THE INFLUENCE OF HOT HUMID CLIMATE ON DESIGN OF HIGH DENSITY HOUSING A CASE STUDY

by

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1 INTRODUCTION

INTRODUCTION

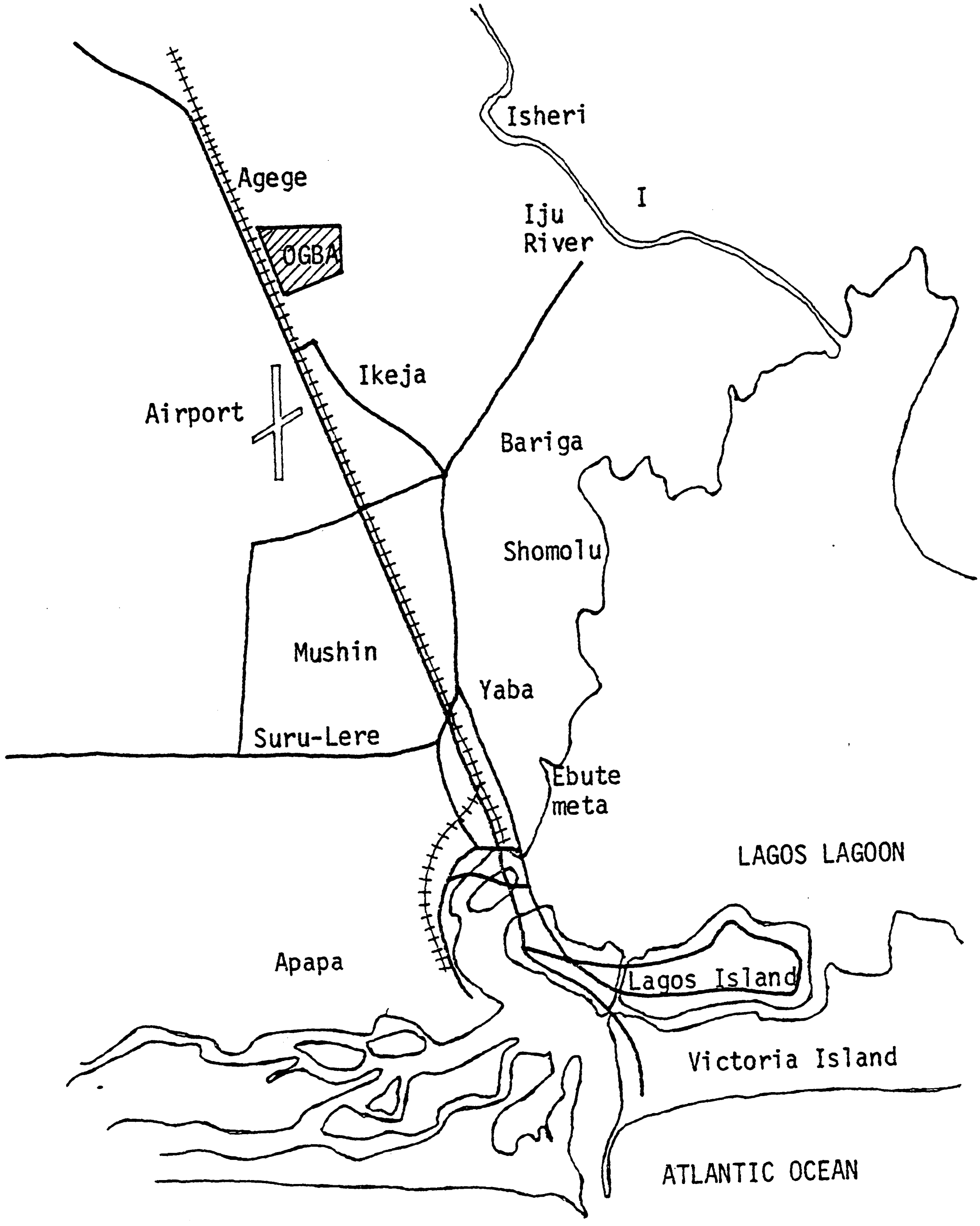
In the tropics, climatic factors have had a dominant influence on the design of traditional architecture. This architecture developed through years of trial and error. It evolved to suit the life style of the people.

Today the mass exodus of people from rural to urban areas is creating a huge demand for urban housing and is creating an unprecedented increase in building construction. This housing crisis has resulted in disregard for climate. Designers and planners are achieving density but are giving little attention to the livability of the environment which they are creating. The challenge is to design buildings which meet architectural objectives and also satisfy bio-climatic requirements.

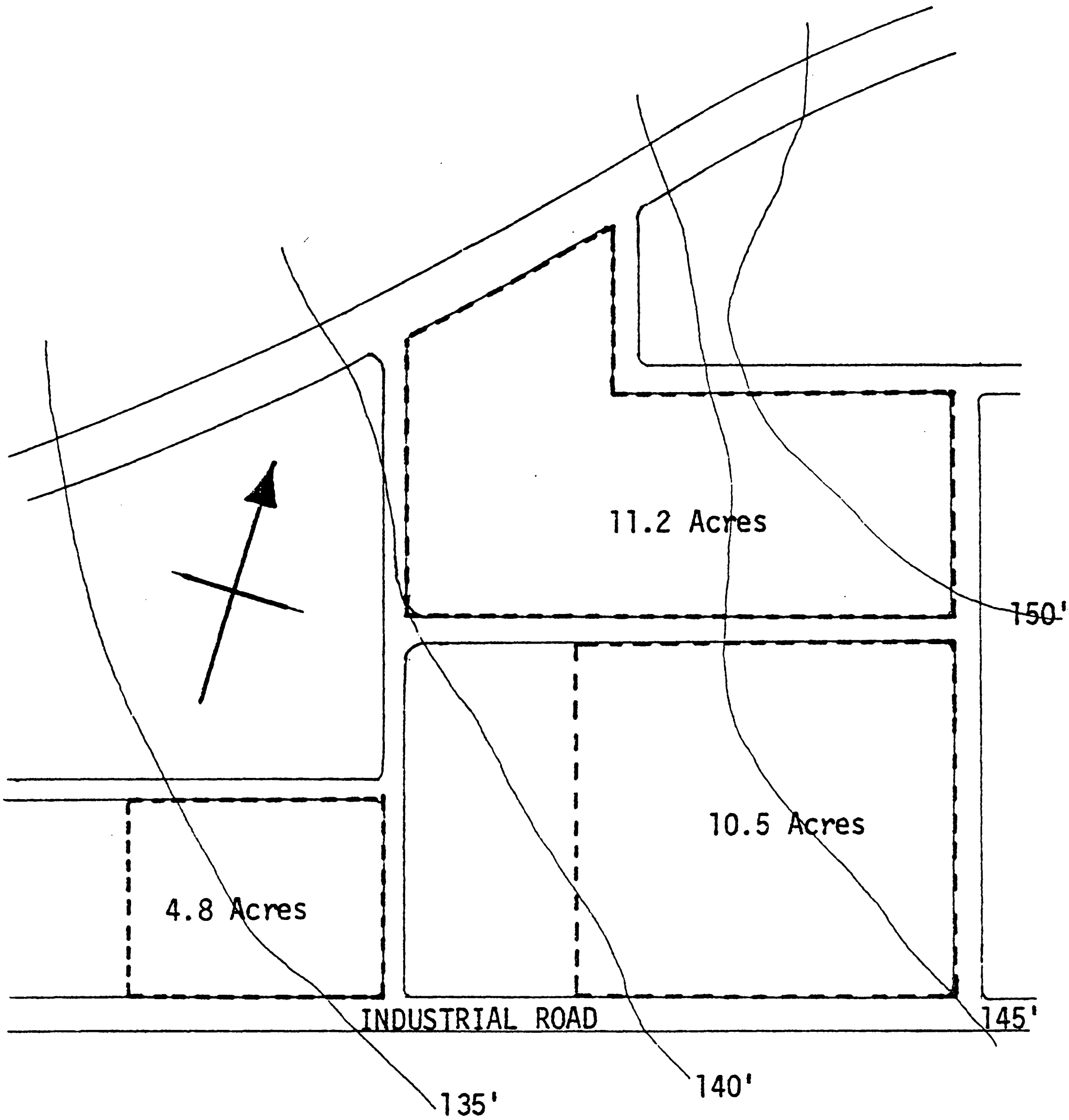
This thesis identifies the hot humid conditions in Lagos, Nigeria, and stresses its impact on the design of a high density housing for the Ijaiye project. The project is located at Ogba village seven kilometers north of Lagos island. Details from the housing program are given in appendix 1. The design was affected by research in the literature describing tropical architecture. The design is not definitive scientifically. It represents a designers approach based on the best available information.

A house is a place where man seeks rest and protection from the undesirable elements of climate. It is habitable only if it provides indoor environmental conditions that will permit sound sleep at night and pursuit of normal physical and mental activities by day. Thus the design development of the building requires a sensitive and intelligent awareness of all climatic factors.

The site is located on latitude 6° N in the northern suburbs of Lagos at Ogba village, within the vicinity of Agege, Isheri and Ikeja, three major residential areas of Lagos. (See Map 1) The site is on an elevation which averages 42 meters above sea level. It occupies 10.5 hectares of land and consists of three housing sites located around land which is to be used for a kindergarten school. Configuration of the site is shown in map 2. It is bounded on the west by a proposed commercial center, on the east by a vacant plot of land allocated to private developers for construction of residential housing. On the south it is bounded by a site allocated for industrial development and in the north by the Agege Isheri road, the major highway in the area.



MAP 1 Location of Site Within Lagos



MAP 2 Site Context

2 THREE FUNDAMENTAL ISSUES THAT INFLUENCED THE DESIGN

FUNDAMENTAL ISSUES THAT INFLUENCED THE DESIGN

The location of the site presents a certain climate with a set of physiological standards that demand sensitivity in the choice of building materials and building configuration. This section presents the major issues involved.

CLIMATIC CONDITIONS

The most prominent characteristic of the climate is that it is hot and continually damp. There is very little seasonal variation. The three major factors that determine the effect of this climate are temperature, humidity and wind. The annual climatic data for Lagos is illustrated in Figure 1. The temperature varies between 23° C and 32° C. Humidity is high during most of the year and varies from a low of 70% at 12 p.m. to a high of 95% at 6 a.m. Winds are generally gentle and almost constant in direction because of the proximity of the Atlantic ocean. The speed varies between 9 to 19 km/hr. In wet season wind gust accompany the rainfall and can reach speeds as high as 32 km/hr. The rainfall is most intense during the monsoon period. The annual rainfall is 1339 mm. The twenty-four hour rainfall varies from a low of 25 mm in December to a high of 170 mm in July. The prevailing south-west trade winds are largely responsible for the rainfall. They pick up moisture while passing over the Atlantic ocean. Solar movement in this latitude is pivotal. The annual solar altitude and bearing during the

CLIMATIC DATA

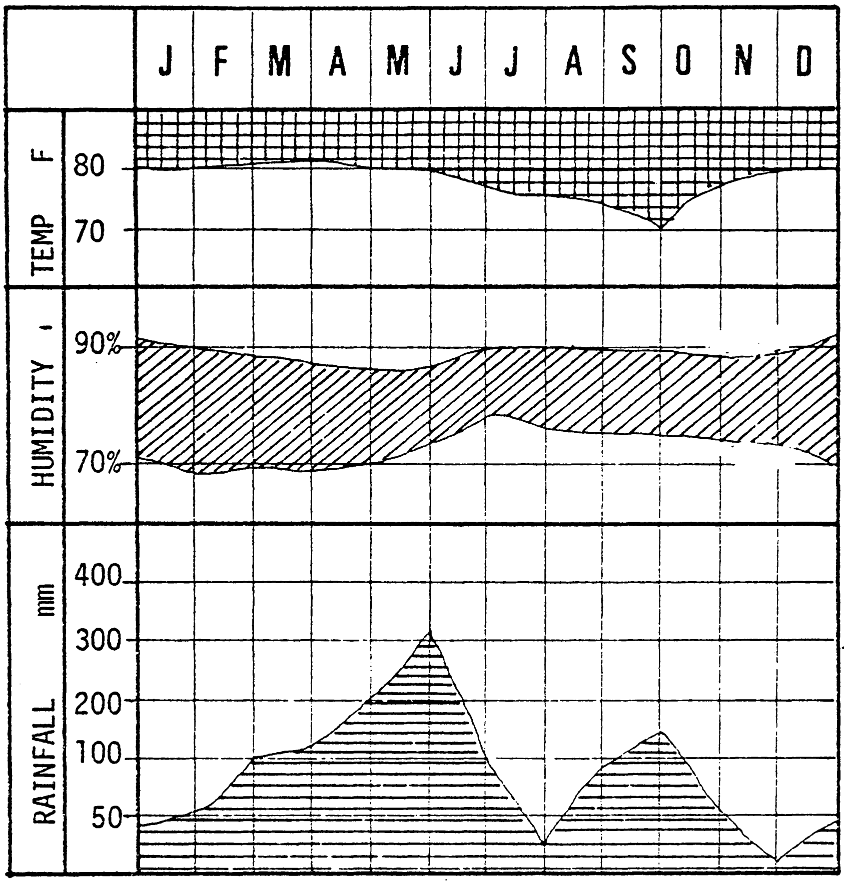


FIGURE 1

Climatic Data for Lagos

SOURCE: World Handbook of Climatic Data.

day in latitude 6° N is illustrated in Figure 2. In winter the sun shines from the southern hemisphere and in summer season from the northern hemisphere. During the equinox the sun is almost directly overhead. Throughout the year there is an average of about twelve hours of sunshine daily. The sun rises at 6 a.m. and sets at 6 p.m.

There are certain problems that are caused by this climate. Frequent rainfall promotes the rapid growth of vegetation which provides good breeding grounds for destructive insects like termites. High humidity promotes the growth of algae, mold and rusting in building materials.

HUMAN COMFORT

The climatic elements mentioned above have a major impact on thermal comfort. Thermal comfort is the criteria for determining the range of conditions under which thermal balance can be maintained between the body and the external environment. Under these climatic conditions heat exchange between the human body and the natural environment is maintained. The human comfort zone delimits the acceptable temperature and humidity ranges. The bio-climatic chart (see Figure 3) displays human responses to the combined effect of humidity, temperature and air velocity. The shaded portion (the comfort zone) represents the acceptable range of conditions which occur when temperature is between 30° C and 20° C, humidity between 30% and 65% of and air movement is not more than 0.1 m/sec. The most reliable way to discharge heat from

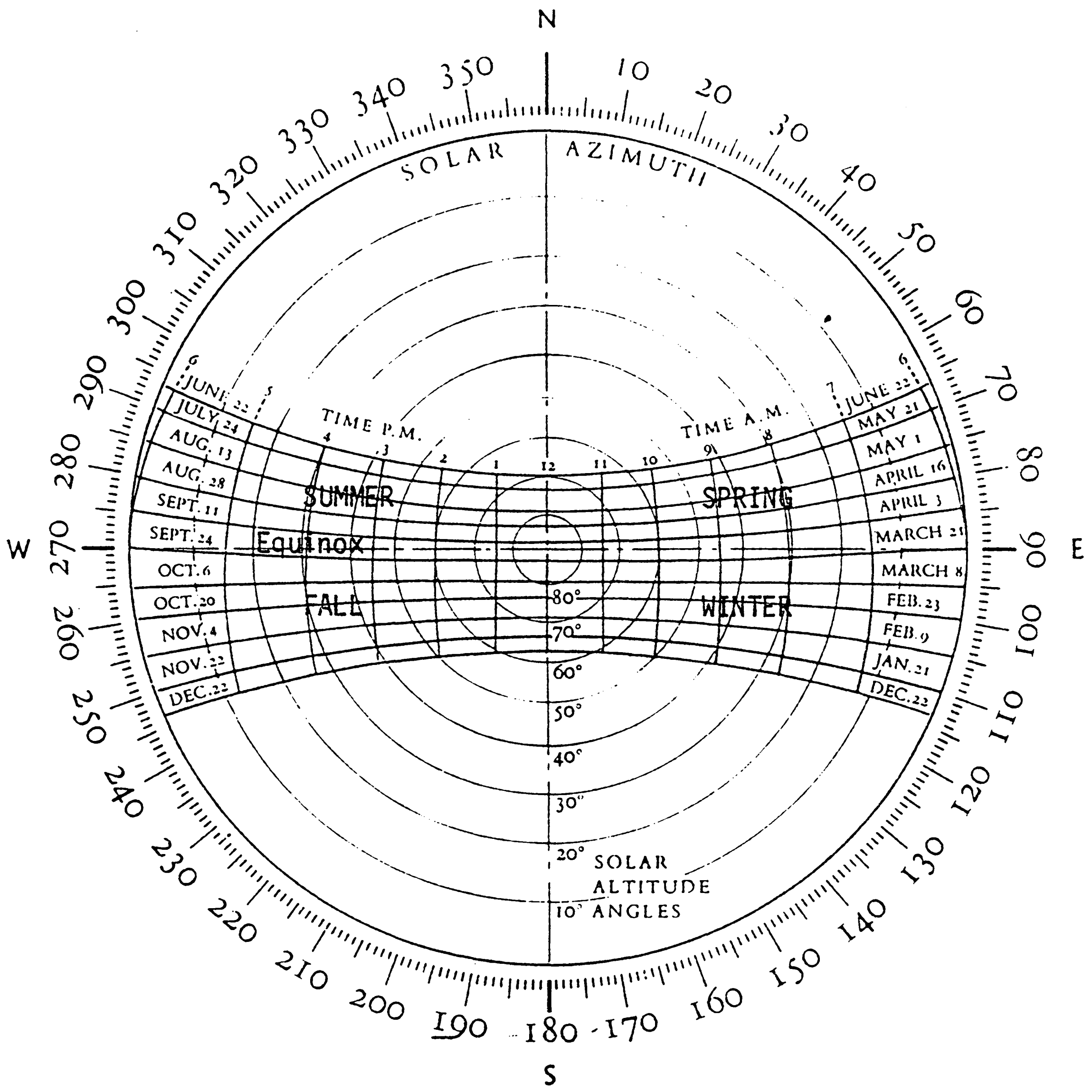


FIGURE 2

Solar altitude and azimuth for selected periods. At the Latitude of this site the sun shines from the north during spring and summer months, and from the south during the fall and winter months.

SOURCE: Manual of tropical housing and building, part one.

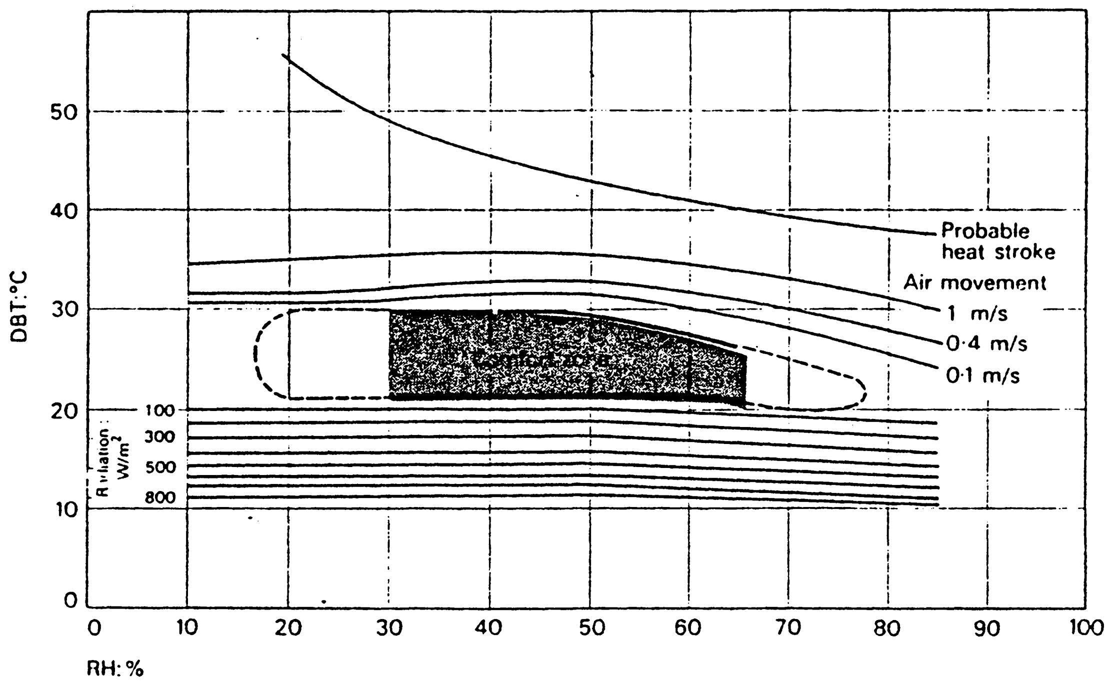


FIGURE 3

Bio-climatic Chart

Thermal comfort can be achieved when temperature is between 30° C and 20° C, humidity is between 30% and 60% and air movement is at an average of 0.1m/sec.

SOURCE: Manual of Tropical Housing and Building Part One: Climate design.

the body in a hot humid environment is by evaporation. This is possible when humidity is less than 100%, and when the process is accelerated by wind velocity or air movement.

The need to create a livable environment imposes certain tolerances on the design of building enclosures. The indication of what tolerances are required can be determined by use of the mahoney tables. The tables shown in appendix 2 are used to aid designers in determining spatial and architectural requirements. The climatic data for Lagos was diagnosed to determine the severity of the climatic stresses. Recommendations were made on how to relieve those stresses through building design. The following recommendations were made:

1. Buildings should be oriented in the east-west axis with the long elevations facing north and south so as to effectively control solar radiation and to take advantage of the prevailing south-west wind.
2. Wide free spaces between buildings should be provided to avoid blocking wind flow to other buildings.
3. Rooms should be single banked so that they can have an inlet and outlet, and thus encourage cross ventilation.
4. Roof and walls should be constructed with light weight materials with small heat capacity so as to avoid accumulating and radiating excessive heat absorbed during the day into the interior at night.

APPROPRIATE BUILDING MATERIALS FOR HOT HUMID CLIMATE

Materials of good thermal characteristics are necessary in order to control indoor temperature fluctuations during the day and night. The choice of building materials rested on two major criteria, the thermal characteristics, and the configuration within which materials are used. The materials which have thermal characteristics suitable for use are those with low heat capacity and short time lag. Heat capacity is the amount of heat a material can absorb when exposed to heat over a period of time. Time lag is a measurement of how long a material takes to respond to temperature change. The technical definitions of these terms is given in appendix 3. The recommended time lag for materials to be used for wall and roof construction in the hot humid climate is 3 hours.[1] The configuration within which the materials are used, that is walls, floors, roofs, and screens must take advantage of the thermal characteristics in process of balancing form, volume, mass and void into combinations which in a most positive way balance positive and negative thermal capacities. The two main variables used to evaluate their performance standards are u-value and the solar heat factor. U value is the amount of heat transmitted from an outside surface to an interior surface of the wall when there is a change in temperature. Solar heat factor is the ratio of solar energy transmitted through a construction due to the solar radiation incident on the construction. The following recommendations have been established as minimum thermal performance standards for roof and wall constructions:[2]

For Walls	U-Value	$2.8 w/m^2/deg$ c
	Solar heat factor	4%
For Roofs	U-Value	$1.1 w/m^2/deg$ c
	Solar heat factor	4%

Also as a performance standard for roofs, it is recommended that the ceiling temperature for any kind of construction, should not exceed outside air temperature by more than 4° C if interior temperature is to be within comfort range.[3] Walls and roof constructions which meet the thermal performance standards are listed in appendix 3.

3 FUNDAMENTAL DESIGN CONCEPTS

FUNDAMENTAL DESIGN CONCEPTS

The conceptual ideas which are presented in this section were generated after study of the three major issues presented in section I, that is climatic data, human comfort and appropriate building materials for hot humid climates. The particular social and economic factors of the community for which this design was evolved are not critical to the design development. They were however present and known and their presence induced sensitivity for appropriate scale, density and arrangement. The design development reflects the fundamental effects of hot humid conditions. It explores building form relative to site and meteorlogical factors. As noted earlier the design is not definitive. It represents a designers approach based on the best available information, and on a return to vernacular response. That particular phenomenon described so eloquently by Benard Rudolfski in 'Architecture Without Architects', maximizes natural climate factors, sensible materials usage, and human comfort responses. This thesis therefore implies a refutation of the imposition of high technology. It approaches a common sense way of building. The diagrams which follow describe the modest premises on which this attitude of building is based.

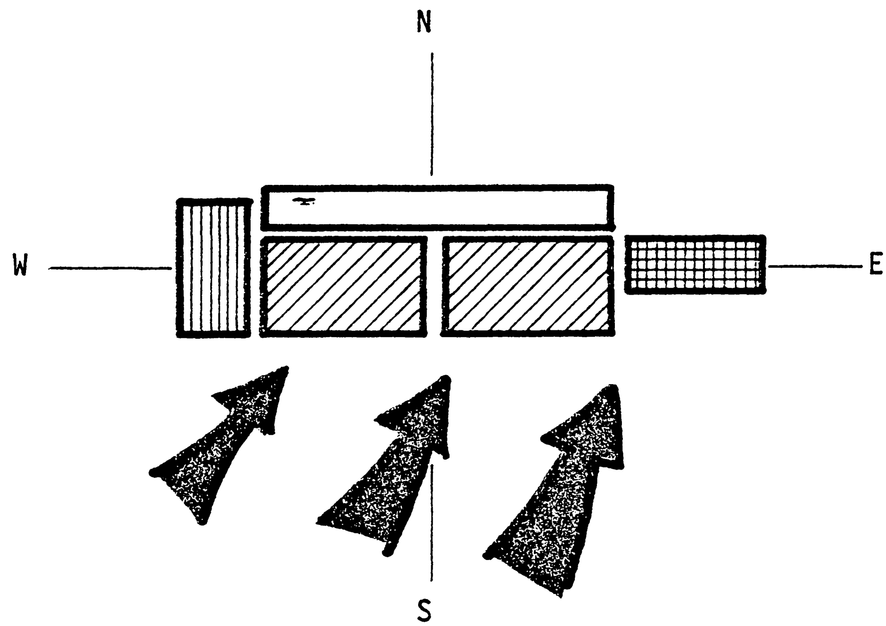


FIGURE 4

Concept for Building Morphology

Arrange building spaces along the east-west axis to maximize exposure to prevailing south-west winds.

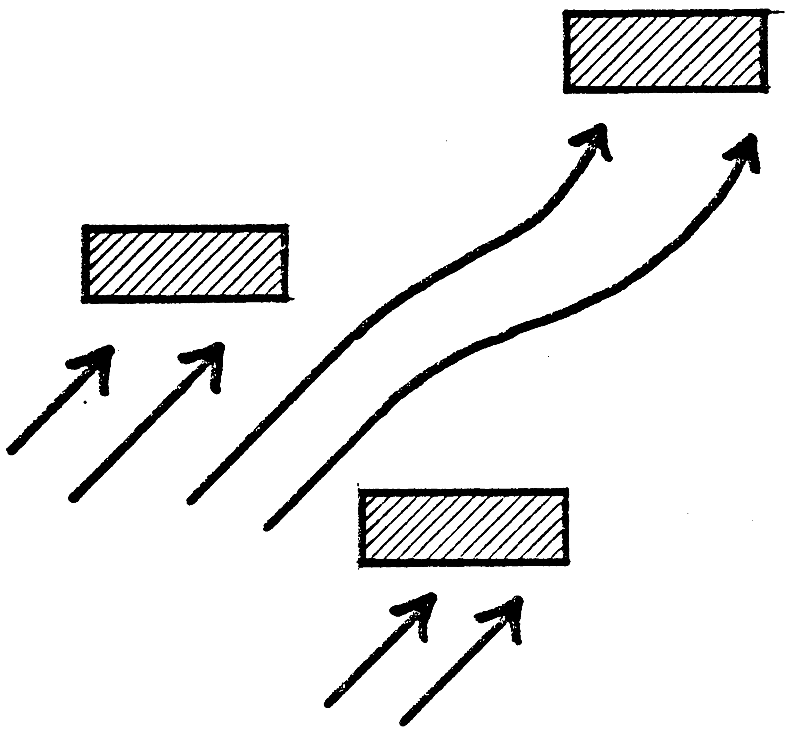


FIGURE 5

Cluster Concept

Stagger buildings around courtyard to allow free flow of air, and adequate distance between building.

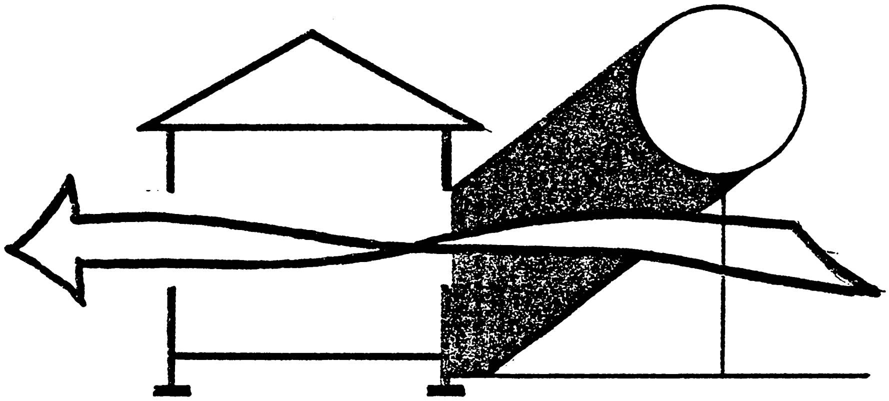


FIGURE 6

Landscaping Concept

Use trees to minimize direct solar heat gain around the building without obstructing air flow.

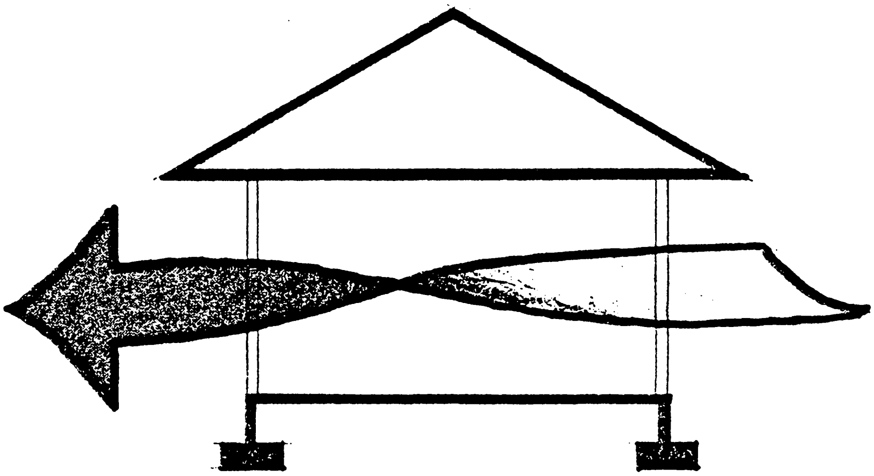


FIGURE 7

Spatial Planning Concept

Open interior planning to maximize air flow inside the building.

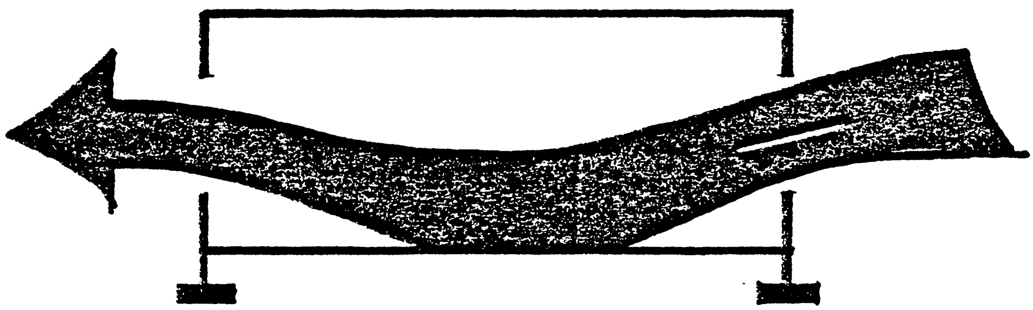


FIGURE 8

Window Design Concept

Design windows to maximize breeze and cross ventilation of the interior.

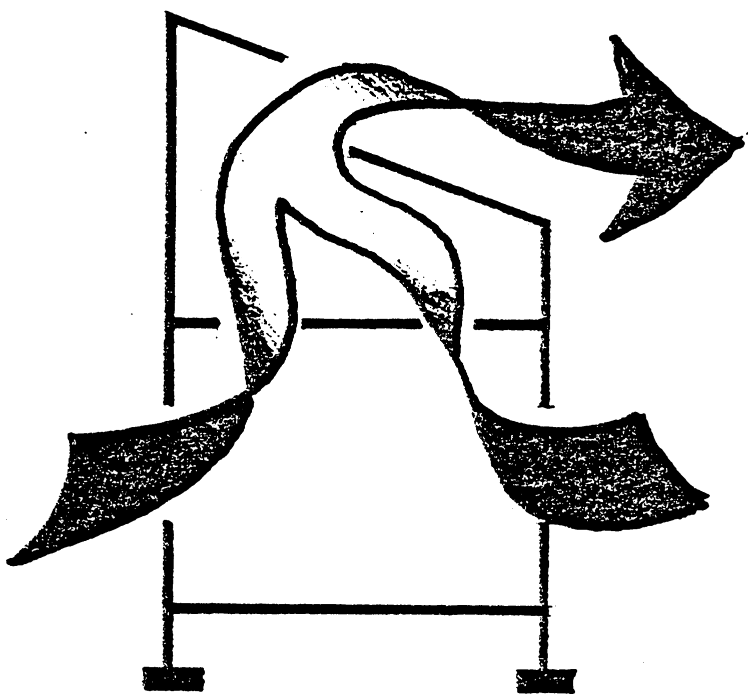


FIGURE 9

Roof Design Concept

Design roof to improve breeze ventilation under all exterior conditions through thermal induction.

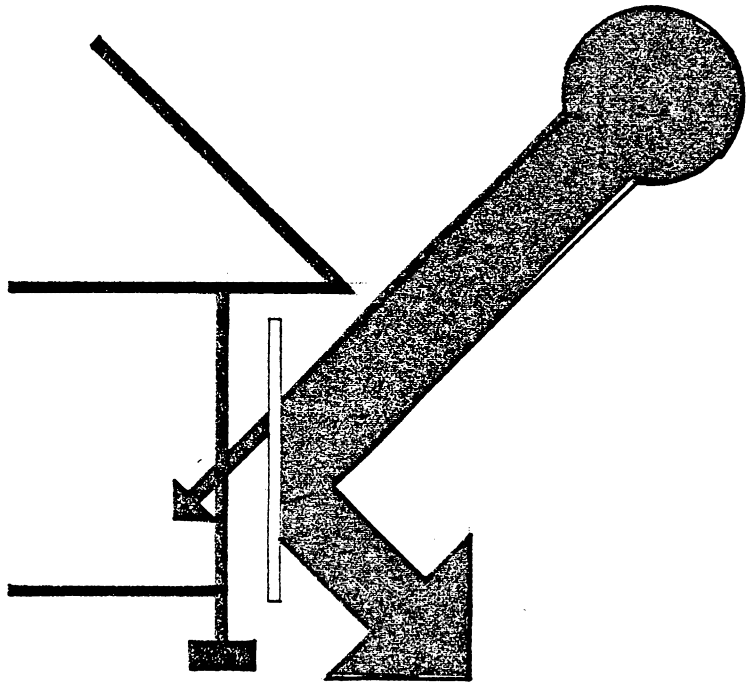


FIGURE 10

Wall Concept

Design walls to minimize heat gain by direct solar radiation.

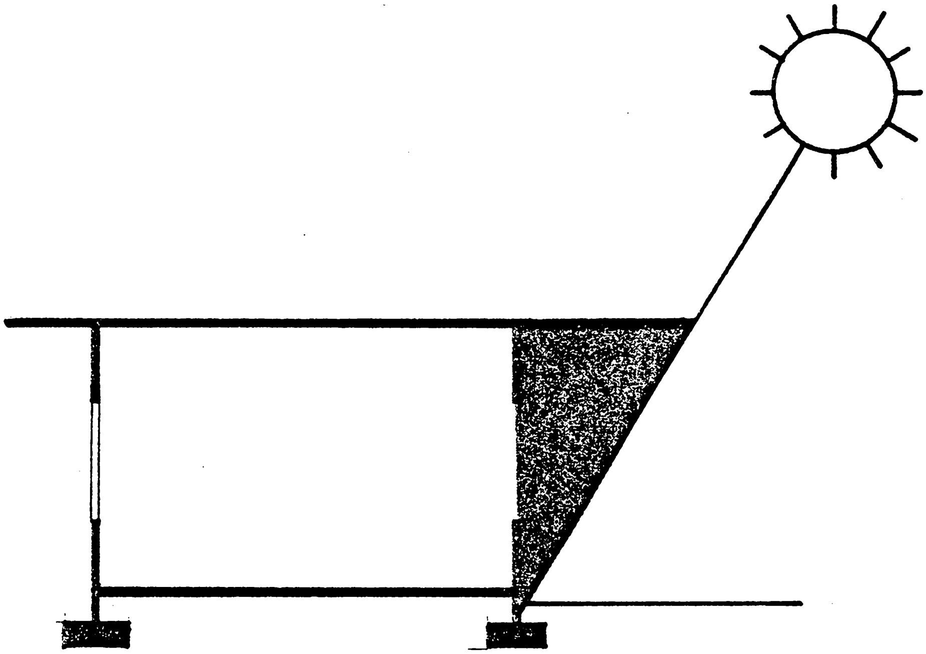


FIGURE 11

Concept for Sun Control System

Design horizontal and vertical components of buildings utilizing sun breakers to minimize direct solar heat gain.

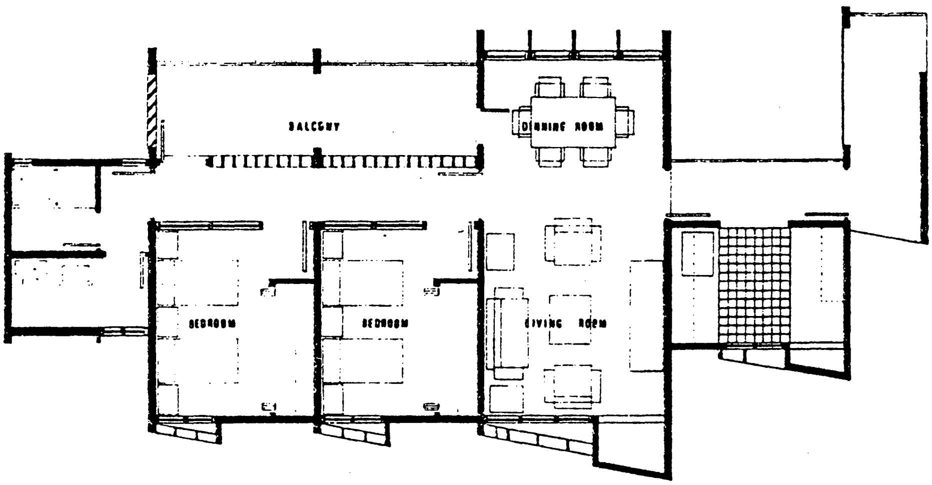
4 PRIMARY DESIGN SOLUTIONS

PRIMARY DESIGN SOLUTIONS

The attitude of the foundation of this thesis, that is to use common sense when designing, led to a number of design decisions:

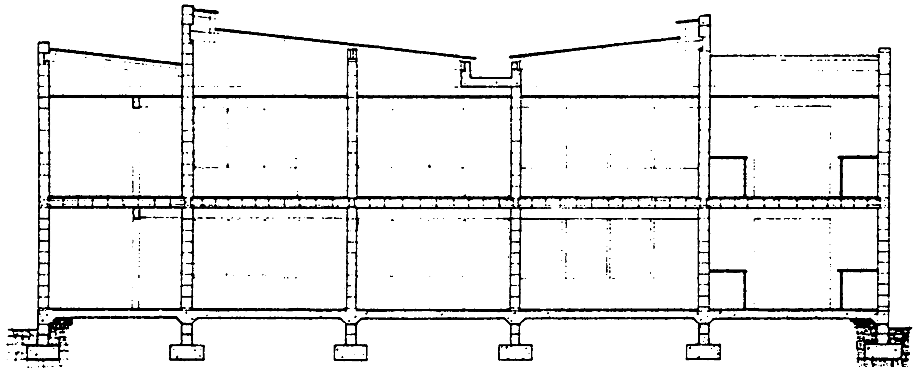
1. The buildings were oriented in the east-west axis, with long elevations facing north and south.
2. Free wide open spaces were provided between the buildings.
3. Large window openings with low sill heights were located in opposite walls of the rooms.
4. Screen walls, window projections and balconies were utilized as sun control devices.
5. The roofs of the buildings were provided with stacks to induce cross ventilation, when prevailing wind velocity is low.
6. Trees and shrubs were used to provide shade in the surrounding areas of the building.

The conclusions drawn through the process of the writing of this thesis were in sympathy with stage of development of social, technical and economic systems in the country. The use of highly technical means for comfort control for instance has been avoided. It is anticipated that this should contribute to the continuation of the country's traditions and life style. The design solutions are presented in the ensuing pages.

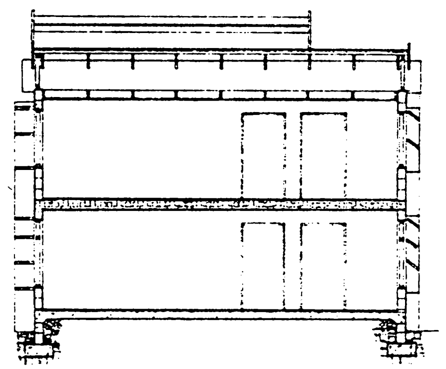


TYPICAL UNIT

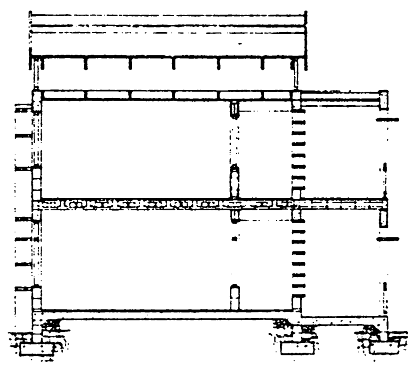
1



SECTION A-A

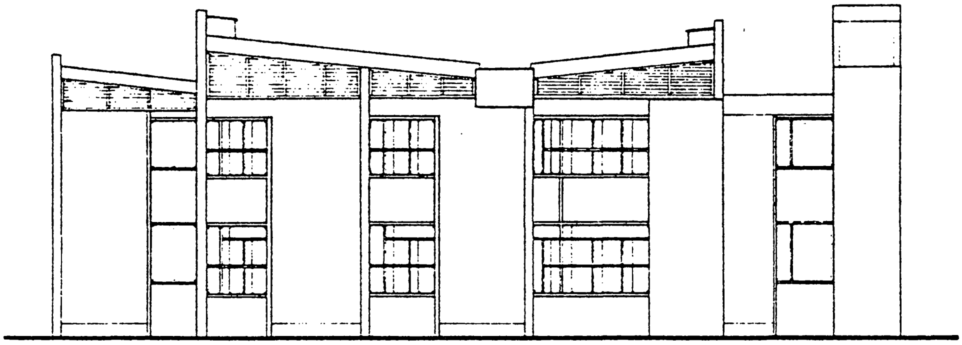


SEC B-B

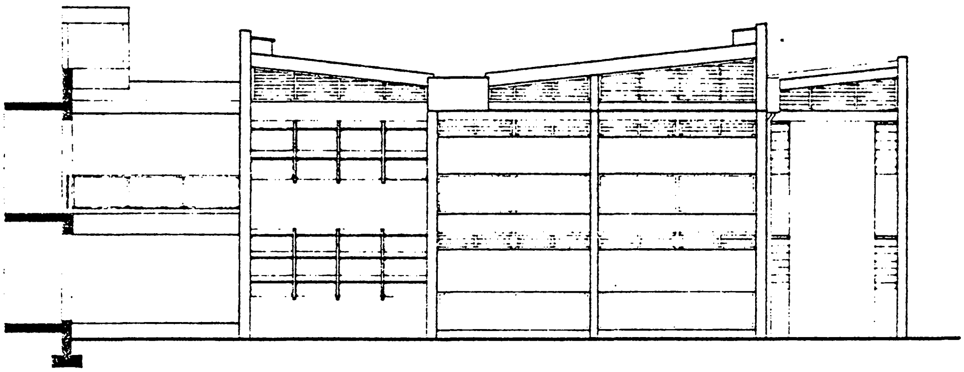


SEC C-C

2

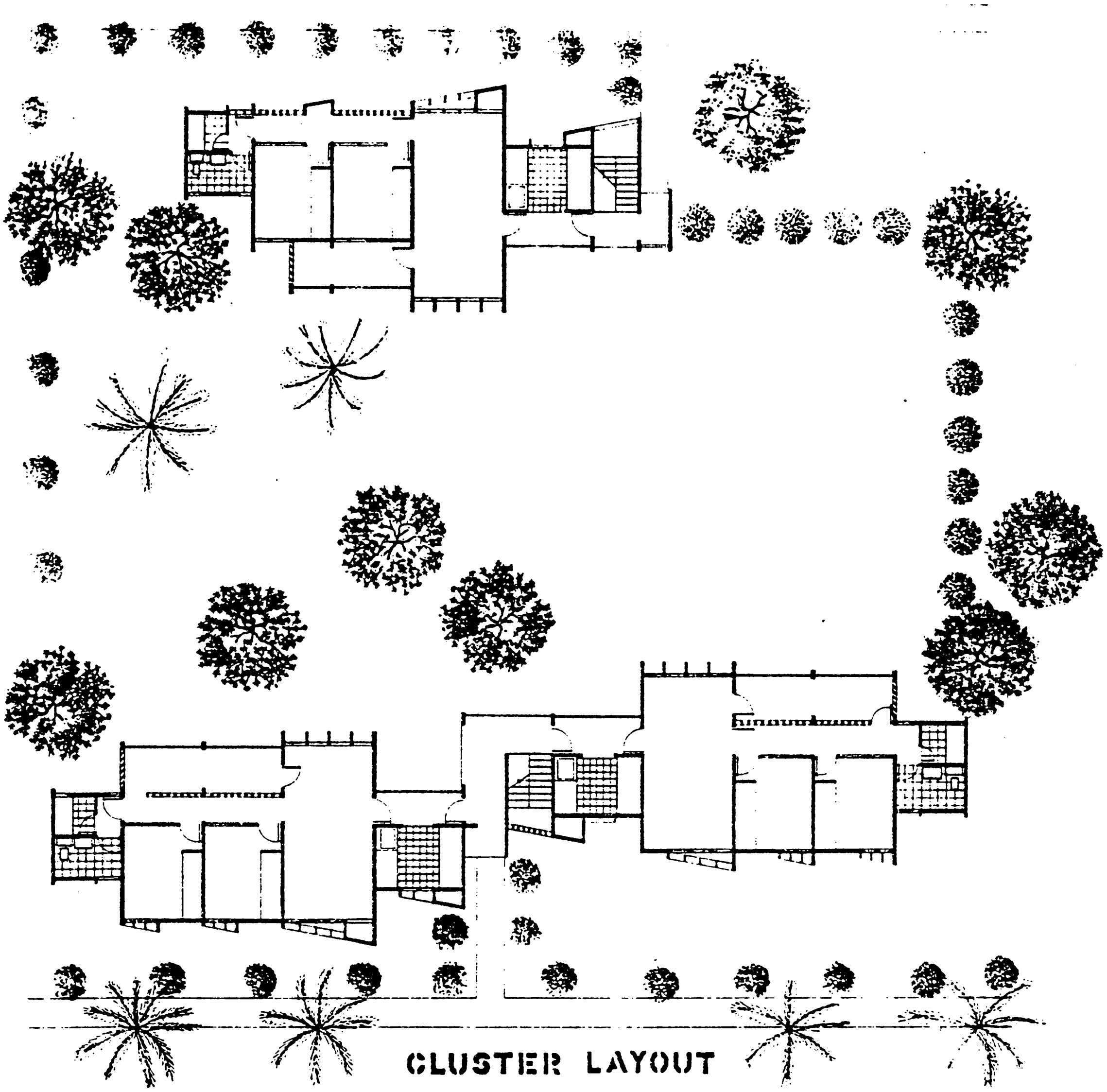


SOUTH ELEV



NORTH ELEV

3



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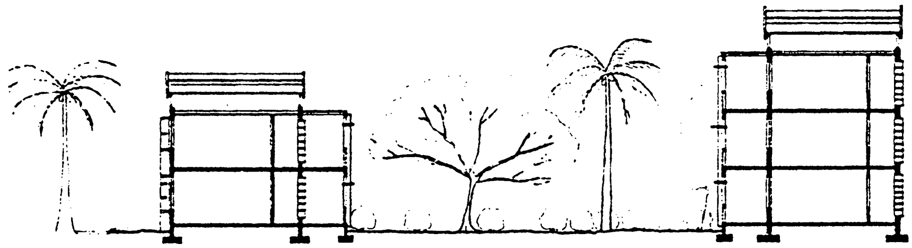
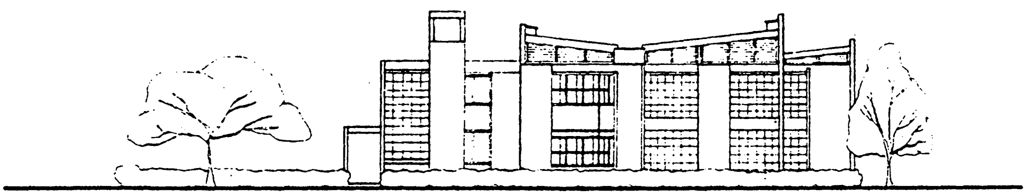
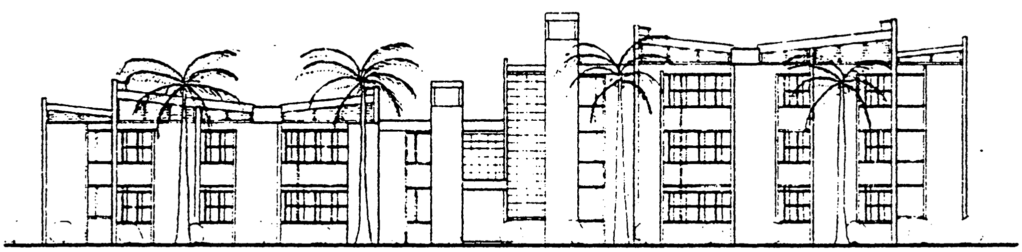


SECTION D-D



NORTH ELEV



SOUTH ELEV

5

SITE PLAN

6

5 DETAILED DESIGN DECISIONS

DETAILED DESIGN DECISIONS

The emphasis on common sense design decision-making which is the fundamental premise and method of this thesis logically led to modest design concepts. They are modest concepts in that they employ the natural properties of their environment and of the materials used, as has vernacular architecture throughout history. They generate an architecture which is honest and direct. At the same time the architecture which results represents a type which has power. There are three main designs which generated the detailed design decisions:

1. Site planning and orientation for ventilation and solar control;
2. Special details for optimizing environmental conditions;
3. Building construction for thermal control.

SITE PLANNING AND ORIENTATION FOR SOLAR AND VENTILATION CONTROL

Orientation is one of the most important factors which influences the effect of solar radiation and ventilation on the thermal conditions inside a building. In a hot humid climate it is very important to orient the building to maximize the cooling effect of ventilation and maximize direct solar heat gain. Solar radiation in this latitude of 6° N favor elongating the building on an east-west axis with longer sides facing north and south. (See Figure 12) Direct solar radiation on the north and south walls are seasonal as illustrated in Figure 13.

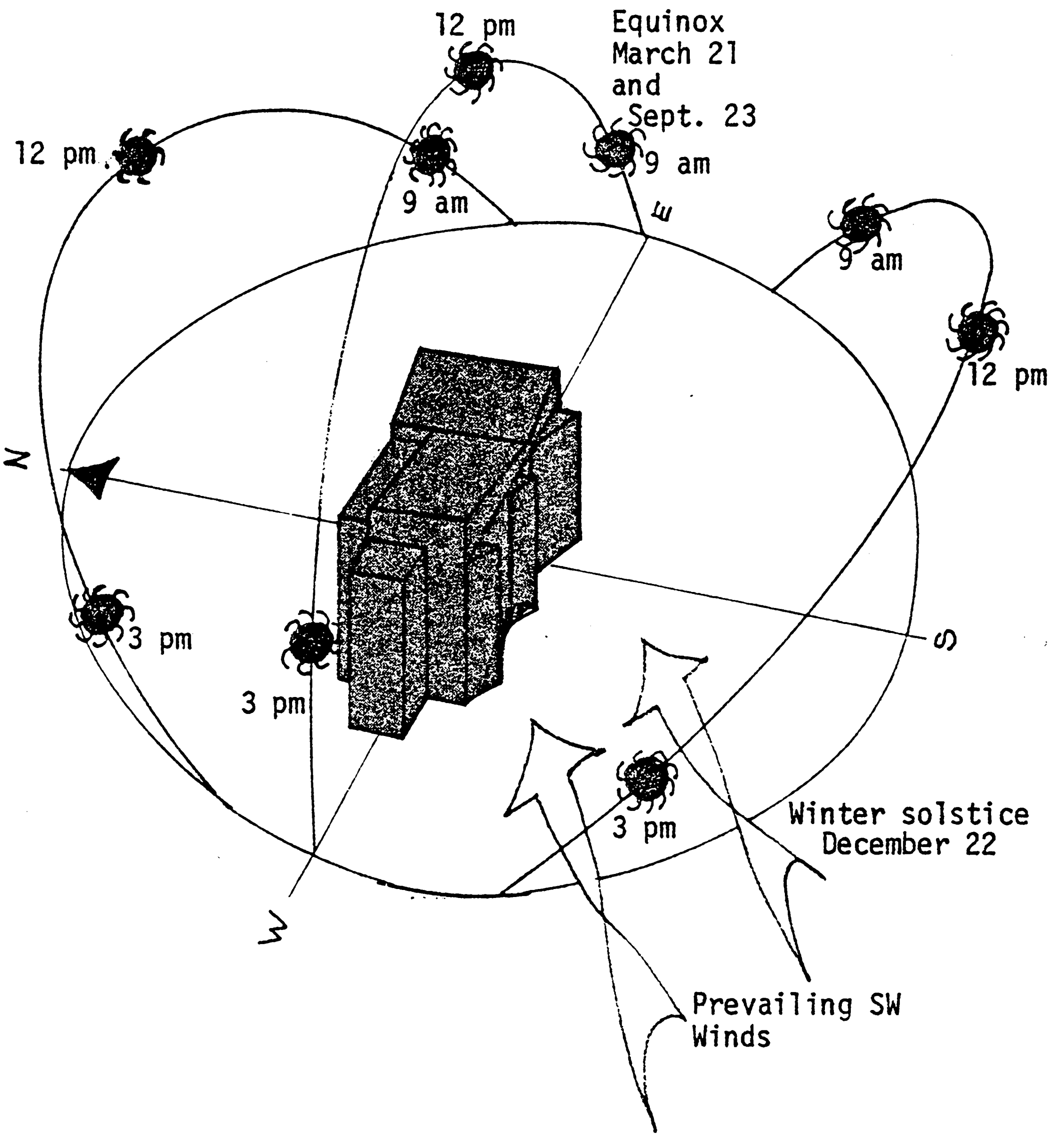


FIGURE 12

Orientation of Typical Building Unit

Buildings are elongated on the east-west axis so as to control direct solar radiation on the north and south walls with sun control devices.

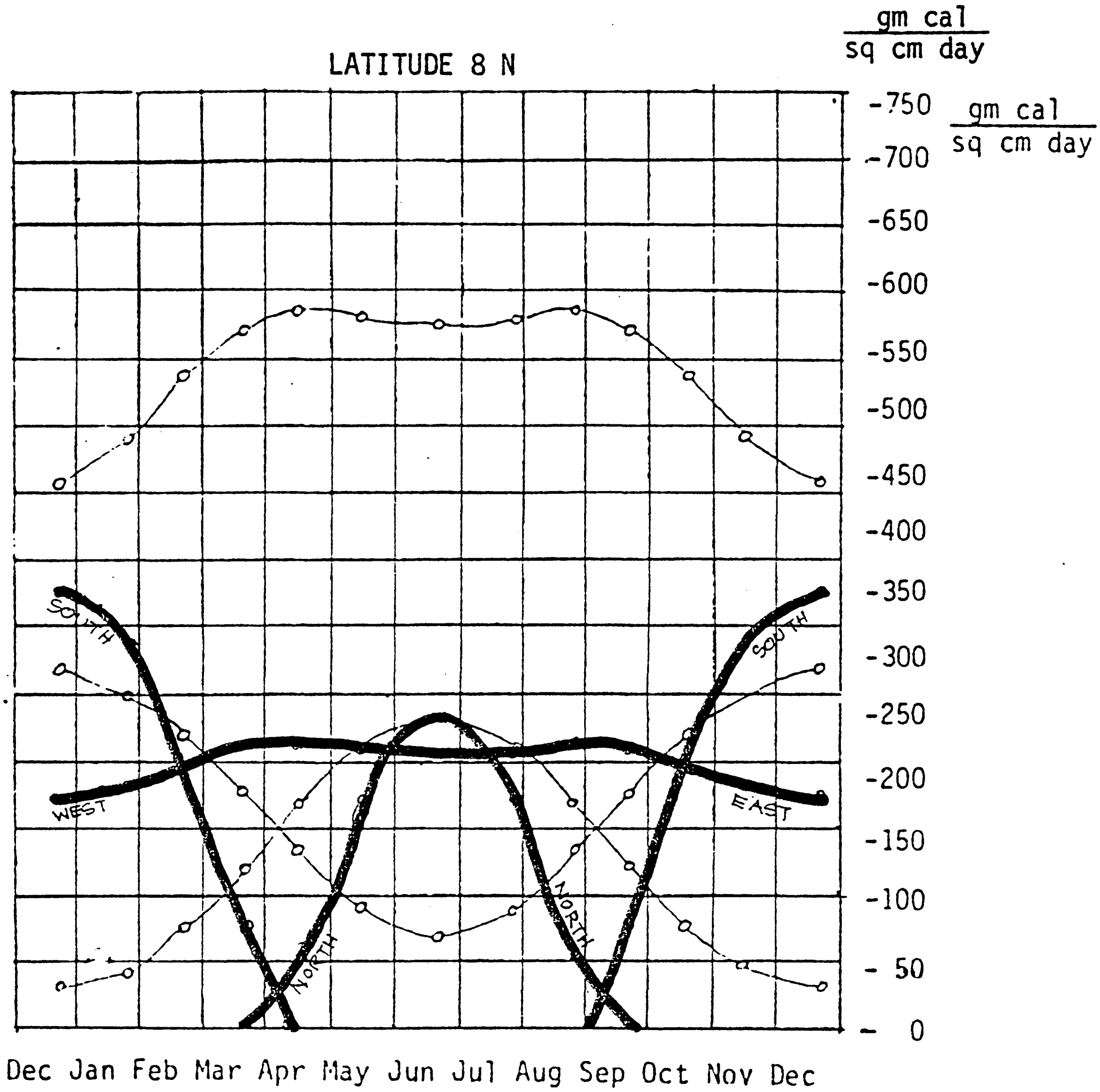


FIGURE 13

Direct Solar Radiation on Walls Of Selected Orientations

Direct solar radiation incident on walls orientated to the north and south is seasonal. On the east and west walls it is constant year round.

SOURCE: Passive Solar Handbook

LEGEND

1 Horizontal
2 North
3 South
4 East & West
5 Northeast & Northwest
6 Southeast & Southwest

Direct radiation occurs on the north side during the months of April to September and on the south side from October to March. In the east and west solar radiation is year round. It can be controlled on the north and south walls with horizontal and vertical sun control devices because of the high altitude of the sun. On the east and west sides control is very difficult because of the low altitude of the sun. With an east west axis orientation the position of the prevailing southwest winds will be oblique to the building. Logically it would seem that to provide optimum ventilation conditions, the inlet windows should be perpendicular to the direction of the wind. However wind tunnel studies at the building research station in Israel shows that better ventilation conditions can be achieved when the wind is oblique to the inlet window in a room with two windows in opposite walls.[4] The results of this experiment is summarized in appendix 4. The buildings on the site are organized into clusters. Each cluster consists of three buildings staggered around a court yard. They are related to one another so that their windshadow does not conflict with one another (See Figure 14). Wind shadow is the low pressure zone created on the leeward side. As the prevailing wind is oblique to the buildings, the depth of the wind shadow is small, and so is the distance required between the buildings. For wind incidenced at 45°, the required distance is (3xh) where h is the height of the building.[5] In clusters in which two storied units of height 7.2 meters are located on the windward side, a minimum distance of (3x7.5) meters or 22.5 meters is maintained. The

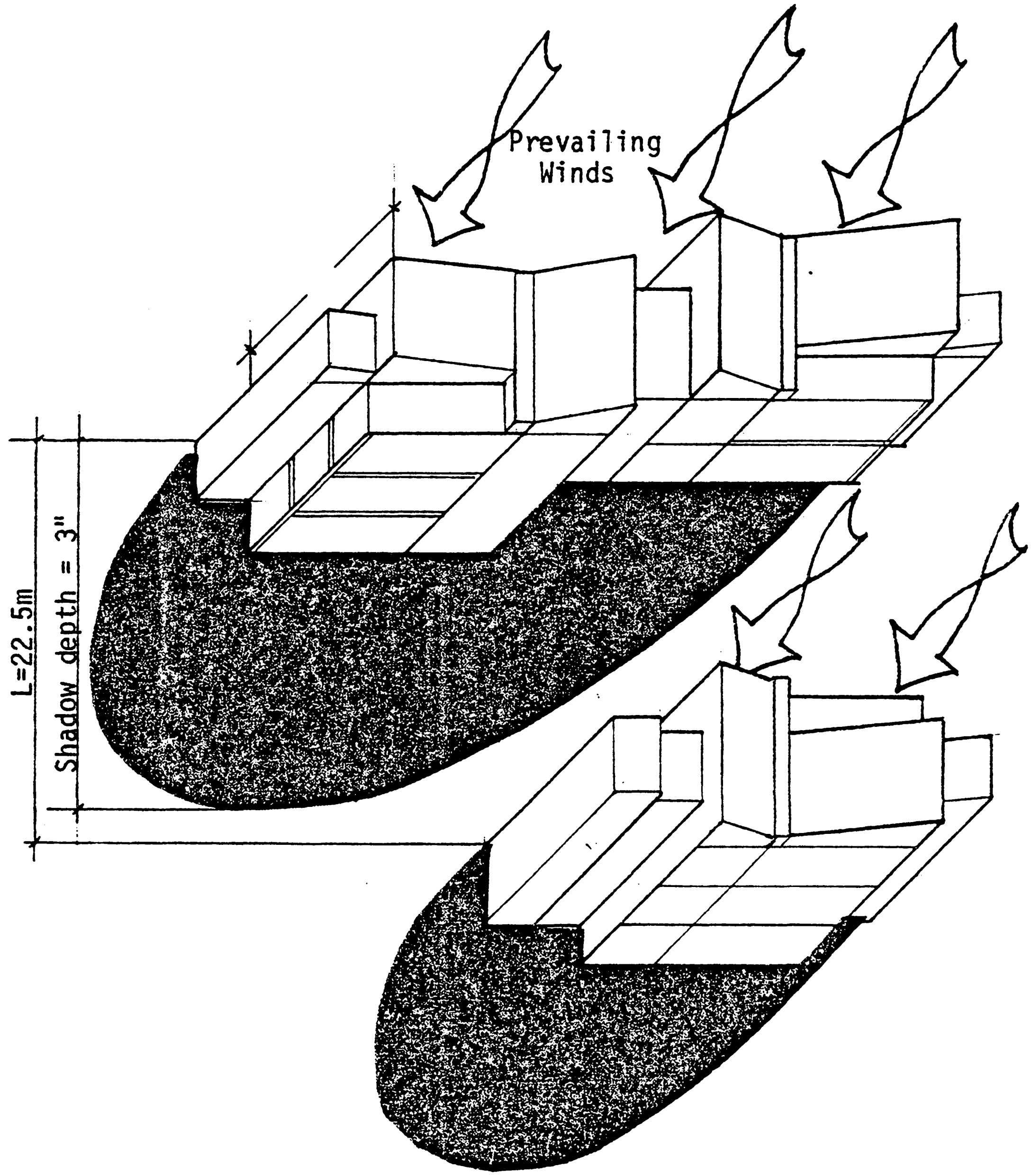


FIGURE 14

Depth of Wind Shadow

A distance which is 3 x the height of the building is maintained between buildings to avoid conflicting with wind shadow areas.

clusters were organized on the site around open areas to create open passages through which air can flow. This concept is illustrated in Figure 15. Adequate distance was also maintained between them to ensure that the buildings do not fall into wind shadow area. The landscaping concept was to provide shade in the external areas without obstructing airflow to the buildings. Shape and size were a critical factor in the selection of trees and shrubs as they affect the movement of air and shading pattern. A list of shapes and sizes of tropical trees suitable for landscaping in the hot humid climate is given in appendix 5. Tangible results from the effort involved in landscaping may not be complete before a period of ten years, as it takes that long for trees to grow to their matured heights. The landscaping concept is illustrated in Figure 16. High branching trees like palm trees and coconut trees were located on the windward side. As their branches are high up there will be less interference of air movement to the buildings. Low branching trees are located on the leeward side, where they do not obstruct air flow and provide shaded ground cover. Column shaped trees were located on the north-west side of the compound, so that they do not interfere with wind flow to the buildings located on the north side of the compound. Shrubs instead of walls were used to define the boundaries of the courtyard. The shrubs in the path of the prevailing wind are spaced apart to allow air to pass, and to minimize the effect of the wind shadow. The effect of tree locations on the shadow patterns for different times of the day at selected months of the year are illustrated in Figures 17 a, b, and c.

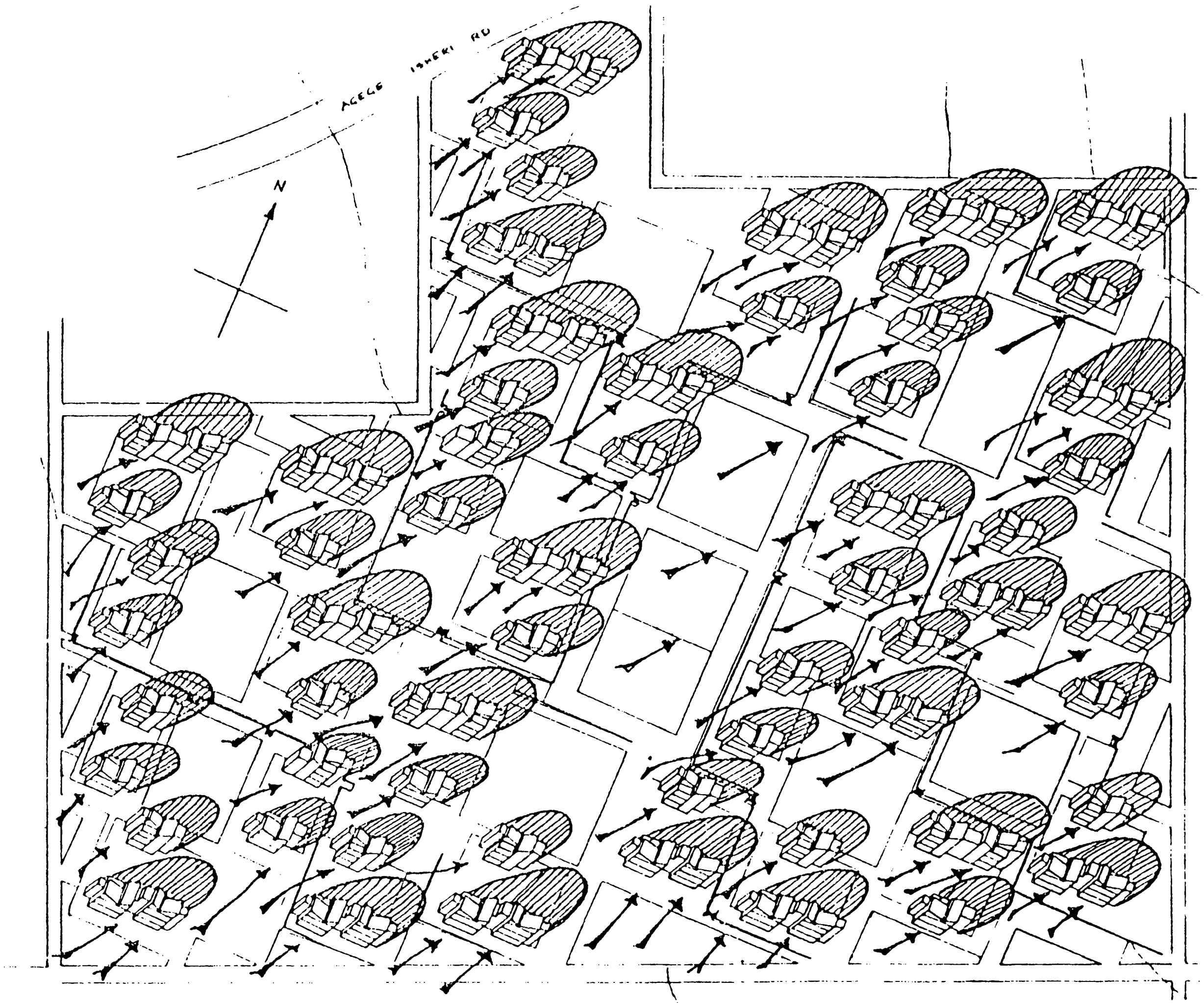


FIGURE 15 Site Layout

The clusters are organized around open areas to create open Free Flow zones through which air can be channeled.

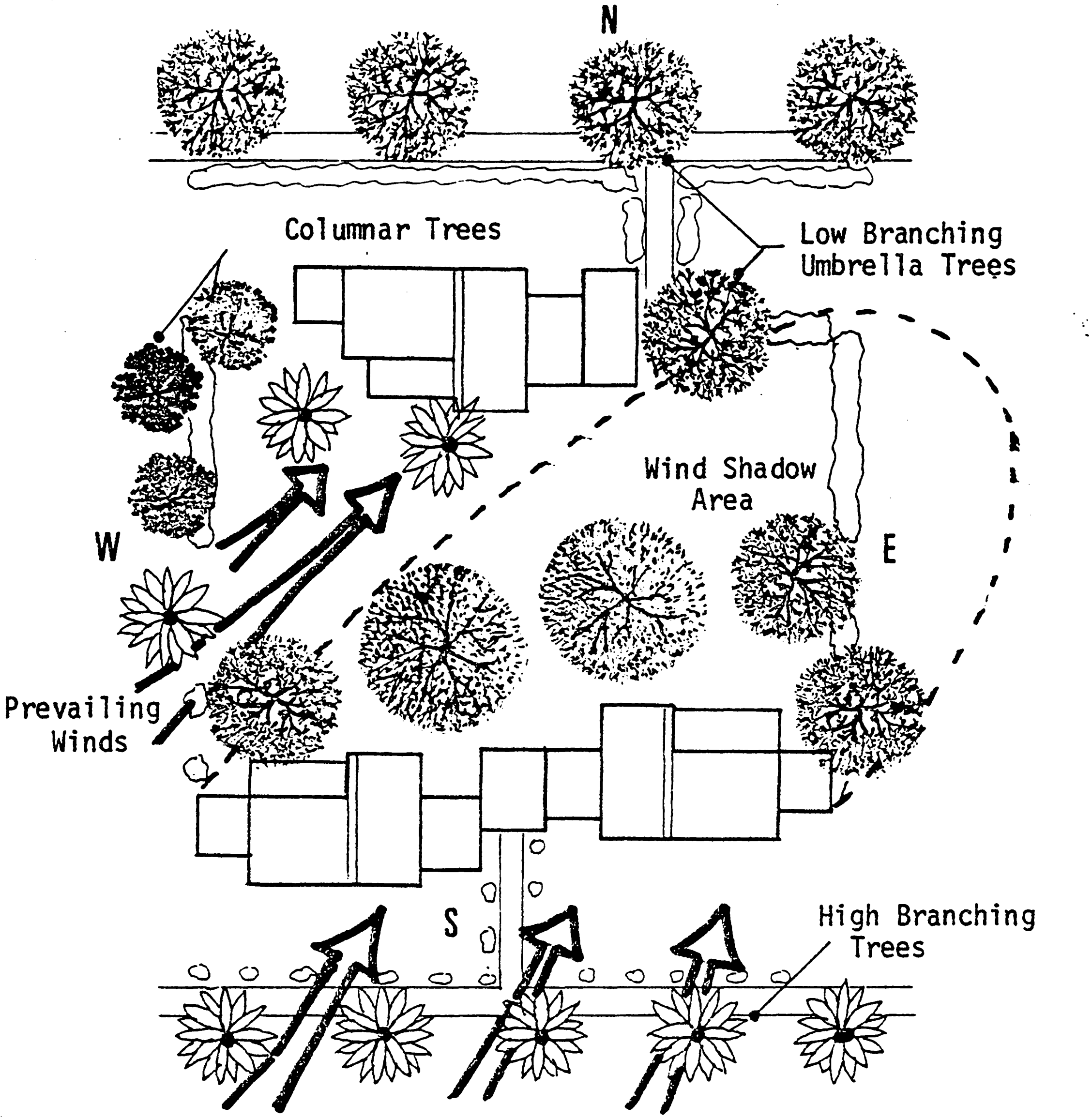


FIGURE 16

Landscaping, Typical Cluster

The trees and shrubs are located to provide shade without obstructing air flow to the buildings.

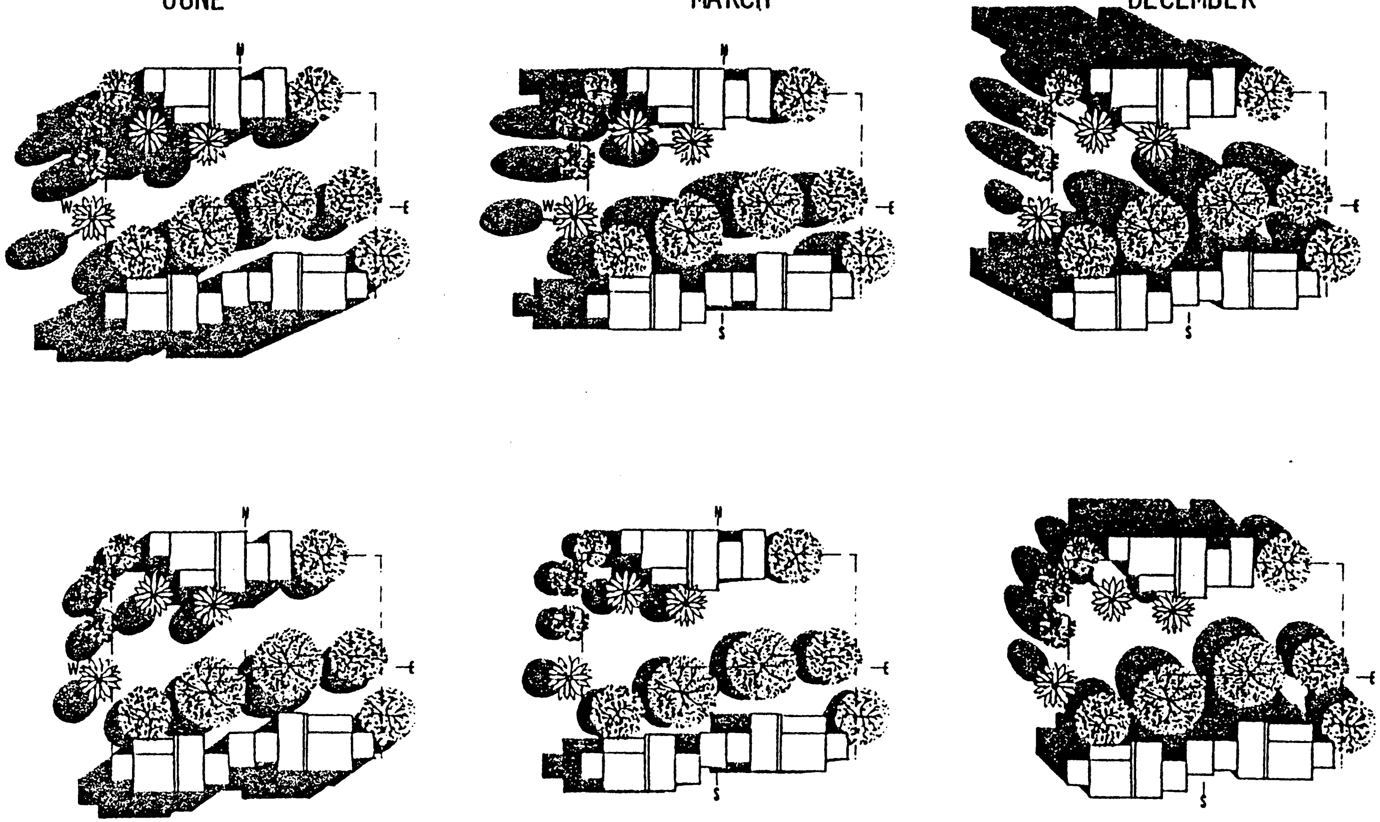


FIGURE 17 a, b, c,

Variation in Shadow Movement Between 8 am and 10 pm, during Selected Months of the Year

Between 10 am and 4 pm shadows cast by trees are employed to cast shade in the surroundings are as of the buildings.

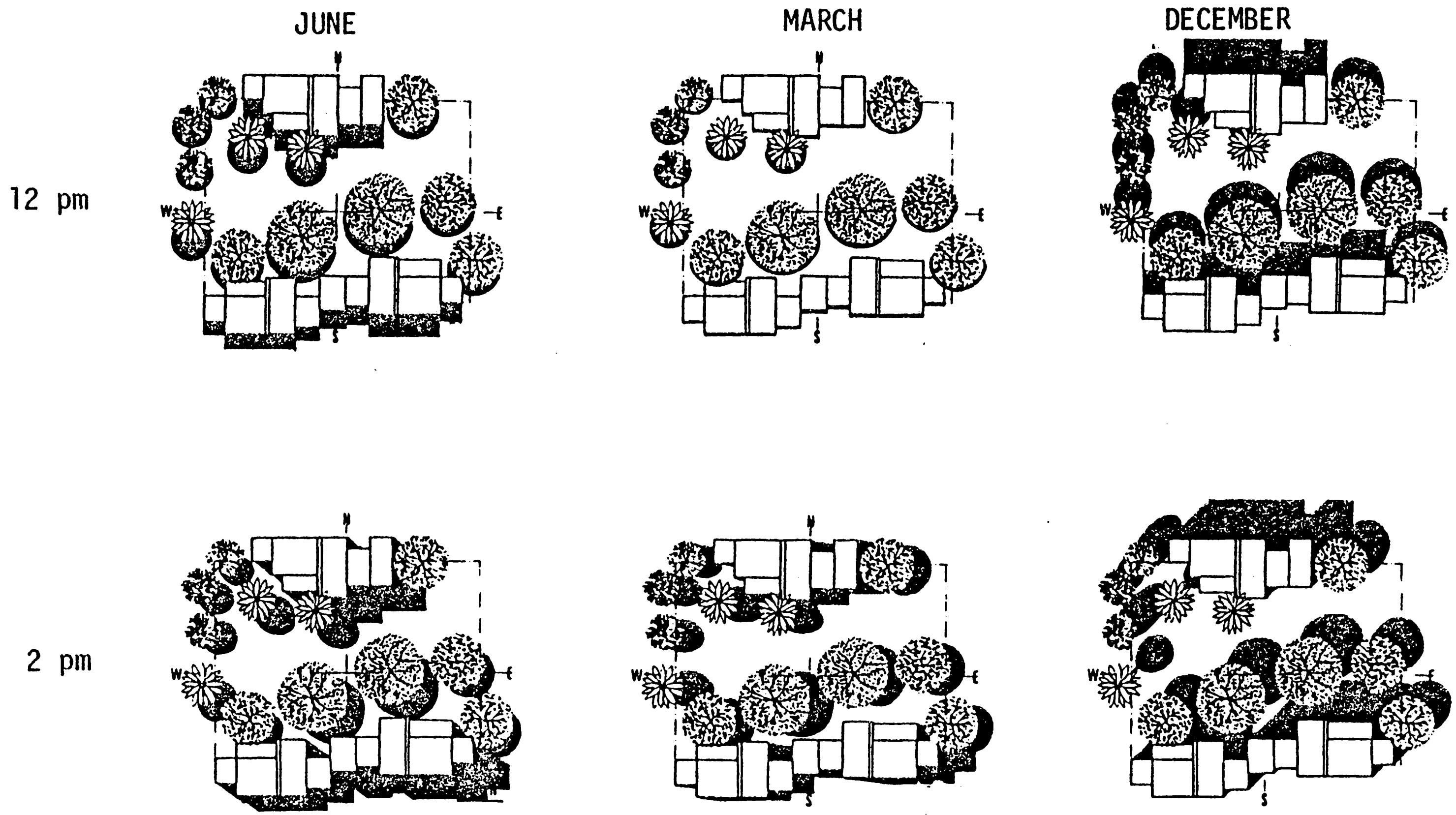


FIGURE 17b

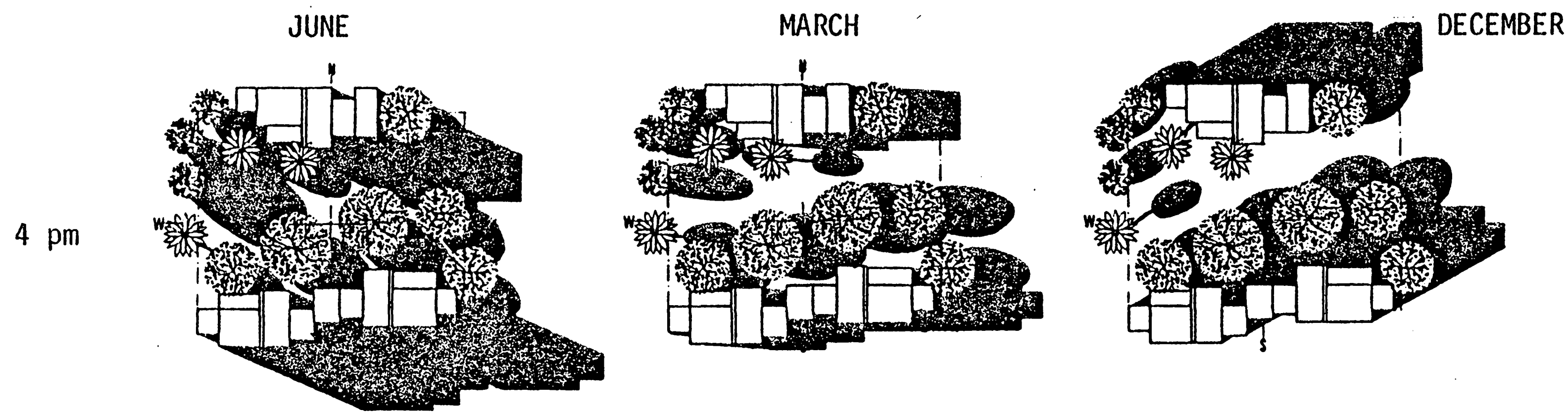


FIGURE 17c

SPECIAL DETAILS FOR OPTIMIZING ENVIRONMENTAL CONDITIONS

The need for comfortable temperature conditions and efficient cross ventilation in the occupied spaces of the building called for sensitivity in the design of windows sun control devices and the roof. Four concerns that influenced the design of the windows were location, size, height of window sill and placement of insect screens. The windows were located directly opposite each other as illustrated in Figure 18. This was to prevent abrupt change in the direction of air flow entering the room and to ensure that the air reached the occupied areas of the rooms. The size of the window needed to move adequate amount of air through the rooms was estimated to be 40 percent of the floor area of the room. This was based on recommendations from the mahoney tables (See appendix 2). The area of the outlet was bigger than that of the inlet as this increases interior wind velocity. The window sill height was located low at 0.85 meter above the ground to allow for adequate air flow at the occupied zone which is estimated to be between 0.85m and 1.8m.[6] This is illustrated in Figure 19. The type of window used must channel air downwards into the occupied zone. Louvered windows which open to an angle of 20° to the horizontal were used because at that angle air is effectively led downward into the living zone.[7] Fly screen causes significant reduction in wind velocity if the prevailing wind is oblique. The wind slips over the screen and does not create enough pressure differential to induce air flow.[8] The screen wall was therefore inclined in such a way that the oblique

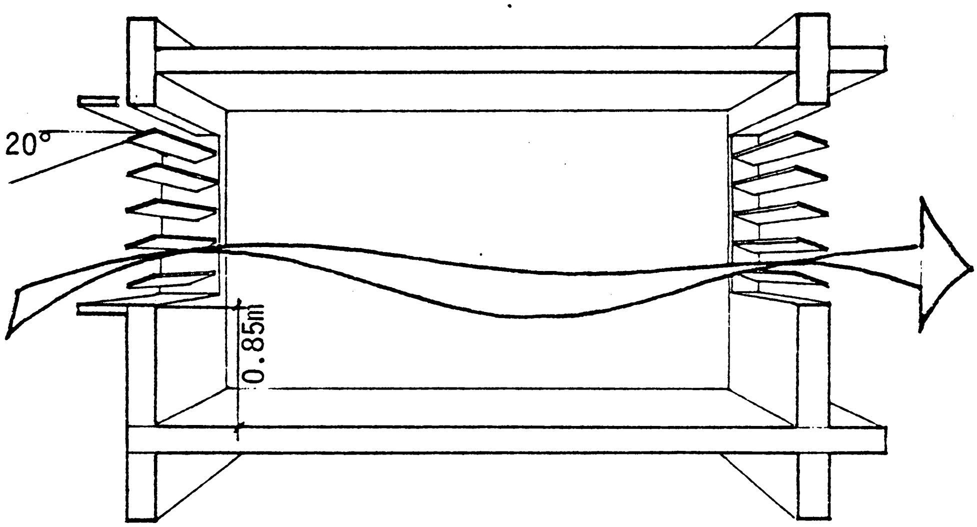


FIGURE 18

Window Location

Windows and screen walls are located directly opposite each other to ensure that air reaches the occupied areas of the room.

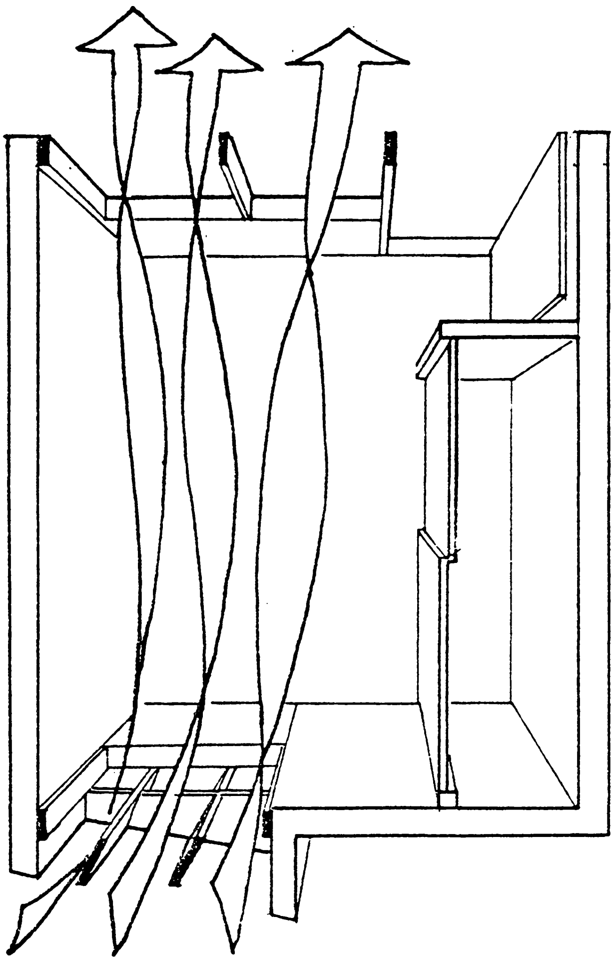


FIGURE 19

Window Type and Placement

Adjustable louvered window with a sill height which has been determined to be 0.85 meters is used in order to maximize effect of air in the living zone.

angle of the prevailing wind was reduced. This is illustrated in Figure 20.

The roof is the element of the building most exposed to sun. As a result excessive heat is trapped in the attic space. To avoid its being transmitted into the room below, it was removed by ventilation. An air space with opening oriented in the direction of the prevailing winds was located between the roof and the ceiling as illustrated in Figure 21. On days when the wind speed was very low, the roof system was designed to induce air flow by stack effect. This is the method by which air flow can be induced by allowing denser cool air to replace lighter warm air. As the air in the room below becomes heated it becomes more bouyant. An opening was provided at the ceiling, so it can escape to the outside via the attic. Openings were located at the end walls above the roof to give the warm air enough room to rise and prevent it from being trapped under the roof.

One principal source of heat gain to the building is through the windows. It is estimated that heat gain can be reduced by 70 to 80 percent if windows are adequately protected from the sun.[9] In this project window projections, balconies and screen walls were used as sun control devices. To avoid over design, the over heated periods of the year when protection from the sun was absolutely necessary were determined. The method used is explained in appendix 6. The solar altitude and azimuth during these periods are shown on the solar chart in Figure 22. The horizontal and vertical elements of the various

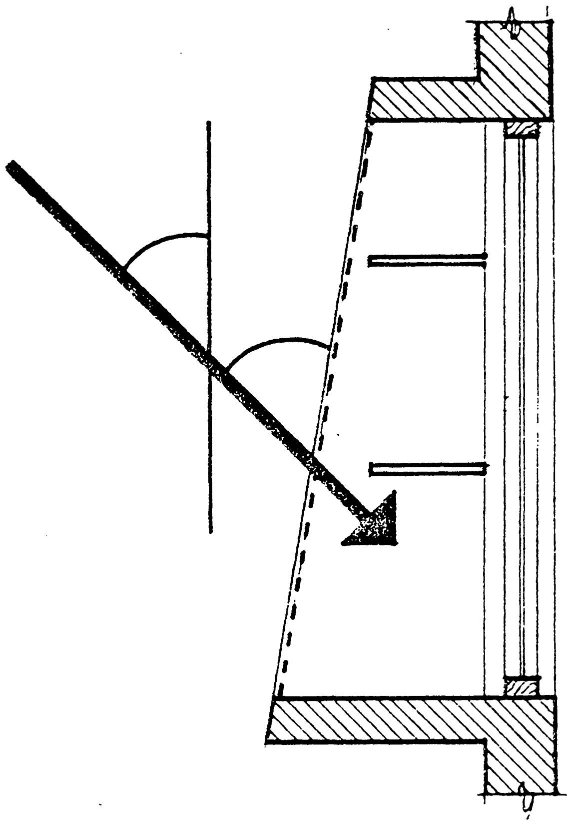


FIGURE 20

Placement of Insect Screen

Insect screens are placed on the outer surface of window projections. These are inclined so that the angle of incidence of prevailing wind is decreased.

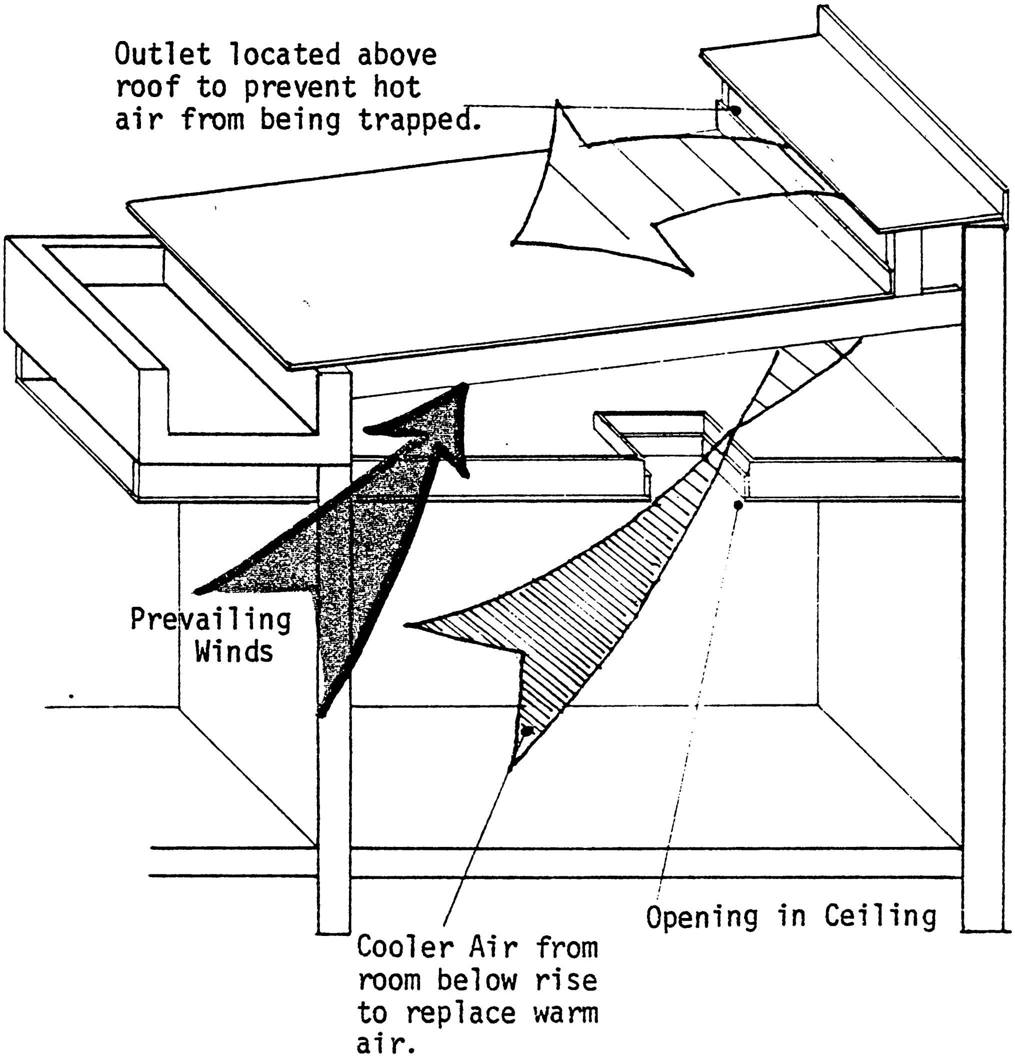


FIGURE 21

Ventilation of Attic Space

As the air in the room gets heated, it becomes boyant and rises through ceiling opening to the opening at the roof top.

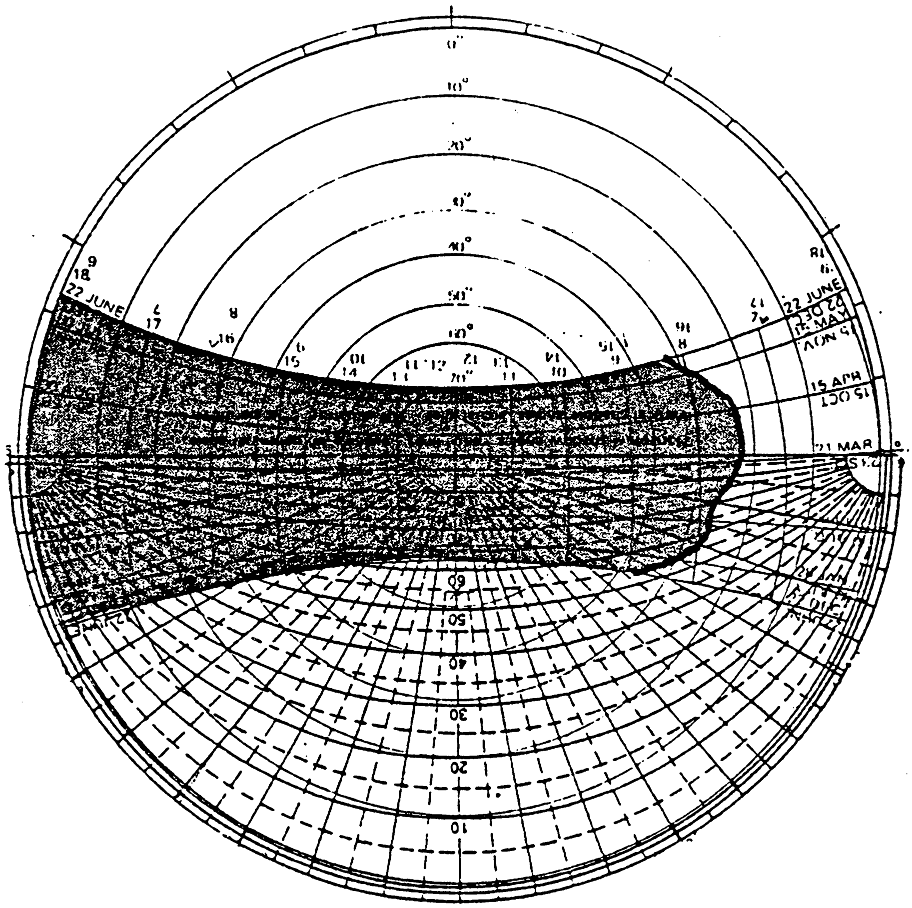


FIGURE 22

Solar Altitude and Aximuth During Over-Heated Periods of the Year

The critical over-heated periods are shown in the shaded portion of the chart.

SOURCE: Manual of Tropical Housing and Building Part One: Climate Design.

shading devices were designed in response to these angles. The angles taken into consideration in the construction of the various shading devices are illustrated in Figures 23 through 25. Their effectiveness in providing shade during over-heated periods are shown in accompanying shading mask diagrams. Clearly taken into account was their orientations. To avoid excessive depth the window shading devices were divided into compartments to form egg crate shading devices. This is illustrated in Figure 23 a, b, and c. The balcony was designed to protect people standing there from direct sunlight. This was achieved by use of overhangs in the front of the balconies and vertical louvers on the east and west sides, to block sun penetration. This is illustrated in Figure 24 a and b. The screen wall which is illustrated in Figure 25 was designed to exclude sunlight and also to reflect it away from the building. The surface of a typical screen cell was included at 45° and surfaced with reflective paint.

BUILDING CONSTRUCTION FOR THERMAL CONTROL

Building response to climatic problems as discussed in the previous section depends on the way building materials and components are put together. This is reflected in the details of the roof, floor and wall construction in this design for the hot humid climate of Lagos. The roof consisted of an outer skin cover of corrugated aluminum sheets placed on purlins supported on joists as illustrated in Figure 26. Joists were used in preference to trusses so as to provide an uninter-

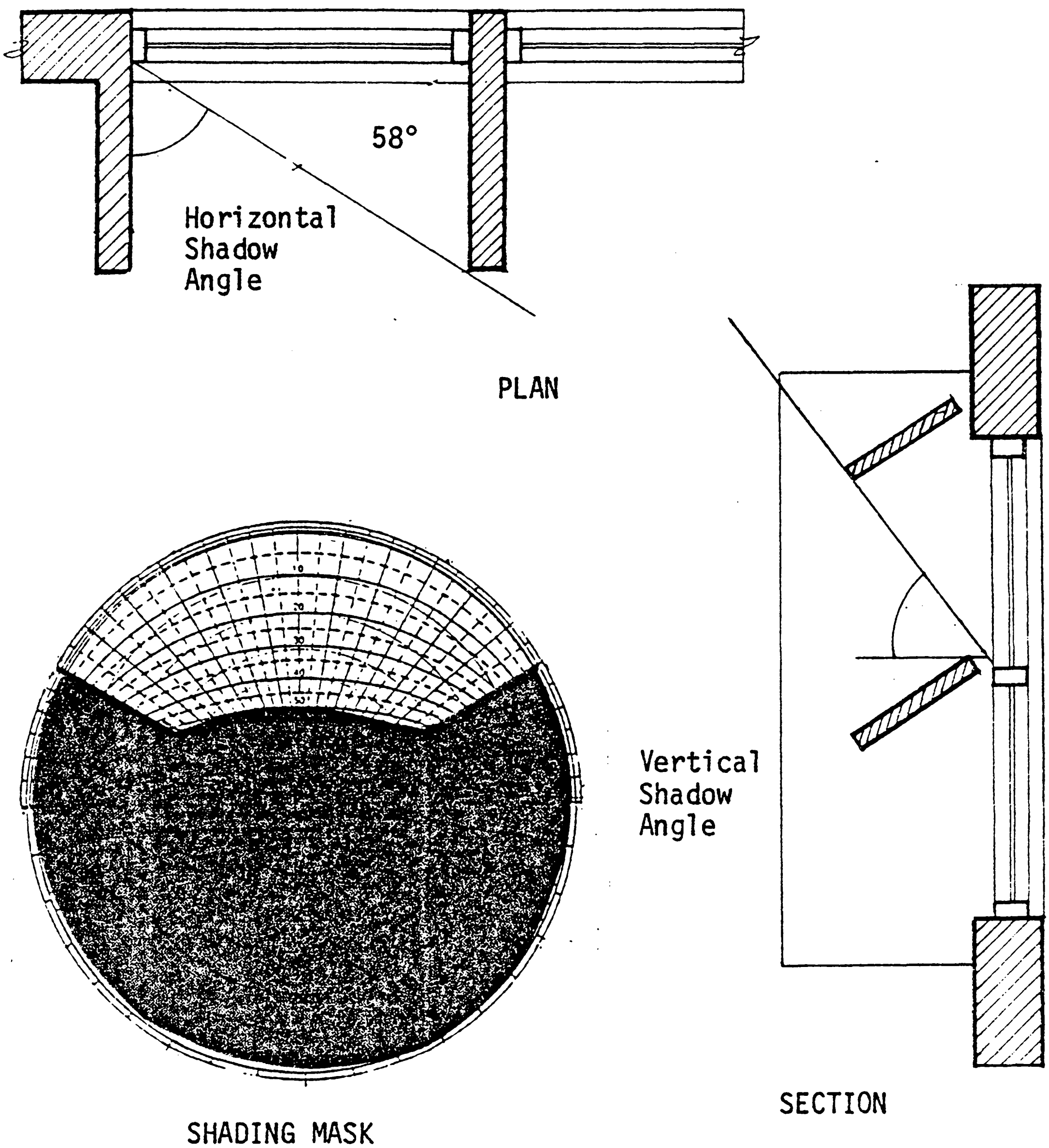


FIGURE 23a

Details of Window Shading Device

Horizontal shadow angle of 58° and shading devices with vertical shadow angle of 57° were used to protect the south facing windows sun during critical periods.

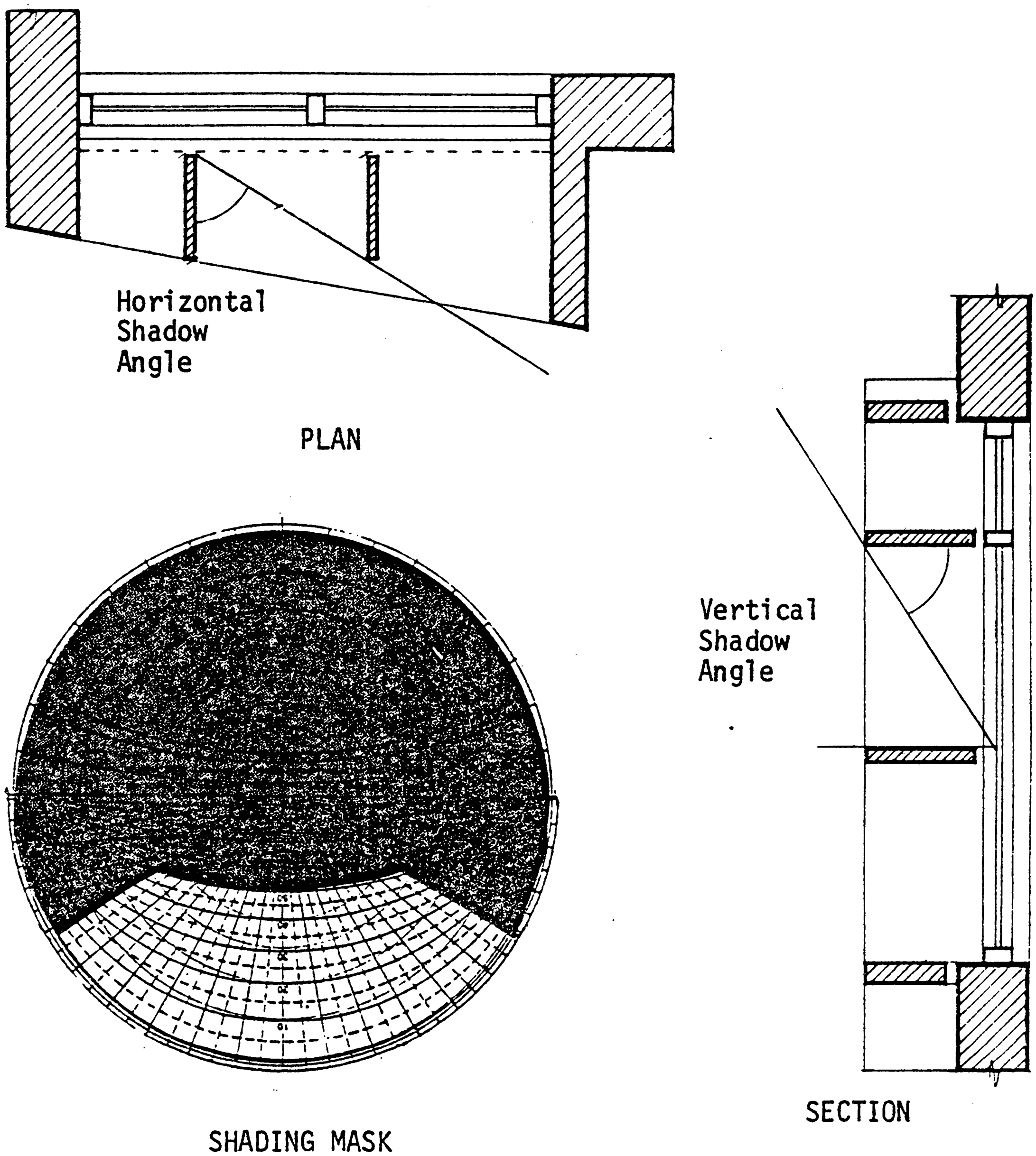


FIGURE 23b

Details of Window Shading Device

Shading devices with horizontal shadow angle of 58° and vertical shadow angle of 57° are used to protect this north facing window.

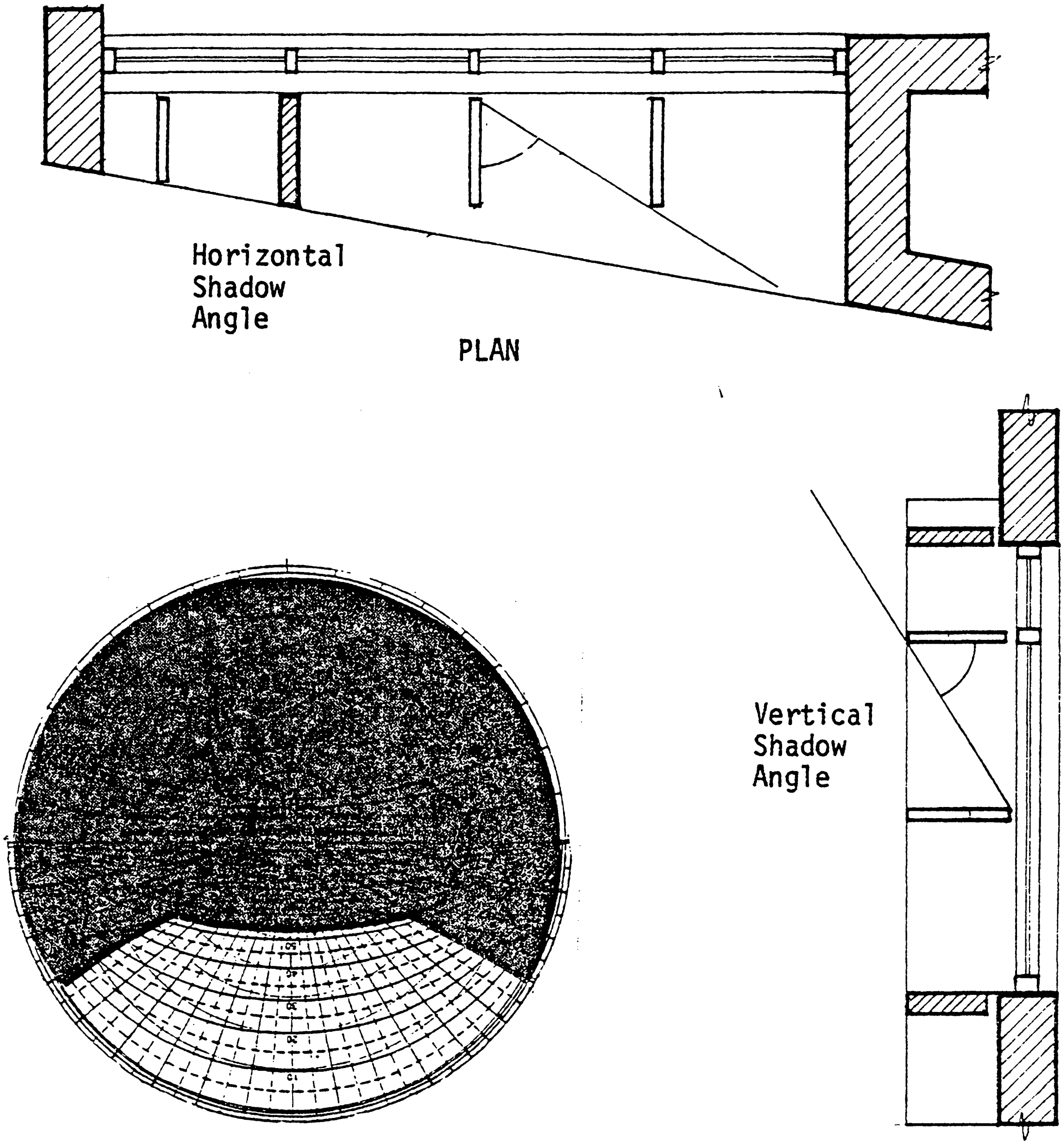


FIGURE 23c

Details of Window Shading Device

Shading device with horizontal shadow angle of 58° and vertical shadow angle of 57° is used to protect this south facing window from the sun during overheated periods.

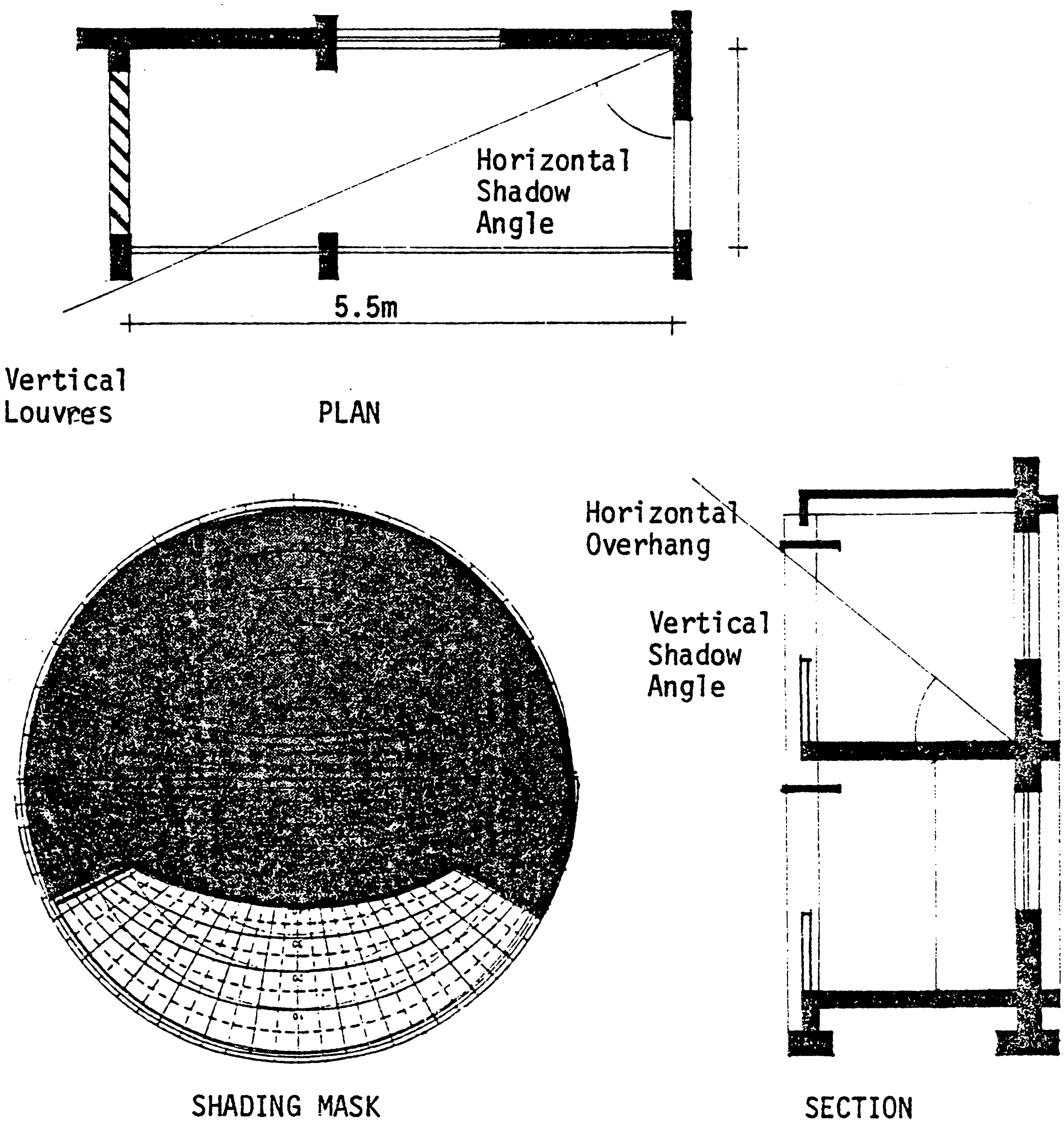


FIGURE 24a

Details of South Facing Balcony

The horizontal and vertical shadow angles of 57° and 60° respectively formed by the vertical louvres and horizontal overhang protect this south facing balcony from sun during overheated periods.

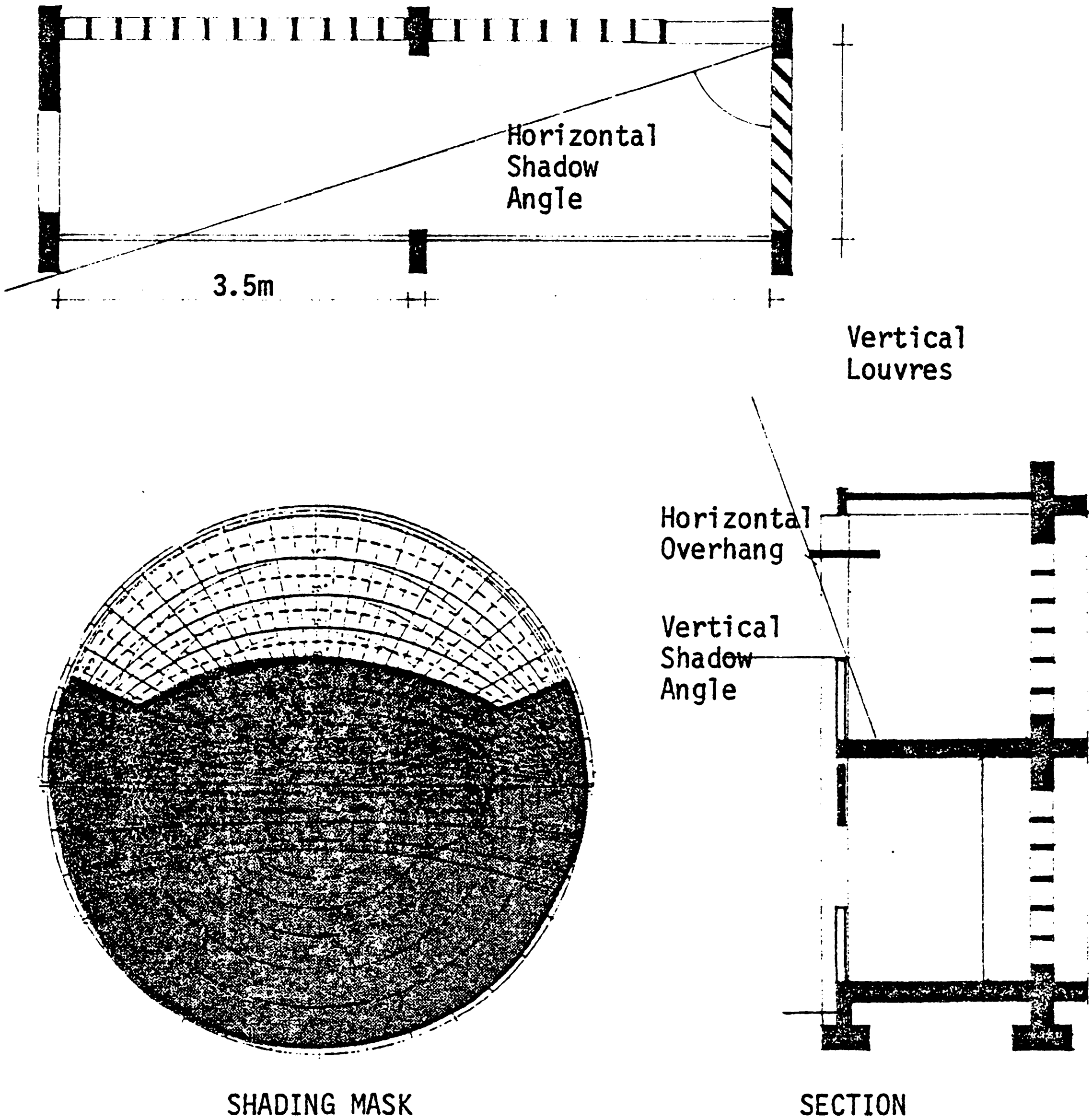


FIGURE 24b

Details of North Facing Balcony

The horizontal and vertical shadow angles of 60° and 72° respectively formed by the vertical louvres and overhang protect this north facing balcony from sun during overheated periods.

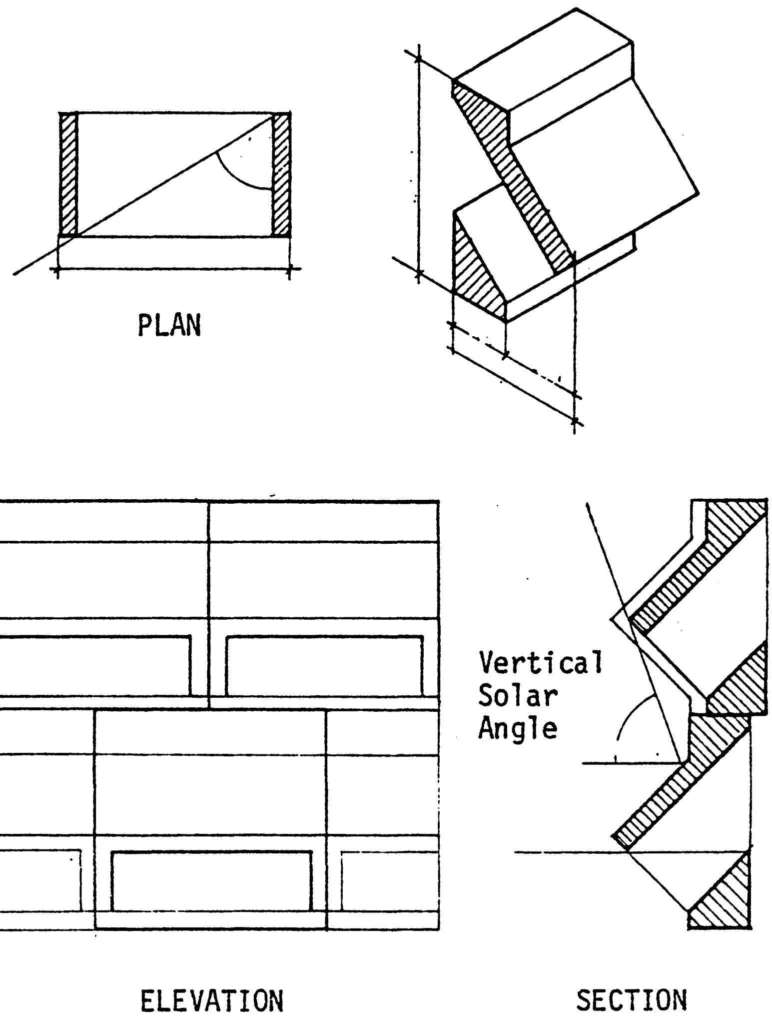


FIGURE 25

Details of Typical Screen Wall Cell

The surface is inclined at 45° to reflect sunlight away from the building.

rupted air space in the attic. The ceiling material is fibre board, and it is covered at the top with aluminum foil. With its high reflectivity, it can reflect much the radiant heat which penetrates through the roof, back into the attic space. This reduces heat flow through the ceiling. Corrugated aluminum sheets were used in preference to asbestos and galvanized iron sheets. Corrugated aluminum sheets provide good thermal protection, and are the most durable in the hot humid climate. Galvanized iron rusts over time and becomes thermally inefficient. Asbestos turns dark gray and becomes thermally inefficient. It is also known to be cancernogenic. The entire roof is anchored to prevent it from being blown away during tropical storms. The details are illustrated in Figure 27. Steel plates were used to connect the joists to (2x4) plates that are anchored to the concrete block walls. The concrete block walls were constructed to absorb a minimum amount of heat. A pocket of air insulation was created between the internal and external surfaces of the wall, as is illustrated in Figure 28. The hollow concrete blocks were surface bonded and coursed to make the cavities open all the way through from top to base. At regular intervals the vertical cavities are filled up with concrete to strengthen the wall. The wall is separated from the foundation wall by one course of bricks which are arranged so that inlets are provided to the wall cavities. The openings are covered with fiberglass screens to prevent insect penetration. The hot humid conditions provide a good breeding ground for termites. Buildings are vulnerable to attack from this

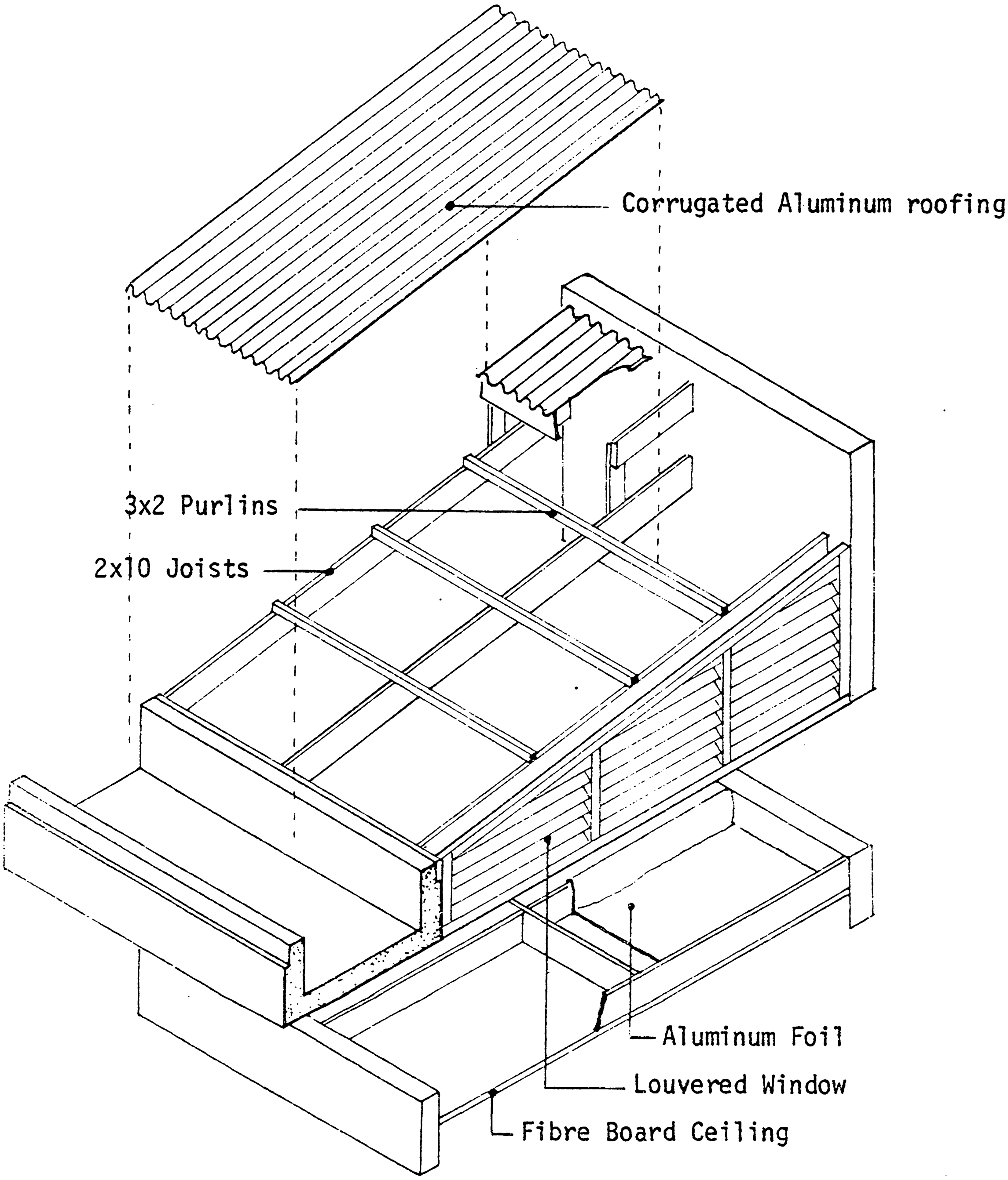


FIGURE 26

Component of the Roof Construction

The roof consists of an outer skin of corrugated aluminum placed on purlins and supported by joists. This creates an uninterrupted air space in the attic.

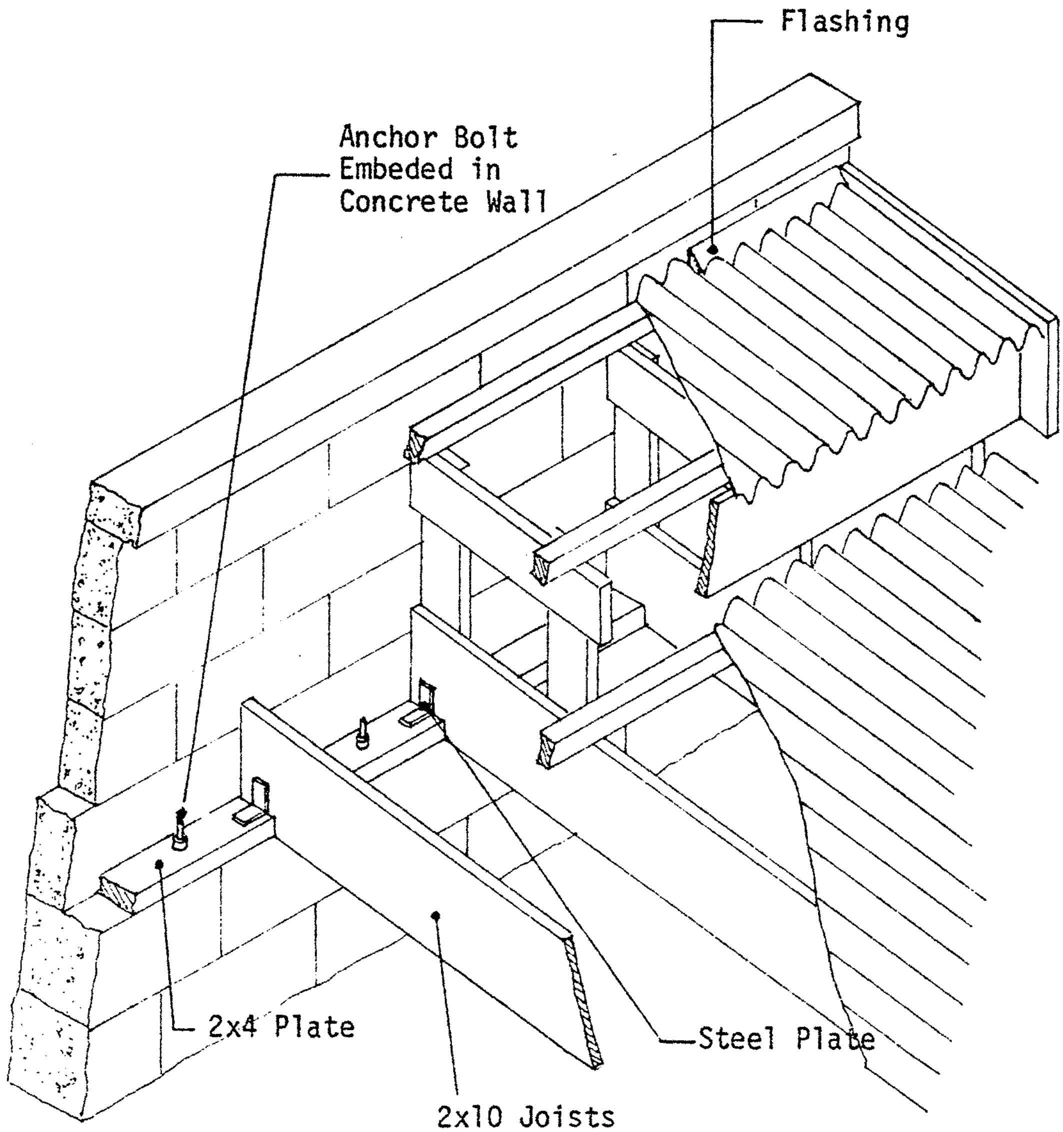


FIGURE 27

Details, Roof Anchorage

The joists of the roof are connected to wooden plates that are anchored on the wall.

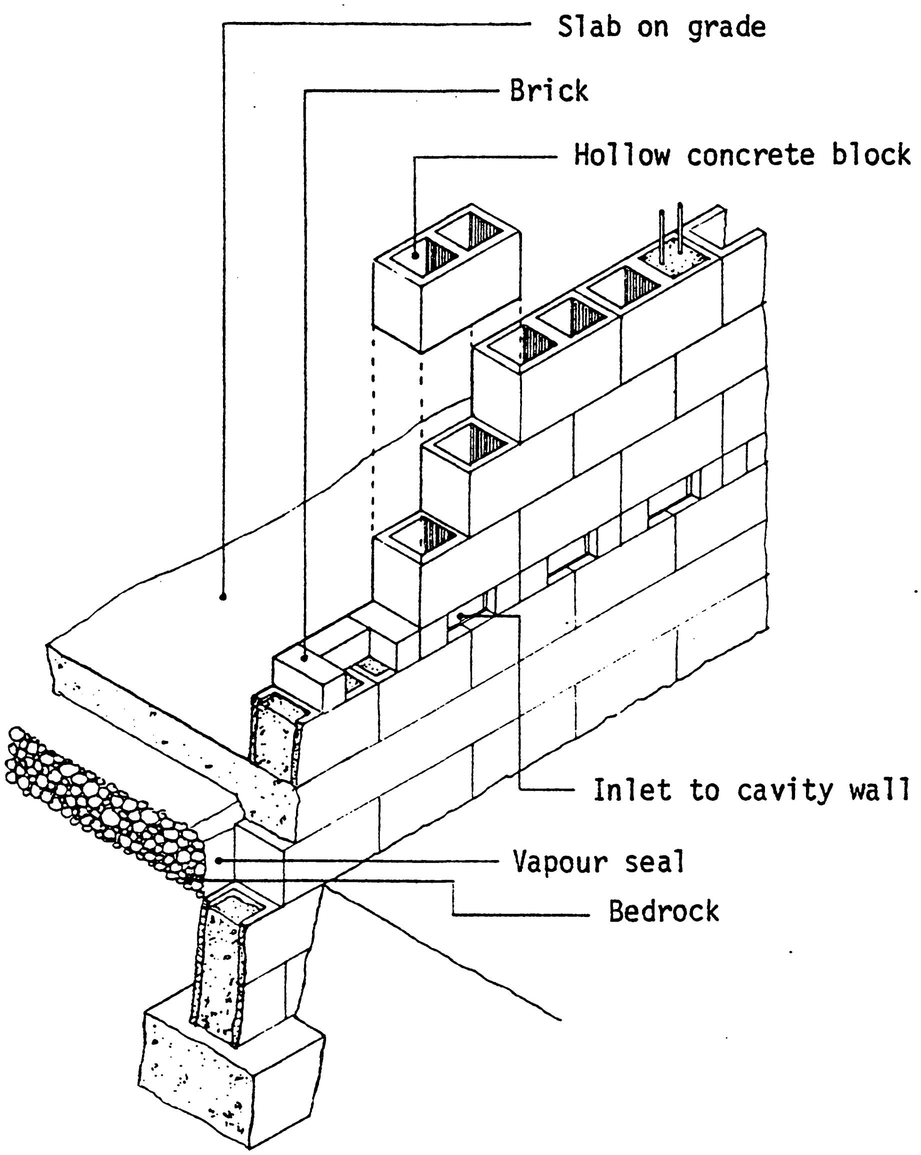


FIGURE 28

Details, Cavity Wall Construction

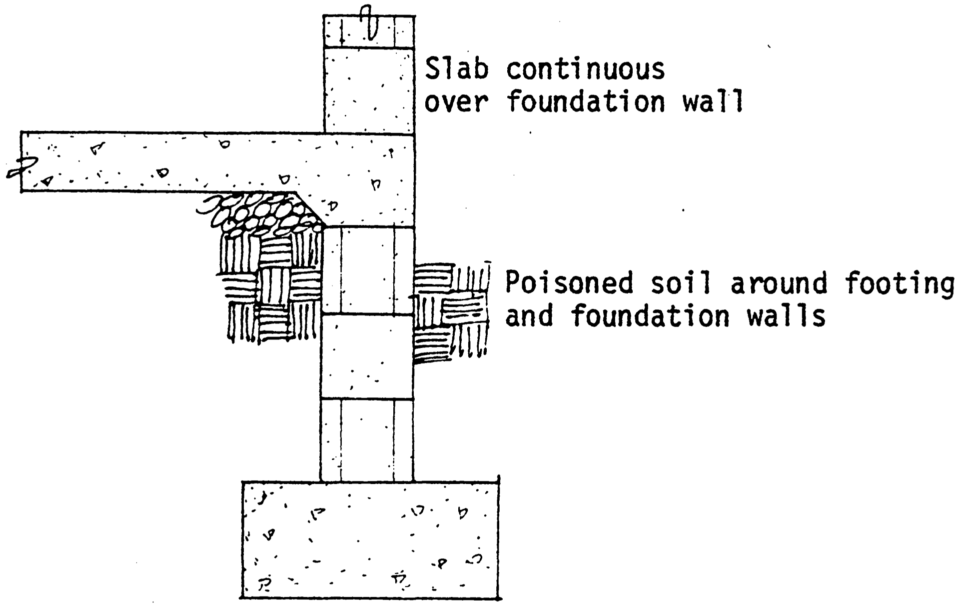
Cavities are created in the wall by surface bonded hollow concrete blocks.

destructive insects and need to be protected. The floor slab of the building were designed to shield the interior of the building from the termites. The design was based on recommendations suggested by the British standards Institution.[10] They recommend the following solutions for protecting buildings from termites:

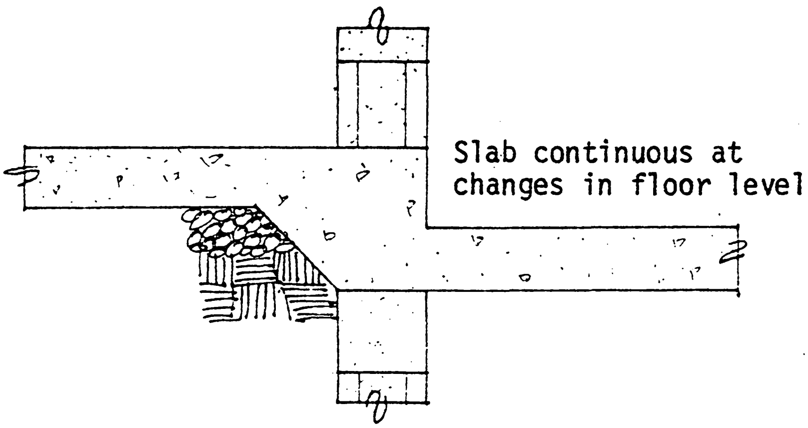
(1) Floor slabs should not be less the 152mm from the ground surface.

(2) Floor slab should run over foundation walls and should be continuous under wall partitions and at floor level changes.

These recommendations are reflected in the details in Figure 29.



FOUNDATION WALL



CHANGES IN FLOOR LEVEL

FIGURE 29

Construction Details, Termite Protection

The interior is protected from termites by making floor slab continuous at floor level changes partitions and over foundation walls.

ENDNOTES

[1]United Nations Department of Social and Economic Affairs, Design of Low Cost Housing and Community Facilities Volume One: Climate and House Design. (New York: UN Publication, 1971), p. 82.

[2]United Nations Department of Social and Economic Affairs, p. 82.

[3]O. H. Koenigsberger; T. G. Ingersoll; A. Mayhew; and S. V. Szokolay, Manual of Tropical Housing and Building Park One: Climate Design; (New York: Longmans Inc., 1973); p. 40.

[4]G. Crivoni, Man Climate and Architecture; (London: Elsevier Publishing Co., 1969); p. 260.

[5]Benjamin H. Evans, Nature of Air Flow Ground Buildings, (College Station: Texas A&M University, 1957); p. 12.

[6]C. P. Kukreja, Tropical Architecture, (New York: McGraw-Hill, 1978); p. 97.

[7]Koenigsberger, et. al., p. 129.

[8]B. Crivoni, p. 275.

[9]Kukreja, p. 74.

[10]Maxwell Fry, Jane Drew, Tropical Architecture in the Humid Zone, (New York: Reinhold Publishing Corporation, 1956); p. 301.

BIBLIOGRAPHY

Arthur Bowen, "Some Historical Indications For Building Design Under Natural Condition in Overheated Regions," in Passive Cooling Handbook. Washington, D. C., Government Publishing Office, 1980.

Evans, Benjamin H., Nature of Air Flow Around Buildings: College Station: Texas A&M Press, 1957.

Fry, Maxwell, and Drew, Jane. Tropical Architecture in the Humid Zone. New York: Reinhold, 1956.

Givoni, B. Man Climate and Architecture: London: Elsevier Co., 1969.

Koenisberger, Otto; Ingersoll, T. G.; Mayhew, A.; and Szokolay, S. V.; Manual of Tropical Housing and Building Part One: Climate Design. London, Longmans, 1973.

Kukreja, C. P., Tropical Architecture. New York: McGraw-Hill, 1978.

U. N. Department of Economic and Social Affairs, Design of Low Cost Housing and Community Facilities Volume One: Climate and Housing Design; New York, 1969.

APPENDIX 1

THE PROGRAM FOR IJAIYE HOUSING PROJECT

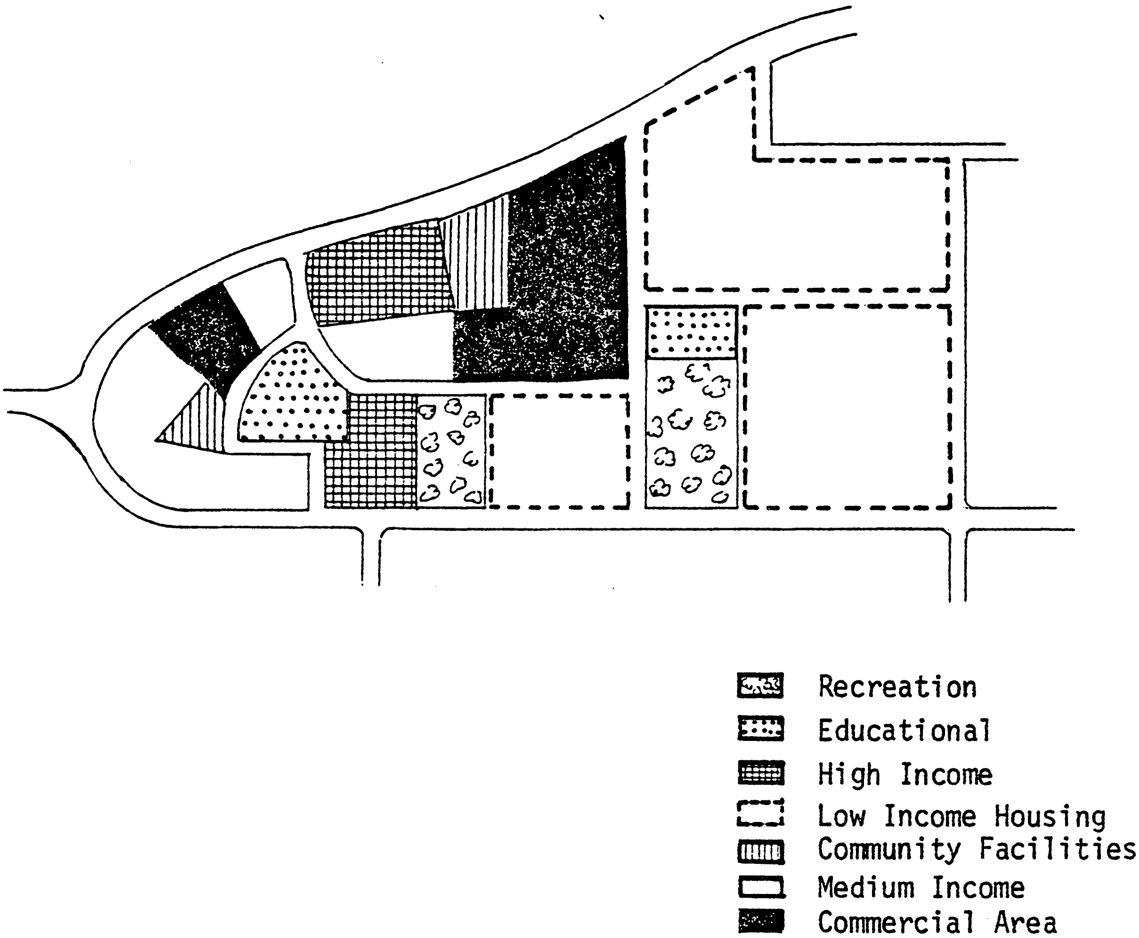
This is the program for the housing project that was used as the case study for this thesis. It is the Ijaiye housing project, and it is located in Ogba village at the outskirts of Lagos. It consists of 300 units of housing for low, medium and high income people. The number of apartments proposed under each category was as follows:

150 for Low Income Housing

100 for Medium Income Housing

50 for High Income Housing

20 hectares of land out of 38 hectares available was allocated for the housing project. The other 18 hectares were allocated to the following community related facilities: school, open market, open recreation areas, community center, and health center. The land allocation is shown in Map 3.



MAP 3 Land Allocation, Ijaiye Housing Project

APPENDIX 2

USE OF MAHONEY TABLES

The mahoney tables are used to determine specifications for layout, orientation, shape, and structure of a building based on evaluation of the climatic data. It consist of three tables.

In table one the climatic data for Lagos; that is, temperature humidity, rainfall, and wind data were analyzed.

In table two the data was diagnosed to determine physiological effects. It shows that thermal stress is high during the day and night throughout much of the year except in July and August. The indicators point out that air movement is very essential. Protection from rain is also recommended.

Table three gives some recommendation on how the building design should respond. The following recommendations were made:

(1) Buildings should be oriented on the east-west axis.

(2) Open spacing for breeze penetration should be provided.

(3) Permanent provisions for air movements in all rooms should be provided.

(4) Openings be (40-80%) of floor area should be provided.

(5) Walls should be light weight with short time lag.

(6) Roof should be light weight and insulated.

(7) Protection from rain is essential.

TABLE 1

Mahoney Tables

Location	LAGOS NIGERIA
Longitude	3° 24'E
Latitude	6° N
Altitude	3 m

Air temperature: °C

	J	F	M	A	M	J	J	A	S	O	N	D	High	AMT
Monthly mean max.	31	33	33	32	31	29	27	27	28	29	31	32	33	27
Monthly mean min.	22	23	23	23	22	22	22	21	22	22	23	22	21	12
Monthly mean range													Low	AMR

Relative humidity: %

	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max. a.m.	92	91	89	90	92	94	91	91	92	95	95	95
Monthly mean min. p.m.	72	70	71	71	75	81	81	78	78	78	74	70
Average												
Humidity group	4	4	4	4	4	4	4	4	4	4	4	4

Humidity group:	1	If average RH:	below 30%
	2		30–50%
	3		50–70%
	4		above 70%

Rain and wind

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Rainfall, mm	155	180	284	325	549	763	786	580	425	450	183	150	2934

	J	F	M	A	M	J	J	A	S	O	N	D
Wind, prevailing	SW	SW	S	S	S	SW	SSW	SSW	SW	SW	Sw	SW
Wind, secondary	W	W	SW	SW	W	SW	SW	SW	SW	SW	NE	NE

Comfort limits		AMT over 20°C		AMT 15–20°C		AMT below 15°C	
		Day	Night	Day	Night	Day	Night
Humidity group:	1	26–34	17–25	23–32	14–23	21–30	12–21
	2	25–31	17–24	22–30	14–22	20–27	12–20
	3	23–29	17–23	21–28	14–21	19–26	12–19
	4	22–27	17–21	20–25	14–20	18–24	12–18

TABLE 2
Diagnosis: °C

	J	F	M	A	M	J	J	A	S	O	N	D	
Monthly mean max.	31	33	33	32	31	29	27	27	28	29	31	32	27 AMT
Day comfort: upper	27	27	27	27	27	27	27	27	27	27	27	27	
lower	22	22	22	22	22	22	22	22	22	22	21	22	
Monthly mean min.	22	23	23	23	22	22	22	21	22	22	23	21	
Night comfort: upper	17	17	17	17	17	17	17	17	17	17	17	17	
lower	21	21	21	21	21	21	21	21	21	21	21	21	
Thermal stress: day	H	H	H	H	H	H	O	O	H	H	H	H	
night	H	H	H	H	H	H	H	H	H	H	H	H	

Indicators

		J	F	M	A	M	J	J	A	S	O	N	D	Totals
Humid:	H1	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	10
	H2							✓	✓					2
	H3			✓	✓	✓	✓	✓	✓	✓	✓			8
Arid:	A1													
	A2													
	A3													

Meaning	Indicator	Applicable when: Thermal stress Day	Thermal stress Night	Rainfall	Humidity group	Monthly mean range
Air movement essential	H1	H			4	
		H			2, 3	Less than 10°
Air movement desirable	H2	O			4	
Rain protection necessary	H3			Over 200 mm		
Thermal capacity necessary	A1				1 2 3	More than 10°
Out door sleeping desirable	A2		H		1, 2	
		H	·		1 2	More than 10°
Protection from cold	A3	C				

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
10	2	8	0	0	0

								Layout
			0–10					
			11, 12		5–12	✓	1	Orientation north and south (long axis east–west)
					0–4		2	Compact courtyard planning
								Spacing
11, 12							3	Open spacing for breeze penetration
2–10						✓	4	As 3, but protection from hot and cold wind
0, 1							5	Compact lay-out of estates
								Air movement
3–12						✓	6	Rooms single banked, permanent provision for air movement
1, 2			0–5					
			6–12				7	Double banked rooms, temporary provision for air movement
0	2–12							
	0, 1						8	No air movement requirement
								Openings
			0, 1		0	✓	9	Large openings, 40–80%
			11, 12		0, 1		10	Very small openings, 10–20%
Any other conditions							11	Medium openings, 20–40%
								Walls
			0–2			✓	12	Light walls, short time-lag
			3–12				13	Heavy external and internal walls
								Roofs
			0–5			✓	14	Light, insulated roofs
			6–12				15	Heavy roofs, over 8 h time-lag
								Out-door sleeping
				2–12			16	Space for out-door sleeping required
								Rain protection
		3–12				✓	17	Protection from heavy rain necessary

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
10	2	8	0	0	0

Size of opening

H1	H2	H3	A1	A2	A3		No.	Recommendation	
			0, 1		0	✓	1	Large:	40–80%
			0, 1		1–12		2	Medium:	25–40%
			2–5				2	Medium:	25–40%
			6–10				3	Small:	15–25%
			11, 12		0–3		4	Very small:	10–20%
			11, 12		4–12		5	Medium:	25–40%

Position of openings

H1	H2	H3	A1	A2	A3		No.	Recommendation
3–12						✓	6	In north and south walls at body height on windward side
1–2			0–5				6	In north and south walls at body height on windward side
1–2			6–12				7	As above, openings also in internal walls
0	2–12						7	As above, openings also in internal walls

Protection of openings

H1	H2	H3	A1	A2	A3		No.	Recommendation
					0–2		8	Exclude direct sunlight
		2–12				✓	9	Provide protection from rain

Walls and floors

H1	H2	H3	A1	A2	A3		No.	Recommendation
			0–2			✓	10	Light, low thermal capacity
			3–12				11	Heavy, over 8 h time-lag

Roofs

H1	H2	H3	A1	A2	A3		No.	Recommendation
10–12			0–2			✓	12	Light, reflective surface, cavity
10–12			3–12				13	Light, well insulated
0–9			0–5				13	Light, well insulated
0–9			6–12				14	Heavy, over 8 h time-lag

External features

H1	H2	H3	A1	A2	A3		No.	Recommendation
				1–12			15	Space for out-door sleeping
		1–12				✓	16	Adequate rainwater drainage

SOURCE: Manual of Tropical Housing and Building Part One: Climate Design.

APPENDIX 3

WALLS AND ROOF CONSTRUCTION TYPES SUITABLE FOR HOT HUMID CLIMATE

This is a list of walls and roofs that meet the thermal requirements of this climate. It is to be used as a device for judging the likely performance of different types of construction before making the crucial decision of choice. The following thermal characteristics are listed for each type of wall and roof construction:

(1) The U Value

(2) The excess ceiling temperature for old and new roof construction

The list is shown in Table 2.

TABLE 2

Thermal Performance of Selected Walls and Floor Construction

Walls		
Brick: solid, unplastered	114 mm	3·64
plastered both sides	114 mm	3·24
solid, unplastered	228 mm	2·67
plastered both sides	228 mm	2·44
Concrete, ordinary, dense:	152 mm	3·58
	203 mm	3·18
Stone, medium, porous.	305 mm	2·84
	457 mm	2·27
Brick, 280 mm cavity, fletton outer skin, commons inner, inside plastered		1·70
Brick with insulating boards, plastered.		
25 mm corkboard		0 85
13 mm fibreboard		1·19
50 mm wood wool slab		0·85
Brick but 16 mm vermiculite plaster on inside		1·47
Brick but rigid boards on battens on inside:		
13 mm asbestos board		1·19
13 mm fibreboard		0·95
50 mm strawboard, plastered		0·74
Brick but inner skin lightweight concrete blocks:		
100 mm aerated concrete blocks		1·13
100 mm clinker concrete blocks		1·30
Concrete block, cavity, 250 mm (100 + 50 + 100), outside rendered, inside plastered:		
aerated concrete blocks		1·19
clinker concrete blocks		1·08
Hollow concrete block, 228 mm, single skin, outside rendered, inside plastered:		
aerated concrete blocks		1·70
clinker concrete blocks		1·59
Corrugated asbestos cement sheets on steel frame		6·53
+13 mm fibreboard		2·04
+50 mm straw or wood wool slab		1·19
+76 mm aerated concrete blocks		2·10
Roofs, pitched		
Corrugated asbestos cement sheets		7·95
+13 mm timber boarding		2·16
+50 mm straw or wood wool slab		1·25
+25 mm quilt on 13 mm boarding		0·85
Corrugated iron sheets or tiles on battens		8·52
+plaster ceiling		3·18
Tiles or slates on boarding and felt with plaster ceiling		1·70
Aluminium deck, 13 mm fibreboard with two layers bituminous felt		2·16
Aluminium deck, 50 mm straw or wood wool slab		1·25
Roofs, flat		
Reinforced concrete slab, 100 mm, screed 63–12 mm, 3 layers bituminous felt		3·35
As above – with insulation on the screed:		
25 mm cork		1·08
50 mm straw or wood wool slab		1·13
two 12 mm fibreboards		1·25
As above – but lightweight s [illegible]d (in lieu of normal)		

127 mm to 76 mm aerated concrete	1·36
127 mm to 76 mm foamed slag concrete	1·47
Timber boarding, 25 mm on 178 mm joists with 3 layers bituminous felt, plaster ceiling	1·82
As above – with insulating slabs on boarding:	
25 mm cork	0·85
13 mm fibreboard	1·25
50 mm straw or wood wool slab	0·91
Floors	
Concrete on ground or hardcore fill	1·13
+grano, terrazzo or tile finish	1·13
+wood block finish	0·85
Timber board on joists, underfloor space ventilated on one side	1·70
+parquet, lino or rubber finish	1·42
Timber board on joists, underfloor space ventilated on more sides	2·27
+parquet, lino or rubber finish	1·98
+25 mm fibreboard under boarding	1·08
+25 mm corkboard under boarding	0·95
+25 mm corkboard under joists	0·79
+50 mm strawboard under joists	0·85
+double sided aluminium foil, draped	1·42

SOURCE: Manual of Tropical Housing and Building Part One: Climate Design

TABLE 3

Thermal Performance for Selected Roof Construction

Roof material	Ceiling material	Construction	*U*-value W/m²degC	*q* W/m²	$T_{..}$ degC	*q* W/m²	$T_{..}$ degC
Corrugated asbestos cement	13 mm fibreboard	a/c* sheets on timber purlins, fibreboard nailed under rafters	1·7	29·3	4·3	62·4	9·4
Corrugated asbestos cement sandwiched with 25 mm fibreglass		sandwich sheets fixed on purlins and rafters	0·8	22·4	3·4	47·9	7·4
100 mm r/c slab 75 mm cement screed	13 mm fibreboard	*in situ* slab, fibreboard on battens	1·3	22·7	3·4	48·2	7·4
Corrugated asbestos cement	13 mm fibreboard	a/c sheets on purlins, fibreboard under horizontal ties	1·7	23·9	3·9	52·3	8·4
Corrugated iron sheets	13 mm fibreboard	iron sheets on purlins, fibreboard under horizontal ties	1·3	13·9	2·3	41·6	7·3
Corrugated iron sheets	13 mm timber board	iron sheets on purlins, timber board under horizontal ties	1·6	17·3	2·9	52·3	8·8
Corrugated iron sheets	5 mm a/c sheets	iron sheets on purlins, a/c sheets under horizontal ties	1·9	20·3	3·1	62·7	9·6
Corrugated asbestos cement	13 mm fibreboard + alum.1 foil	a/c sheets on purlins, foil over fibreboard fixed under rafters	1·2	21·4	3·3	46·0	7·0
Corrugated asbestos cement	13 mm timber board + alum. foil	a/c sheets on purlins, foil over timber boards fixed under rafters	1·6	29·3	4·4	62·7	9·5
Corrugated asbestos cement	5 mm a/c sheets + alum foil	a/c sheets on purlins, foil over a/c ceiling fixed under rafters	1·7	29·3	4·4	62·7	9·5
Corrugated iron sheets	13 mm fibreboard + alum. foil	iron sheets on purlins, foil over fibreboard fixed under rafters	1·0	16·0	2·5	47·9	7·4
Corrugated iron sheets	13 mm timber board + alum. foil	iron sheets on purlins, foil over timber boards fixed under rafters	1·3	20·2	3·0	60·5	9·2
Corrugated iron sheets	5 mm a/c sheets + alum foil	iron sheets on purlins, foil over a/c ceiling fixed under rafters	1·4	23·0	3·4	69·0	10·3
Red clay tiles	13 mm fibreboard 25 mm fibreglass + alum. foil	tiles on battens on rafters, foil on fibreglass on fibreboard under rafters	0·62	23·0	3·3	23·0	3·3
Red clay tiles	13 mm timber board, 25 mm fibreglass + alum. foil	tiles on battens on rafters, foil on fibreglass on boards under rafters	0·74	27·1	4·0	27·1	4·0
Red clay tiles	5 mm a/c sheets, 25 mm fibreglass + alum. foil	tiles on battens on rafters, foil on fibreglass on a/c under rafters	0·80	29·3	4·4	29·3	4·4
Corrugated asbestos cement	13 mm fibreboard, 25 mm fibreglass + alum foil	a/c sheets on purlins, foil on fibreglass on fibreboard under under rafters	0·68	11·6	1·7	25·2	3·6

Roof material	Ceiling material	Construction	U-value W/m²degC	q W/m²	$T_{..}$ degC	q W/m²	$T_{..}$ degC
Corrugated asbestos cement	13 mm timber board, 25 mm fibreglass + alum. foil	a/c sheets on purlins, foil on fibreglass on boards under rafters	0·74	12·6	1·9	27·1	4·0
Corrugated asbestos cement	5 mm a/c sheets, 25 mm fibreglass + alum. foil	a/c sheets on purlins, foil on fibreglass on a/c ceiling under rafters	0·80	13·5	2·4	29·3	4·4
Corrugated alum. sheets	13 mm fibreboard	alum. on timber purlins, fibreboard under rafters	1·3	16·1	2·5	22·4	3·4
Corrugated alum. sheets	13 mm timber board	alum. on timber purlins, timber board under rafters	1·6	20·2	3·0	28·3	4·3
Corrugated alum. sheets	5 mm a/c sheets	alum. on timber purlins, a/c under rafters	1·9	22·1	3·3	31·2	4·6
Corrugated alum. sheets	100 mm reinforced concrete slab	alum. on timber purlins, reinforced concrete slab horizontal	1·6	20·2	3·0	28·3	4·3
Corrugated alum. sheets	13 mm resin bonded jute board	alum. sheets on timber purlins, board under rafters	1·4	16·7	2·5	23·6	3·6
Corrugated alum. sheets	50 mm strawboard	alum. on timber purlins, strawboard under rafters	1·08	11·0	1·8	15·4	2·6
Corrugated alum. sheets	25 mm wood wool slab	alum. on timber purlins, wood wool under rafters	1·42	14·5	2·2	20·5	3·1
Corrugated alum. sheets	10 mm plasterboard	alum. on timber purlins, plasterboard under rafters	1·88	19·2	2·9	27·4	3·5
Corrugated alum. sheets	25 mm cork slab	alum. on timber purlins, cork under rafters	1·27	13·2	2·0	18·6	2·7
Corrugated alum. sheets	100 mm reinforced concrete slab, 75 mm cement screed, 18 mm plastering	alum. on timber purlins, reinforced concrete slab horizontal underside plastered	1·23	17·3	2·4	24·6	3·4

SOURCE: Manual of Tropical Housing and Building Part One: Climate Design.

A P P E N D I X 4

EFFECT OF WIND DIRECTION ON AVERAGE AIR VELOCITY

The results of wind tunnel tests on effect of wind direction on average air velocity in a room with windows in opposite walls, is summarized in table 4. It shows that the percentage of air velocity inside the building was greater when prevailing winds was oblique to the inlet, than when it was perpendicular.

TABLE 4

Effect of Wind Direction on Average Air Velocity

Inlet width	Outlet width	Windows in opposite walls		Windows in adjacent walls	
		Wind perpend.	Wind oblique	Wind perpend.	Wind oblique
1/3	1/3	35	42	45	37
1/3	2/3	39	40	39	40
2/3	1/3	34	43	51	36
2/3	2/3	37	51	—	—
1/3	3/3	44	44	51	45
3/3	1/3	32	41	50	37
2/3	3/3	35	59	—	—
3/3	2/3	36	62	—	—
3/3	3/3	47	65	—	—

SOURCE: Man Climate and Architecture.

A P P E N D I X   5

PLANTING IN THE HUMID TROPICS

To aid in the selection of vegetation for the landscape design, a list of trees, shrubs and plants suitable for planting in this climate is presented. The shapes of known trees is presented in table 6.

TABLE 5

Trees and Shrubs Suitable For Planting in Hot Humid Climate

Some large trees suitable for avenues*
(Heights given where known)

Swietenia macrophylla (British Honduras Mahogany), 70–80 ft.
Cedrella Mexicana (W.I. Cedar), 80–120 ft.
Palmae spp.
Peltophorum ferrugineum, 50–60 ft.
Terminalia Catappa, 60–80 ft. (Almond). Very good for shade
Poinciana regia (Delonix regia), 40–50 ft. (Flame Tree)
Chrysophyllum cainito (Star Apple), 60 ft.
Hymenea courbaril (Stinking Toe), 100 ft.
Parkia biglandulosa (Locust)
Grevillea robusta (Silky Oak), 60–100 ft.
Catalpa longissima (Yoke Wood)
Homalium dolichophyllum
Hymenostegia Afzelii
Khaya Senegalensis
Tamarindus indicus
Fagraea fragrans (Tembusu)

Some trees suitable for smaller avenues
(Heights given where known)

Cassia siamea
Casuarina equisetifolia (Whistling Pine)
Guaicum officinale (Lignum Vitae), 30 ft. plus
Cordia sebestana, 20–25 ft.
Tabebuia pentaphylla (Pink Poui)
Cupressus benthamii (Fir Tree)
Cæsalphinia Pulcherrima (Pride of Barbados)
Nim
Acacia spp.
Palmæ spp.
Eucalyptus
Murraya exotica
Monddora tenufolia
Securidaca spp.
Barteria nigritiana
Dalbergia sisoo
Glicidia maculata
Sclerocarya birræa
Spondias magnifera
Azidarachta indica

* Also suitable for single planting and landscaping.

Trees suitable for clumps, groves and single planting

Ficus benjamina (Ceylon Willow). Large and spreading, 60 ft. plus. Very good for shade
Ficus bengalensis (Fig). Large and spreading, 100 ft. plus
Enterolobium cyclocarpum (Devil's Ear), 80 ft. Spreading (100 ft. plus)
Blighia sapida (Akee), 50 ft.
Pithecellobium saman (*Samanea Saman*), Saman Rain Tree, 100 ft. plus
Triplaris surimanensis (Long John), 60 ft. Tall, not spreading more than 20 ft. Quick growing
Triplaris cumingiana (Long John), 60 ft. Tall, not spreading more than 20 ft. Quick growing
Lagerstræmia flos-reginæ (Queen's Flower), 60 ft.
Spathodea campanulata (Tulip Tree), 50–60 ft.
Araucaria spp.
Hura crepitans (Sandbox), 60 ft.
Brownea coccinea
Cassia nodosa
Cassia fistula
Bauhinia galpini (semi-climber)
Parmentiera cereifera (Candle Tree)
Plumeria acutifolia (Frangipani)
Posoqueria longiflora
Erythrina umbrosa
Michelia champaca
Kigelia pinata (Sausage Tree)
Tecoma spectabilis (Poui)
Genipa americana, 40–50 ft.
Gliricidia sepium (Quick Stick Madura)
Datura suaveolens (Angels' Trumpets)

Cordia
Casuarina equestifolia
Milletia spp.
Punica granatum
Ochna spp.
Ourates spp.
Distrosachys glomerata
Baphia nitida
Erythrina altissima
Erythrina senegalensis
Chrysophyllum spp.
Holharrhena Wulfsburgii
Rauwolfia vomitoria
Stereospermum spp.
Eucalyptus spp.
Parkia spp.
Anogeissus leiocarpus
Lonchocarpus Griffonianus
Moringa pterygosperma
Oncoba spinosa
Combretum abbreviatum
Nerium oleander
Allamanda spp.

Hedges

Hibiscus sp.
Euphorbia milii (splendens)
Euphorbia pulcherrima (Poinsettia)
Breynia nivosa
Galphimia glauca (Shower of Gold)
Barleria cristata (Blue Bell)
Allamanda schottii (Alamander)
Pithecolobum dulce (Madras Thorn)
Pithecolobum unguiscarti (Bread and Cheese)
Eugenia spp. (Pitanga Cherry)
Bougainvillea spp.
Panax fruticosum
Thevetia nerifolia
Bauhinia refescens
Casuarina equestifolia (Whistling Pine)
Thespesia populula
Lawsonia alba (Henna)
Acalypha tricolor
Nim
Flacourtia flavescens
Eugenia sp.
Coffea sp.
Fluggea virosa
Baphia nitida
Sesbania ægyptica
Connarus africanus
Aralia filicofolia
Bambusa nana
Croton
Malpighia glabra (Barbados Cherry)
Carissa edulis
Acalypha vars.
Duranta plumeri
Punica granatum
Murraya exotica
Lagerstrœmia indica
Balanities ægyptica
Zisyphus spp.
Commiphra africana
Quisqualis indica
Aralia guilfoylei
Barleria cristata
Justicia gendarussa
Panax fruticosum

Quick growing climbers for shade, i.e. covering verandahs, etc.

Argyreia specrosa
Allamanda hendersonii
Bignonia venusta
Bougainvillea sp.
Clerodendron speciosum
Clerodendron thomsonæ
Lonicera japonica
Pandorea ricasoliana
Petrea volubilis
Quisqualis indica
Thunbergia grandiflora

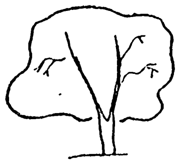
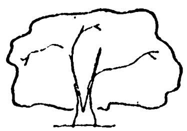
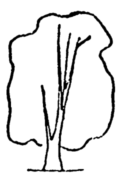
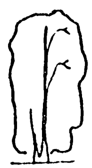
Clinging plant for rough walls

Ficus stipulata

SOURCE: Tropical Architecture in the Humid Zone.

TABLE 6

Classification of Trees According to Shape

	Colour of flowers							
SHAPE OF TREE	GREEN	WHITE	RED	YELLOW	BLUE	ORANGE	MAUVE	PINK
	Acacia moniliformis	Melia indica (Neem). Pterospermum. Acerifolium (flowers: cream). Crataeva Religiosa.	Spathodea campanulata. Erythrina indica. Erythrina suberosa.	Cassia Fistula. Peltophorum inerme. Schleichera trijuga.	Jacaranda mimosæfolia.	Butea monosperma (Dhak, or Flame of the Forest).	Melia azadirachta (Persian lilac). Milletia ovalifolia (flowers: lilac). Lagerstroemia Flos-reginæ (flowers: mauve-purple). Lagerstroemia Throlli. Kagelia pinnata.	
	Diospyros embryopteris. Ficus infectoria (Pakur). Tamarindus Indica. Ficus retusa.	Plumeria acutifolia. Plumeria alba. Pongamia glabra.	Delonix regia (Gul Mohur).	Thespesia populnea.				Cassia Javanica. Cassia nodosa. Enterolobium saman (Rain tree).
	Casuarina equisetifolia. Acacia auriculiformis (Australian acacia). Phyllanthus Emblica.	Bauhinia acuminata. Dillenia indica. Chorisia speciosa.	Bombax malabaricum (Silk cotton).	Cassia siamea. Grevillea robusta.	Guiacum officinale (Lignum vitæ).	Colvillea racemosa.		Bauhinia Variegata. Cassia renigera. B. Triandra.
	Eugenia jambolana. Eugenia fruticosa. Calophyllum inophyllum.	Bigonia crispa. Ailanthus excelsa. Cedrella toona. Bassia latifolia (Mahua).						
	Palms: Corypha taliera. Livistonia chinensis. Oreodoxa regia (bottle palm).							

SOURCE: Tropical Architecture in the Humid Zone.

APPENDIX 6

THE OVER-HEATED PERIODS OF THE YEAR

To avoid over designing a shading device it is necessary to determine those times of the day when protection is needed from the sun. The comfort zone in the hot humid climate is estimated to lie between 22° C and 27° C (See Figure 3). For temperatures above the lower limit of the comfort zone it is recommended that protection should be provided against direct solar radiation. The period when shading is needed is shown in the shaded portion of the isopleth diagram for Ikeja an area near Ogba village (See Figure 30). The isopleth diagram shows an hourly temperature variation for the whole year. To determine the solar azimuth and altitude, the over heated times indicated in the isopleth diagram are shaded in the solar chart diagram illustrated in Figure 30.

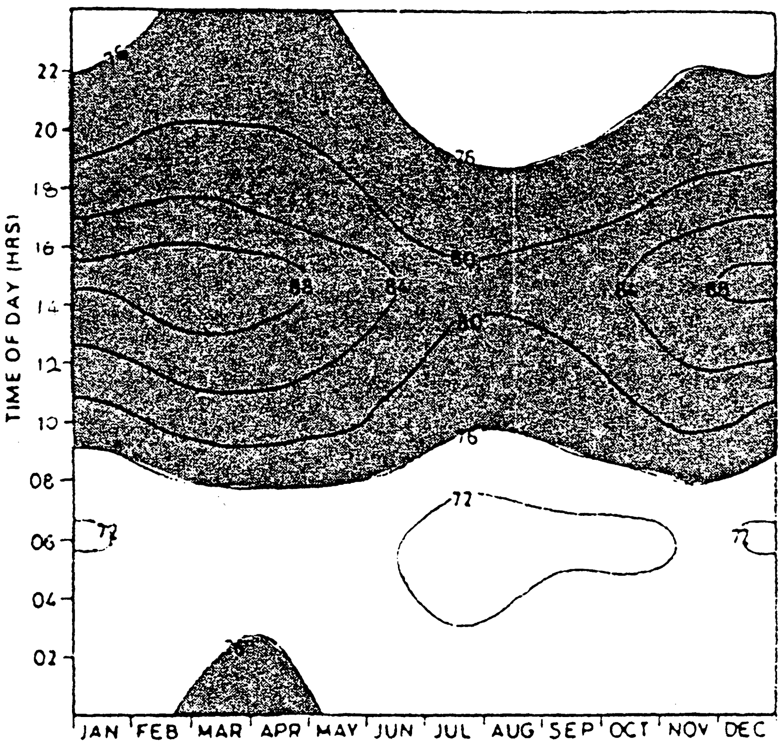


FIGURE 30

Annual Hourly Temperature Graph for Ikeja.

SOURCE: The climates of West Africa.

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THE INFLUENCE OF HOT HUMID CLIMATE
ON DESIGN OF HIGH DENSITY HOUSING
A CASE STUDY

by

Akim Olatunde Layeni

(ABSTRACT)

This thesis explores the effect of climate on the development of high density housing. With the situation in Lagos there is a tendency to neglect the effect of climate. The low income housing project proposed under the Ijaiye housing scheme is used as a vehicle to investigate this climatic concerns. The conditions that generated the design included site conditions, climate, human comfort criteria, building materials, and construction. The issues that were dealt with include ventilation, protection from direct solar radiation, treatment of common spaces, orientation, drainage, and the choice of building materials. The design solution submitted in this thesis is influenced by various sources from the field of tropical architecture with the understanding that these studies are not definitive and that further investigation still needs to be made.