of the upper floor. The size of the model is determined by the dimensions of the wind tunnel (12") which represents a suburban gradient height (1200 ft). By comparing the calculated stagnant pressure at different heights for both the wind tunnel and Khartoum (Appendix D), the outlet and inlet heights were selected. The criterion of this selection was to obtain the same ratio between outlet and inlet in both cases (wind tunnel and Khartoum). The resultant scale (wind scale) was found to be 1" = 5 ft. approximately (Photo. 6).

Keeping the outlet chimney at constant height (10" or 50 ft.), three inlet stack heights and two opening sizes were tested (Fig.5.21).

5.8.5 The Wind Tunnel :

The wind tunnel facility at M.I.T. was used to test the model. Its test section is .3 ms high, .3 ms. wide, and 1.5 ms. long (1 x 1 x 5 ft) Fig.5.21 c. It is a non-recirculating type ie. air is drawn from and to the same laboratory. The air velocity through the tunnel was changed by controlling the speed of a motor placed at the end of the tunnel. Wind velocities as high as 120 mph can be reached in this tunnel.

A slanted multi-tube manometer (Fig.5.21 a) is used to compare wind velocity pressure by using a length of a small-diameter tube bent on the horizontal plane to measure total pressure and local static pressure (Appendix D). The instruments used to measure pressure at different heights is the Pitot tube rake which contains several hollowed metal tubes with front openings (Fig.5.21 b).

In order to generate a turbulent wind profile, a wooden panel with many cubes each measuring .5 x .5 x .5 in. is fixed to the ground upwind of the model. To obtain the correct turbulent air flow and velocity gradient through the wind tunnel flat wooden spires 11" high were installed at the neck of the tunnel (Fig.5.21 c).

5.8.6 Experimental Procedure :

The air velocity at a point 15 cm. high (6") is set at 7.5 mph to simulate the average wind speed at Khartoum at the corresponding scale height. The model is then filled with smoke to visualize the interior air movement patterns through a transparent side of the model. The time taken for the smoke to clear completely from the model is recorded. Seven alternatives were tested ; three inlet stack heights with two different opening areas and the seventh alternative was set-up to evaluate the separation of the double stack to the tower head height. A solid block representing a neighboring building is located in front of the model at a distance equal to half of the model height.

5.8.7 Discussion of the Results :

The new air scoop design make use of the exponential increase of wind velocity with height. Figure 5.19 shows a schematic drawing of the whole system where a short outlet scoop is positioned on the building parameter to catch the wind at lower levels and distribute it to the different living spaces. Because the operation of this scheme depends on the difference between the suction pressure at the tower head and the stagnent pressure at the inlet scoop, the higher the difference between the two the better. In the absence of wind the solar induced thermal stack effect functions better with maximum inlet outlet height difference. The higher the difference in temperature between outlet and inlet, the larger the suction pressure. Therefore in the new design, inlet scoops can be located on the lintel or even the sill level. Depending on the geometry of the building, the ventilation can be drawn from one or several inlet stacks located on the building parameter. The wind tunnel experiment showed that not only a higher wind velocity in the interior spaces is maintained (Appendix D), but also a better distribution pattern observed with larger aperture difference in height (Fig.5.22). This was evidenced by passing turbulent air stream through smoke-filled model spaces.

In order to ventilate a two-storey house, a double-stack scheme was provided with a common outlet above the building roof to avoid short circuiting the air flow from the upper level. The separation of the stacks was not carried on to the head of the outlet stack to minimize the friction effect (Fig.5.23). The experiment showed that when the two stacks are separated to the tower head level, the friction had increased the evacuation time of the smoke from the model by a factor of six.

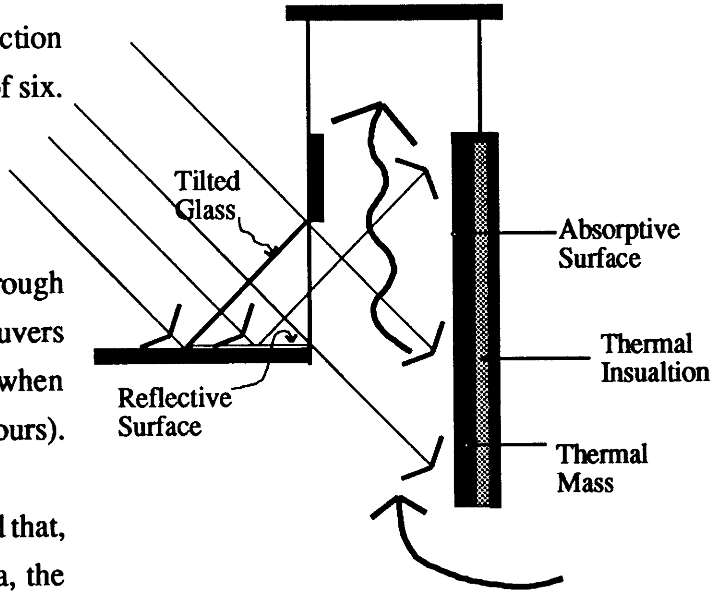


Fig.5.24. The Proposed Solar Chimney.

5.8.8 Other Features :

The inlet air is cooled evaporatively by passing the air stream through wetted pads located at the window level. These windows have movable louvers to control both air flow speed and direction and to close them completely when neither ventilation or cooling is desired (in winter nights and early morning hours).

A mathematical model simulating the wind force behavior showed that, with an outlet air chimney of 40 ft. high and 40 ft. sq. cross sectional area, the minimum cfm obtained is 7032 (when using inlet air scoops 25 ft. high). Above this height, the suction pressure generated at the tower head balances and overrides the positive pressure at the inlet opening, thus reversing the air flow direction. The obtained cfm (7032) with a pad efficiency of 75% and friction due to aperture, opening, and dust shelves of 70% is equivalent to 91700 Btuh. Comparing this figure with the cooling loads in section 4.3, one can see the potential of this design since it can balance the heat gain throughout the year.

In the absence of wind, the outlet wind tower acts as a solar chimney which gets heated by the incident solar radiation on the dark interior surfaces facing west and north west sides. The sun is allowed to enter the chimney through a 45° tilted glazed window to get maximum energy with minimum losses due to reflection (Fig.5.24). Since the stack effect is proportional to the square root of the temperature, the design makes use of the sol-air temperature instead of the outdoor temperature to obtain higher air flow velocities.

The mathematical model in Appendix D shows that the stack effect will create enough draw to meet the cooling requirements when the inlet scoops are provided with the wetted pads (same evaporative scheme).

Because of the time lag of the thermal storage masses, only half of the heat energy is used to creat the thermal stack effect, the stored heat in the mass of the chimey is released after sunset and keep almost the same rate of air flow in the night. The calculation of the cfm values in Appendix D assume instantaneous heat flow. In order to calculate the same flow either in day or night divide the given cfm values by a factor of two. The thermal mass storage characteristics in this scheme is used to create a sufficient wind flow either to ventilate or evaporatively cool the interior spaces in day and night.

5.8.9 Comparison with Other Air Scoops :

Other air scoops do not have the following features found in the above design :

1) It creates better air circulation since air suction is more efficient than air pressure.

2) Air distribution in the interior space is more controlled since only one exit for air is provided.

3) Since the lower the inlet the better its performance in both thermal and wind force schemes, it is possible to locate the inlets below the sill level to assure better cross sectional air movements.

4) Depending on the geometry of the building, one could decide where to locate the outlet chimney e.g. when having a square plan, a central chimney generates a uniform air movement in the living spaces. For linear plans, locating the chimney on the west side and the inlet on the east side facing north will give the same effect.

5) It is possible to have one big or several smaller inlets if the space cooling requirements differ. This flexibility facilitates zonal layouts e.g. toilets and kitchens.

6) Changing the louvers tilt allows directing the cool air towards the ceiling and cooling the structure interior masses.

7) In contrast with other systems, this scheme maintains the same air flow direction during the day and night operations when either wind force or thermal dynamics are in action.

8) The maximum air velocity obtained from other scoops is 0.1 m/ s (19.7 ft/ min). This is compared to the new design is 11% and 15% of the cooling effect provided by wind force and thermal stack effect respectively.

9) This system substitutes the need for operable windows for ventilation in the hot hours of the day, henceforth, controls the hot air, dust, and insects protrusion into the living spaces. In the other scoops (conventional and new) the need for open windows is essential to assist the air flow.

5.8.10 Comparison with Conventional Evaporative Coolers :

When the wind is blowing, the new design operating in June generates cooling effect equivalent to two conventional evaporative air coolers. Comparing this with the initial cost, the air scoop costs 50% more than the two evaporative coolers. This additional cost can be paid back after about five years even when using wall and roof insulation (Appendix E).

The other important factor in evaluating this system is its independence from the electrical supply which is subject to frequent shut-offs over the year. This in fact is a major criterion in considering this system as compared to other electrical cooling systems.

Finally, this is an architectural element that can be installed in existing buildings as well as considered in new designs that will thus do without attaching evaporative coolers on the skin of the building.

CHAPTER SIX

ARCHITECTURAL IMPLICATIONS

6.1 ISSUES IN ARCHITECTURAL EXPRESSION :

First, we have to distinguish between the architectural expression and the external appearance of the building. The latter is merely the physical manipulation of building solids manifested in a 3-D conceptual environment. On the other hand, architectural expression is dependent on the coexistence of two aspects. First, the physical aspects of the built environment e.g. building materials, climatic constraints and potentials and how these are put together to satisfy the users requirements. Secondly, the social factors which are determined by tradition, religion, and economic prospects of a certain society. Since in this thesis the scope concentrates on the houses built by architects among the whole spectrum of the built environment, the architectural expression dealt with here is the *designed* expression.

6.1.1 Designers Concerns :

Since the first part of the architect's responsibility is related to the physical aspects of the building, the designer should at least be knowledgeable of basic principles and understand their architectural implications. However, this is the easiest among the two aspects because of the assumption that proper architectural education and post graduation professional experience is sufficient to cover these areas.

The second aspect of the architectural expression is indeed a complex one since it deals with immeasurable aspects of social life. It requires a clear understanding of the social dynamics and formulation of the living entity of a house. The most commonly used word of house in Arabic is *beit.* This word has two meanings ; the first is the physical existence of the house, and the second is family. The second meaning implies the spirit (social identity) of the house, and the people using the spaces (interior and exterior). In order to get the architect to be able to design a *beit* , he/ she should be honest, objective, understanding, and considerate. Unfortunately, this is very much like a utopia because in most cases these requirements conflict with the professional demands e.g. time limitations and professional pressures. Architects are not prophets, but they are messengers who convey certain beliefs and views on the how things should be done and why. So, the evaluation of a success of a house design is almost an impossible task because the time factor which is involved in this process of design transformation is hard to measure in the long run.

The suggested environmental responsive deign tries to answer both questions within the architectural frame of reference. The main concentration is then the implementation of the innovative systems without neglecting the prevailing social trends and aspirations.

6.1.2 Expression :
A Reflection of Tradition or Manipulation of Technology ? :

During the sixties, Sudanese architecture had adopted the new technology as a reflection of modern architectural movements. This was encouraged as evidenced by the rapid acceptance of the society in Khartoum to these styles as an indication of prosperity and prestige. In the seventies, the economical situation forced the designers to rationalize on the designs and building standards in such a way that the houses built at that time were almost standardized and eventually looked the same. In this decade, architects are trying to explore new areas of design under worse economical conditions. One of the area explored was the traditional house design and in most cases this ended up with adoption of some architectural features. This implementation remains artificial unless clear understanding of the functions of these elements or features in the traditional house is maintained. Some of these features served structural purposes e.g. arches, and some helped in modifying the interior comfort conditions or both e.g. thick walls, domes, and window screens *(mashrabia).* With this in mind, new materials can be used innovatively without losing the touch of the regional style under consideration. The creative use of new building materials e.g. Low-E glass (Section 4.8.1) or improving the present construction techniques e.g. using thermal insulation (Section 4.6 and 4.7) is better justified as long as it takes into consideration the social *ambiance*.

6.1.3 Solar Expression :

In broad terms, the question here is, how environmental responsive design concepts can be expressed within the overall architectural integrity without disturbing the balance between physical and non-physical aspects of the built environment. The answer is in two parts : First, thermal comfort is a necessity that has to be satisfied and considered from the very beginning of the design stages. Once this has become a design criterion, the building is then perceived as a skin that filters and responds to the outdoor environment, thus establishing an organic link between the living entity of the house and the outside. However, the built form in the Hot-Arid regions has always reflected a rejective solar expression. This can be altered completely when selective transmitters or Low-E glass are chosen. This in fact will improve the thermal conditions with the possibility of using larger glazed surface areas (Section 4.9). Another counter intuitive cooling approach that depends on receiving and welcoming the solar radiation in some parts of the building (Section 5.8.1). An example of this, was represented in the thesis when dealing with the solar chimney which utilizes the hot air circulation to cool the indoor air temperatures and modify the internal environmental conditions.

In conclusion, the solar expression can be partially receptive as compared to the belief that buildings in these climates should be solar rejective ie. self contained (internal looking), and maintain minimum exterior openings.

6.2 ARCHITECTURAL EXAMPLES :

6.2.1 The House Design :

The objective of giving this example is to show how the architectural design can be affected by implementing some of the passive cooling systems discussed in the previous chapters. The final product which is a design of a house is meant to contain the typical spaces for a large-family two-storey house in Khartoum. The built area of the house is 301.5 m^2 (3015 ft^2), ceiling height of 3.25 ms. (10.7 ft.), and raised .60 ms. (2 ft.) above ground level. The house has a reinforced concrete frame structure filled with one and half exterior brick wall with 5 cm. (2") thick Polystyrene insulation. The interior partitions are one brick 23 cm. (9") thick plastered from both sides with 1 cm. cement sand plaster (1:6) mix. The roof is a reinforced concrete slab 10 cm. (4") thick, insulated with 5 cm. (2") thick Expanded Polystyrene panels and finished with 2 cm. (3/4") thick white cement sand tiles. The glass chosen in this project is single Light-Green Low-E on all sides.

In this example, a design proposal is presented to show the possibility of having a number of inlet stacks for each space or one inlet air scoop that feeds the whole house. This solution is reflected on the elevations (Figs. 6. 4).

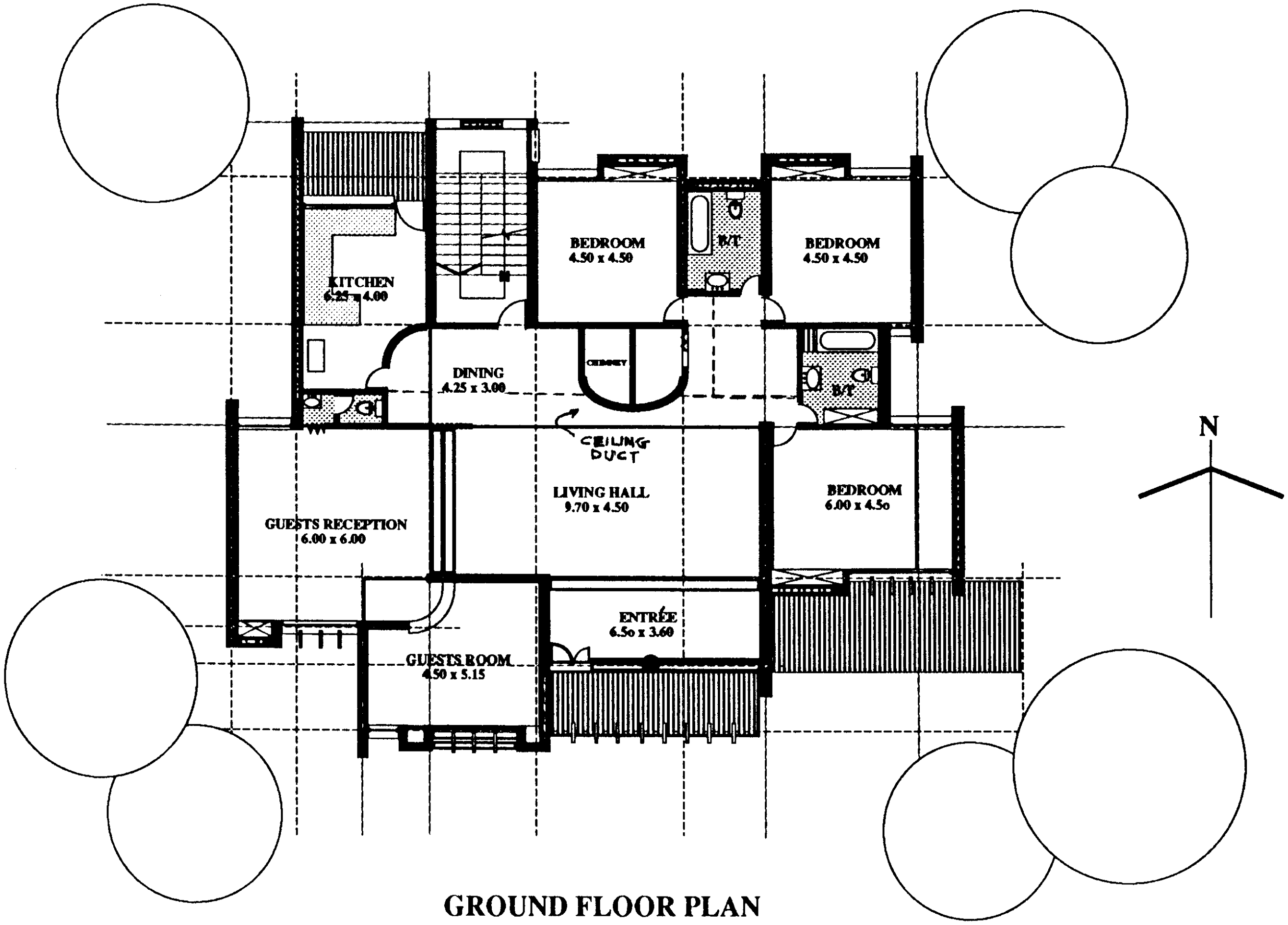
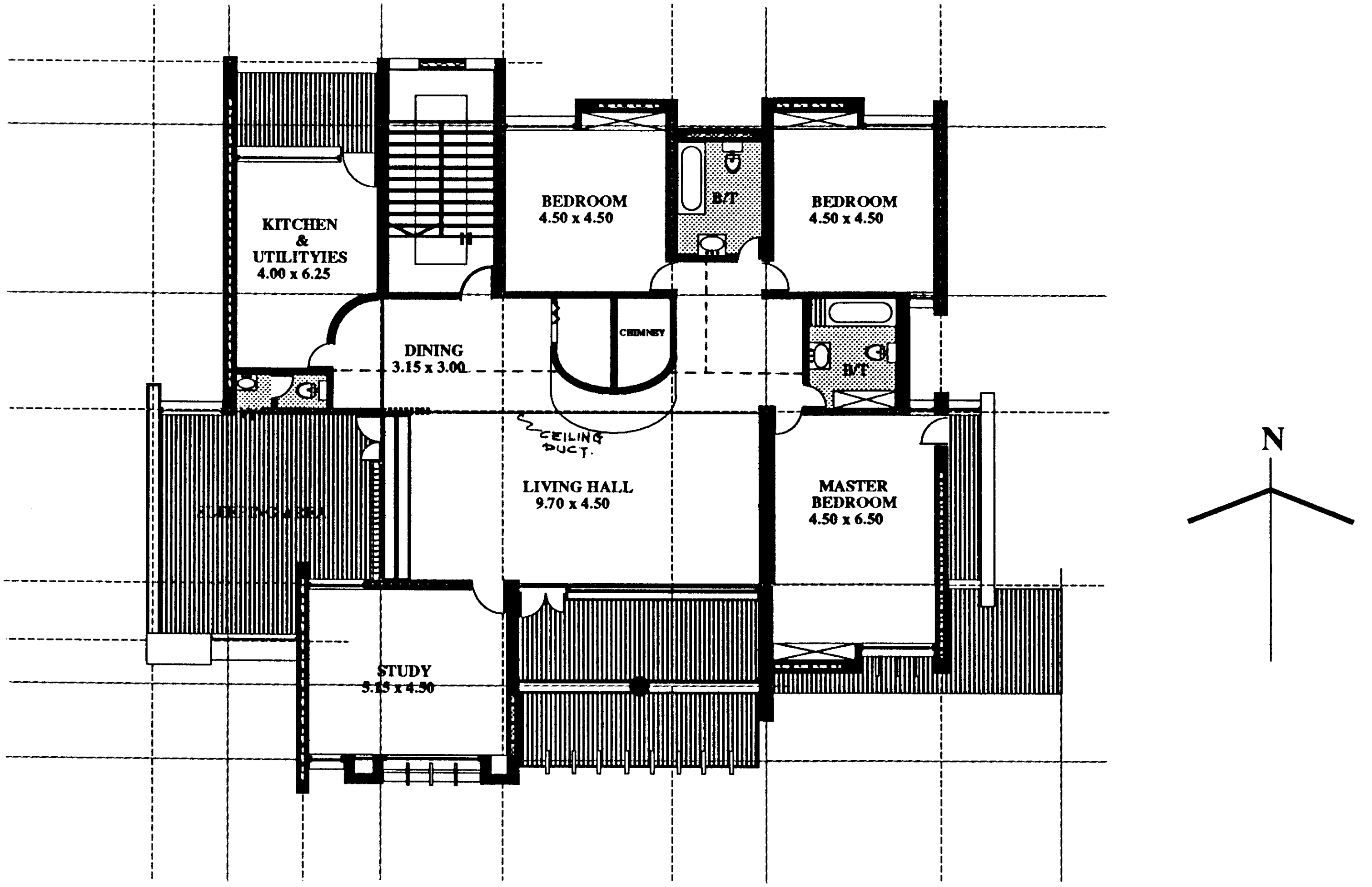
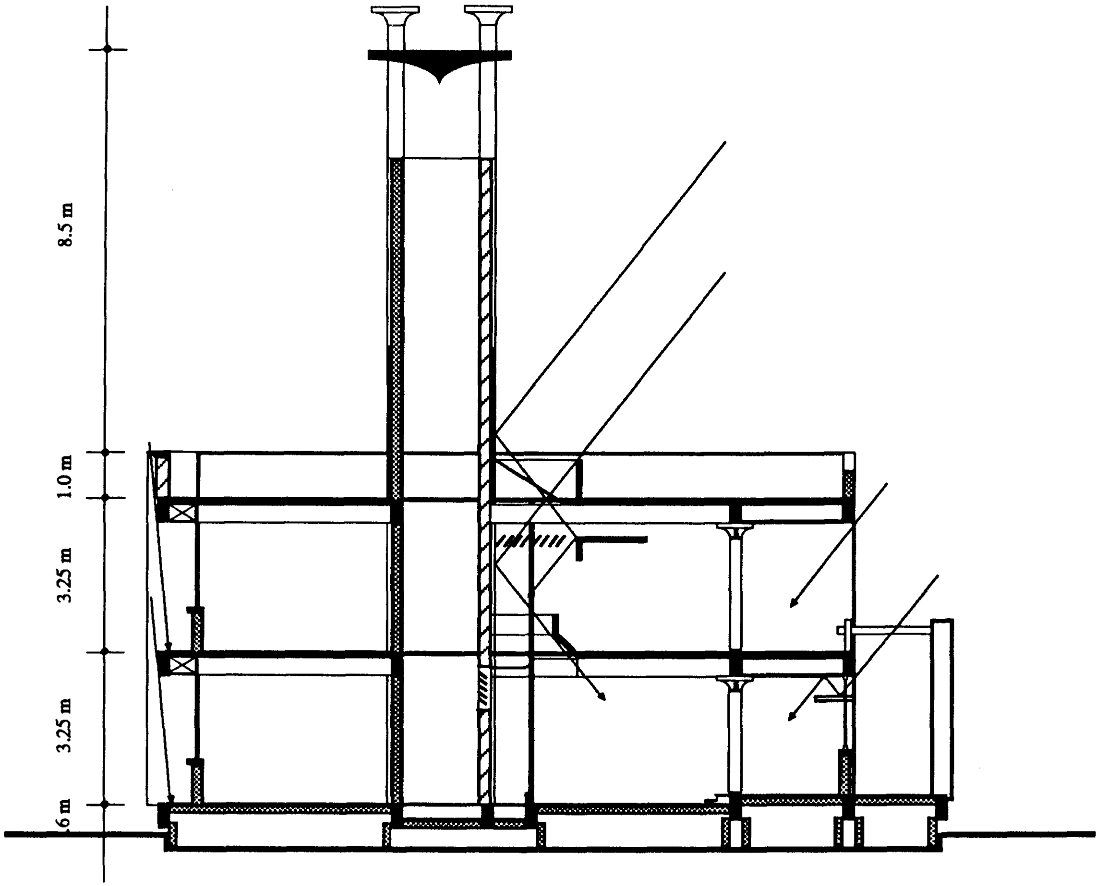


Fig. 6.1. Ground Floor Plan of Model Design. (all dimensions are in meters). Air Scoops are distributed in all spaces taking the shape of the conventional built cupboards.



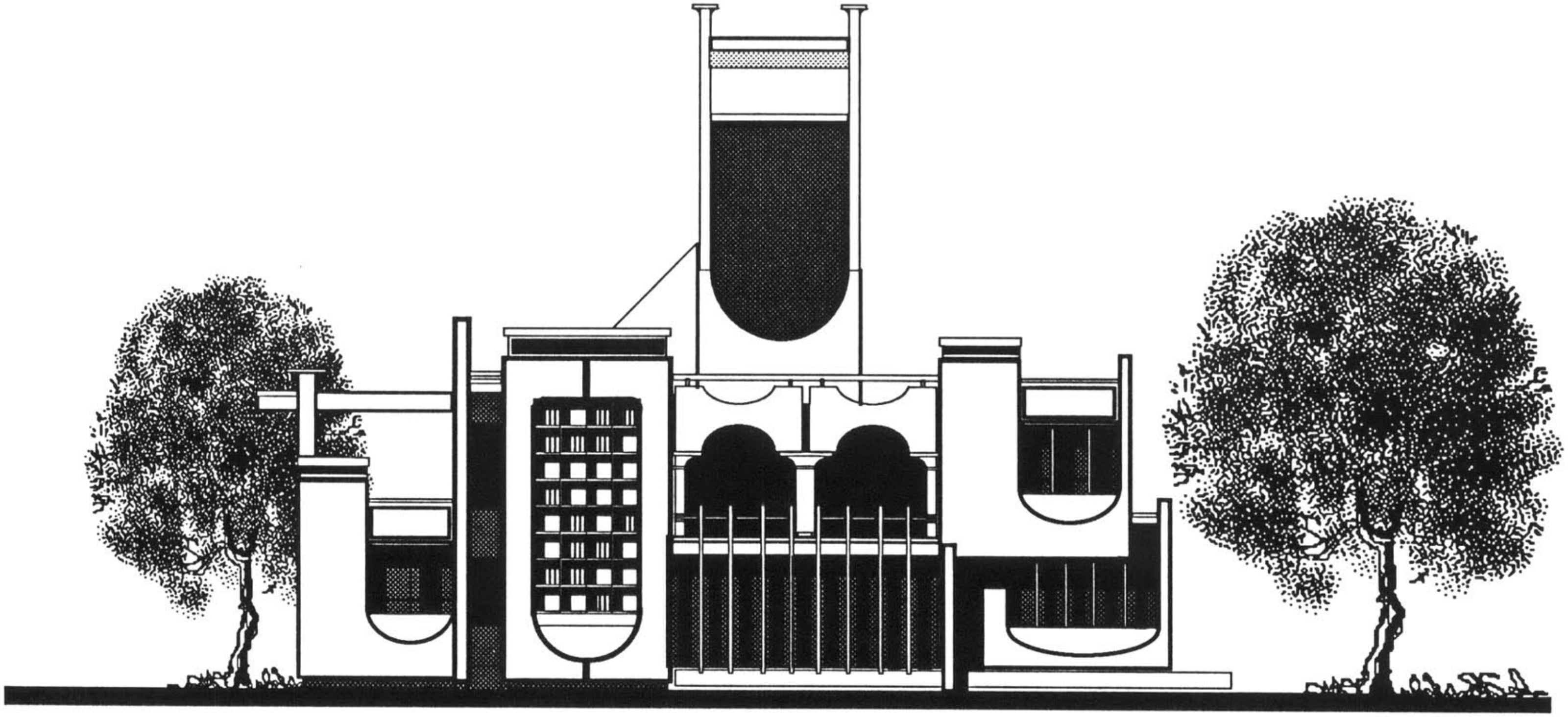
FIRST FLOOR PLAN

Fig. 6.2. First Floor Plan of the Model House (all dimensions are in meters).



SECTION

Fig. 6.3. Schematic Section of the House showing Solar Control Techniques to provide Both sun shading and natural lighting in the differentspaces. The Chimney dominates the interior spaces as well as the exterior facades. It can be used as the main structural support of the house



South Elevation

Fig. 6.4. The South Elevation expresses a mixture of regional and modern styles. Inlet scoops are integrated with the wall panels forming a homogeneous composition to balance the chimney.

6.2.2 Passive Cooling Considerations in Plans :

Layout and distribution of spaces in the plan respond to the external environmental conditions in the following ways :

1) The ratio of length to width is 1:1.3 by which minimum heat gain is maintained as suggested in Section 4.7.2.
2) West orientation is avoided for bedrooms and living spaces which are frequently used. These spaces are buffered by positioning utility spaces and other rooms which are not frequently used e.g. guest reception rooms.
3) Except for bedrooms, other spaces are open to generate better air circulation with minimum obstructions.
4) A chimney is located on the center of the house to maintain a central air suction from all spaces. This is particularly applicable for square plans. For rectangular plan configurations, the chimney is better located on the west side of the house (Section 5.8.9).
5) Toilets and kitchens are located on two perpendicular axes linked directly to the chimney by ceiling ducts to avoid spreading of odors in living spaces.
6) The walls project beyond building corners to provide shading against low early morning and late afternoon sun angles (Section 4.10).

7) Because of the thermal properties of the Light-Green Low-E glazing, size of the windows is larger than the typical house in Khartoum.

6.2.3 Cooling Considerations in Sections :

Considering the height in design is as important as the plan in terms of creating indoor environments that satisfy thermal requirements. The following steps were taken in the example design :

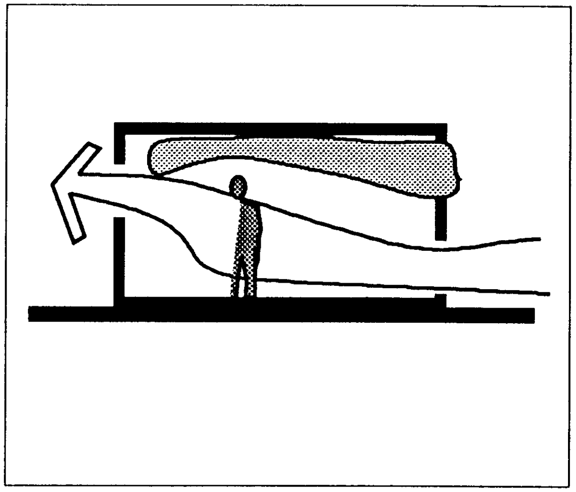


Fig. 6.5. Effect of Ceiling Height in Trapping Stratified Hot Air.

1) Ceiling height is 3.25 cm. (10.7 ft.) to trap hot air under the ceiling. Once this layer gets thick it seeps out with air flow to the chimney without mixing with colder air at the living space level 2 ms. (6.7 ft) as seen in Fig. 65).

2) Raising the ground floor above the ground level does not only protects the floor slab from movement of the soil, but also provides an insulation buffer against relatively high soil temperature (Section 3.3.3).

3) In order to avoid glare generated by having one natural lighting source from the southern window in living hall, the design suggests bringing daylight deeper into the space through small skylights on the roof.

4) Parapet walls are 1 m. (3.3 ft.) high to protect the sleeping areas from wind at high speed (e.g. sand storms) and also provide privacy to the occupants (Fig. 6. 9).

6.3 ELEMENTS OF THE DESIGN :

6.3.1 The Chimney :

The chimney in both alternatives represents an architectural feature that can be used to dramatically emphasize the character of the house. North and south sides of the tower are protected from the sun by timber lattice screens. East and West sides are protected by an insulated one-and-half brick wall extending to the tower head. The visual effect of the tower is balanced by the elaborate facade treatment that is originally introduced by shading devices.

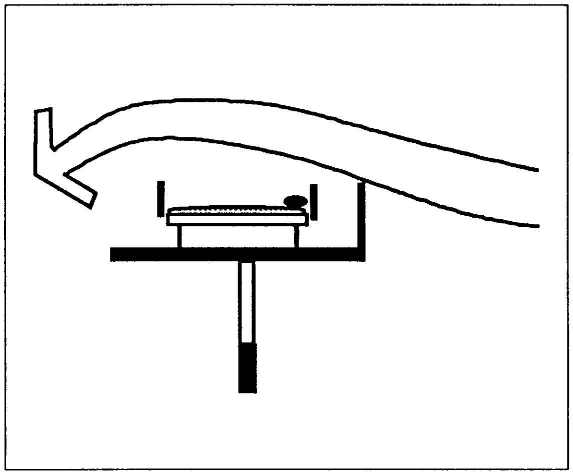


Fig. 6.6. Wind Sheltering Effect of High Parapet Walls.

The chimney is 12.15 ms. (40 ft.) high and 3.7 m^2 (40 ft^2) in area to satisfy the thermal requirements of interior spaces. It is composed of two stacks (same as the model in the experiment Fig. 5.23) and each serves a separate level. On each level the stack performs as a spatial focal point where the members of the family sit together and dine comfortably (thermally) in the middle of the house. The natural light in both designs to fall indirectly to the central area. This was done by designing a sky light that allows only the low angle sun to penetrate and obstruct the sun rays in the hot periods of the day or year. The bounced light is reflected on the chimney wall which is curved to provide better distribution of the light in the deep interior spaces. Bedrooms and utility rooms are lit through shaded glass windows which are partially operable and partially fixed to control the amount of outdoor fresh air if outdoor conditions permits that.

During the hot, windy days the velocity of the air at high altitudes passing through the tower head is increased when squeezed at the nozzle. The suction pressure created is enough to draw the indoor air at a rate similar to that of two evaporative coolers (Appendix E). Air is allowed to enter the living spaces through movable louvers to avoid mixing the coming air with stratified air below the ceiling during the day. During the nights, the air is directed to the ceiling to make use of the thermal storage inertial of the concrete slab. When the wind is calm, the chimney still functions depending on the stack effect which is thermally driven and introducing enough air draft to provide the required ventilation into the house. In order to increase the rate of heat flow into the spaces, a 45° a slanted window is designed to heat the interior of the chimney. The thermal masses of the stack stores about half the heat which is released after sun-set. This amount of heat generates almost the same air draft from the interiors.

6.3.2 The Inlet Air Scoops :

The inlet air scoop layout is the main difference between the two possible designs. The first design (figs. 6.1-6.4) contains an inlet scoop for each space to maintain the best possible air circulation within the building for both cooling and ventilation. The second possible design may have one main inlet that allows the air to pass through the main living spaces. For the kitchen and toilets, separate inlet scoops are provided to exhaust foul air directly to the chimney through ceiling ducts without mixing with air in other spaces in the two alternatives. Each inlet has a wetted pad at an opening under sill level at which the direction of the air flow is controlled by movable louvers. During the day, air is directed to the floor where the furniture raises and than exhausts to the chimney at human height level. During the night, the air is directed to the ceiling to cool down the mass (concrete slab) and let the cold air move downward because of its higher density.

Architecturally, the first design alternative integrates the several inlet air scoops (in elevation) with exterior wall panels. This was done by extending the exterior wall above the parapet and allowing the air scoop to be visually expressed without breaking either the verticality or horizontality of the facade treatment. In the guest room side (south-west corner), the stacks feeding the two floors are separated by a large shaded glass area. This was expressed as one big element that contains two smaller sections and linked with eggcrate timber shading devices for better shading control. The other design possibility has a main inlet air scoopthat can be visually expressed as a feature that balances the high wind tower, which is also functionally true. In such cases when only one inlet air scoop is used, the design should attempt to separate the inlet and outlet stacks as much as the design permits. It is also important to determine the wind flow diagram in such a way that air should pass the main living spaces with minimum obstructions.

6.3.3 Thermal Insulation :

From the research conducted in Chapter Three, using thermal insulation on roofs is a reasonable move to reduce heat gain, but any addition of more layers does not reduce the share of the roofs in the total heat gain substantially as compared to the first layer commonly specified in the Sudan. In both designs, wall insulation is added to the architectural details to minimize the heat gain and to decrease the radiant heat flow from the internal surfaces. This creates a better feeling of comfort because the effect of the mean radiant temperature is more sensed than air temperature although mistakenly taken to be the air temperature that causes all the feeling thermal discomfort.

6.3.4 Low-E Glass :

Because of the low U-value and solar transmission properties of the these selective transmitters, the Low-E glass is used to demonstrate the architectural potentials that can be utilized to create the required expression. First the possibility of having large window areas on the south and north exposures without sacrificing the thermal comfort requirements. Secondly, the high daylight transmission properties of this glass facilitates a better daylighting design and a appreciable link to the outside in the less private areas of the house.

6.3.5 Shading :

The shading analysis in Section 4.10 suggested in most orientations a combination of vertical and horizontal shading devices. The two design alternatives explore different ways for this combination.

Exterior walls are staggered to provide self shading for the structure. This was done in two configurations : The first was projecting the exterior walls (Section 6.2.1), and the second way was to project the upper floor. The second configuration allows having more usable space in the first floor. This also reduces the diffused solar insolation since the area of bright sky dome which is seen by the window is reduced too (Fig. 6.7).

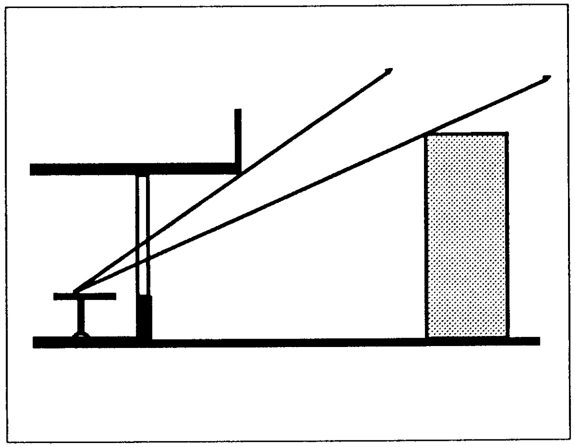


Fig. 6. 7. The Effect of Cantilevered Self Shading.

6.4 ADDITION TO EXISTING HOUSES:

The chimney/ air scoop scheme is also added to the model house studied in Chapter Three (Appendix F) to examine both the visual and thermal impact of such an addition. Although the spatial requirements of the chimney may sometimes contradict with other functional requirements, the scheme is flexible to differentsite orientations and building configurations. The technology involved in this scheme does not require high skill level of builders, instead it is using the same construction technology available in the Sudan.

6.5 DESIGN OPPORTUNITIES :

More examples are given in sketch form to show the numerous design opportunities that can be generated from the basic air scoop/ chimney configuration. Exploring different expressions that convey specific messages e.g. conserving traditional styles (Fig. 6.8 and 6.9) or reflecting new trends based on utilizing basic geometric forms (Fig. 6.10 and 6.11).

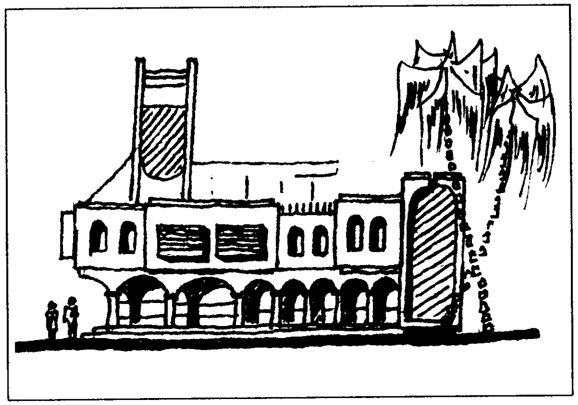


Fig. 6.8. Traditional Design with Off-Centered Chimney.

Using the locally available building materials and building standards that architects are familiar with, facilitates the chimney/ air scoop to be implemented on all levels and with all building standards. It is also flexible enough to accept whatever new building technology that emerges in building industry in the Sudan as evidenced by the application of the Low-E glass in the design package demonstrated in this thesis.

6.6 LOW-COST IMPLEMENTATIONS :

Implementation of cooling systems suggested in this study, is very difficult for low-income housing groups because all these systems represent future investments which substitute mechanical cooling systems and pay back from the energy savings. This is not the case in the low-income housing sector where energy consumed is basically from biomass (wood) resources and is used extensively for cooking. The minimum strategies that can be used to increase thermal comfort on the individual house level can be summarized as follows :

1) Reduce window size.
2) Avoid using glass on windows.
3) Locate windows on north and south facades.
4) Use trees for cooling and shading.
5) Ceiling height should not be less than three meters to avoid mixing the stratified hot air with lower and cooler air layers.
6) If possible, provide small openings below ceiling height to prevent hot air accumulation.

In summary, these are the indigenous practices that can be implemented in the housing for low income groups. But on the planning level, the housing authorities should take into account the thermal comfort aspects and measures which modify neighborhood microclimate. Such actions can be in the form of reducing roads width, or considering the wind and sun movement in road net work planning. Modifying building regulations in terms of building heights should also be one of the major criteria of energy responsive community planning. On the individual house level, conventional wind catchers can be built on the windward side of the house and cool the passing air by unglazed clay water containers or jars (Fig. 5.16). The application of the passive cooling measures in the planning level is an interesting topic for further study, but is beyond the scope of this thesis.

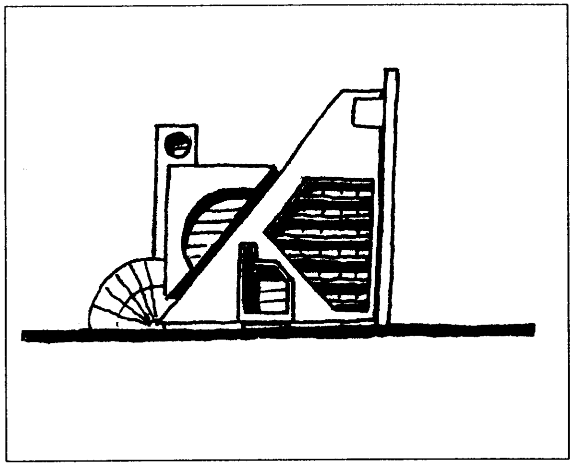


Fig. 6.10. Modern Configuration of Chimney/ Air Scoop Scheme.

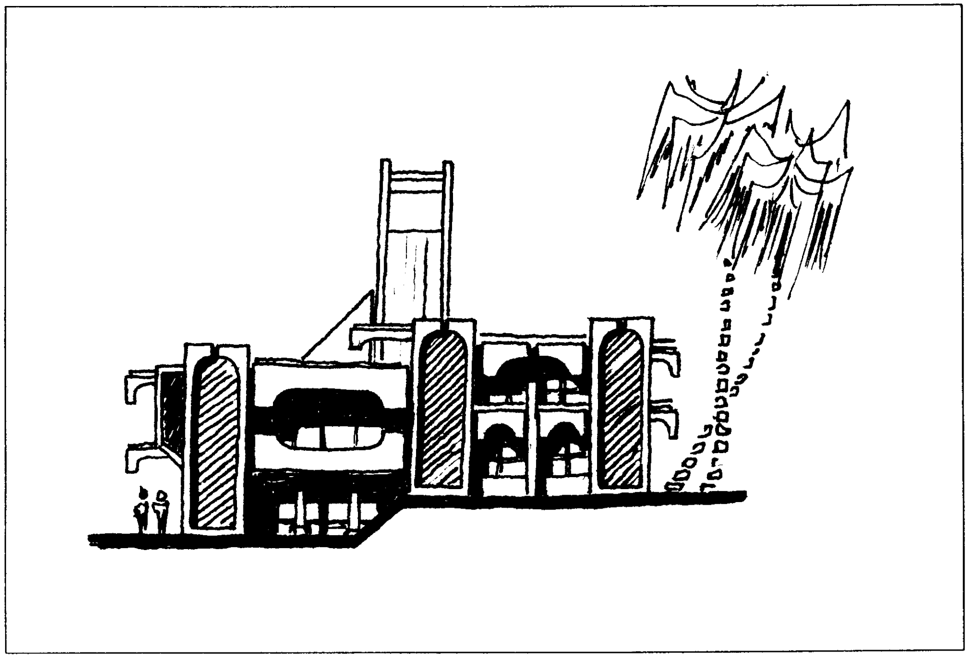


Fig. 6.9. Traditional House with Central Chimney.

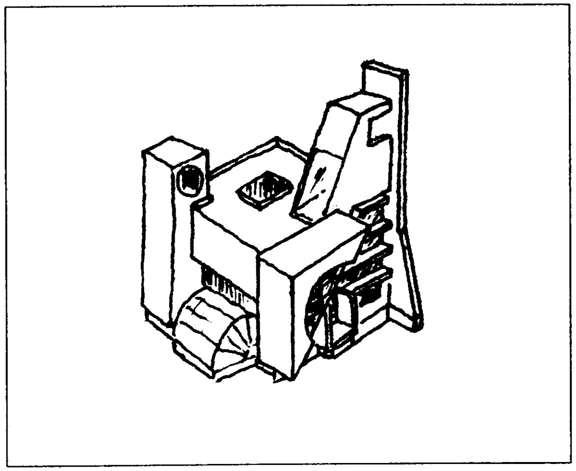


Fig. 6.11. A 3-D View.

CHAPTER SEVEN

CONCLUSIONS

Design Tools and Guide Lines

7.1 DESIGN GUIDE LINES :

The basic steps that can be taken in environmental responsive design practices in Hot-Arid climates are summarized in the following :

1) The length-to-width to height ratio should be decided with respect to sun movement and wind directions according to the orientation of the site and building configuration.

2) Climatic zoning of interior and exterior spaces should be considered in harmony with functional and social requirements of occupants.

3) Building materials should be carefully considered under economic, structural, and climatic constraints. The design potentials created by considering the above criteria can be represented in numerous

architectural expressions, reflecting traditional, modern, or combination of both styles.

4) Choice of cooling systems should be taken into account during the early design stages. This choice depends on building form (section 4.7.2), type and thickness of construction materials (resistance to heat flow), type and area of glazing materials (section 4.8 and 4.9), and efficiency of shading devices (section 4.10).

5) A number of different passive cooling systems are presented in this thesis, namely ; mechanical evaporative air coolers (section 5.3), roof ponds (section 5.4.2), roof sprinklers (section 5.4.3), nocturnal radiation cooling systems (section 5.3), and air scoops (section 5.7). Each of these cooling systems affect the architecture in a different way depending on location of the system, components, and limitation of use.

6) Each of the cooling systems discussed requires occupants' awareness of its properties and operation. Among these, evaporative coolers are the easiest to operate in Khartoum because of their common use. The air scoop/ chimney scheme comes close in this aspect to evaporative coolers because of its similar operational modes.

7.2 ECONOMICAL TRADEOFFS :

In order to obtain reasonable thermal comfort in the Hot-Arid climates, the designer should take into consideration one or a combination of the cooling strategies discussed in previous chapters. This can be in the form of :

1) Additional materials, ie. for roofs and/ or walls (invisible elements).
2) Additional building elements, ie. air scoop/ chimney and shading devices (visible architectural features).
3) Using hybrid systems, ie. conventional or two-stage evaporative coolers.
4) Using glass types of improved thermal qualities, ie. Low-E glass because of their thermal resistance to heat flow through both conduction and solar transmission also because of their high daylight transmission that allows the interior spaces to be lit naturally.

Application of these systems imply additional costs ie. to be regarded as investment on capital costs. Nevertheless, evaluation of a system cannot be completely measured through economical measures. Thermal comfort attained by mechanical cooling systems, especially desert-type evaporative coolers can be economically appealing because of the relatively low electricity rates as compared to the high inflation rates in the Sudan. But this is not the whole story because when there is no electricity, the most efficient evaporative cooler with the least power costs produces no cooling at all. That is why passive cooling systems are favoured in this thesis as the logical alternative for cooling in the developing world.

7.3 ECONOMICAL SCENARIOS :

The critical question here is what to use and to what extent. The simplest and most economical way to reduce heat gain without affecting the appearance of a building is to use thermal insulation on the roof and walls. Adding a 5 cm. (2") thick Rigid Polystyrene board on the weather side of the walls reduces 23% of the heat flow. When comparing with the energy consumed by an evaporative air cooler, this reduction is translated to 272[1] LS or about five years payback period (simple). Wall insulation needs to be supplemented with other mechanical or natural cooling systems to obtain the required thermal comfort. In appendix E, the calculations showed that when insulating the external walls of the house, one evaporative cooler was still required to balance the heat gain.

The suggested air scoop/ chimney can substitute for two 4500 cfm evaporative cooler units and pays back from energy savings in one year when using DS clear single pane glass and conventional wall construction (uninsulated). This

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[1] LS = Sudanese Pound = $ .22 Official Price, $ .11 Free Market Price (1987).

scheme shows a great potential of use in the developing world because of its easy construction and operation. When using the air scoop/ chimney with insulated walls, the payback period jumps to 12 years. Comparing this with the typical life span of a house in Khartoum (30-40 years), this payback period is reasonable especially since the thermal comfort is noticeably improved. This improvement is caused by reduction of thermal radiation from interior wall surfaces.

The economical evaluation of the Low-E glass when it is combined with the suggested cooling package (air scoop/ chimney and wall and roof insulation) in the example model is not very appealing. Use of new materials should rather be encouraged on the experimental level to improve their thermal properties. In the existing model house studied (Chapter Four), using single Light-Green Low-E glass has increased the payback period to 43 years. This can be explained in the following :

1) Very high cost of Low-E glass[2] .
2) Because of the low heat gain to be removed as a result of using thermal insulation on walls and roofs, the number of hours that an equivalent desert-type evaporative air cooler is much less. This translates to a much smaller annual energy savings or higher payback period.

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[2] All glass products in Sudan are imported.

3) Relatively low rates of electricity (subsidized).
4) High inflation rates.

7.4 THE ARCHITECTURAL QUESTION :

Architecturally, passive cooling systems can be divided into two categories : the first contains systems which do not affect the external appearance of the building but are integrated with building construction and the second contains these that are apparent and can be used in the architectural expression.

The air scoop/ chimney cooling scheme can be used architecturally as a dramatic feature that can easily determine the architectural identity of an individual house or the entire neighborhood. Shading devices and glazed surfaces can be explored to find the best relations that are socially acceptable, economically feasible, and above all thermally suitable. Playing with these elements bearing in mind the architectural responsibilities mentioned in the first chapter, designers should be able to identify the elements of the environmental responsive design that can be expressed architecturally. The question of regionalism is not a simple tradeoff between indigenous and modern architectural solutions. The house designs presented in this thesis try to harmonize the regional expression using the new building materials with todays aspirations. These plans were meant not to deviate from the shared image of an internal layout of a typical modern house in Khartoum. This is done to prove that implementation of new building technologies and materials should not necessarily produce high-tech. designs but preferably share the universally acceptable visual characteristics of an image of a regional urban morphology. This will be the first step towards forming an architectural identity in Khartoum.

7.5 SUMMARY OF COOLING MOVES :

Two moves were taken into account when the cooling potentials of Hot-Arid climates were considered. The first is the solar control strategies that suit Khartoum climatic conditions. These include the use of man-made and natural shading devices. The eggcrate configuration was found to suit the shading requirements of all exposures including the north orientation which was believed to require only horizontal canopies for shading. Vertical fins on southern exposures can provide the required shading without the need for horizontal canopies because of the self shading effect of the high noon sun. Natural shading devices include planting trees of predetermined heights, crown diameter, and branch pattern specifications to shade against the sun during the hot hours of the day in summer and allow afternoon and early morning sun during winter. The next solar control move investigated is the effect of changing glazed surface area. This study showed that the modern trend of having large windows is not justifiable when clear DS single-pane glass is used, instead, Low-E glass can be a better alternative despite its relatively high cost. These types of glass which are coated with selective transmitters can maintain the high window-to-floor area ratio with the same amount of heat gain depending on the type of glass used. Double and Light-Green single Low-E glass were studied and their thermal impact on total heat gain was analyzed.

The last solar control move considered is the use of thermal insulation on roofs and walls. This study proved that the use of 2" Expanded Polystyrene board on roof slab reduces the amount of heat gain and minimizes the roof share to a level beyond which any additional insulation on the roof is thermally and economically unjustifiable. In this thesis, adding insulation on exterior walls was studies to minimize the cooling loads on the mechanical and natural cooling systems and increase the indoor thermal comfort at the same time. A layer 2" thick of Expanded Polystyrene (which is manufactured locally in the Sudan) reduces heat conduction through wall fabric by a factor of 23%. This was found to be more economically justifiable than using a cavity wall that reduces the share of the wall by a factor 6% of the total heat gain.

The second strategy was to promote heat losses from the interior. A number of cooling systems were studied under the climatic conditions of Khartoum. Among these, evaporative cooling was found most appropriate in the hot, arid climatic conditions of the region. Mechanical cooling systems such as the desert-type evaporative coolers were taken into account as cheap devices for cooling and humidifying indoor condition with the expense of operating an electric fan. The two-stage evaporative cooler overcomes the limitations of the ordinary types where this system first cools down the air temperature sensibly and thus reduces its WBT, then passes the cool air through wetted pads to get lower outlet temperature without increasing the relative humidity to uncomfortable levels. Conventional and newly developed air scoops as a convective and evaporative cooling system using natural sources was evaluated and a number of recommendations were suggested. From this analysis, a new air scoop scheme was suggested to overcome the limitations of the existing designs. The new system is a combination of a chimney that draws the air by either the venturi produced by a nozzle at the tower peak or thermal stack effect (solar chimney), and a common air scoop located on the building parameter to filter, cool, and direct the air in the interior spaces. The operation of this setting depends on the suction pressure generated at the tower head instead of the static pressure commonly utilized as the driving force in conventional air scoops. For a better performance of this system, one of two configurations can be used. The first is to have a central chimney with a number of inlet scoops on the the house parameter. This configuration allows using plan proportions similar to the length-to-width ratios which are recommended in Section 4.7.2 (squarish). The other possibility of Chimney/ air scoop scheme is to have the chimney on the west side and one main inlet ait scoop on the other edge of the house to promote a sufficient air movement through the buiding interior. This configuration is most appropriate with the rectangular plans . In Both cases, the distance betweeen the outlet and inlet stacks should be maximum and the air flow should be designed to pass through the main living areas. Because of the different indoor air quality requirements of the tiolets and kithchens, these spaces need to be linked separately to the chimney through ducts to avoid contaminating the air in other spaces. These systems have the following advantages; 1) they create more air flow with better circulation since the air is directed to a single point (preferably the living area), 2) by directing air flow in daytime and nighttime operation, the interior masses can also be cooled down during the nights, 3) allow having as low (in height) inlet air scoops as possible, 4) facilitate compact plan layout without concerning about cross ventilation from windows, 5) provides a controlled air flow that can be designed and shaped during the early design stages.

7. 6 LOOKING AHEAD :

That architecture is both an art and a science is clearly manifested in the issues dealing with environmental perspectives where inclination towards one can only produce either functionless sculptures or lifeless structures. This unique mixture which reflects the regional identity and follows the life patterns of the occupants, will indeed satisfy the aspirations of modern architecture which grows in coherence with the surrounding environment. However, architects' personal preferences should also be encouraged within broad outlines of basic thermal comfort requirements. This may be in the form of building regulations specifying the maximum Btu's/ ft2 year, minimum U-values of roofs and walls or maximum area of glazed surfaces and orientations. These issues require further study in order to reach a general frame-work of environmental responsive design. The second thing to be further studied is the implementation of proposed air scoop/ chimney in other building types e.g. schools, office buildings, and large scale buildings. This might involve elaborate distribution systems and thus requires the study of the effect of having a number of chimneys in the same building.

APPENDICES

APPENDIX A

APPENDIX A

A.1 KHARTOUM GENERAL CLIMATIC DATA :

(KTM)	DAILY MAXIMUM (30 YEARS)				DAILY MINIMUM (30 YEARS)				MEAN DAY TE		RADIATIC	B. SUN DURATIC		REL. HUM.	CLOUD AMOUNT (0-8)				RAIN FALL		A. PRE		WIND
MONTH	MEAN C.	FEH.	HIGHEST	FEH.	MEAN C.	FEH.	LOWEST	FEH.	DEGREE	(FEH.	MJMSQ.	HOURS	%AGE	MEAN	0000 HR.	0600 HR.	1200 HR.	1800 HR.	MMS	INCHES	MEAN	DIR.	SPEED
JANUARY	31.1	88	39.7	103.5	15.7	60.3	7	44.6	23.4	74.1		10.2	91	28	0.9	2.1	2	1.8	0	0	966.9	N	10
FEBRUAR	33.4	92.1	42.5	108.5	17.1	62.8	7.6	45.7	25.3	77.5		10.5	90	23	0.8	2	2	1.8	0	0	965.9	N	10
MARCH	37	98.6	45.2	113.4	20.3	68.5	11.6	52.9	28.7	83.7		10.2	85	19	1.1	2.4	2.4	2	0	0	964	N	11
APRIL	40.1	104.2	46.2	115.2	23.5	74.3	12.7	54.9	31.8	89.2		10.6	85	18	0.9	2.1	2.1	1.6	0	0	962.3	N	9
MAY	42	107.6	46.8	116.2	26.6	79.9	18.5	65.3	34.3	93.7		10.1	79	20	1.8	2.6	2.6	2.2	4	1.6	962.1	SSW	7
JUNE	41.4	106.5	46.3	115.3	27.1	80.8	20.2	68.4	34.3	93.7		9.3	71	29	2.6	3.7	3.6	3	5	2	962.6	SSW	9
JULY	38.1	100.6	44.5	112.1	25.5	77.9	19.1	66.4	31.8	89.2		8.7	67	46	4.5	5.2	5.2	5	46	18.1	963.5	SSW	9
AUGEST	36.4	97.5	43.3	109.9	24.7	76.5	18	64.4	30.5	86.9		8.9	70	55	4.7	5.4	5.3	4.9	75	29.5	963.8	S	8
SEPTEMB	38.5	101.3	44	111.2	25.5	77.9	17.7	63.9	32	89.6		9.2	75	44	4	4.9	4.5	4.3	25	9.8	963.4	SSW	8
OCTOBER	39.2	102.6	42.6	108.7	25.2	77.4	17.5	63.5	32.2	90		10	85	29	1.9	2.6	3	2.4	5	2	963.5	N	7
NOVEMB	35.2	95.4	41	105.8	21	69.8	12.8	55	28.1	82.6		10.6	93	28	0.6	1.5	1.6	1.1	1	0.4	965.7	N	9
DECEMB	31.8	89.2	39	102.2	17	62.6	6	42.8	24.4	75.9		10.2	91	31	0.7	1.8	1.8	1.3	0	0	965.1	N	10
YEAR	37	98.6	46.8	116.2	22.5	72.5	6	42.8	29.7	85.5		9.9	82	31	2	3	3.4	2.6	161	63.4	964.1	-	-
(WSD)																							
JANUARY	30.3	86.5	38.2	100.8	13.8	56.8	7.8	46	22.1	71.8				32		1.6			0	0	968.9	N	9
FEBRUAR	34.1	93.4	42.5	108.5	16.8	62.2	9	48.2	25.5	77.9				30		1.6			0	0	967.1	N	11
MARCH	36.7	98.1	44.5	112.1	18.7	65.7	11.7	53.1	27.7	81.9				28		1.6			0	0	965.6	NE	12
APRIL	40.7	105.3	46	114.8	23.3	73.9	16	60.8	32	89.6				22		1			0	0	964	NE	9
MAY	41.7	107.1	45.5	113.9	26.2	79.2	19.4	66.9	33.9	93				26		1.9			0	0	963.8	NE	9
JUNE	41.6	106.9	45.6	114.1	26.2	79.2	19.3	66.7	33.9	93				33		1.5			1	0.4	963.9	S	12
JULY	38.3	100.9	43.4	110.1	24.6	76.3	18.4	65.1	26.5	79.7				48		3.9			21	8.3	964.4	SW	14
AUGEST	38	100.4	43	109.4	24.9	76.8	18.5	65.3	31.5	88.7				51		4			56	22	964.9	SSW	14
SEPTEMB	39.2	102.6	43	109.4	25.7	78.3	19	66.2	32.5	90.5				41		4.1			17	6.7	965	VAR	9
OCTOBER	39.3	102.7	42.4	108.3	24.4	75.9	15.5	59.9	31.9	89.4				37		1.5			2	0.8	965.1	VAR	9
NOVEMB	35.3	95.5	42.2	108	19.6	67.3	12.5	54.5	27.5	81.5				37		0.6			0	0	967	N	9
DECEMB	31.5	88.7	36	96.8	15.7	60.3	9.9	49.8	23.6	74.5				36		2.3			0	0	968.4	N	9
YEAR	35	95	46	114.8	21.7	71.1	7.8	46	29.1	84.4				35		2.1			97	38.2	965.6	-	-
(SHMBT)																							
JANUARY	30.4	86.7	38.9	102	14.2	57.6	5	41	22.3	72.1	20.27	10.2	91	30		1.3	2	1.6	0	0	968.5	N	7
FEBRUAR	32.7	90.9	42.5	108.5	15.2	59.4	7	44.6	23.9	75	22.73	10.5	90	23		1.4	1.9	1.4	0	0	967.2	N	7
MARCH	36.3	97.3	44.7	112.5	18.2	64.8	9.5	49.1	27.3	81.1	23.57	10.2	85	18		1.5	2.1	1.3	0	0	965.4	N	7
APRIL	39.5	103.1	46.5	115.7	21.1	70	10	50	30.3	86.5	25.71	10.6	85	16		1.2	1.6	1.1	0	0	963.5	N	6
MAY	41.6	106.9	47.5	117.5	24.6	76.3	13.8	56.8	33.1	91.6	24.58	10.1	79	19		1.6	2.3	1.7	3	1.2	963.5	N	6
JUNE	41	105.8	46.2	115.2	26.1	79	17.4	63.3	33.5	92.3	23.36	9.3	71	27		2.3	3.1	2.4	3	1.2	964	SSW	6
JULY	37.7	99.9	43.7	110.7	25.1	77.2	19.3	66.7	31.4	88.5	22.82	8.7	67	44		3.9	4.8	4.5	46	18.1	964.7	SSW	6
AUGEST	35.9	96.6	42.5	108.5	24.5	76.1	18	64.4	30.2	86.4	22.65	8.9	70	52		4.2	4.7	4.4	75	29.5	965.3	S	7
SEPTEMB	37.8	100	43	109.4	24.6	76.3	18	64.4	31.2	88.2	22.82	9.2	75	41		3.6	4.1	3.8	28	11	964.6	SSW	6
OCTOBER	38.7	101.7	42.3	108.1	23.3	73.9	15.2	59.4	31	87.8	21.48	10	85	29		1.6	3.1	2.2	3	1.2	965	N	6
NOVEMB	34.6	94.3	41	105.8	19.7	67.5	10.7	51.3	27.1	80.8	20.64	10.6	93	28		0.8	1.3	0.8	0	0	966.9	NNW	6
DECEMB	31	87.8	39	102.2	15.6	60.1	7	44.6	23.3	73.9	19.47	10.2	92	32		1	1.9	1.1	0	0	968.3	N	7
YEAR	36.4	97.5	47.5	117.5	21	69.8	5	41	28.7	83.7	22.5	9.9	82	30		2	2.7	2.2	158	62.2	9656	-	-

Source: Meteorological Station- Khartoum.

Khartoum Solar Radiation Intensities (MJ/ M^2) :

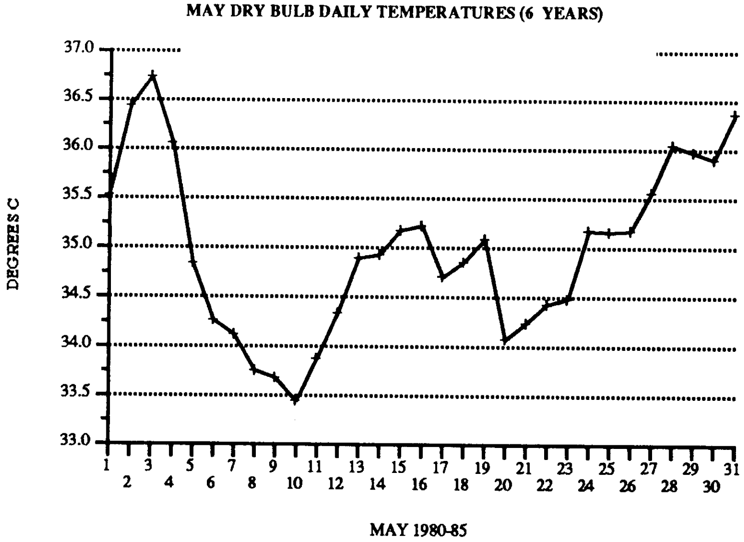
MONTH	JANUARY		FEBRUARY		MARCH		APRIL	
DAY	TOTAL	SOLAR	TOTAL	SOLAR	TOTAL	SOLAR	TOTAL	SOLAR
1	19.21	10.6	20.77	10.6	22.78	9.1	20.55	9
2	20.02	10.7	20.46	10.7	24.08	10.2	20.83	9
3	19.9	10.7	19.99	10.7	24.7	10.6	22.03	9.6
4	19.08	10.6	20.91	10.7	24.03	10.7	23.87	9.8
5	19.86	10.6	20.86	10.7	24.52	10.9	25.42	11.2
6	19.72	10.6	21.02	10.7	24.54	10.9	25.47	11.5
7	20.6	10.6	21.22	10.7	24.07	11	26.09	11.3
8	20.41	10.6	20.87	10.8	21.96	9.4	25	10.9
9	21.13	10.7	22.01	10.8	22.99	10.7	26.41	11.1
10	20.52	10.7	22.07	10.7	22.45	10.1	25.17	11.4
11	20.58	10.7	23.72	10.7	23.14	10.3	25.01	10.8
12	21.17	10.7	23.48	10.8	22.54	8.7	24.23	10.5
13	20	10.6	22.28	10.5	23.17	10.4	22.92	8.9
14	19.81	10.5	22.06	10.4	22.28	10.2	24.38	9.9
15	20.84	10.6	20.8	9.9	21.51	10	24.49	10.4
16	20.75	10.7	21.33	10.7	22.41	10.2	25.68	11.2
17	20.61	10.7	22.39	10.7	22.92	10.6	26.57	11.8
18	20.44	10.7	22.72	10.8	23.27	10.4	27.16	11.7
19	20	10.4	22.79	10.9	25.18	10.8	25.38	11.4
20	20.4	10.7	20.37	8	25.21	11	25.92	11.8
21	19.83	10.7	22.4	10.7	24.52	10.9	24.61	11.7
22	19.34	10.5	22.93	10.9	23.51	11.1	24.09	11.2
23	17.86	7.5	22.6	10.9	23.59	11	23.98	11
24	21.2	10.7	23.11	10.8	23.32	11	24.05	10.5
25	21.17	10.8	23.53	10.7	22.98	10.2	24.17	11
26	20.67	10.8	23.27	10.8	22.59	10.2	24.38	10.9
27	20.22	10	21.88	10.4	14.43	3.6	24.31	11
28	21.07	10.8	22.08	10.4	9.23	0	24.6	11
29	20.94	10	21.23	10.5	21.84	9	24.24	11.2
30	21.44	10.9			20.88	7.3	23.89	10.6
31	21.05	10.8			21.24	9.1		
SUM	629.84	326.2	635.15	306.6	695.88	299.6	734.9	323.3
MEAN	20.32	10.52	21.9	10.57	22.45	9.66	24.5	10.78

(Continued) :

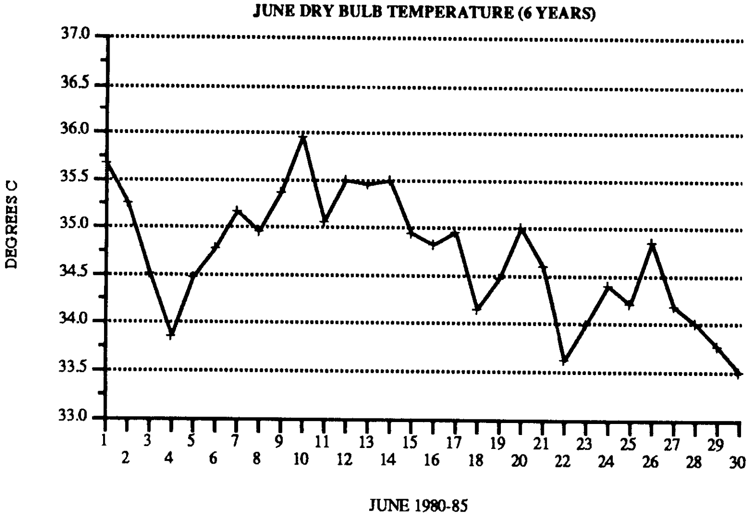
MAY		JUNE		JULY		AUGEST	
TOTAL	SOLAR	TOTAL	SOLAR	TOTAL	SOLAR	TOTAL	SOLAR
25.49	11.7	16.26	4.5	16.46	3.9	23.88	11.4
25.26	11.8	21.34	10.6	18.89	4.9	23.23	11.3
25.15	11.7	17.47	5	15.1	2.5	21.39	9.2
24.48	10.7	21.2	6.3	14.17	2.8	21.29	10
24.16	10.9	15.66	3.2	21.58	9.7	23.97	11.1
23.83	10.7	19.03	7	19.18	4.5	17.58	5.4
24.62	11.4	22.22	10.6	24.16	11.6	21.28	9.4
24.55	11.3	24.55	11.2	23.18	11.5	16.08	1.9
23.68	11	22.74	11	20.41	8.9	18.6	5.4
23.93	10.4	21.52	9.3	23.08	11.5	20.56	7.1
24.59	10.7	23.52	10.9	17.88	4.7	17.26	3.3
25.22	11.4	21.59	10.2	22.04	9.8	22.45	8.7
27.66	12.1	19.98	8.8	23.49	10.1	13.45	1.9
24.03	11	18.43	6.9	22.23	10.7	21.96	8.9
23.3	10.6	18.09	5.5	23.78	8.3	21.89	9.7
21.82	10.1	18.53	5.6	23.46	9.8	21.88	10.3
19.28	7.7	22.15	10	20.85	8.6	23.29	11.2
20.97	10	24.76	11.4	22.61	10.4	23.68	11.3
21.96	9.6	24.07	11.8	21.66	9.4	23.17	10
20.03	8.3	24.26	11.6	23.13	10.5	19.49	4.7
20.81	8.4	22.29	10.8	20.88	8.3	23.11	10.7
21.03	8.6	18.58	4.5	22.54	10.8	23.75	11.2
19.83	8.2	21.72	9.3	23.08	10.5	19.26	5.4
21.97	10.4	19.74	5.5	21.56	9.9	22.17	9.4
23.29	11.1	21.47	10.2	19.78	7.3	22.95	9.5
23.47	11.2	23.4	10.7	22.73	9.6	23.06	10.1
23.8	10.6	21.61	9.5	22.37	10.3	23.87	11.1
24.29	11.4	20.09	6.6	21.98	8.4	23.11	11.2
23.63	11	19.97	6.9	23.89	10.5	21.48	9.4
23.96	11	21.74	10.3	22.09	10.5	21.62	8.8
23.22	10.7			22.84	11	23.25	10.7
723.31	325.7	627.98	255.7	661.08	271.2	664.01	259
23.33	10.51	20.93	8.52	21.33	8.75	21.42	8.63

(Continued) :

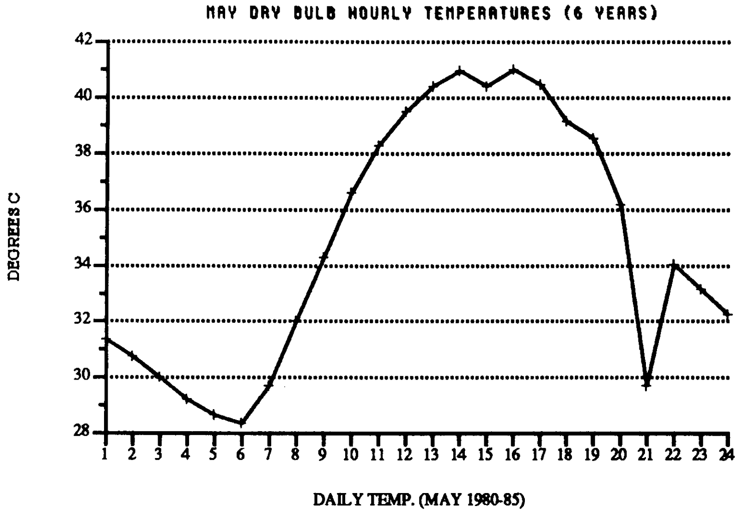
SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
TOTAL	SOLAR	TOTAL	SOLAR	TOTAL	SOLAR	TOTAL	SOLAR
22.26	10.6	20.42	9.2	18.65	10	19.49	10.8
23.57	10.8	17.48	5.8	8.77	9.2	18.33	10.1
22.72	10.2	20.69	9.8	19.9	10.6	18.06	9.8
22.14	10	21.12	10	19.86	10.6	17.46	9.6
22.31	6.3	21.52	10.2	19.47	10.3	18.02	10
22.57	10.3	20.75	10.3	20.61	10	17.21	9.4
22.24	10	17.33	4.8	20.83	10.7	18.48	10.2
21.84	10.2	21.74	10.5	20.41	10.3	18.51	10.1
23.24	10.2	21.08	10.3	20.34	10.4	18.1	10.2
22.14	10	20.43	9.8	21.08	10.9	18.47	10.2
22.32	10.4	19.94	10	19.51	10.6	18.73	9.3
22.58	10.6	19.15	10	19.39	10.7	20.41	10
19.85	9.5	20.47	10.1	18.18	9.6	19.95	10.2
18.82	6	19.52	9.2	20.09	10.3	19.43	10
22.82	9.8	20.83	10.3	19.54	10.3	18.64	10.3
21.44	9.2	20.87	10.3	18.69	10	19.34	10.5
21.64	10.3	19.79	9.3	18.24	10.2	19.28	10.6
22.19	9.8	20.26	10.3	19.47	10.4	18.95	10.5
22.13	10.4	20.79	10.4	20.72	10.9	18.69	10.6
22.07	10.6	20.35	10.5	20.77	10.9	18.92	10.5
21.12	10	20.52	10.5	19.89	10.2	18.74	10.6
21.93	10.2	20.2	10.4	19.42	9.7	17.86	9.2
21.03	9.1	19.79	10.3	20.53	9.5	18.13	9.9
22.09	10.4	17.78	9.6	18.99	9.9	17.22	10
21.21	9.9	19.44	10.4	20.22	10.5	16.48	9.9
21.59	9.1	19.62	10.2	19.33	10	16.32	9.7
18.79	8.3	19.86	10.7	19.31	10.4	11.84	1.6
21.03	10.2	20.25	10.6	20.84	10.6	16.48	9.6
19.05	6.7	20.16	10.6	20.31	10.7	16.44	9.7
19.73	8.5	19.19	10.4	19.37	10.7	18.25	10.2
		19.15	10.5			18.11	10.4
648.46	287.6	620.49	305.3	582.73	309.1	560.34	303.7
21.62	9.59	20.02	9.85	19.42	10.3	18.08	9.8



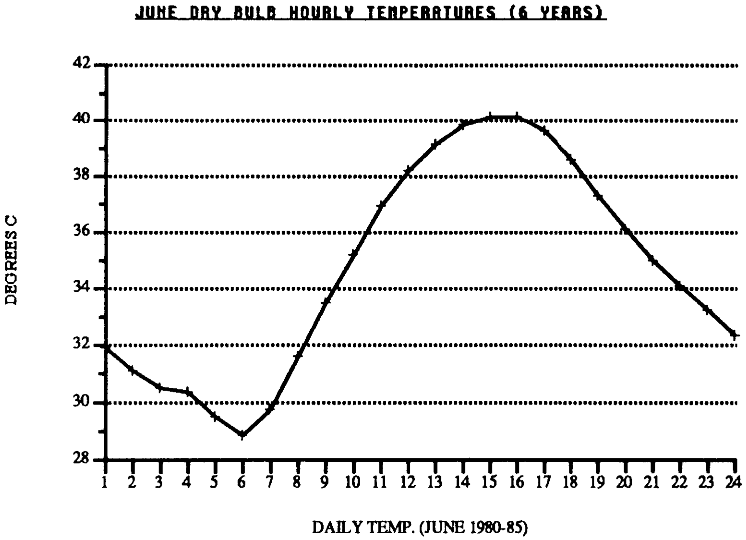
May Average Daily Temperature- Khartoum.



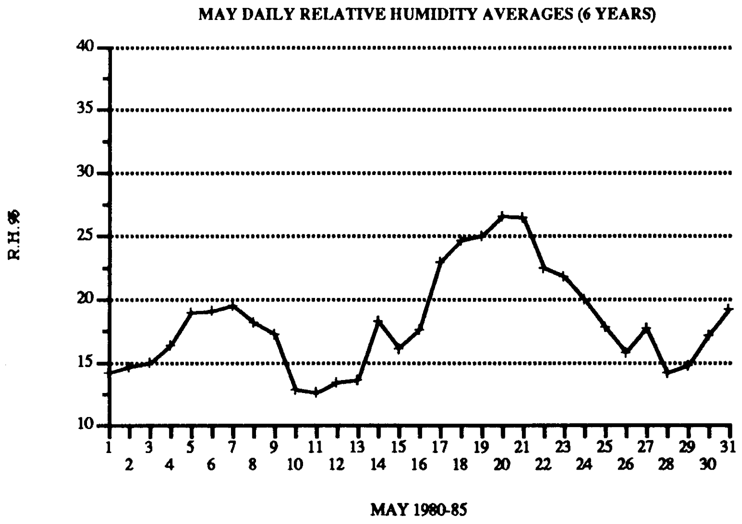
June Average Daily Temperature- Khartoum.



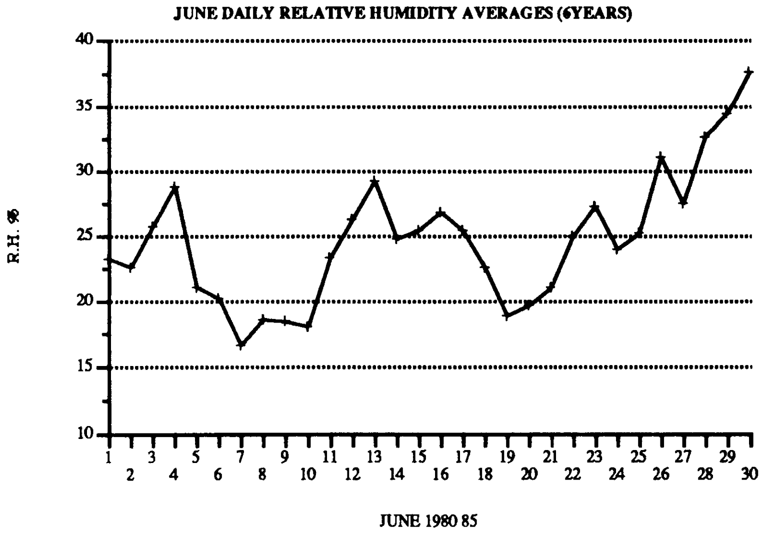
May Average Hourly Temperature- Khartoum.



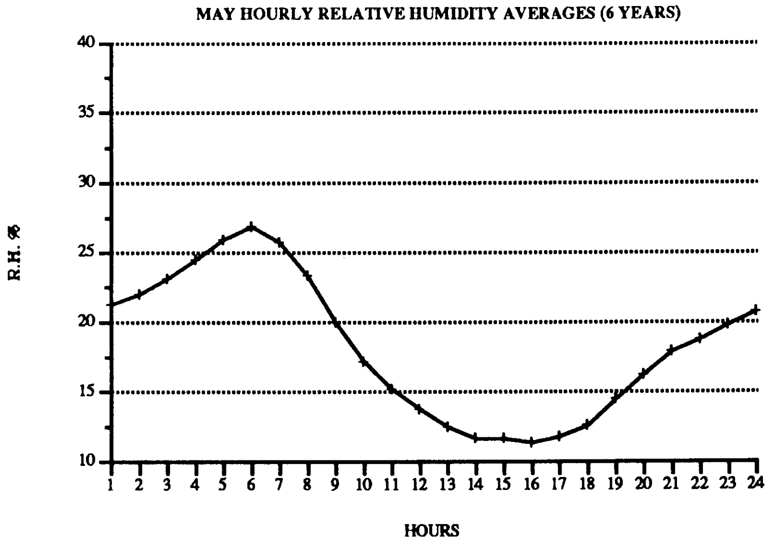
June Average Hourly Temperature- Khartoum.



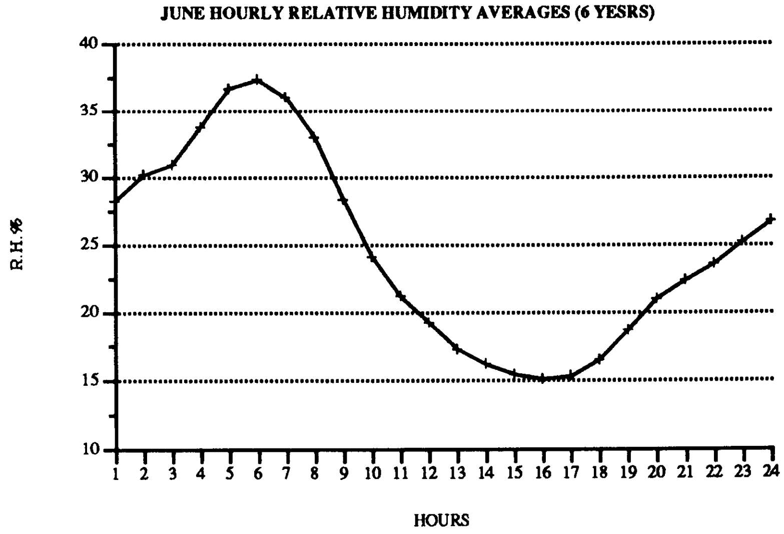
May Average Daily Relative Humidity- Khartoum.



JuneAverage Daily Relative Humidity- Khartoum.



May Average Hourly Relative Humidity- Khartoum.



June Average Hourly Relative Humidity- Khartoum.

APPENDIX B

SHADE TREES IN KHARTOUM

From "Notes on the Important Shade Trees Grown in Khartoum" a paper by Prof. A. H. El Nady, Faculty of Agriculture , University of Khartoum.

B.1 AZADIRACHTA INDICA (NEEM) :

This tree is native to the drier parts of the world. It is the most useful tree in the dry tropics. It is not suited to the desert and semi-desert climate except under irrigation. Neem is an evergreen tree which shed its leaves partially during the dry season. It is an excellent shade tree requiring about 450 mm of rain fall or more. It grows satisfactorily without irrigation if water table is not more than 18 meters deep, but develops poorly if water logged. Neem can withstand atmospheric drought and high temperature if given adequate ground water.

Neem can tolerate a wide range of soil conditions provided that soils are reasonably deep and not too acidic preferable PH of 6.5 or more. It can grow on sand, silt, heavy clay soils, or even black cotton soils and on dry stony soils.

Dominant stem height in old plantations in Sudan reached about 22-27 m. and about 50-90 cm. in diameter (trunk), with a rounded crown and dense leaves. Crown (canopy) area is also large and can reach up to 10 meters in diameter or more.

B.2 FICUS ELASTICA (LABAKH) :

One of the dominant trees in Khartoum especially along the River Nile and as a shade tree along main streets. It is a tall tree up, to 28 m. in height, and reaches more than 100 cm. in diameter of the trunk at maturity. The canopy is very large and can reach up to 50 m. in diameter provided that adequate space and proper pruning is done on seasonal basis. Mostly propagated by large branches and cuttings. Labakh is a very dense shade tree and can grow under both direct sunlight and shade. It requires plenty of irrigation water at regular intervals when grown in dry and semi-dry climates.

Labakh is sensitive to drought conditions but has a deep root system which can reach ground water if less than 18 meters. It requires , well drained fertile soils and is sensitive to high slat in the soil. Pruning is required by thinning of some branches. It has thick leaves resistant to pests and diseases.

B.3 FIUCUS BENJAMINA (LABAKH) :

Another species of the Genus Ficus, very promising as an ornamental tree. Evergreen and has a tendency of columnar or conical growth with semi-drooping branches and undulated leaf margins. Light sparce up to 7 meters high with a large spherical or conical canopy depending on pruning. It is adapted to both shade and direct sunlight. Requires plenty of water at regular intervals. It needs acidic, fertile soils which are well drained. Pruning either by deheading or thinning is required and it resists pests and diseases.

B.4 ALBIZIA LEBBEK (DIGN EL BASHA) :

This tree grows in a great variety of soils and climates. It is a large deciduous tree suitable for dry tropical and semi-tropical climates and requires irrigation if ground water is not adequate in deserts and semi-deserts regions.

Height is up to 20 meters and the trunk diameter reaches 70 cm. Crown is rather dense and quick growing. It can reach a height of 30 meters and a trunk diameter of 2-3 meters when conditions are suitable. Its main use is as an ornamental shade tree.

B.5 KHAYA SENEGALENSIS (MAHOGANY) :

Large semi-evergreen shade tree which can grow up to 20-45 meters high and up to 120 cm. in trunk diameter at maturity. It has a light shining foliage with white dense crown and thick trunk. It drops its leaves during the dry season, which are succeeded quickly by new leaves. It is used both as shade tree and production of excellent timber. It is very common in Khartoum Province.

B.6 EUCALIPTUS CAMALDULENSIS (BAN) :

Medium to tall up to 30 meters high with a trunk diameter that can reach up to 80 cm. Ban has a light foliage which is evergreen. Suited to typical sandy alluvial soils. In arid and semi-arid areas it grows successfully and adapts to a wide range of climates. It tolerates both drought and high salt concentration. It has a sparce narrow canopy with tall stem and tender branches. It requires irrigation in the absence of shallow water. Ban is the fastest growing tree in Khartoum green belt (South Khartoum).

B.7 CONOCARPUS LANCIFOLIOS (DAMAS) :

Evergreen tree up to 20-30 meters high. The crown spreads with dark green bark . Best soils are sandy with shallow water table. It requires irrigation in sites when water table is more than 8 meters. Excellent shade tree, tolorant to high salt concentration. It grows well on fertile soils. Damas is one of the most promising trees in Sudan for subdesert climates provided that shallow ground water is available. It has a straight pole and narrow crown and can withstand both drought and water logging for several months.

B.8 CASSIA SIAMEA (CASIA) :

Evergreen tree with medium canopy area up to 30 meters in height and 70 cm. diameter. It is only successful on fertile and very well drained soils. It requires soils which are relatively rich in nutrients and is fairly drought resistant.

B.9 TERMINALIA BRAZILIA (BRAZILIA) :

A new exotic shade tree which is now becoming very popular in Khartoum. It has large dark green leaves. It branches in successive rings at intervals giving an attractive appearance. Brazilia is a semi-evergreen tree but loses more leaves than the Neem during the dry season and quickly retains its leaves. It requires very large quantities of irrigation water. It is a successful shade tree because of its dense canopy. In Khartoum it reaches up to 8 meters in height and about 25-30 cm. in trunk diameter. Very successful in light soils.

APPENDIX C

APPENDIX C

Cooling Load Calculations

Peak Load Calculations :

Among the methods available to calculate the peak cooling loads, the CLTD (Cooling Load Temperature Difference) and the CLF (Cooling Load Factor) method is used to take into account the sol-air temperature and the effect of the mass which retards and dampens the heat flow through the building material. The conduction loads for external walls, and the heat conduction through glass are determined by the use of the CLTD factors, while other sensible heat gains through glass or from appliances are computed using the CLF to modify the instantaneous heat flow. Both the CLTD and CLF procedures include the time lag effect between the sensible heat gain and the cooling loads due to temporary storage of the radiation components in the internal thermal masses of the building.

1.1 Original Building Load calculations for Jan.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.08				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						28		
CLTD (corrected)						12		
Heat Gain Trough The Roof							2593	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				3.125				
U-Value (1/R)				0.32				
(A) Norht Wall								
Area					420			
CLTD (corrected)						3		
Heat Gain							403	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						22		
Heat Gain							2394	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						13		
Heat Gain							3578	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						9		
Heat Gain							2270	BTU/Hr.
Total Conduction through walls							8644	BTU/Hr.
[3] Glass (Conduction)								
U-Value (Single Glass)				1.04				
(A) North								
Area					490			
CLTD (corrected)						3		
Heat Gain							1529	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						3		
Heat Gain							421	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						3		
Heat Gain							218	BTU/Hr.
Total Conduction through Glass							2168	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				1				
(A) North								
Area (Shaded) at 1500 hr.					490			
Area (Lit)					0			
SHGF (Shaded)			31					
SHGF (Lit)			30					
CLF						0.76		
Heat Gain Through Shaded Areas							11544	BTU/Hr.
Heat Gain Through Lit Areas							0	BTU/Hr.
Total Gain Through North Side							11544	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			38					
CLF						0.53		
Heat Gain Through South Side							2719	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			34					
CLF						0.29		
Heat Gain Through East Side							690	BTU/Hr.
Total Solar Gain Through Glass							14954	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[7] Ventilation								
Volume of air/hour							324000	
cfm							5400	
Temperature Difference deg. F	3							
Factor		1.1						
(1) Sensible Heat Gain							17820	BTU/Hr.
Air/humidity ratio difference (W)		0.005						
(2) Latent Heat Gain							138521	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							*47448*	BTU/Hr.
(2) Latent Heat							*142421*	BTU/Hr.

1.2 Original Building Load calculations for Jun.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.08				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						34		
Heat Gain Trough The Roof							7347	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				3.125				
U-Value (1/R)				0.32				
(A) Norht Wall								
Area					420			
CLTD (corrected)						25		
Heat Gain							3360	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						21		
Heat Gain							2285	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						33		
Heat Gain							9082	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						23		
Heat Gain							5800	BTU/Hr.
Total Conduction through walls							20527	BTU/Hr.
[3] Glass (Conduction)								
U-Value (Single Glass)				1.04				
(A) North								
Area					490			
CLTD (corrected)						17		
Heat Gain							8663	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						17		
Heat Gain							2387	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						17		
Heat Gain							1238	BTU/Hr.
Total Conduction through Glass							12288	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				1				
(A) North								
Area (Shaded) at 1500 hr.					425			
Area (Lit)					65			
SHGF (Shaded)			45					
SHGF (Lit)			66					
CLF						0.76		
Heat Gain Through Shaded Areas							14535	BTU/Hr.
Heat Gain Through Lit Areas							3260	BTU/Hr.
Total Gain Through North Side							17795	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			40					
CLF						0.53		
Heat Gain Through South Side							2862	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			46					
CLF						0.29		
Heat Gain Through East Side							934	BTU/Hr.
Total Solar Gain Through Glass							21591	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[7] Ventilation								
Volume of air/hour							288000	
cfm							4800	
Temperature Difference deg. F	17							
Factor		1.1						
(1) Sensible Heat Gain							89760	BTU/Hr.
Air/humidity ratio difference (W)		0.005						
(2) Latent Heat Gain							123130	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							*152781*	BTU/Hr.
(2) Latent Heat							*127030*	BTU/Hr.

1.3 Original Building Load calculations for Sept.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.08				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						37		
Heat Gain Trough The Roof							7995	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				3.125				
U-Value (1/R)				0.32				
(A) Norht Wall								
Area					420			
CLTD (corrected)						11		
Heat Gain							1478	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						13.5		
Heat Gain							1469	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						21.5		
Heat Gain							5917	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						17.5		
Heat Gain							4413	BTU/Hr.
Total Conduction through walls							13277	BTU/Hr.
[3] Glass (Conduction)								
U-Value (Single Glass)				**1.04**				
(A) North								
Area					490			
CLTD (corrected)						11		
Heat Gain							5606	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						11		
Heat Gain							1544	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						11		
Heat Gain							801	BTU/Hr.
Total Conduction through Glass							7951	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				1				
(A) North								
Area (Shaded) at 1500 hr.					450			
Area (Lit)					40			
SHGF (Shaded)			37					
SHGF (Lit)			36					
CLF						0.76		
Heat Gain Through Shaded Areas							12654	BTU/Hr.
Heat Gain Through Lit Areas							1094	BTU/Hr.
Total Gain Through North Side							13748	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			41					
CLF						0.53		
Heat Gain Through South Side							2934	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			41					
CLF						0.29		
Heat Gain Through East Side							832	BTU/Hr.
Total Solar Gain Through Glass							17514	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[7] Ventilation								
Volume of air/hour							252000	
cfm							4200	
Temperature Difference deg. F	11							
Factor		1.1						
(1) Sensible Heat Gain							50820	BTU/Hr.
Air/humidity ratio difference (W)		0.005						
(2) Latent Heat Gain							107738	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							*98826*	BTU/Hr.
(2) Latent Heat							*111638*	BTU/Hr.

2.1 TheFlipped Building Load calculations for Jan.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						28		
CLTD (corrected)						12		
Heat Gain Trough The Roof							2593	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
		0.19		0				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				3.125				
U-Value (1/R)				0.32				
(A) North Wall								
Area					340			
CLTD (corrected)						3		
Heat Gain							326	BTU/Hr.
(B) South Wall								
Area					420			
CLTD (corrected)						22		
Heat Gain							2957	BTU/Hr.
(C) East Wall								
Area					788			
CLTD (corrected)						13		
Heat Gain							3278	BTU/Hr.
(D) West Wall								
Area					860			
CLTD (corrected)						9		
Heat Gain							2477	BTU/Hr.
Total Conduction through walls							9038	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Double Low-E Glass)			0.96	1.04				
(A) North								
Area					135			
CLTD (corrected)						3		
Heat Gain							422	BTU/Hr.
(B) South								
Area					490			
CLTD (corrected)						3		
Heat Gain							1531	BTU/Hr.
(C) West								
Area					70			
CLTD (corrected)						3		
Heat Gain							219	BTU/Hr.
Total Conduction through Glass							2172	BTU/Hr.

[4] Glass (Solar)								
SC (Double Low-E Glazing)				1				
(A) North								
Area (Shaded) at 1500 hr.					135			
Area (Lit)					0			
SHGF (Shaded)			31					
SHGF (Lit)			30					
CLF						0.76		
Heat Gain Through Shaded Areas							3181	BTU/Hr.
Heat Gain Through Lit Areas							0	BTU/Hr.
Total Gain Through North Side							3181	BTU/Hr.
(B) South								
Area (all Shaded)					490			
SHGF			38					
CLF						0.53		
Heat Gain Through South Side							9869	BTU/Hr.
(C) west								
Area (not Shaded)					70			
SHGF			210					
CLF						0.4		
Heat Gain Through West Side							5880	BTU/Hr.
Total Solar Gain Through Glass							18929	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	3							
Sensible Heat Gain							1980	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.005						
Latent Heat Gain							15391	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							35981	BTU/Hr.
(2) Latent Heat							19291	BTU/Hr.

2.2 TheFlipped Building Load calculations for Jun.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						34		
Heat Gain Trough The Roof							7347	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
		0.19		0				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				3.125				
U-Value (1/R)				0.32				
(A) Norht Wall								
Area					340			
CLTD (corrected)						25		
Heat Gain							2720	BTU/Hr.
(B) South Wall								
Area					420			
CLTD (corrected)						21		
Heat Gain							2823	BTU/Hr.
(C) East Wall								
Area					788			
CLTD (corrected)						33		
Heat Gain							8322	BTU/Hr.
(D) West Wall								
Area					860			
CLTD (corrected)						23		
Heat Gain							6330	BTU/Hr.
Total Conduction through walls							20194	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Glass)			0.96	1.04				
(A) North								
Area					135			
CLTD (corrected)						17		
Heat Gain							2391	BTU/Hr.
(B) South								
Area					490			
CLTD (corrected)						17		
Heat Gain							8677	BTU/Hr.
(C) West								
Area					70			
CLTD (corrected)						17		
Heat Gain							1240	BTU/Hr.
Total Conduction through Glass							12307	BTU/Hr.

[4] Glass (Solar)								
SC(Low-E Glazing)				1				
(A) North								
Area (Shaded) at 1500 hr.					135			
Area (Lit)					0			
SHGF (Shaded)			45					
SHGF (Lit)			66					
CLF						0.76		
Heat Gain Through Shaded Areas							4617	BTU/Hr.
Heat Gain Through Lit Areas							0	BTU/Hr.
Total Gain Through North Side							4617	BTU/Hr.
(B) South								
Area (all Shaded)					490			
SHGF			40					
CLF						0.53		
Heat Gain Through South Side							10388	BTU/Hr.
(C) West								
Area (not Shaded)					70			
SHGF			207					
CLF						0.4		
Heat Gain Through West Side							5796	BTU/Hr.
Total Solar Gain Through Glass							20801	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	17							
Sensible Heat Gain							11220	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.005						
Latent Heat Gain							15391	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							73138	BTU/Hr.
(2) Latent Heat							19291	BTU/Hr.

2.3 TheFlipped Building Load calculations for Sept..

U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						37		
Heat Gain Trough The Roof							7995	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
		0.19		0				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				3.125				
U-Value (1/R)				0.32				
(A) Norht Wall								
Area					340			
CLTD (corrected)						11		
Heat Gain							1197	BTU/Hr.
(B) South Wall								
Area					420			
CLTD (corrected)						13.5		
Heat Gain							1814	BTU/Hr.
(C) East Wall								
Area					788			
CLTD (corrected)						21.5		
Heat Gain							5422	BTU/Hr.
(D) West Wall								
Area					860			
CLTD (corrected)						17.5		
Heat Gain							4816	BTU/Hr.
Total Conduction through walls							13249	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value Double Low-E Glass)			0.96	1.04				
(A) North								
Area					135			
CLTD (corrected)						11		
Heat Gain							1547	BTU/Hr.
(B) South								
Area					490			
CLTD (corrected)						11		
Heat Gain							5615	BTU/Hr.
(C) West								
Area					70			
CLTD (corrected)						11		
Heat Gain							802	BTU/Hr.
Total Conduction through Glass							7964	BTU/Hr.

[4] Glass (Solar)								
SC (Double Low-E Glazing)				1				
(A) North								
Area (Shaded) at 1500 hr.					135			
Area (Lit)					0			
SHGF (Shaded)			37					
SHGF (Lit)			36					
CLF						0.76		
Heat Gain Through Shaded Areas							3796	BTU/Hr.
Heat Gain Through Lit Areas							0	BTU/Hr.
Total Gain Through North Side							3796	BTU/Hr.
(B) South								
Area (all Shaded)					490			
SHGF			41					
CLF						0.53		
Heat Gain Through South Side							10648	BTU/Hr.
(C) West								
Area (not Shaded)					70			
SHGF			227					
CLF						0.4		
Heat Gain Through East Side							6356	BTU/Hr.
Total Solar Gain Through Glass							20800	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	11							
Sensible Heat Gain							7260	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.006						
Latent Heat Gain							17424	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							58536	BTU/Hr.
(2) Latent Heat							21324	BTU/Hr.

3.1 The Building Heat Gain Load Calculation when Double Low-E glass, and Roof and Wall Insulation are used for Jan.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						28		
CLTD (corrected)						12		
Heat Gain Trough The Roof							2593	
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) North Wall								
Area					420			
CLTD (corrected)						3		
Heat Gain							92	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						22		
Heat Gain							548	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						13		
Heat Gain							819	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						9		
Heat Gain							520	BTU/Hr.
Total Conduction through walls							1979	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Glass)			3.2	0.31				
(A) North								
Area					490			
CLTD (corrected)						3		
Heat Gain							459	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						3		
Heat Gain							127	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						3		
Heat Gain							66	BTU/Hr.
Total Conduction through Glass							652	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				0.45				
(A) North								
Area (Shaded) at 1500 hr.					490			
Area (Lit)					0			
SHGF (Shaded)			31					
SHGF (Lit)			30					
CLF						0.76		
Heat Gain Through Shaded Areas							5195	BTU/Hr.
Heat Gain Through Lit Areas							0	BTU/Hr.
Total Gain Through North Side							5195	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			38					
CLF						0.53		
Heat Gain Through South Side							1224	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			34					
CLF						0.29		
Heat Gain Through East Side							311	BTU/Hr.
Total Solar Gain Through Glass							6729	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	3							
Sensible Heat Gain							1980	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.005						
Latent Heat Gain							15391	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							15201	BTU/Hr.
(2) Latent Heat							19291	BTU/Hr.

3.2 The Building Heat Gain Load Calculation when Double Low-E glass, and Roof and Wall Insulation are used for Jun.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						34		
Heat Gain Trough The Roof							7347	
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) North Wall								
Area					420			
CLTD (corrected)						25		
Heat Gain							769	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						21		
Heat Gain							523	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						33		
Heat Gain							2079	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						23		
Heat Gain							1328	BTU/Hr.
Total Conduction through walls							4699	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Glass)			3.2	0.31				
(A) North								
Area					490			
CLTD (corrected)						17		
Heat Gain							2603	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						17		
Heat Gain							717	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						17		
Heat Gain							372	BTU/Hr.
Total Conduction through Glass							3692	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				0.45				
(A) North								
Area (Shaded) at 1500 hr.					425			
Area (Lit)					65			
SHGF (Shaded)			45					
SHGF (Lit)			66					
CLF						0.76		
Heat Gain Through Shaded Areas							6541	BTU/Hr.
Heat Gain Through Lit Areas							1467	BTU/Hr.
Total Gain Through North Side							8008	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			40					
CLF						0.53		
Heat Gain Through South Side							1288	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			46					
CLF						0.29		
Heat Gain Through East Side							420	BTU/Hr.
Total Solar Gain Through Glass							9716	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft.			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	17							
Sensible Heat Gain							11220	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.005						
Latent Heat Gain							15391	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							37943	BTU/Hr.
(2) Latent Heat							19291	BTU/Hr.

3.3 The Building Heat Gain Load Calculation when Double Low-E glass, and Roof and Wall Insulation are used for Sept.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						37		
Heat Gain Trough The Roof							**7995**	
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) North Wall								
Area					420			
CLTD (corrected)						11		
Heat Gain							**338**	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						13.5		
Heat Gain							**336**	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						21.5		
Heat Gain							**1354**	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						17.5		
Heat Gain							**1010**	BTU/Hr.
Total Conduction through walls							**3039**	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Glass)			3.2	**0.31**				
(A) North								
Area					490			
CLTD (corrected)						11		
Heat Gain							**1684**	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						11		
Heat Gain							**464**	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						11		
Heat Gain							**241**	BTU/Hr.
Total Conduction through Glass							**2389**	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				**0.45**				
(A) North								
Area (Shaded) at 1500 hr.					450			
Area (Lit)					40			
SHGF (Shaded)			37					
SHGF (Lit)			36					
CLF						0.76		
Heat Gain Through Shaded Areas							**5694**	BTU/Hr.
Heat Gain Through Lit Areas							**492**	BTU/Hr.
Total Gain Through North Side							**6187**	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			41					
CLF						0.53		
Heat Gain Through South Side							**1320**	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			41					
CLF						0.29		
Heat Gain Through East Side							**375**	BTU/Hr.
Total Solar Gain Through Glass							**7881**	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							**1269**	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							**3900**	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft.			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	11							
Sensible Heat Gain							**7260**	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.006						
Latent Heat Gain							**17424**	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							**29834**	BTU/Hr.
(2) Latent Heat							**21324**	BTU/Hr.

4.1 The Building Heat Gain Load Calculation when Single Clear Low-E glass, and Roof and Wall Insulation are used for Jan.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						28		
CLTD (corrected)						12		
Heat Gain Trough The Roof							2593	
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) Norht Wall								
Area					420			
CLTD (corrected)						3		
Heat Gain							92	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						22		
Heat Gain							548	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						13		
Heat Gain							819	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						9		
Heat Gain							520	BTU/Hr.
Total Conduction through walls							1979	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Glass)			1.45	0.69				
(A) North								
Area					490			
CLTD (corrected)						3		
Heat Gain							1014	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						3		
Heat Gain							279	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						3		
Heat Gain							145	BTU/Hr.
Total Conduction through Glass							1438	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				0.84				
(A) North								
Area (Shaded) at 1500 hr.					490			
Area (Lit)					0			
SHGF (Shaded)			31					
SHGF (Lit)			30					
CLF						0.76		
Heat Gain Through Shaded Areas							9708	BTU/Hr.
Heat Gain Through Lit Areas							0	BTU/Hr.
Total Gain Through North Side							9708	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			38					
CLF						0.53		
Heat Gain Through South Side							2286	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			34					
CLF						0.29		
Heat Gain Through East Side							580	BTU/Hr.
Total Solar Gain Through Glass							12575	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft.			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	3							
Sensible Heat Gain							1980	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.005						
Latent Heat Gain							15391	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							21833	BTU/Hr.
(2) Latent Heat							19291	BTU/Hr.

4.2 The Building Heat Gain Load Calculation when Single Clear Low-E glass, and Roof and Wall Insulation are used for Jun.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						34		
Heat Gain Trough The Roof							7347	
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) North Wall								
Area					420			
CLTD (corrected)						25		
Heat Gain							769	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						21		
Heat Gain							523	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						33		
Heat Gain							2079	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						23		
Heat Gain							1328	BTU/Hr.
Total Conduction through walls							4699	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Glass)			1.45	0.69				
(A) North								
Area					490			
CLTD (corrected)						17		
Heat Gain							5745	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						17		
Heat Gain							1583	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						17		
Heat Gain							821	BTU/Hr.
Total Conduction through Glass							8148	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				0.84				
(A) North								
Area (Shaded) at 1500 hr.					425			
Area (Lit)					65			
SHGF (Shaded)			45					
SHGF (Lit)			66					
CLF						0.76		
Heat Gain Through Shaded Areas							12223	BTU/Hr.
Heat Gain Through Lit Areas							2742	BTU/Hr.
Total Gain Through North Side							14964	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			40					
CLF						0.53		
Heat Gain Through South Side							2407	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			46					
CLF						0.29		
Heat Gain Through East Side							785	BTU/Hr.
Total Solar Gain Through Glass							18156	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	17							
Sensible Heat Gain							11220	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.005						
Latent Heat Gain							15391	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							50839	BTU/Hr.
(2) Latent Heat							19291	BTU/Hr.

4.3 The Building Heat Gain Load Calculation when Single Clear Low-E glass, and Roof and Wall Insulation are used for Sept.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						37		
Heat Gain Trough The Roof							7995	
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) North Wall								
Area					420			
CLTD (corrected)						11		
Heat Gain							339	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						13.5		
Heat Gain							336	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						21.5		
Heat Gain							1354	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						17.5		
Heat Gain							1010	BTU/Hr.
Total Conduction through walls							3039	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Glass)			1.45	0.69				
(A) North								
Area					490			
CLTD (corrected)						11		
Heat Gain							3717	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						11		
Heat Gain							1024	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						11		
Heat Gain							531	BTU/Hr.
Total Conduction through Glass							5272	BTU/Hr.
[4] Glass (Solar)								
SC (Single Glazing)				0.84				
(A) North								
Area (Shaded) at 1500 hr.					450			
Area (Lit)					40			
SHGF (Shaded)			37					
SHGF (Lit)			36					
CLF						0.76		
Heat Gain Through Shaded Areas							10641	BTU/Hr.
Heat Gain Through Lit Areas							920	BTU/Hr.
Total Gain Through North Side							11561	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			41					
CLF						0.53		
Heat Gain Through South Side							2467	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			41					
CLF						0.29		
Heat Gain Through East Side							700	BTU/Hr.
Total Solar Gain Through Glass							14728	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft.			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	11							
Sensible Heat Gain							7260	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.006						
Latent Heat Gain							17424	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							39563	BTU/Hr.
(2) Latent Heat							21324	BTU/Hr.

5.1 The Building Heat Gain Load Calculation when Single Light-Green Low-E glass, and Roof and Wall Insulation are used for Jan.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						28		
CLTD (corrected)						12		
Heat Gain Trough The Roof							2593	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) Norht Wall								
Area					420			
CLTD (corrected)						3		
Heat Gain							92	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						22		
Heat Gain							548	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						13		
Heat Gain							819	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						9		
Heat Gain							520	BTU/Hr.
Total Conduction through walls							1979	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Light Green Low-E Glazing)			1.45	**0.69**				
(A) North								
Area					490			
CLTD (corrected)						3		
Heat Gain							1014	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						3		
Heat Gain							279	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						3		
Heat Gain							145	BTU/Hr.
Total Conduction through Glass							1438	BTU/Hr.
[4] Glass (Solar)								
SC (Single Light Green Low-E Glazing)				**0.53**				
(A) North								
Area (Shaded) at 1500 hr.					490			
Area (Lit)					0			
SHGF (Shaded)			31					
SHGF (Lit)			30					
CLF						0.76		
Heat Gain Through Shaded Areas							6166	BTU/Hr.
Heat Gain Through Lit Areas							0	BTU/Hr.
Total Gain Through North Side							6166	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			38					
CLF						0.53		
Heat Gain Through South Side							1452	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			34					
CLF						0.29		
Heat Gain Through East Side							369	BTU/Hr.
Total Solar Gain Through Glass							7987	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft.			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	3							
Sensible Heat Gain							1980	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.005						
Latent Heat Gain							15391	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							17245	BTU/Hr.
(2) Latent Heat							19291	BTU/Hr.

5.2 The Building Heat Gain Load Calculation when Single Light-Green Low-E glass, and Roof and Wall Insulation are used for Jun.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						34		
Heat Gain Trough The Roof							7347	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) Norht Wall								
Area					420			
CLTD (corrected)						25		
Heat Gain							769	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						21		
Heat Gain							523	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						33		
Heat Gain							2079	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						23		
Heat Gain							1328	BTU/Hr.
Total Conduction through walls							4699	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Light Green Low-E Glazing)			1.45	0.69				
(A) North								
Area					490			
CLTD (corrected)						17		
Heat Gain							5745	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						17		
Heat Gain							1583	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						17		
Heat Gain							821	BTU/Hr.
Total Conduction through Glass							8148	BTU/Hr.
[4] Glass (Solar)								
SC (Single Light Green Low-E Glazing)				0.53				
(A) North								
Area (Shaded) at 1500 hr.					425			
Area (Lit)					65			
SHGF (Shaded)			45					
SHGF (Lit)			66					
CLF						0.76		
Heat Gain Through Shaded Areas							7763	BTU/Hr.
Heat Gain Through Lit Areas							1741	BTU/Hr.
Total Gain Through North Side							9504	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			40					
CLF						0.53		
Heat Gain Through South Side							1529	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			46					
CLF						0.29		
Heat Gain Through East Side							499	BTU/Hr.
Total Solar Gain Through Glass							11532	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft.			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	17							
Sensible Heat Gain							11220	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.005						
Latent Heat Gain							15391	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							44214	BTU/Hr.
(2) Latent Heat							19291	BTU/Hr.

5.3 The Building Heat Gain Load Calculation when Single Light-Green Low-E glass, and Roof and Wall Insulation are used for Sept.

[1] External Roof								
U-Value :	x	k	C	R	Area	Temp.	Heat Gain	
Air Film (still)			1.47	0.68				
3/4" Cement Sand Plaster			6.66	0.15				
4" R. C. Slab	4	12		0.333				
3Layers of Bituminous Felt			6.5	0.154				
1.75" Cement Sand Levelling Screed	1.75	5		0.35				
2" Expanded Polystyrene	2	0.2		10				
Screed to Fall 1in 100			6.66	0.15				
1"Cement Sand Tiles			6.66	0.15				
Air Film (7.5 MPH.)			4	0.25				
R total				12.22				
U-Value (1/R t)				0.082				
Roof Area					2640			
CLTD (not corrected) at 1500 ST						36		
CLTD (corrected)						37		
Heat Gain Trough The Roof							7995	BTU/Hr.
[2] Exterior Walls								
U- Value								
Air Film (7.5 MPH)			4	0.25				
4"Facing Brick	4	9		0.444				
2" Expanded Polystyrene Extruded	2	0.19		10.53				
8" Common Brick	8	5		1.6				
3/4 " Cement Sand Plaster			6.66	0.15				
Air Film (still)			1.47	0.68				
R total				13.65				
U-Value (1/R)				0.073				
(A) Norht Wall								
Area					420			
CLTD (corrected)						11		
Heat Gain							338	BTU/Hr.
(B) South Wall								
Area					340			
CLTD (corrected)						13.5		
Heat Gain							336	BTU/Hr.
(C) East Wall								
Area					860			
CLTD (corrected)						21.5		
Heat Gain							1354	BTU/Hr.
(D) West Wall								
Area					788			
CLTD (corrected)						17.5		
Heat Gain							1010	BTU/Hr.
Total Conduction through walls							3039	BTU/Hr.
[3] Glass (Conduction)			R					
U-Value (Single Light Green Low-E Glazing)			1.45	0.69				
(A) North								
Area					490			
CLTD (corrected)						11		
Heat Gain							3717	BTU/Hr.
(B) South								
Area					135			
CLTD (corrected)						11		
Heat Gain							1024	BTU/Hr.
(C) East								
Area					70			
CLTD (corrected)						11		
Heat Gain							531	BTU/Hr.
Total Conduction through Glass							5272	BTU/Hr.
[4] Glass (Solar)								
SC (Single Light Green Low-E Glazing)				0.53				
(A) North								
Area (Shaded) at 1500 hr.					450			
Area (Lit)					40			
SHGF (Shaded)			37					
SHGF (Lit)			36					
CLF						0.76		
Heat Gain Through Shaded Areas							6758	BTU/Hr.
Heat Gain Through Lit Areas							585	BTU/Hr.
Total Gain Through North Side							7343	BTU/Hr.
(B) South								
Area (all Shaded)					135			
SHGF			41					
CLF						0.53		
Heat Gain Through South Side							1567	BTU/Hr.
(C) East								
Area (all Shaded)					70			
SHGF			41					
CLF						0.29		
Heat Gain Through East Side							445	BTU/Hr.
Total Solar Gain Through Glass							9354	BTU/Hr.
[5] People								
(1) Sensible Heat								
(a) Number of occupants		12						
(b) Sensible Heat/occupant	225							
(c) CLF						0.47		
Heat Gain							1269	BTU/Hr.
(2) Latent Heat								
Latent Heat/occupant	325							
Heat Gain							3900	BTU/Hr.
[6] Through Infiltration								
(1) sensible Heat Gain								
Air Changes/hour (no insulation)				1				
Infiltration/square foot of area					0.15			
space Area Sq.Ft.			4000					
Infiltration						600		
Factor		1.1						
Temperature Difference deg. F	11							
Sensible Heat Gain							7260	BTU/Hr.
(2) Latent Heat Gain								
Air/humidity ratio difference (W)		0.006						
Latent Heat Gain							17424	BTU/Hr.
Total Heat Gain								
(1) Sensible Heat							34190	BTU/Hr.
(2) Latent Heat							21324	BTU/Hr.

APPENDIX D

APPENDIX D

ECONOMIC ANALYSIS

E.1 WALL INSULATION :

E.1.1 SAVING IN ENERGY CONSUMPTION :

(A) Total Annual Heat Gain (Uninsulated Walls) :

	Peak Cooling Load	Occurance	Days	Hours	Btu'/ Year
Min.	31608	2	30.4	24	46122393.6
Max.	74241	7	30.4	24	379163635
Med.	55260	3	30.4	24	120953088
Total					546239117

(B) Total Annual Heat Gain (2" Expanded Polystyrene wall insulation) :

	Peak Cooling Load	**Occurance**	**Days**	**Hours**	**Btu'/ Year**
Min.	24946	2	30.4	24	36401203.2
Max.	58241	7	30.4	24	297448435
Med.	45041	3	30.4	24	98585740.8
Total					432435379

(C) Total heat gain reduction = 1.11×10^8 Btu/ year

(D) One evaporative air cooler (3000 cfm - 1/3 hp)[1]

Heat removed per hour = cfm x min x heat capacity of air x temperature difference

= 3000 x 60 x .018 x 17

= 55080 Btuh

(E) Equivalent cooling hours ECH[2] = (Total annual heat gain)/ rate of heat removal

= $(1.11 \times 10^8)/ 55080$

= 2015 hours/ year

(F) Annual energy savings = ECH x Kwh x LS/ Kw

Appendix D ---

[1] Stein. et al. pp.368.

[2] Equivalent hours are the number of hours per year required from one evaporative cooler to remove a certain amount of heat load.

= 2015 x .45 x .3

= 272 LS year[3]

E.1.2 NUMBER OF EVAPORATIVE COOLERS NEEDED :

(A) Before wall insulation :

cfm = 74241/ (60 x .018 x 17 x .75[4]
= 5392

This is equivalent to two evaporative air cooler units (3000 cfm)

(B) After wall insulation :

cfm = 85241/ (60 x .018 x 17 x .75
= 4230

which is approximately equivalent to one 4000 cfm evaporative cooler.

(C) Saving in initial costs = (2 x 4,500) - (1 x 5,500)
= 3,500 LS

(D) Cost of insulation = cost x m^2 x area
= 30 x 165
= 4,950 LS

(E) Additional costs = 4,950 - 3,500
= 1,450 LS

Appendix D

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[3] LS = Sudanese Pound = $ .22 Official Price, $ .11 Free Market Price (1987).

[4] Pad efficiency.

(F) Simple Payback Period = Additional cost/ saving per year

= 1450/ 272

≈ 5 years

E.2 AIR SCOOP/ CHIMNEY :

E.1.1 WITH INSULATED WALLS AND DS GLASS :

(A) cfm for a chimney 40 ft high and 40 ft^2 area

= 7032[5]

Taking pad and aperture friction into account ;

cfm = 7032 x .75 x .7

= 3960

(B) Rate of heat removal = 3692 x 60 x .018 x 17

= 67785 Btuh

(C) Annual heat gain with uninsulated walls and DS glass (E.1.A)

= 5.46×10^8

(D) Number of Equivalent Cooling Hours = $(5.46 \times 10^8)/ 67785$

= 8055 hours

(E) Annual energy savings = 8055 x .45 x .3

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[5] Appendix E.

= 1087 LS

(F) Initial construction cost = 10,000 LS

(G)Savings in air coolers = 2 x 4,500

= 9,000 LS

(H) Additional costs = 10,000 - 9,000

= 1,000 LS

(I) Simple Payback Period = 1000/ 1087

≈ <u>1 year</u>

E.2.2 WITH INSULATED WALL :

(A) Annual heat gain (E.1.B) = 4.35×10^8 Btu/ year

(B) Number of Equivalent Cooling Hours = $(4.35 \times 10^8)/ 67785$

= 866 LS

(C) Initial costs = 10,000 + 4950

= 14,950 LS

(D) Initial savings = 1 x 4,500

(E) Additional costs = 14,950 - 4,500

= 10,450 LS

(F) Simple Payback Period = 10,450/ 866

≈ <u>12 years</u>

E.2.3 WITH SINGLE LIGHT-GREEN LOW-E GLAZING :

(A) Total annual heat gain :

	Peak Cooling Load	**Occurance**	**Days**	**Hours**	**Btu'/ Year**
Min.	17245	2	30.4	24	25163904
Max.	44214	7	30.4	24	225809741
Med.	34190	3	30.4	24	74835072
Total					325808717

(B) Number of Equivalent Cooling Hours = $(3.3 \times 10^8)/ 67785$

= 4868 hours/ year

(C) Annual energy savings = 4868 x .45 x .3

= 657 LS

(D) Additional cost of glass LS/ m^2 = 1.5 \$/ ft^2 x 10 ft^2/ m^2 x 8.5 LS/ \$

= 255 LS/ m^2

Additional costs = 255 x 70

= 17,850 LS

Total cost = 17,850 + 10,450

= 28,300 LS

(E) Simple Payback Period = 28,300/ 657

≈ <u>43 years</u>

APPENDIX E

APPENDIX E

WIND TUNNEL EXPERIMENT

	P at x	Vx	Vg	Vx/Vg	log Vx/Vg	H"	G	log H/G	Exponent
1	22.43	1.886E-06	4.1	0.00000046	-6.3373249	0.3125	12	-1.5843312	0.25
2	22.43	0.00001968	4.1	0.0000048	-5.3162349	0.5625	12	-1.3290587	0.25
3	22.43	0.0001968	4.1	0.000048	-4.316725	1	12	-1.0791812	0.25
4	22.4299989	0.001025	4.1	0.00025	-3.6123599	1.5	12	-0.90309	0.25
5	22.4299898	0.003198	4.1	0.00078	-3.112605	2	12	-0.7781513	0.25
6	22.4299393	0.00779	4.1	0.0019	-2.7249649	2.5	12	-0.6812412	0.25
7	22.4297443	0.01599	4.1	0.0039	-2.40824	3	12	-0.60206	0.25
8	22.427966	0.0451	4.1	0.011	-1.9358427	3.9375	12	-0.4839607	0.25
	22.414871	0.123	4.1	0.03	-1.520845	5	12	-0.3802112	0.25
	22.3632811	0.2583	4.1	0.063	-1.20412	6	12	-0.30103	0.25
	21.823159	0.779	4.1	0.19	-0.704365	8	12	-0.1760913	0.25
	18.556976	1.968	4.1	0.48	-0.316725	10	12	-0.0791812	0.25

	Gradient wind Velocity			
	23.7841423			
H"	G	Vg	Velocity	Pressure
0.31	12	23.7841423	9.55442792	3.42326598
0.56	12	23.7841423	11.0668192	4.59279327
1	12	23.7841423	12.7788621	6.12372436
1.5	12	23.7841423	14.1421356	7.5
2	12	23.7841423	15.1967137	8.66025404
2.5	12	23.7841423	16.0685684	9.68245837
3	12	23.7841423	16.8179283	10.6066017
3.94	12	23.7841423	18.0010287	12.1513888
5	12	23.7841423	19.1088558	13.6930639
6	12	23.7841423	20	15
8	12	23.7841423	21.4913986	17.3205081
10	12	23.7841423	22.7243873	19.3649167

1. Height of the model outlet scoop (chimney) = 10 " (50 ft).
1.1 Chimney Area = 0.63 in^2 (10 ft^2)

HEIGHT ABOVE GND.	WIND SPEED MPH	WIND SPEED M/Sec.	Static Pressure	Suction Pressure	Pressure Differential	Velocity at Inlet ft/sec	Velocity at Inlet ft/min	CFM Area*Speed
1.00	4.84	2.16	0.06	0.17	0.11	9.72	583.20	5832
1.25	5.15	2.30	0.07	0.17	0.10	9.27	556.20	5562
1.50	5.42	2.42	0.07	0.17	0.10	9.27	556.20	5562
1.75	5.66	2.53	0.08	0.17	0.09	8.79	527.40	5274
2.00	5.87	2.62	0.09	0.17	0.08	8.29	497.40	4974
2.25	6.07	2.71	0.09	0.17	0.08	8.29	497.40	4974
2.50	6.25	2.79	0.10	0.17	0.07	7.75	465.00	4650
2.75	6.42	2.87	0.10	0.17	0.07	7.75	465.00	4650
3.00	6.58	2.94	0.11	0.17	0.06	7.18	430.80	4308
3.25	6.73	3.01	0.11	0.17	0.06	7.18	430.80	4308
3.50	6.87	3.07	0.12	0.17	0.05	6.55	393.00	3930
3.75	7.00	3.13	0.12	0.17	0.05	6.55	393.00	3930
4.00	7.13	3.19	0.13	0.17	0.04	5.86	351.60	3516
4.25	7.25	3.24	0.13	0.17	0.04	5.86	351.60	3516
4.50	7.37	3.29	0.14	0.17	0.03	5.08	304.80	3048
4.75	7.48	3.34	0.14	0.17	0.03	5.08	304.80	3048
5.00	7.59	3.39	0.14	0.17	0.03	5.08	304.80	3048
5.25	7.70	3.44	0.15	0.17	0.02	4.14	248.40	2484
5.50	7.80	3.49	0.15	0.17	0.02	4.14	248.40	2484
5.75	7.89	3.53	0.16	0.17	0.01	2.93	175.80	1758
6.00	7.99	3.57	0.16	0.17	0.01	2.93	175.80	1758
6.25	8.08	3.61	0.16	0.17	0.01	2.93	175.80	1758
6.50	8.17	3.65	0.17	0.17	**0.00**	**0.00**	**0.00**	**0**
6.75	8.26	3.69	0.17	0.17	**0.00**	**0.00**	**0.00**	**0**
7.00	8.34	3.73	0.18	0.17	**-0.01**	**2.93**	**175.80**	**1758**
7.25	8.42	3.76	0.18	0.17	**-0.01**	**2.93**	**175.80**	**1758**
7.50	8.50	3.80	0.18	0.17	**-0.01**	**2.93**	**175.80**	**1758**
7.75	8.58	3.84	0.19	0.17	**-0.02**	**4.14**	**248.40**	**2484**
8.00	8.66	3.87	0.19	0.17	**-0.02**	**4.14**	**248.40**	**2484**
8.25	8.73	3.90	0.19	0.17	**-0.02**	**4.14**	**248.40**	**2484**
8.50	8.81	3.94	0.20	0.17	**-0.03**	**5.08**	**304.80**	**3048**
8.75	8.88	3.97	0.20	0.17	**-0.03**	**5.08**	**304.80**	**3048**
9.00	8.95	4.00	0.20	0.17	**-0.03**	**5.08**	**304.80**	**3048**
9.25	9.02	4.03	0.20	0.17	**-0.03**	**5.08**	**304.80**	**3048**
9.50	9.09	4.06	0.21	0.17	**-0.04**	**5.86**	**351.60**	**3516**
9.75	9.15	4.09	0.21	0.17	**-0.04**	**5.86**	**351.60**	**3516**
10.00	9.22	4.12	0.21	0.17	**-0.04**	**5.86**	**351.60**	**3516**
10.25	9.28	4.15	0.22	0.17	**-0.05**	**6.55**	**393.00**	**3930**
10.50	9.34	4.17	0.22	0.17	**-0.05**	**6.55**	**393.00**	**3930**
10.75	9.41	4.21	0.22	0.17	**-0.05**	**6.55**	**393.00**	**3930**
11.00	9.47	4.23	0.23	0.17	**-0.06**	**7.18**	**430.80**	**4308**
11.25	9.53	4.26	0.23	0.17	**-0.06**	**7.18**	**430.80**	**4308**
11.50	9.59	4.29	0.23	0.17	**-0.06**	**7.18**	**430.80**	**4308**
11.75	9.64	4.31	0.23	0.17	**-0.06**	**7.18**	**430.80**	**4308**
12.00	9.70	4.34	0.24	0.17	**-0.07**	**7.75**	**465.00**	**4650**

1. Height of the model outlet scoop (chimney) = 10 " (50 ft).
1.2 Chimney Area = .89 in^2 (20 ft^2)

HEIGHT ABOVE GND.	WIND SPEED MPH	WIND SPEED M/Sec.	Static Pressure	Suction Pressure	Pressure Differential	Velocity at Inlet ft/sec	Velocity at Inlet ft/min	CFM Area*Speed
1.00	4.84	2.16	0.06	0.17	0.11	9.72	583.20	11664
1.25	5.15	2.30	0.07	0.17	0.10	9.27	556.20	11124
1.50	5.42	2.42	0.07	0.17	0.10	9.27	556.20	11124
1.75	5.66	2.53	0.08	0.17	0.09	8.79	527.40	10548
2.00	5.87	2.62	0.09	0.17	0.08	8.29	497.40	9948
2.25	6.07	2.71	0.09	0.17	0.08	8.29	497.40	9948
2.50	6.25	2.79	0.10	0.17	0.07	7.75	465.00	9300
2.75	6.42	2.87	0.10	0.17	0.07	7.75	465.00	9300
3.00	6.58	2.94	0.11	0.17	0.06	7.18	430.80	8616
3.25	6.73	3.01	0.11	0.17	0.06	7.18	430.80	8616
3.50	6.87	3.07	0.12	0.17	0.05	6.55	393.00	7860
3.75	7.00	3.13	0.12	0.17	0.05	6.55	393.00	7860
4.00	7.13	3.19	0.13	0.17	0.04	5.86	351.60	7032
4.25	7.25	3.24	0.13	0.17	0.04	5.86	351.60	7032
4.50	7.37	3.29	0.14	0.17	0.03	5.08	304.80	6096
4.75	7.48	3.34	0.14	0.17	0.03	5.08	304.80	6096
5.00	7.59	3.39	0.14	0.17	0.03	5.08	304.80	6096
5.25	7.70	3.44	0.15	0.17	0.02	4.14	248.40	4968
5.50	7.80	3.49	0.15	0.17	0.02	4.14	248.40	4968
5.75	7.89	3.53	0.16	0.17	0.01	2.93	175.80	3516
6.00	7.99	3.57	0.16	0.17	0.01	2.93	175.80	3516
6.25	8.08	3.61	0.16	0.17	0.01	2.93	175.80	3516
6.50	8.17	3.65	0.17	0.17	**0.00**	**0.00**	**0.00**	**0**
6.75	8.26	3.69	0.17	0.17	**0.00**	**0.00**	**0.00**	**0**
7.00	8.34	3.73	0.18	0.17	**-0.01**	**2.93**	**175.80**	**3516**
7.25	8.42	3.76	0.18	0.17	**-0.01**	**2.93**	**175.80**	**3516**
7.50	8.50	3.80	0.18	0.17	**-0.01**	**2.93**	**175.80**	**3516**
7.75	8.58	3.84	0.19	0.17	**-0.02**	**4.14**	**248.40**	**4968**
8.00	8.66	3.87	0.19	0.17	**-0.02**	**4.14**	**248.40**	**4968**
8.25	8.73	3.90	0.19	0.17	**-0.02**	**4.14**	**248.40**	**4968**
8.50	8.81	3.94	0.20	0.17	**-0.03**	**5.08**	**304.80**	**6096**
8.75	8.88	3.97	0.20	0.17	**-0.03**	**5.08**	**304.80**	**6096**
9.00	8.95	4.00	0.20	0.17	**-0.03**	**5.08**	**304.80**	**6096**
9.25	9.02	4.03	0.20	0.17	**-0.03**	**5.08**	**304.80**	**6096**
9.50	9.09	4.06	0.21	0.17	**-0.04**	**5.86**	**351.60**	**7032**
9.75	9.15	4.09	0.21	0.17	**-0.04**	**5.86**	**351.60**	**7032**
10.00	9.22	4.12	0.21	0.17	**-0.04**	**5.86**	**351.60**	**7032**
10.25	9.28	4.15	0.22	0.17	**-0.05**	**6.55**	**393.00**	**7860**
10.50	9.34	4.17	0.22	0.17	**-0.05**	**6.55**	**393.00**	**7860**
10.75	9.41	4.21	0.22	0.17	**-0.05**	**6.55**	**393.00**	**7860**
11.00	9.47	4.23	0.23	0.17	**-0.06**	**7.18**	**430.80**	**8616**
11.25	9.53	4.26	0.23	0.17	**-0.06**	**7.18**	**430.80**	**8616**
11.50	9.59	4.29	0.23	0.17	**-0.06**	**7.18**	**430.80**	**8616**
11.75	9.64	4.31	0.23	0.17	**-0.06**	**7.18**	**430.80**	**8616**
12.00	9.70	4.34	0.24	0.17	**-0.07**	**7.75**	**465.00**	**9300**

1. Height of the model outlet scoop (chimney) = 10 " (50 ft).

1.3 Chimney Area = 1.1 in^2 (30 ft^2)

HEIGHT ABOVE GND.	WIND SPEED MPH	WIND SPEED M/Sec.	Static Pressure	Suction Pressure	Pressure Differential	Velocity at Inlet ft/sec	Velocity at Inlet ft/min	CFM Area*Speed
1.00	4.84	2.16	0.06	0.17	0.11	9.72	583.20	17496
1.25	5.15	2.30	0.07	0.17	0.10	9.27	556.20	16686
1.50	5.42	2.42	0.07	0.17	0.10	9.27	556.20	16686
1.75	5.66	2.53	0.08	0.17	0.09	8.79	527.40	15822
2.00	5.87	2.62	0.09	0.17	0.08	8.29	497.40	14922
2.25	6.07	2.71	0.09	0.17	0.08	8.29	497.40	14922
2.50	6.25	2.79	0.10	0.17	0.07	7.75	465.00	13950
2.75	6.42	2.87	0.10	0.17	0.07	7.75	465.00	13950
3.00	6.58	2.94	0.11	0.17	0.06	7.18	430.80	12924
3.25	6.73	3.01	0.11	0.17	0.06	7.18	430.80	12924
3.50	6.87	3.07	0.12	0.17	0.05	6.55	393.00	11790
3.75	7.00	3.13	0.12	0.17	0.05	6.55	393.00	11790
4.00	7.13	3.19	0.13	0.17	0.04	5.86	351.60	10548
4.25	7.25	3.24	0.13	0.17	0.04	5.86	351.60	10548
4.50	7.37	3.29	0.14	0.17	0.03	5.08	304.80	9144
4.75	7.48	3.34	0.14	0.17	0.03	5.08	304.80	9144
5.00	7.59	3.39	0.14	0.17	0.03	5.08	304.80	9144
5.25	7.70	3.44	0.15	0.17	0.02	4.14	248.40	7452
5.50	7.80	3.49	0.15	0.17	0.02	4.14	248.40	7452
5.75	7.89	3.53	0.16	0.17	0.01	2.93	175.80	5274
6.00	7.99	3.57	0.16	0.17	0.01	2.93	175.80	5274
6.25	8.08	3.61	0.16	0.17	0.01	2.93	175.80	5274
6.50	8.17	3.65	0.17	0.17	**0.00**	**0.00**	**0.00**	**0**
6.75	8.26	3.69	0.17	0.17	**0.00**	**0.00**	**0.00**	**0**
7.00	8.34	3.73	0.18	0.17	**-0.01**	**2.93**	**175.80**	**5274**
7.25	8.42	3.76	0.18	0.17	**-0.01**	**2.93**	**175.80**	**5274**
7.50	8.50	3.80	0.18	0.17	**-0.01**	**2.93**	**175.80**	**5274**
7.75	8.58	3.84	0.19	0.17	**-0.02**	**4.14**	**248.40**	**7452**
8.00	8.66	3.87	0.19	0.17	**-0.02**	**4.14**	**248.40**	**7452**
8.25	8.73	3.90	0.19	0.17	**-0.02**	**4.14**	**248.40**	**7452**
8.50	8.81	3.94	0.20	0.17	**-0.03**	**5.08**	**304.80**	**9144**
8.75	8.88	3.97	0.20	0.17	**-0.03**	**5.08**	**304.80**	**9144**
9.00	8.95	4.00	0.20	0.17	**-0.03**	**5.08**	**304.80**	**9144**
9.25	9.02	4.03	0.20	0.17	**-0.03**	**5.08**	**304.80**	**9144**
9.50	9.09	4.06	0.21	0.17	**-0.04**	**5.86**	**351.60**	**10548**
9.75	9.15	4.09	0.21	0.17	**-0.04**	**5.86**	**351.60**	**10548**
10.00	9.22	4.12	0.21	0.17	**-0.04**	**5.86**	**351.60**	**10548**
10.25	9.28	4.15	0.22	0.17	**-0.05**	**6.55**	**393.00**	**11790**
10.50	9.34	4.17	0.22	0.17	**-0.05**	**6.55**	**393.00**	**11790**
10.75	9.41	4.21	0.22	0.17	**-0.05**	**6.55**	**393.00**	**11790**
11.00	9.47	4.23	0.23	0.17	**-0.06**	**7.18**	**430.80**	**12924**
11.25	9.53	4.26	0.23	0.17	**-0.06**	**7.18**	**430.80**	**12924**
11.50	9.59	4.29	0.23	0.17	**-0.06**	**7.18**	**430.80**	**12924**
11.75	9.64	4.31	0.23	0.17	**-0.06**	**7.18**	**430.80**	**12924**
12.00	9.70	4.34	0.24	0.17	**-0.07**	**7.75**	**465.00**	**13950**

1. Height of the model outlet scoop (chimney) = 10 " (50 ft).
1.4 Chimney Area = 1.27 in^2 (40 ft^2)

HEIGHT ABOVE GND.	WIND SPEED MPH	WIND SPEED M/Sec.	Static Pressure	Suction Pressure	Pressure Differential	Velocity at Inlet ft/sec	Velocity at Inlet ft/min	CFM Area*Speed
1.00	4.84	2.16	0.06	0.17	0.11	9.72	583.20	23328
1.25	5.15	2.30	0.07	0.17	0.10	9.27	556.20	22248
1.50	5.42	2.42	0.07	0.17	0.10	9.27	556.20	22248
1.75	5.66	2.53	0.08	0.17	0.09	8.79	527.40	21096
2.00	5.87	2.62	0.09	0.17	0.08	8.29	497.40	19896
2.25	6.07	2.71	0.09	0.17	0.08	8.29	497.40	19896
2.50	6.25	2.79	0.10	0.17	0.07	7.75	465.00	18600
2.75	6.42	2.87	0.10	0.17	0.07	7.75	465.00	18600
3.00	6.58	2.94	0.11	0.17	0.06	7.18	430.80	17232
3.25	6.73	3.01	0.11	0.17	0.06	7.18	430.80	17232
3.50	6.87	3.07	0.12	0.17	0.05	6.55	393.00	15720
3.75	7.00	3.13	0.12	0.17	0.05	6.55	393.00	15720
4.00	7.13	3.19	0.13	0.17	0.04	5.86	351.60	14064
4.25	7.25	3.24	0.13	0.17	0.04	5.86	351.60	14064
4.50	7.37	3.29	0.14	0.17	0.03	5.08	304.80	12192
4.75	7.48	3.34	0.14	0.17	0.03	5.08	304.80	12192
5.00	7.59	3.39	0.14	0.17	0.03	5.08	304.80	12192
5.25	7.70	3.44	0.15	0.17	0.02	4.14	248.40	9936
5.50	7.80	3.49	0.15	0.17	0.02	4.14	248.40	9936
5.75	7.89	3.53	0.16	0.17	0.01	2.93	175.80	7032
6.00	7.99	3.57	0.16	0.17	0.01	2.93	175.80	7032
6.25	8.08	3.61	0.16	0.17	0.01	2.93	175.80	7032
6.50	8.17	3.65	0.17	0.17	**0.00**	**0.00**	**0.00**	**0**
6.75	8.26	3.69	0.17	0.17	**0.00**	**0.00**	**0.00**	**0**
7.00	8.34	3.73	0.18	0.17	**-0.01**	**2.93**	**175.80**	**7032**
7.25	8.42	3.76	0.18	0.17	**-0.01**	**2.93**	**175.80**	**7032**
7.50	8.50	3.80	0.18	0.17	**-0.01**	**2.93**	**175.80**	**7032**
7.75	8.58	3.84	0.19	0.17	**-0.02**	**4.14**	**248.40**	**9936**
8.00	8.66	3.87	0.19	0.17	**-0.02**	**4.14**	**248.40**	**9936**
8.25	8.73	3.90	0.19	0.17	**-0.02**	**4.14**	**248.40**	**9936**
8.50	8.81	3.94	0.20	0.17	**-0.03**	**5.08**	**304.80**	**12192**
8.75	8.88	3.97	0.20	0.17	**-0.03**	**5.08**	**304.80**	**12192**
9.00	8.95	4.00	0.20	0.17	**-0.03**	**5.08**	**304.80**	**12192**
9.25	9.02	4.03	0.20	0.17	**-0.03**	**5.08**	**304.80**	**12192**
9.50	9.09	4.06	0.21	0.17	**-0.04**	**5.86**	**351.60**	**14064**
9.75	9.15	4.09	0.21	0.17	**-0.04**	**5.86**	**351.60**	**14064**
10.00	9.22	4.12	0.21	0.17	**-0.04**	**5.86**	**351.60**	**14064**
10.25	9.28	4.15	0.22	0.17	**-0.05**	**6.55**	**393.00**	**15720**
10.50	9.34	4.17	0.22	0.17	**-0.05**	**6.55**	**393.00**	**15720**
10.75	9.41	4.21	0.22	0.17	**-0.05**	**6.55**	**393.00**	**15720**
11.00	9.47	4.23	0.23	0.17	**-0.06**	**7.18**	**430.80**	**17232**
11.25	9.53	4.26	0.23	0.17	**-0.06**	**7.18**	**430.80**	**17232**
11.50	9.59	4.29	0.23	0.17	**-0.06**	**7.18**	**430.80**	**17232**
11.75	9.64	4.31	0.23	0.17	**-0.06**	**7.18**	**430.80**	**17232**
12.00	9.70	4.34	0.24	0.17	**-0.07**	**7.75**	**465.00**	**18600**

2. Height of the model outlet scoop (chimney) = 8 " (40 ft).
2.1 Chimney Area = 0.63 in^2 (10 ft^2)

HEIGHT ABOVE GND.	WIND SPEED MPH	WIND SPEED M/Sec.	Static Pressure	Suction Pressure	Pressure Differential	Velocity at Inlet ft/sec	Velocity at Inlet ft/min	CFM Area*Speed
1.00	4.84	2.16	0.06	0.15	0.09	8.79	527.40	5274
1.25	5.15	2.30	0.07	0.15	0.08	8.29	497.40	4974
1.50	5.42	2.42	0.07	0.15	0.08	8.29	497.40	4974
1.75	5.66	2.53	0.08	0.15	0.07	7.75	465.00	4650
2.00	5.87	2.62	0.09	0.15	0.06	7.18	430.80	4308
2.25	6.07	2.71	0.09	0.15	0.06	7.18	430.80	4308
2.50	6.25	2.79	0.10	0.15	0.05	6.55	393.00	3930
2.75	6.42	2.87	0.10	0.15	0.05	6.55	393.00	3930
3.00	6.58	2.94	0.11	0.15	0.04	5.86	351.60	3516
3.25	6.73	3.01	0.11	0.15	0.04	5.86	351.60	3516
3.50	6.87	3.07	0.12	0.15	0.03	5.08	304.80	3048
3.75	7.00	3.13	0.12	0.15	0.03	5.08	304.80	3048
4.00	7.13	3.19	0.13	0.15	0.02	4.14	248.40	2484
4.25	7.25	3.24	0.13	0.15	0.02	4.14	248.40	2484
4.50	7.37	3.29	0.14	0.15	0.01	2.93	175.80	1758
4.75	7.48	3.34	0.14	0.15	0.01	2.93	175.80	1758
5.00	7.59	3.39	0.14	0.15	0.01	2.93	175.80	1758
5.25	7.70	3.44	0.15	0.15	**0.00**	**0.00**	**0.00**	**0**
5.50	7.80	3.49	0.15	0.15	**0.00**	**0.00**	**0.00**	**0**
5.75	7.89	3.53	0.16	0.15	**-0.01**	**2.93**	**175.80**	**1758**
6.00	7.99	3.57	0.16	0.15	**-0.01**	**2.93**	**175.80**	**1758**
6.25	8.08	3.61	0.16	0.15	**-0.01**	**2.93**	**175.80**	**1758**
6.50	8.17	3.65	0.17	0.15	**-0.02**	**4.14**	**248.40**	**2484**
6.75	8.26	3.69	0.17	0.15	**-0.02**	**4.14**	**248.40**	**2484**
7.00	8.34	3.73	0.18	0.15	**-0.03**	**5.08**	**304.80**	**3048**
7.25	8.42	3.76	0.18	0.15	**-0.03**	**5.08**	**304.80**	**3048**
7.50	8.50	3.80	0.18	0.15	**-0.03**	**5.08**	**304.80**	**3048**
7.75	8.58	3.84	0.19	0.15	**-0.04**	**5.86**	**351.60**	**3516**
8.00	8.66	3.87	0.19	0.15	**-0.04**	**5.86**	**351.60**	**3516**
8.25	8.73	3.90	0.19	0.15	**-0.04**	**5.86**	**351.60**	**3516**
8.50	8.81	3.94	0.20	0.15	**-0.05**	**6.55**	**393.00**	**3930**
8.75	8.88	3.97	0.20	0.15	**-0.05**	**6.55**	**393.00**	**3930**
9.00	8.95	4.00	0.20	0.15	**-0.05**	**6.55**	**393.00**	**3930**
9.25	9.02	4.03	0.20	0.15	**-0.05**	**6.55**	**393.00**	**3930**
9.50	9.09	4.06	0.21	0.15	**-0.06**	**7.18**	**430.80**	**4308**
9.75	9.15	4.09	0.21	0.15	**-0.06**	**7.18**	**430.80**	**4308**
10.00	9.22	4.12	0.21	0.15	**-0.06**	**7.18**	**430.80**	**4308**
10.25	9.28	4.15	0.22	0.15	**-0.07**	**7.75**	**465.00**	**4650**
10.50	9.34	4.17	0.22	0.15	**-0.07**	**7.75**	**465.00**	**4650**
10.75	9.41	4.21	0.22	0.15	**-0.07**	**7.75**	**465.00**	**4650**
11.00	9.47	4.23	0.23	0.15	**-0.08**	**8.29**	**497.40**	**4974**
11.25	9.53	4.26	0.23	0.15	**-0.08**	**8.29**	**497.40**	**4974**
11.50	9.59	4.29	0.23	0.15	**-0.08**	**8.29**	**497.40**	**4974**
11.75	9.64	4.31	0.23	0.15	**-0.08**	**8.29**	**497.40**	**4974**
12.00	9.70	4.34	0.24	0.15	**-0.09**	**8.79**	**527.40**	**5274**

2. Height of the model outlet scoop (chimney) = 8 " (40 ft).
2.2 Chimney Area = 0.89 in^2 (20 ft^2)

HEIGHT ABOVE GND.	WIND SPEED MPH	WIND SPEED M/Sec.	Static Pressure	Suction Pressure	Pressure Differential	Velocity at Inlet ft/sec	Velocity at Inlet ft/min	CFM Area*Speed
1.00	4.84	2.16	0.06	0.15	0.09	8.79	527.40	5274
1.25	5.15	2.30	0.07	0.15	0.08	8.29	497.40	4974
1.50	5.42	2.42	0.07	0.15	0.08	8.29	497.40	4974
1.75	5.66	2.53	0.08	0.15	0.07	7.75	465.00	4650
2.00	5.87	2.62	0.09	0.15	0.06	7.18	430.80	4308
2.25	6.07	2.71	0.09	0.15	0.06	7.18	430.80	4308
2.50	6.25	2.79	0.10	0.15	0.05	6.55	393.00	3930
2.75	6.42	2.87	0.10	0.15	0.05	6.55	393.00	3930
3.00	6.58	2.94	0.11	0.15	0.04	5.86	351.60	3516
3.25	6.73	3.01	0.11	0.15	0.04	5.86	351.60	3516
3.50	6.87	3.07	0.12	0.15	0.03	5.08	304.80	3048
3.75	7.00	3.13	0.12	0.15	0.03	5.08	304.80	3048
4.00	7.13	3.19	0.13	0.15	0.02	4.14	248.40	2484
4.25	7.25	3.24	0.13	0.15	0.02	4.14	248.40	2484
4.50	7.37	3.29	0.14	0.15	0.01	2.93	175.80	1758
4.75	7.48	3.34	0.14	0.15	0.01	2.93	175.80	1758
5.00	7.59	3.39	0.14	0.15	0.01	2.93	175.80	1758
5.25	7.70	3.44	0.15	0.15	**0.00**	**0.00**	**0.00**	**0**
5.50	7.80	3.49	0.15	0.15	**0.00**	**0.00**	**0.00**	**0**
5.75	7.89	3.53	0.16	0.15	**-0.01**	**2.93**	**175.80**	**1758**
6.00	7.99	3.57	0.16	0.15	**-0.01**	**2.93**	**175.80**	**1758**
6.25	8.08	3.61	0.16	0.15	**-0.01**	**2.93**	**175.80**	**1758**
6.50	8.17	3.65	0.17	0.15	**-0.02**	**4.14**	**248.40**	**2484**
6.75	8.26	3.69	0.17	0.15	**-0.02**	**4.14**	**248.40**	**2484**
7.00	8.34	3.73	0.18	0.15	**-0.03**	**5.08**	**304.80**	**3048**
7.25	8.42	3.76	0.18	0.15	**-0.03**	**5.08**	**304.80**	**3048**
7.50	8.50	3.80	0.18	0.15	**-0.03**	**5.08**	**304.80**	**3048**
7.75	8.58	3.84	0.19	0.15	**-0.04**	**5.86**	**351.60**	**3516**
8.00	8.66	3.87	0.19	0.15	**-0.04**	**5.86**	**351.60**	**3516**
8.25	8.73	3.90	0.19	0.15	**-0.04**	**5.86**	**351.60**	**3516**
8.50	8.81	3.94	0.20	0.15	**-0.05**	**6.55**	**393.00**	**3930**
8.75	8.88	3.97	0.20	0.15	**-0.05**	**6.55**	**393.00**	**3930**
9.00	8.95	4.00	0.20	0.15	**-0.05**	**6.55**	**393.00**	**3930**
9.25	9.02	4.03	0.20	0.15	**-0.05**	**6.55**	**393.00**	**3930**
9.50	9.09	4.06	0.21	0.15	**-0.06**	**7.18**	**430.80**	**4308**
9.75	9.15	4.09	0.21	0.15	**-0.06**	**7.18**	**430.80**	**4308**
10.00	9.22	4.12	0.21	0.15	**-0.06**	**7.18**	**430.80**	**4308**
10.25	9.28	4.15	0.22	0.15	**-0.07**	**7.75**	**465.00**	**4650**
10.50	9.34	4.17	0.22	0.15	**-0.07**	**7.75**	**465.00**	**4650**
10.75	9.41	4.21	0.22	0.15	**-0.07**	**7.75**	**465.00**	**4650**
11.00	9.47	4.23	0.23	0.15	**-0.08**	**8.29**	**497.40**	**4974**
11.25	9.53	4.26	0.23	0.15	**-0.08**	**8.29**	**497.40**	**4974**
11.50	9.59	4.29	0.23	0.15	**-0.08**	**8.29**	**497.40**	**4974**
11.75	9.64	4.31	0.23	0.15	**-0.08**	**8.29**	**497.40**	**4974**
12.00	9.70	4.34	0.24	0.15	**-0.09**	**8.79**	**527.40**	**5274**

2. Height of the model outlet scoop (chimney) = 8 " (40 ft).
2.3 Chimney Area = 1.1 in^2 (30 ft^2)

HEIGHT ABOVE GND.	WIND SPEED MPH	WIND SPEED M/Sec.	Static Pressure	Suction Pressure	Pressure Differential	Velocity at Inlet ft/sec	Velocity at Inlet ft/min	CFM Area*Speed
1.00	4.84	2.16	0.06	0.15	0.09	8.79	527.40	15822
1.25	5.15	2.30	0.07	0.15	0.08	8.29	497.40	14922
1.50	5.42	2.42	0.07	0.15	0.08	8.29	497.40	14922
1.75	5.66	2.53	0.08	0.15	0.07	7.75	465.00	13950
2.00	5.87	2.62	0.09	0.15	0.06	7.18	430.80	12924
2.25	6.07	2.71	0.09	0.15	0.06	7.18	430.80	12924
2.50	6.25	2.79	0.10	0.15	0.05	6.55	393.00	11790
2.75	6.42	2.87	0.10	0.15	0.05	6.55	393.00	11790
3.00	6.58	2.94	0.11	0.15	0.04	5.86	351.60	10548
3.25	6.73	3.01	0.11	0.15	0.04	5.86	351.60	10548
3.50	6.87	3.07	0.12	0.15	0.03	5.08	304.80	9144
3.75	7.00	3.13	0.12	0.15	0.03	5.08	304.80	9144
4.00	7.13	3.19	0.13	0.15	0.02	4.14	248.40	7452
4.25	7.25	3.24	0.13	0.15	0.02	4.14	248.40	7452
4.50	7.37	3.29	0.14	0.15	0.01	2.93	175.80	5274
4.75	7.48	3.34	0.14	0.15	0.01	2.93	175.80	5274
5.00	7.59	3.39	0.14	0.15	0.01	2.93	175.80	5274
5.25	7.70	3.44	0.15	0.15	**0.00**	**0.00**	**0.00**	**0**
5.50	7.80	3.49	0.15	0.15	**0.00**	**0.00**	**0.00**	**0**
5.75	7.89	3.53	0.16	0.15	**-0.01**	**2.93**	**175.80**	**5274**
6.00	7.99	3.57	0.16	0.15	**-0.01**	**2.93**	**175.80**	**5274**
6.25	8.08	3.61	0.16	0.15	**-0.01**	**2.93**	**175.80**	**5274**
6.50	8.17	3.65	0.17	0.15	**-0.02**	**4.14**	**248.40**	**7452**
6.75	8.26	3.69	0.17	0.15	**-0.02**	**4.14**	**248.40**	**7452**
7.00	8.34	3.73	0.18	0.15	**-0.03**	**5.08**	**304.80**	**9144**
7.25	8.42	3.76	0.18	0.15	**-0.03**	**5.08**	**304.80**	**9144**
7.50	8.50	3.80	0.18	0.15	**-0.03**	**5.08**	**304.80**	**9144**
7.75	8.58	3.84	0.19	0.15	**-0.04**	**5.86**	**351.60**	**10548**
8.00	8.66	3.87	0.19	0.15	**-0.04**	**5.86**	**351.60**	**10548**
8.25	8.73	3.90	0.19	0.15	**-0.04**	**5.86**	**351.60**	**10548**
8.50	8.81	3.94	0.20	0.15	**-0.05**	**6.55**	**393.00**	**11790**
8.75	8.88	3.97	0.20	0.15	**-0.05**	**6.55**	**393.00**	**11790**
9.00	8.95	4.00	0.20	0.15	**-0.05**	**6.55**	**393.00**	**11790**
9.25	9.02	4.03	0.20	0.15	**-0.05**	**6.55**	**393.00**	**11790**
9.50	9.09	4.06	0.21	0.15	**-0.06**	**7.18**	**430.80**	**12924**
9.75	9.15	4.09	0.21	0.15	**-0.06**	**7.18**	**430.80**	**12924**
10.00	9.22	4.12	0.21	0.15	**-0.06**	**7.18**	**430.80**	**12924**
10.25	9.28	4.15	0.22	0.15	**-0.07**	**7.75**	**465.00**	**13950**
10.50	9.34	4.17	0.22	0.15	**-0.07**	**7.75**	**465.00**	**13950**
10.75	9.41	4.21	0.22	0.15	**-0.07**	**7.75**	**465.00**	**13950**
11.00	9.47	4.23	0.23	0.15	**-0.08**	**8.29**	**497.40**	**14922**
11.25	9.53	4.26	0.23	0.15	**-0.08**	**8.29**	**497.40**	**14922**
11.50	9.59	4.29	0.23	0.15	**-0.08**	**8.29**	**497.40**	**14922**
11.75	9.64	4.31	0.23	0.15	**-0.08**	**8.29**	**497.40**	**14922**
12.00	9.70	4.34	0.24	0.15	**-0.09**	**8.79**	**527.40**	**15822**

2. Height of the model outlet scoop (chimney) = 8 " (40 ft).

2.4 Chimney Area = 1.27 in^2 (40 ft^2)

HEIGHT ABOVE GND.	WIND SPEED MPH	WIND SPEED M/Sec.	Static Pressure	Suction Pressure	Pressure Differential	Velocity at Inlet ft/sec	Velocity at Inlet ft/min	CFM Area*Speed
1.00	4.84	2.16	0.06	0.15	0.09	8.79	527.40	21096
1.25	5.15	2.30	0.07	0.15	0.08	8.29	497.40	19896
1.50	5.42	2.42	0.07	0.15	0.08	8.29	497.40	19896
1.75	5.66	2.53	0.08	0.15	0.07	7.75	465.00	18600
2.00	5.87	2.62	0.09	0.15	0.06	7.18	430.80	17232
2.25	6.07	2.71	0.09	0.15	0.06	7.18	430.80	17232
2.50	6.25	2.79	0.10	0.15	0.05	6.55	393.00	15720
2.75	6.42	2.87	0.10	0.15	0.05	6.55	393.00	15720
3.00	6.58	2.94	0.11	0.15	0.04	5.86	351.60	14064
3.25	6.73	3.01	0.11	0.15	0.04	5.86	351.60	14064
3.50	6.87	3.07	0.12	0.15	0.03	5.08	304.80	12192
3.75	7.00	3.13	0.12	0.15	0.03	5.08	304.80	12192
4.00	7.13	3.19	0.13	0.15	0.02	4.14	248.40	9936
4.25	7.25	3.24	0.13	0.15	0.02	4.14	248.40	9936
4.50	7.37	3.29	0.14	0.15	0.01	2.93	175.80	7032
4.75	7.48	3.34	0.14	0.15	0.01	2.93	175.80	7032
5.00	7.59	3.39	0.14	0.15	0.01	2.93	175.80	7032
5.25	7.70	3.44	0.15	0.15	**0.00**	**0.00**	**0.00**	**0**
5.50	7.80	3.49	0.15	0.15	**0.00**	**0.00**	**0.00**	**0**
5.75	7.89	3.53	0.16	0.15	**-0.01**	**2.93**	**175.80**	**7032**
6.00	7.99	3.57	0.16	0.15	**-0.01**	**2.93**	**175.80**	**7032**
6.25	8.08	3.61	0.16	0.15	**-0.01**	**2.93**	**175.80**	**7032**
6.50	8.17	3.65	0.17	0.15	**-0.02**	**4.14**	**248.40**	**9936**
6.75	8.26	3.69	0.17	0.15	**-0.02**	**4.14**	**248.40**	**9936**
7.00	8.34	3.73	0.18	0.15	**-0.03**	**5.08**	**304.80**	**12192**
7.25	8.42	3.76	0.18	0.15	**-0.03**	**5.08**	**304.80**	**12192**
7.50	8.50	3.80	0.18	0.15	**-0.03**	**5.08**	**304.80**	**12192**
7.75	8.58	3.84	0.19	0.15	**-0.04**	**5.86**	**351.60**	**14064**
8.00	8.66	3.87	0.19	0.15	**-0.04**	**5.86**	**351.60**	**14064**
8.25	8.73	3.90	0.19	0.15	**-0.04**	**5.86**	**351.60**	**14064**
8.50	8.81	3.94	0.20	0.15	**-0.05**	**6.55**	**393.00**	**15720**
8.75	8.88	3.97	0.20	0.15	**-0.05**	**6.55**	**393.00**	**15720**
9.00	8.95	4.00	0.20	0.15	**-0.05**	**6.55**	**393.00**	**15720**
9.25	9.02	4.03	0.20	0.15	**-0.05**	**6.55**	**393.00**	**15720**
9.50	9.09	4.06	0.21	0.15	**-0.06**	**7.18**	**430.80**	**17232**
9.75	9.15	4.09	0.21	0.15	**-0.06**	**7.18**	**430.80**	**17232**
10.00	9.22	4.12	0.21	0.15	**-0.06**	**7.18**	**430.80**	**17232**
10.25	9.28	4.15	0.22	0.15	**-0.07**	**7.75**	**465.00**	**18600**
10.50	9.34	4.17	0.22	0.15	**-0.07**	**7.75**	**465.00**	**18600**
10.75	9.41	4.21	0.22	0.15	**-0.07**	**7.75**	**465.00**	**18600**
11.00	9.47	4.23	0.23	0.15	**-0.08**	**8.29**	**497.40**	**19896**
11.25	9.53	4.26	0.23	0.15	**-0.08**	**8.29**	**497.40**	**19896**
11.50	9.59	4.29	0.23	0.15	**-0.08**	**8.29**	**497.40**	**19896**
11.75	9.64	4.31	0.23	0.15	**-0.08**	**8.29**	**497.40**	**19896**
12.00	9.70	4.34	0.24	0.15	**-0.09**	**8.79**	**527.40**	**21096**

THERMAL STACK EFFECT

Calculation of the Solar Intensity								
Time = 3:00 pm. Solar Time								
Month	**Horizontal**	**Profile Ang.**	**P. To Sun**	**Inc. Wall**	**S.I of Wall**			
Jan. 21	150	47	43	88	200			
Jun. 21	194	55	35	80	190			
Sep. 21	185	50	40	85	211			
Month	**SHGF**	**SHGF (wall)**	**Absorb.**	**Wind Coeff.**	**Avge Temp.**	**R. Losses**	**Emmissivity**	**Sol-Air**
					deg. F	**BTUh/Ft sq.**		**Temp.**
Jan. 21	200	227	0.7	3	103.5	23	0.9	130
Jun. 21	190	216	0.7	3	115.3	22	0.9	140
Sep. 21	211	240	0.7	3	111.2	17.5	0.9	139
Air flow Induced by Thermal Force								
Q=kA(hΔt)								
A= The area of the opening								
K= 9.4								
Indoor Air Temp. =85 deg. F								
Assume Area of Opening =40 ft. sq.								
h = Vertical Distance between Openings								
Month	**k**	**Area**	**Δt**					
Jan. 21	9.4	40	45					
Jun. 21	9.4	40	55					
Sep. 21	9.4	40	54					

JANUARY :								
h ms.	**Δt**	**k**	**V ft./min**	**cfm**	**cfm x Frict.**	**Heat Flow**		
10	45	9.4	199	7978	4188	203615		
11	45	9.4	209	8367	4393	213553		
12	45	9.4	218	8739	4588	223049		
13	45	9.4	227	9096	4775	232156		
14	45	9.4	236	9439	4956	240920		
15	45	9.4	244	9770	5129	249376		
16	45	9.4	252	10091	5298	257554		
17	45	9.4	260	10401	5461	265481		
18	45	9.4	268	10703	5619	273178		
19	45	9.4	275	10996	5773	280663		
20	45	9.4	282	11282	5923	287955		
21	45	9.4	289	11561	6069	295066		
22	45	9.4	296	11833	6212	302009		
23	45	9.4	302	12098	6352	308797		
24	45	9.4	309	12359	6488	315438		
25	45	9.4	315	12614	6622	321943		
26	45	9.4	322	12863	6753	328319		
27	45	9.4	328	13108	6882	334573		
28	45	9.4	334	13349	7008	340712		
29	45	9.4	340	13585	7132	346743		
30	45	9.4	345	13817	7254	352671		
31	45	9.4	351	14046	7374	358501		
32	45	9.4	357	14271	7492	364237		

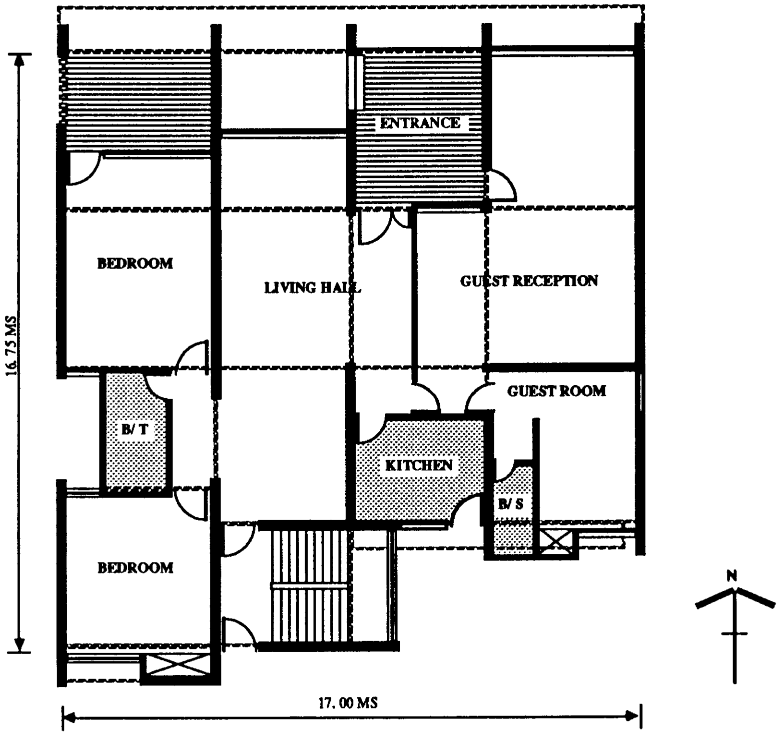
June :								
h ms.	Δt	k	V ft./min	cfm	cfm x Frict.	Heat Flow		
10	55	9.4	221	8857	4650	278667		
11	55	9.4	232	9289	4877	292269		
12	55	9.4	243	9702	5094	305265		
13	55	9.4	252	10099	5302	317730		
14	55	9.4	262	10480	5502	329723		
15	55	9.4	271	10848	5695	341296		
16	55	9.4	280	11203	5882	352489		
17	55	9.4	289	11548	6063	363338		
18	55	9.4	297	11883	6239	373871		
19	55	9.4	305	12209	6410	384116		
20	55	9.4	313	12526	6576	394095		
21	55	9.4	321	12835	6738	403827		
22	55	9.4	328	13137	6897	413330		
23	55	9.4	336	13432	7052	422620		
24	55	9.4	343	13721	7204	431709		
25	55	9.4	350	14004	7352	440612		
26	55	9.4	357	14282	7498	449337		
27	55	9.4	364	14554	7641	457897		
28	55	9.4	371	14821	7781	466299		
29	55	9.4	377	15083	7919	474553		
30	55	9.4	384	15341	8054	482666		
31	55	9.4	390	15595	8187	490644		
32	55	9.4	396	15844	8318	498495		

September :								
h ms.	Δt	k	V ft./min	cfm	cfm x Frict.	Heat Flow		
10	54	9.4	219	8751	4595	268813		
11	54	9.4	229	9179	4819	281934		
12	54	9.4	240	9587	5033	294470		
13	54	9.4	249	9978	5239	306495		
14	54	9.4	259	10355	5436	318064		
15	54	9.4	268	10718	5627	329228		
16	54	9.4	277	11070	5812	340025		
17	54	9.4	285	11411	5991	350490		
18	54	9.4	294	11741	6164	360651		
19	54	9.4	302	12063	6333	370534		
20	54	9.4	309	12376	6498	380160		
21	54	9.4	317	12682	6658	389548		
22	54	9.4	325	12981	6815	398715		
23	54	9.4	332	13272	6968	407676		
24	54	9.4	339	13558	7118	416444		
25	54	9.4	346	13837	7265	425031		
26	54	9.4	353	14111	7408	433449		
27	54	9.4	360	14380	7550	441706		
28	54	9.4	366	14644	7688	449811		
29	54	9.4	373	14903	7824	457773		
30	54	9.4	379	15158	7958	465599		
31	54	9.4	385	15409	8089	473295		
32	54	9.4	391	15655	8219	480868		

APPENDIX F

APPENDIX F

The Model House for Cooling Loads



GROUND FLOOR PLAN

Fig. F.1. Ground Floor Plan of the house used for the calculation loads.

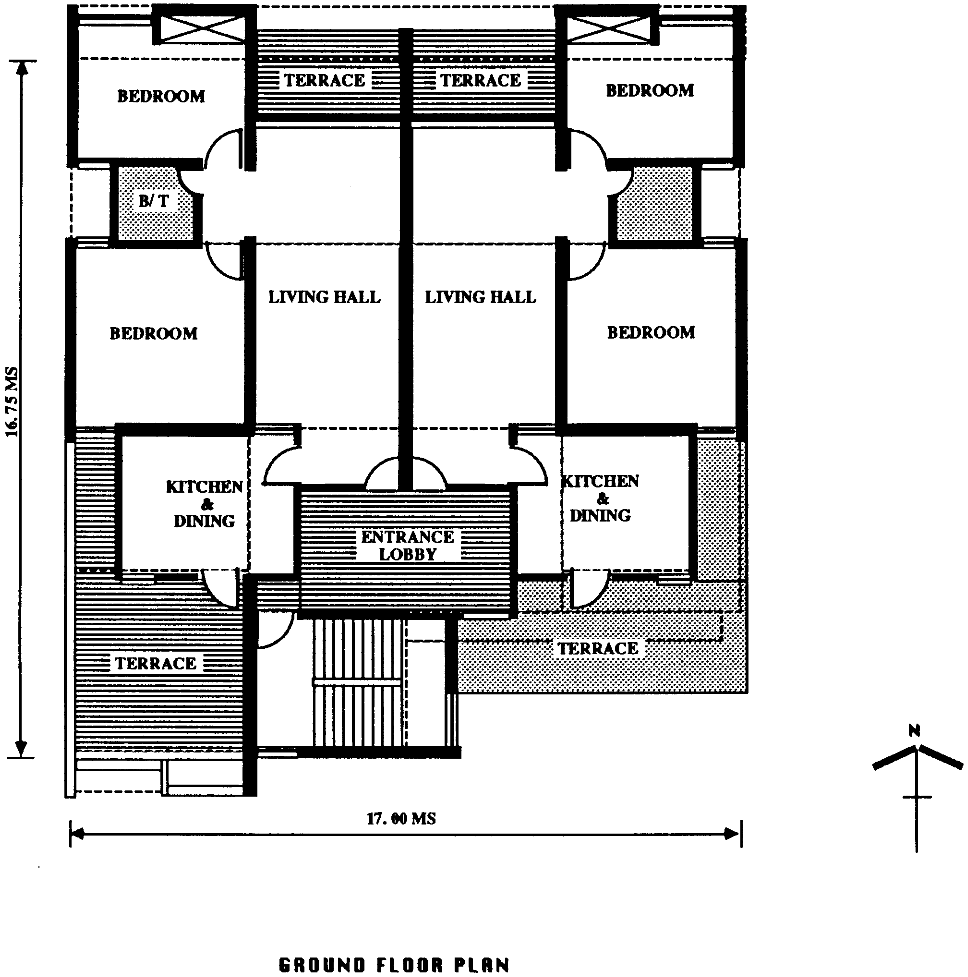
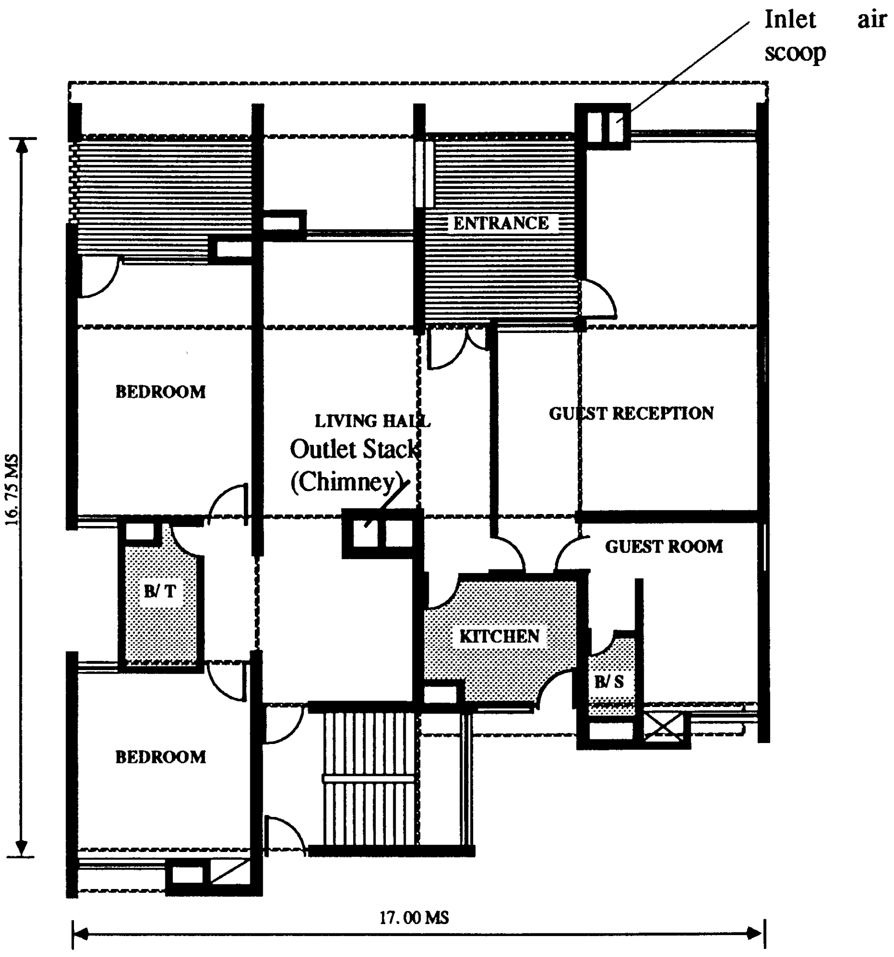


Fig. F.2. First Floor Plan of the house used for Cooling Loads calculation.



GROUND FLOOR PLAN

Fig. F.3. The previous House plans represented in this Appendix can be environmentally modified and controlled by adding a chimney and air scoop in the existing spaces.

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BIBLIOGRAPHY

Ahmed, A. M. "On Ceiling Heights and Human Comfort" 1974. In Buildings in Hot Climates. Ed. Overseas Division of the Building Research Establishment, United Kingdom, 1980. P.P.391-397.

Ahmed, A. M. "The thermal Performance of Concrete Roofs and Reed Shaded Panels Under Arid Summer Conditions" 1975. In Buildings in Hot Climates. Ed. Overseas Division of the Building Research Establishment, United Kingdom, 1980. P.P.399-407.

Al-Azzawi, Subhi . "Oriental Houses in Baghdad". Part 1, 1985. UR, The International Magazine for Arab Culture. P.P. 3-14.

Al-Azzawi, Subhi . "Oriental Houses in Baghdad". Part 2, 1985. UR, The International Magazine for Arab Culture. P.P. 30-41.

Al-Azzawi, Subhi . "Oriental Houses in Baghdad". Part 3, 1985. UR, The International Magazine for Arab Culture. P.P. 7-21.

Alawi, Jessar, Juwayhel, and Maraphie. eds. Solar Energy Prospect in the Arab World. *Second Arab International Solar Energy Conference*. Pergamon Press, Oxford 1986.

Allen, Moore and Mahone. Beginning Exercises in Energy Conscious Design. US. Dept. of Energy, Washington, 1981.

Arthur Bowen, Eugenen Clark, and Kenneth Labs. Passive Cooling. Part two. American Section of International Solar Energy Society.

ASHRAE. Cooling and Heating Load Calculations Manual. Atlanta, GA, 1980.

Atkinson, G. A. Principles of Tropical Designs. Architectural Review, Vol. 128, No. 761, London, 1960.

Bahadori, M. Design of Cooling System for the settlement of Nomads in Algeria. International Seminar on Bioclimatic Design, University of Catalina, Italy, 1981.

Braden and Steiner. Successful Solar Energy Solutions. Van Nostrand, Reinhold Co. New York, 1980

Brown, G. Z., Reynold, J. and Ubbenholde, S. Design Procedures for Daylighting, Passive Solar Heating and Cooling. US Dept. of Energy. Washington, 1981.

Brown, G.Z. Sun, Wind, and Light. Architectural Design Strategies. John Wiley and Son's. New York 1985.

Cook, Jeffrey. Passive Design for Desert Houses. Arizona Solar Commission, Phoenix, Arizona, 1981

Cowan, Henry J. Solar Energy Applications in the Design of Buildings. Applied Science Publishing Ltd. London, 1980.

Dellisola, A. J. and Kirk, S. J. Life-Cycle Costing for Design Professionals. McGraw Hill Book Co. New York, 1981

Dorf, Richard. The Energy Factbook. McGraw-Hill Co. New York 1981.

Dubin, Fred S. and Long, C. G. Energy Conservation Standards. for Building Design, construction and Operation. McGraw Hill Book Co. New York, 1978

El Bushra, E. An Atlas of Khartoum Conurbation. University of Khartoum Press. khartoum, 1981.

El Nady, A. H. (prof.). Notes on the Important Shade Trees Grown in Khartoum. (research paper). Dept. of Forestry and Dept. of Agronomy, Faculty of Agriculture, U. of K. 1987.

El-Wakil, S. and Sirag, M. A. El-Manakh Wa Amarat El-Manatiq El-Harra Tobgi Publishing

Co. Cairo, 1985

Erly and Jaffe eds. Site Planning for Solar Access. Dept. of Housing and Urban Development. Chicago, 1979.

Evans, Martin. Housing, Climate, and Comfort. Halsted Press, Architectural Press 1980

Evans. Benjamin H. Daylighting in Architecture. McGraw-Hill Book CO. New York, 1981

Faber and Kell. Heating And Airconditioning of Buildings. 5th. Ed. Architectural Press, London, 1971.

Fanger, P. O. Thermal Comfort. MacGraw Hill Book Co. New York, 1970.

Fry and Drew. Tropical Architecture in the Dry and Humid Zones. 2nd. ed. Krieger Publishing Co. Malbar, Fla,1982

Geiger, R. The Climate Near the Ground. 5th. ed. Harvard Press. Cambridge, MA, 1975.

Givoni, B. Man, Climate, and Architecture. Van Nostrand Reinhold Co. New York 1981.

Givoni, B. Options and Applications of Passive Cooling, Energy and Buildings. Vol. 7, No. 4, Dec. 1984, pp. 297-300.S

Glenn and Kolar eds. The Renewable Challenge. Conference Papers Procedures. American Solar Energy Society, Annual Meeting, Houston, Texas. New York 1982

Golany, Gideon. Urban Planning for Arid Zones. Wiley-Interscience Publications. New York,1978.

Johnson, Timothy E. Solar Architecture, The Direct Gain Approach. McGraw Hill Book Co. New York,1981.

Johnson, Timothy, Cool Windows. Solar Age. Vol. 9, Aug. 1984, pp. 28-31.

Knowles, Ralph L. Sun Rhythm Form. The MIT Press. Cambridge, MA, 1981.

Konya, Allan. Design Primer for Hot Climates The Architectural Press Ltd. London 1980.

Kukrega C.P.Tropical Architecture, TATA McGraw-Hill Co. Delhi, 1978.

Loftness , Vivian. Climate/ Energy Graphics, US Dept. of Energy 1981.

Mamazian, Ali .Direct Use of Solar Radiation for Heating and Cooling for Residential Buildings in Hot Arid Climates. PhD. Thesis U. of Michigan 1981.

Mazria, Edward . The Passive Solar Energy Book,Rodale Press. Emmaus, PA, 1979.

Melarago, M. G. Wind in Architectural and Environmental Design. Van Nostrand Reinhold Publishing. New York, 1982.

Meteorological Department, Khartoum , Climatic Data, Sudan.

Michels, Tim. Solar Energy Utilization. Van Nostrand Reinhold, New York, 1979.

Michelson, William M. Behavioral Research Methods in Environmental Design. Dowden, Hutchington & Ross, Inc. Stroudsburg, PA, 1975.

Mukhtar Y. A. “Roofs in Hot Dry Climates with Special Reference to Northern Sudan” 1978. In Buildings in Hot Climates. Ed. Overseas Division of the Building Research Establishment, United Kingdom, 1980. P.P.409-425.

NEA. Energy News. Vol. 2#1,2 &3. Vol.3 #1.

NEA. Sudan Energy Handbook. National Energy Administration, Ministry of Energy and Mining. Khartoum, 1981.

NEPC. The National Energy Plan 1985-2000. National Energy Plan Committee, NEA, Ministry of Energy and Mining. Khartoum, 1985.

Norberg-Schulz, Christian. Genuis Loci. Towards a Phenomenolgy of Architecture. Rizzoli International Publications, Inc. New York, 1981.

Oklay, David. Tropical Houses. B. T. Batsford., Ltd. London, 1961.

Olgay, A. and Olgay, Victor. Solar Control and Shading Devices. Princeton University Press, Princeton. New York, 1975.

Olgay, Victor. Design with Climate. Princeton University Press, Princeton, New Jersey, 1973.

Oliver, Paul ed. Shelter and Society. Praeger Publishers, Inc. New York, 1969.

Patrovics, W. A. The Thermal Performance of Fixed and Variable Selective Transmitters in Commercial Architecture. S.M.Arch.S Thesis, Dept. of Architecture, M.I.T. 1984.

Posorki, R. and Ahmed, S. Evaluation of the Meteorological Data of Suba (Khartoum): with Respect to Renewable Energy Applications. SEP/ GTZ and RERI, Khartoum, 1984.

Powel, Jeanne W. An Economic Model for Passive Solar Designs in Commercial Environments. Dept. of Commerce, National Bureau of Standards. Washington, 1980.

Rasmussen, Steen Eiler. Experiencing Architecture. MIT Press Cambridge, MA.1985.

Reekie, R. Fraser. Design in the Built Environment. Crane, Russak and Comany, Inc. New York 1972.

Ridgway, J. Energy Efficient Community Planning. The JG Press Inc/ The Elements. Emmaus, PA. 1979.

Rose, David J. Learning about Energy. Plenum Press. New York 1986.

Sayigh. ed. Solar Energy Applications in Buildings. Academic Press, New York , 1979

Sayigh. ed. Solar Energy Engineering. Academic press, New York. 1977.

Sherratt. Integrated Environment in Building Design. Halsted Press, Wiley. New York, 1974.

Sperling, R. Roofs for Warm Climates. Ministry of Public Buildings and Works, BRS, Garston, Watford, England, 1981.

Stein, Reynold and McGuinness. Mechanical and Electrical Equipments for Buildings. Wiley and Sons. New York 1986.

Straaten, J. F. Van. Thermal Performance of Buildings. Elsevier Publishing Co. London, 1967.

Streeter and Wylie. Fluid Mechanics. 7th. ed. McGraw Hill Book Co. New York, 1979.

Szokolay, S. V. Solar Energy and Building. 2nd. ed. Halsted Press Division , Wiley. New York, 1978.

Tang, Joseph C. (S.M.Arch.S Thesis). A Passive Cooling Design for Multi Family Residences in Hot Humid Climates. MIT Dept. of Architecture, May 1983.

Total Environmental Action Inc. Los Almos Scientific lab. Los Almos National lab. Passive Solar Design Handbook. Nostrand and Reinhold Co. Los Almos ,1984

Veziroglu, T. Nejat. Solar Cooling and Heating. Vol. 2 &3. Hemisphere Publishing Corp. Washington, 1978.

Wad Al ed. Passive Solar : Subdivisions, Windows, Underground. American Solar Energy Society. New York, 1983.

Watson and Labs. Climatic Design. McGraw-Hill Co. New York, 1983

Watson, Donald and Glover, Raymond. Solar Control Workbook. Association of Collegiate Schools of Architecture. Washington D. C.1981.

Watson, Donald ed. Energy Conservation through Building Design. Mcgraw-Hill, Inc. New York, 1979.

Winter, S. Associates. The Passive Solar Construction Handbook. Rodale Press. Emmaus, PA.1983

Wittenberg, G. ,Turner, W. and Way, G. Climate Based Cooling. US Dept. of Energy 1981.