

NATIONAL SEMINAR
ON
ARCHITECTURE
CLIMATE AND THE
ENVIRONMENT



**NIGERIAN BUILDING AND ROAD
RESEARCH INSTITUTE**

RESEARCH, DEVELOPMENT
AND CURRENT PRACTICE
IN NIGERIA

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ENVIRONMENT**

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FOREWORD

The popular impression of building research is the development of alternative and cheaper structural building elements which can replace costly conventional ones. As a result, research on the influence of climate and the external environment on housing design does not readily receive recognition and acclaim. Nevertheless, a house that is cheap and structurally sound but has an uncomfortable internal environment is justifiably criticised by its occupants as a failure and a liability, which may involve expensive remedial action. For a house to be properly designed to ensure basic internal comfort, the professional architect, as well as the perceptive owner, requires a basic understanding of how climate affects housing design, and must have the relevant parameters to aid him in this exercise.

Accordingly from its very inception, the Nigerian Building and Road Research Institute placed equal emphasis on both building materials and environmental research. In this bound seminar proceedings, the research results of the Institute's work on the effect of the Nigerian climate and environment on the architectural design of buildings are collated together so that they can be critically assessed by practising architects and research scientists. Recognising that other tertiary institutions of higher learning and practising professionals have also devoted a significant attention to this very important subject, the Institute decided to invite contributions from such organisations and professionals so that the subject can be given a wide and national coverage, that it rightly deserves.

The seminar papers contained in this proceedings cover the essential aspects of the effects of the Nigerian climate on thermal comfort and lighting in buildings, acoustic design of buildings, solar energy data and important case histories by authoritative experts in their fields of specialisation. I believe that this is the first time that such an exercise has been undertaken for Nigeria. I have no doubt in my mind that the data and guidelines contained in these papers will provide materials for invaluable exchange of views between research scientists and practising architects. It is hoped that as a result of this interaction, firm guidelines for design will be formulated for general use.

A. O. MADEDOR
Director.

19 September, 1988.

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DESIGN OF BUILDINGS FOR THERMAL COMFORT IN THE DIFFERENT NIGERIAN CLIMATIC ZONES

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ABSTRACT:

Climatic variables must be considered in order to develop efficient and economical designs of buildings for thermal comfort. Nigeria has been divided into four climatic zones for building design purposes based on meteorological data collected over forty years. The main characteristics of these zones are given in relation to design requirements of various building elements for thermal comfort.

1. INTRODUCTION:

One of the most important factors which influence the architectural design and ultimate efficiency of buildings is the climate. Climate determines the optimum orientation of buildings, spacing and grouping of houses, size and location of windows, choice, type and specifications of the structural elements. The over-all conceptual forms of buildings in the different regions of the world show the immense influence of climate on both the design and technology of such buildings. Climatic elements which affect the thermal performance of buildings are air temperature, solar radiations, long-wave radiation, humidity and wind (Straaten et al, 1969). Any design data or meaningful appraisal of the thermal performance of buildings must be based on a combined or integrated effect of all these weather elements. The temperature of the air, its moisture content and wind can be regarded as random variables influenced by many factors such as topography, height above sea-level, proximity to sea or other large water masses, vegetation etc. Design data from these weather elements, therefore, have to be based on probability occurrence of these elements that will justify specific design requirements. Also, assessment of these elements has to be done on an hourly basis as mean daily design criteria do not mean much under conditions of transient heat flow. Solar radiation intensity depends on location, cloud type and density, atmospheric pollution, and to some extent, is random in nature. Design data based on these elements have to be cautiously used and judiciously interpreted for design of buildings especially in urban centres where the micro-climate at specific locations may differ significantly from where the weather data have been obtained.

Apart from the influence of climatic elements on design of buildings for thermal comfort there are other basic design considerations, which, if intelligently applied during building design stage, will greatly enhance the comfortability of such buildings. This paper attempts, therefore, to address some design guidelines for a comfortable building in the different climatic regions of Nigeria.

2. CLIMATE OF NIGERIA:

Nigeria lies within 4°N to 14°N latitudes and 2.5°E to 14.5°E longitudes. The Southern part of the country, along the sea coast, is warm and humid; whereas the Northern part is hot and dry. It therefore has hot dry, cool dry and humid seasons of varying length depending on location. There are two upland areas in the North – the Jos Plateau and Cameroon Highlands. These have the same seasons with moderate temperatures. The South of the country has a warm to hot humid climate with a residual harmattan season and a double rainy season. The higher delta area suffers from intensive rainfall throughout the year.

2.1 Climatic Zones:

Broadly speaking, there are two distinct climatic types that are of importance when considering building design in the tropics. These are warm humid and warm dry climates - (Straaten et al, 1969). Apart from humidity considerations, the main difference between them is the magnitude of the daily air temperature variation. The warm humid climate is characterised by relatively small daily fluctuations in air temperature but in warm dry climates, these daily variations of air temperature can be large. An earlier study by the International Development Agency (IDA) Education Project in Nigeria divided the country into seven zones which were specifically worked out for standardised buildings with very limited scope. The zones were not defined basically on climatic factors. From an analysis of the maximum and minimum dry bulb temperature, relative humidity, total annual rainfall and prevalent wind directions of 23 Stations spread over the country; four climatic zones have been proposed for use in the design of buildings in Nigeria.

These zones are:

- Zone 1: Hot Dry
- Zone 2: Temperate dry
- Zone 3: Hot Humid
- Zone 4: warm Humid.

It is not possible, nor necessary, to locate the exact boundaries of each zone on a map - as one zone merges gradually and almost imperceptibly, into the next. The area under each zone - Fig. 1 is, however, a fair representation of the climatic zone in that area for building design purposes.

2.2 Climatic Description of each Zone:

Hot Dry (Zone 1): This comprises the areas where the mean daily maximum dry bulb temperature during the dry season equals or exceeds 35°C and the relative humidity does not exceed 40 per cent. During this dry season, with peak period between January - March, the daily range of temperature is high and is of the order of 15 - 20°C. The mean annual rainfall varies from 528mm. in Nguru to 960mm. in Yola. Height above mean sea level (m.s. l) is more than 300m.

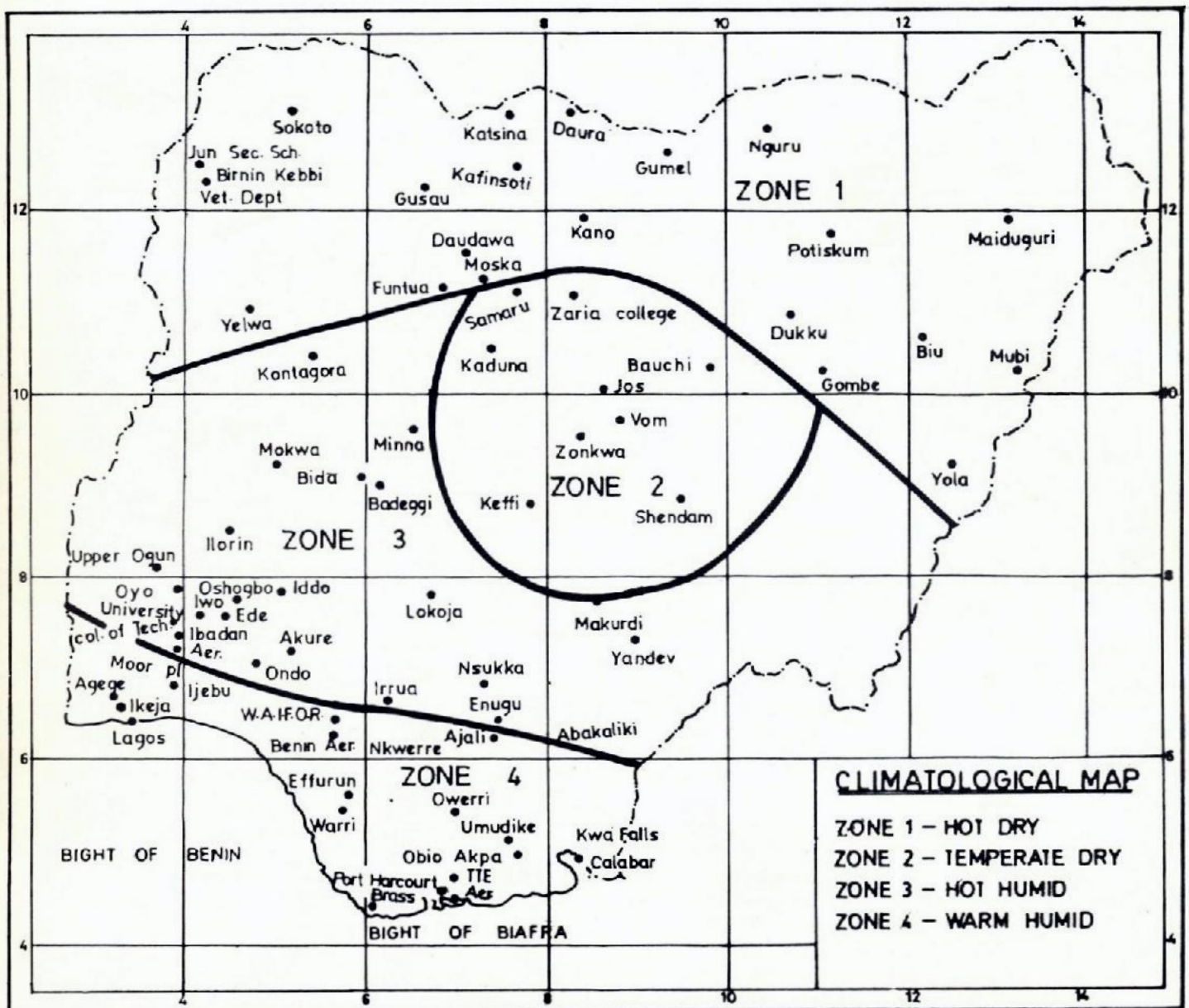
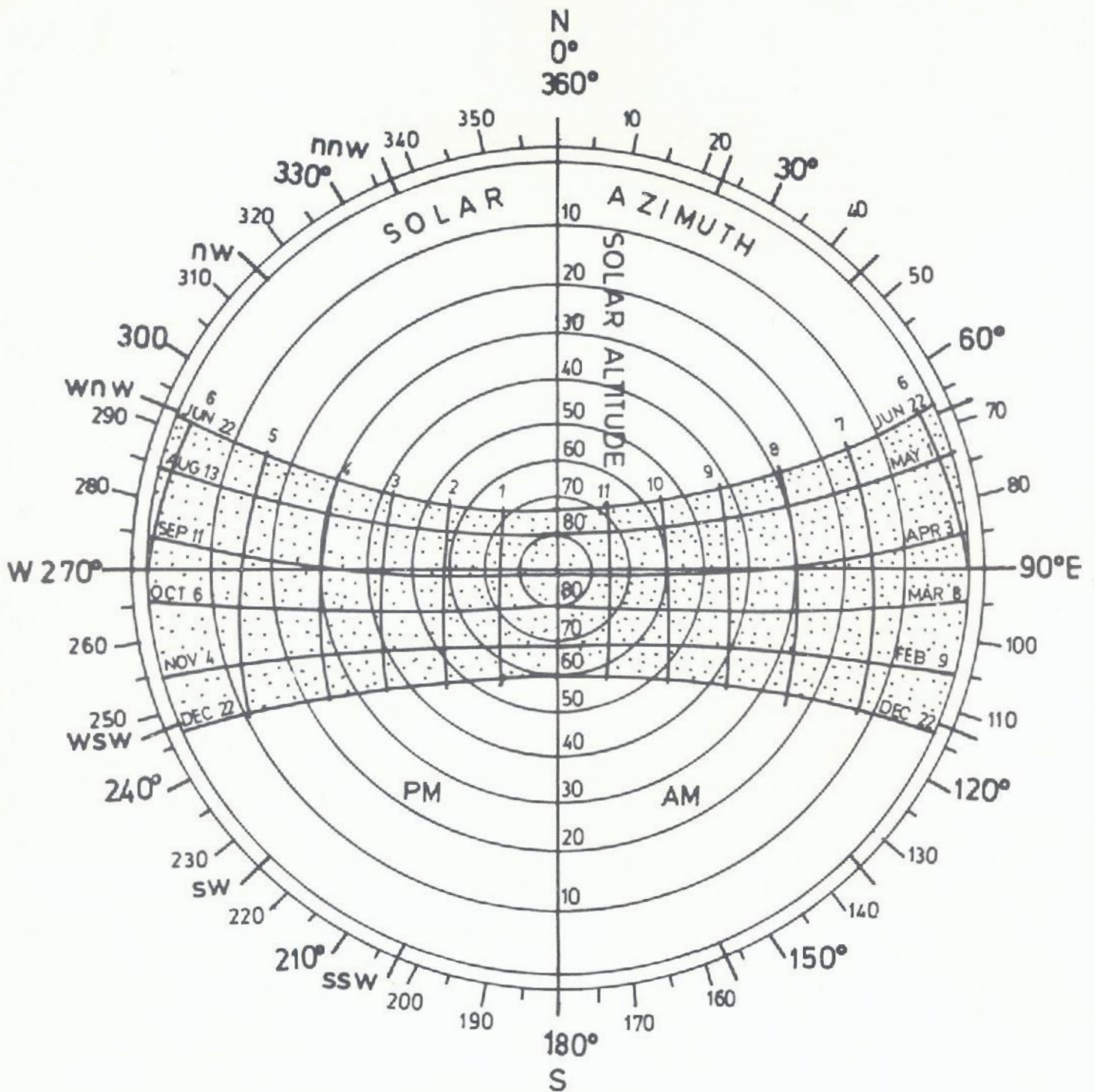


FIG. 1

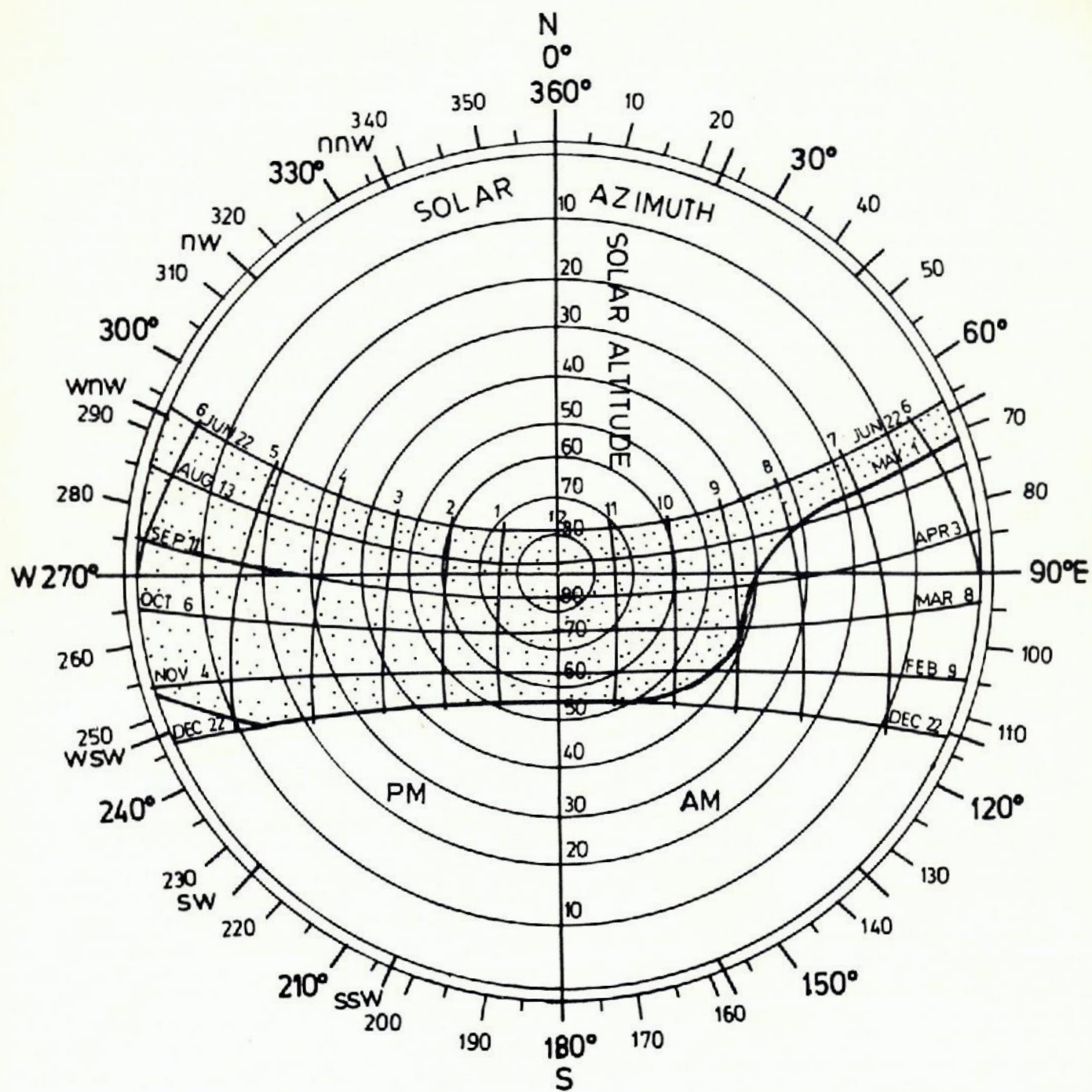
6°N



LAGOS (WARM HUMID)

Fig. 2(a): Comfort Chart

12°N



MAIDUGURI (HOT-DRY)

Fig. 2(b): Comfort Chart

Temperate Dry (Zone 2): In this zone, mean maximum dry bulb temperature exceeds or equals 30°C during the dry season. The relative humidity does not exceed 40 per cent during this period. The daily range of temperature is not very high. It is of the order of 10°C. Annual rainfall varies from 1077mm. to 1399mm. in Zaria and Jos respectively. Height above mean sea level (m.s.l) is more than 300m.

Hot humid (Zone 3): Mean daily maximum dry bulb temperature during the dry season exceeds or equals 30°C. In this zone. The relative humidity is of the order of 40 – 70 percent during the hot season. The daily range of air temperature is less than 10°C. Annual rainfall is about 1183.0mm. and 1787.0mm. in Lokoja and Enugu respectively. Height above mean sea level lies between 100m – 300m.

Warm Humid (Zone 4):

This zone comprises areas where mean daily maximum dry bulb temperature during the dry season exceeds or equals 30°C and relative humidity lies between 70 to 100 per cent. The daily range of air temperature is less than 8°C. The average rainfall during the year is high. In Warri, the rainfall is 2788 mm. annually while in Lagos, it is 1185.0mm. Height above mean sea level is below 100m – (Agarwal and Komolafe, 1983).

2.3 Climatic Data Sheet:

Climatic data of 23 cities are given in tables 2 and 3. These data include (a) Maximum dry bulb temperature for February and August; (b) Minimum dry bulb temperature for February and August; (c) Average relative humidity of February and August; (d) Total annual rainfall; (e) Prevalent wind directions and frequency of occurrence – (Agarwal and Komolafe, 1984). The range of temperature between day and night is required as the thermal performance of buildings cannot be decided only by mean values – particularly when the difference between maximum and minimum is quite large. The values for February and August are representative of dry and wet seasons and also indicate the extent of annual variation. The most prevalent wind directions and their occurrence are given for the design of windows for natural ventilation. The number of months during a year shows the prevalent wind direction in that area and the period of the year when natural ventilation can be effectively utilised for comfort. The annual total rainfall data are useful for overhang design, protection against rain and type of roof construction necessary.

3. THERMAL COMFORT REQUIREMENTS:

Thermal comfort is a state of the environment where one can perform one's activities without much strain or stress effectively and efficiently. In residential buildings, thermal comfort demands that users can perform daily activities during the daytime without much strain or stress on their health and can have a

sound sleep during the night. Thermal environment in buildings depends on the following:

- (a) Dry bulb temperature;
- (b) Relative humidity;
- (c) Air velocity;
- (d) Radiation from different surfaces indicated by the globe temperature.

These four climatic elements are the dominant variables which affect thermal comfort within a building. The extent to which they can be controlled to create an optimum environment depends on the economics of building design, climatic zones and a thorough understanding of the heat transfer properties of building materials used for construction. Optimum use should be made of natural ventilation by proper orientation of buildings and location of windows. However, for further comfort, use of ceiling or table fans may be necessary in bed rooms or living rooms. This is because winds are generally calm in the tropics, and hence, air motion produced by natural means may be inadequate for comfort ventilation. The climate of a particular region is a major consideration for building design to suit thermal comfort requirements. The four climatic zones proposed for building design in Nigeria represent an attempt at design to suit the climate. It must be noted, however, that the climatic elements analysed to give the climatic zones are measurements from open - air spaces like air-ports or meteorological stations. The micro-climate of building sites or climatic elements at specific places may be needed in a proper consideration of design of buildings for comfort in urban and city areas.

3.1 Thermal Comfort Indices:

It is universally agreed that thermal comfort is subjective. Though complete agreement may be obtained on what is thermally uncomfortable, it is unlikely that more than 60 – 70 per cent of a group of people will agree that any particular situation is thermally comfortable – (Agarwal and Komolafe, 1984). Thermal comfort indices refer to a range or set of conditions under which thermal comfort is experienced. Thermal comfort can also be represented by a single scale of measure which comprises the effect of air temperature, humidity, air movement and mean radiant temperature. Many efforts have been made to develop such scales. One such scale is the Corrected Effective Temperature monogram. This is a scale of thermal comfort which combines the effect of air temperature, humidity, air movement and the radiant temperature. Other Scales are (a) The Equivalent Temperature – a combination of air temperature, radiant temperature and air movement. It does not include humidity; (b) Equivalent Warmth Scale which is an attempt at including humidity in the Equivalent Temperature Scale; (c) Equatorial Comfort Index developed by Webb which uses air temperature, humidity and air movement. Radiant temperature is ignored. Webb's Equatorial Comfort Index is however, felt to be

TABLE 1.

CLIMATIC ZONES OF NIGERIA

S. NO.	NAME OF THE STATE	REPRESENTATIVE CITIES	HEIGHT ABOVE M.S.L.	MEAN MAX. DRY BULB TEMPERATURE (°C)	RELATIVE HUMIDITY PER CENT	CLIMATIC ZONE
1.	BORNO, SOKOTO, PART OF KADUNA, BAUCHI, KANO AND GONGOLA.	MAIDUGURI, YELWA, KATSINA, BAUCHI, KANO AND YOLA	300m	35 - 40	UP TO 40%	HOT DRY (H.D.)
2.	PART OF KADUNA, ZARIA, ABUJA, PLATEAU AND BENUE	ZARIA, JOS, ABUJA	300m	30 - 35	UP TO 40%	TEMPERATE DRY (T.D.)
3.	NIGER, KWARA, OYO, ONDO, ANAMBRA AND IMO	BIDA, ILORIN, LOKOJA, IBADAN ONDO AND ENUGU	300m 100m	30 - 35	40 - 70%	HOT HUMID (H.H.)
4.	LAGOS, BENDEL, RIVERS, CROSS RIVER AND OGUN	LAGOS, IKEJA, BENIN CITY, PORT HARCOURT AND CALABAR	100m	25 - 32	70 - 100%	WARM HUMID (W.H.)

TABLE 2

TEMPERATURE AND HUMIDITY DATA

S.NO.	CITY	TEMPERATURE (MAXIMUM)		TEMPERATURE (MINIMUM)		RELATIVE HUMIDITY		CLIMATIC ZONE	
		FEB.	AUG.	FEB.	AUG.	FEB.	AUG.		
1.	PORT HARCOURT	33.0	28.3	22.8	20.8	76	90	WARM HUMID	
2.	CALABAR	32.7	27.6	23.3	22.2	79	90	W	H
3.	WARRI	33.2	28.4	23.2	22.4	80	88	W	H
4.	BENIN CITY	33.1	27.9	23.0	21.7	81	84	W	H
5.	LAGOS	31.2	27.5	25.4	23.5	81	84	W	H
6.	ENUGU	34.6	29.3	22.3	22.2	71	81	HOT HUMID	
7.	IKEJA	32.9	28.6	23.1	23.2	70	82	H	H
8.	ONDO	34.5	28.3	21.1	20.3	71	88	H	H
9.	IBADAN	34.2	27.5	22.4	21.1	65	84	H	H
10.	OSHOGBO	34.4	29.2	23.1	22.6	59	80	H	H
11.	LOKOJA	35.7	29.9	23.1	22.6	58	81	H	H
12.	ILORIN	35.9	28.9	20.9	20.9	57	82		H H
13.	BIDA	37.3	29.7	23.3	22.2	51	81		H H
14.	GUSAU	37.8	29.1	20.6	20.9	41	80	HOT DRY	
15.	YOLA	40.1	30.1	24.1	22.3	37	83	H	D
16.	JOS	30.9	23.9	18.1	16.6	24	80	TEMPERATE DRY	
17.	BAUCHI	36.8	28.9	19.9	19.7	27	82	T	D
18.	KADUNA	35.3	27.3	20.5	19.6	37	84	T	D
19.	YELWA	38.5	29.6	24.6	22.6	40	82	T	D
20.	ZARIA	26.3	28.4	20.3	19.8	30	82	T	D
21.	KANO	38.4	29.8	23.3	20.9	35	80	H	D
22.	NGURU	40.1	31.0	22.8	22.3	27	74	H	D
23.	KATSINA	38.8	29.7	23.3	20.5	26	77	H	D

TABLE 3

RAINFALL AND WIND DATA

S.NO.	CITY	TOTAL YEARLY RAINFALL (mm)	WIND DIRECTION	
			DIRECTION	NO. OF MONTHS
1.	PORT HARCOURT	2400.0	S.S.W.	12
2.	CALABAR	2119.0	S.S.W.	12
3.	WARRI	2788.0	W.S.W.	12
4.	BENIN CITY	2058.0	W	12
5.	LAGOS	1185.0	S.W.	12
6.	ENUGU	1787.0	W.S.W.	12
7.	IKEJA	1564.0	S.W.	12
8.	ONDO	1590.0	S.S.W.	12
9.	IBADAN	1228.0	S.W.	12
10.	OSHOGBO	1222.0	S.W.	12
11.	LOKOJA	1183.0	S.S.W.	12
12.	ILORIN	1283.0	W.S.W.	09
13.	BIDA	1224.0	S.S.W.	08
14.	GUSAU	951.0	S.W.	08
15.	YOLA	960.0	W.S.W.	06
16.	JOS	1399.0	S.W.	12
17.	BAUCHI	1089.0	S.W.	04
18.	KADUNA	1281.0	S.W.	06
19.	YELWA	1022.0	S.W.	07
20.	ZARIA	1077.0	S.W.	06
21.	KANO	843.0	S.W.	04
22.	NGURU	528.0	S.W.	03
23.	KATSINA	714.0	S.W.	04

applicable to indoor tropical conditions, where the climate is warm, humid and oppressive. On this scale, thermal comfort occurs between the index of 24°C and 29°C with majority of the people comfortable at an index of 26°C. Carl Mahony has developed limits of comfortable temperature and humidity in a given Climatic Zone both for day and night conditions for residential buildings. These can be easily applied to assess optimum thermal comfort conditions in buildings.

3.2 Thermal Comfort Zones in Nigeria:

Thermal Comfort levels of individuals depend on many variables such as level of activity, age, sex, health, race and acclimatisation in particular location. Thermal Comfort Studies have been initiated by the Nigerian Building and Road Research Institute on a rational and scientific basis. Comfort Surveys have been conducted in Ibadan and similar surveys are going on in the Lagos area. These surveys are being conducted over a period of 1 year so that a complete

thermal circle is observed. Questionnaires are designed to give building characteristics and the subjective response of occupants to the thermal environment. Environmental parameters like air temperature, relative humidity and air movement are measured or assessed. Radiant temperature is ignored as it has been found that there is little or no difference between the globe and dry bulb thermometer measurements of air temperature in residential buildings in the tropics – (Webb, 1959). Analysis of these data is in progress. From a previous limited survey conducted by the Nigerian Building and Road Research Institute in 1982, the following comfort zones are observed: – Table 4

From response of people on thermal comfort in each month of the year during the day and night indoors, thermal comfort charts based on effective temperature charts have been made for Latitudes ranging from 5°N to 14°N. There are a number of cities on the same latitude with varying and different climatic data.

TABLE 4.
COMFORT ZONES

S/N	CLIMATIC ZONES	COMFORT ZONES	REMARKS
1.	Hot Dry	21°C – 26°C	Standardisation of comfort Zones is evident. This is possible as the climatic Zones are not significantly too different.
2.	Temperate Dry	18°C – 24°C	
3.	Hot Humid	21°C – 26°C	
4.	Warm Humid	21°C – 26°C	

TABLE 5:
CLIMATIC ZONES AND COMFORT INDEX RANGE

LATITUDE	PLACE	CLIMATIC ZONES	COMFORT ZONES°C
10°N	Bauchi, Gusau, Minna, Yola	Hot Dry	21 – 26
10°N	Jos, Kaduna, Ibadan Ilorin	Temperate Dry	18 – 24
8°N	Ondo Lokoja, Makurdi	Hot Humid	21 – 26
6°N	Benin City, Lagos Warri	Warm Humid	21 – 26
4°N	Port Harcourt, Calabar	Warm Humid	21 – 26
12°N	Kano, Sokoto, Maiduguri, Katsina	Hot Dry	21 – 26

The Comfort Charts will help architects and designers to determine the time and months during which discomfort occurs. The clear part on the comfort chart represents comfort zone and shaded portion - discomfort zone. This will help in determining the month of the year when shading will be needed. Appropriate shading device can then be applied. Two Comfort Charts are shown in Fig. 2, for Warm Humid and Hot Dry Zones.

4. BUILDING FORM AND ORIENTATION:

For a tropical climate, consideration of adequate ventilation and minimisation of thermal load from solar radiation should form the basis of building form and orientation. In Nigeria, a rectangular shape for building has been found acceptable. Any assessment of the form of a building has to be based on energy balance in the building. This will involve insolation input from external sources, the thermal and insulation properties of the walls and roofs with the ventilation rate required to give an acceptable comfort level in the building.

An analysis of the prevalent wind direction in Nigeria shows that for natural ventilation a NE-SW orientation is best for using prevalent wind for ventilation within the building while a North-South orientation is best for minimum solar radiation input. It, therefore, seems that an optimum orientation for minimising solar radiation input into a building while at the same time utilise prevalent wind for natural ventilation will be intermediate between these two directions - See Figs. 3 and 4.

4.1 Location and size of Windows:

Windows should be well distributed on the windward wall. The outlet openings on the leeward side should be diagonally opposite the inlet openings. In case of rooms with only one wall exposed to the outside, provision of two windows on that wall is preferred to that of a single window. Windows of living rooms should open directly to an open space. In places, where building sites are restricted, open space may have to be created in the building by providing adequate court-yards. As the distribution of wind speeds and flow patterns, indoors, are mainly governed by the location of inlet openings, it is desired that inlet openings (windows) should be located at a low level. Window height should be about 1.1m. Maximum window area should not exceed 30-40 per cent of floor area (Komolafe and Akingbade, 1986). Internal screens like curtains or venetian blinds are necessary to protect windows and other glass areas from direct solar radiation. Verandahs should be provided as these enhance air motion inside. For thermal comfort, it is necessary to have air flow at the level of occupancy. Maximum air movement at a particular plane is achieved by keeping the sill height of the openings at 0.85 of the height of the plane where activity is going on - See Figs. 5-9.

5. Thermal Performance and Choice of Building Materials.

In the warm, oppressive climate of the tropic, thermal performance and durability should be the major criteria for choice of materials for building construction - (Olufowobi, 1987). In order to achieve desirable thermal conditions indoors, maximum values of thermal parameters for walls, roofs, doors and windows have to be prescribed. These values will determine choice of materials for the various building sections. The thermal conductivities of some local building materials have been determined. These are given in Table 6. Table 7, gives the variation of the thermal conductivities of some insulation materials with temperature while Table 8 gives the variation of thermal conductivity of flexible polyurethane foam with moisture at 50°C. Specific thermal standards have not been prescribed for building materials in Nigeria. These will eventually evolve from the work being done in the Nigerian Building and Road Research Institute. As at now, choice of material for construction can be based on available thermal data like the ones in Tables 6-8. The requirements for thermal comfort indoors are however, (a) low overall thermal transfer coefficient of the materials (b) appropriate design measures to limit heat input from solar radiations and (c) adequate ventilation either from natural or other means. Some specific guidelines for choice of materials in the different climatic zones are given below:-

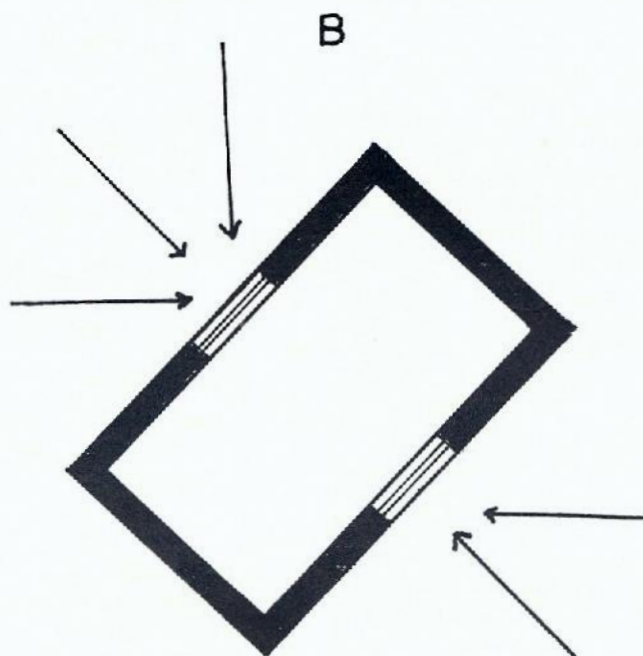
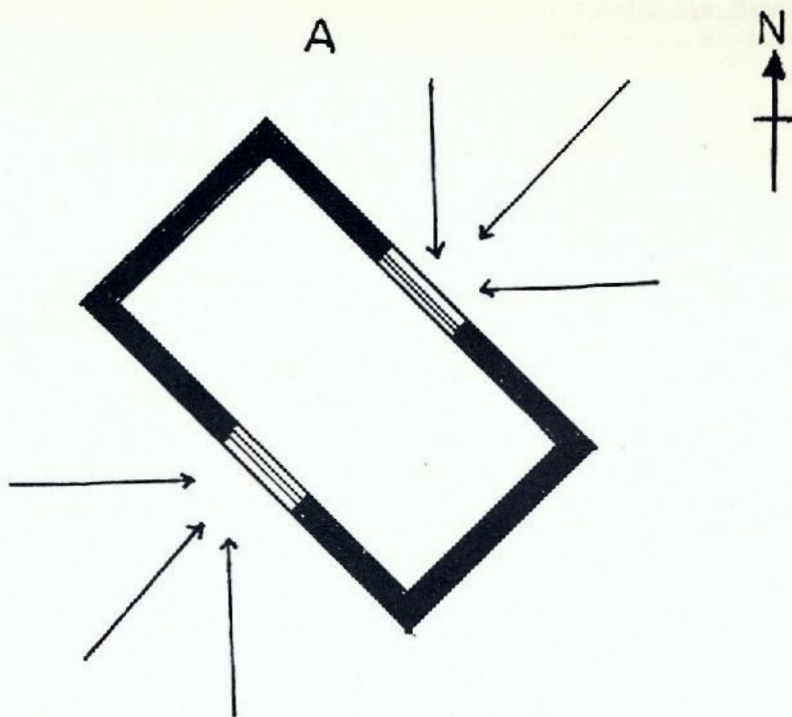
5.1. Walls:

(1) Hot Dry Zone;

Walls should be massive with 5 to 6 hours of time lag. Use of clay bricks is preferred because of their low thermal conductivity. The clay bricks can be stabilised with about 5% cement if the quality of clay is in doubt. The bricks may be solid bricks for load-bearing walls while perforated clay bricks are better for non-load bearing walls. The perforation enhances ventilation inside the building and helps thermal insulation of the walls. In case of hollow concrete blocks, the thickness should not be less than 23.0cm. If possible, east and west walls are to be properly insulated. Shading of walls also improve thermal performance.

(2) Temperate Zone:

Light-weight structures with short time lag will be sufficient. Clay bricks, if available, are preferred to other materials. Thickness of hollow concrete blocks should not be less than 15.0cm. Light colour and shading will improve thermal performance.



KEY

→ Direction of wind

FIG. 3: OPTIMUM ORIENTATION FOR VARIOUS WIND DIRECTIONS.

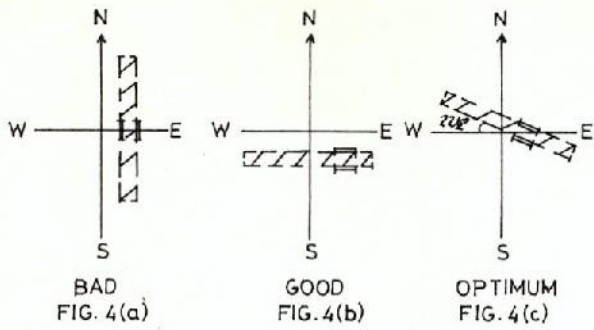


FIG. 4: BUILDING ORIENTATION WITH RESPECT TO THERMAL AND VENTILATION CONSIDERATION

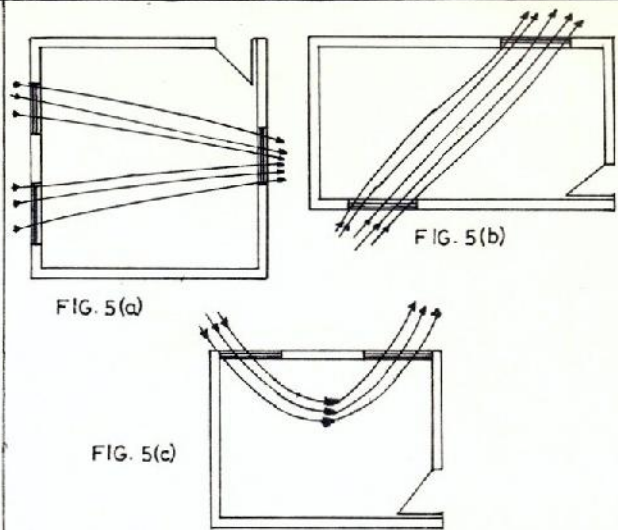
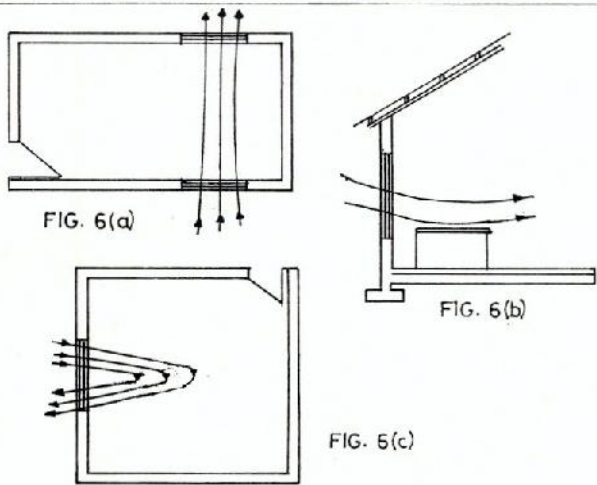


FIG. 5(a): INLET OPENINGS LOCATED ON THE WINDWARD WALL.
 FIG. 5(b): WINDOWS LOCATED DIAGONALLY OPPOSITE TO EACH OTHER INDUCE BETTER VENTILATION.
 FIG. 5(c): AT LEAST TWO WINDOWS ON THE ONLY EXPOSED WALL.



FIGS 6(a) c): NEED FOR PROPER PLACEMENT OF WINDOWS TO INDUCE VENTILATION AT OCCUPANCY LEVEL.

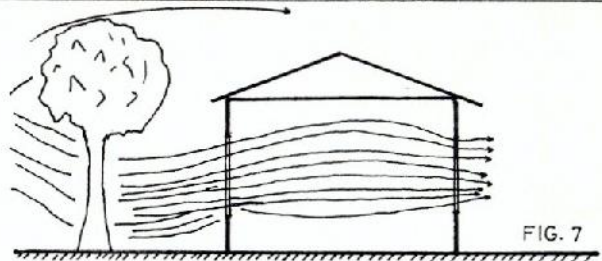


FIG. 7

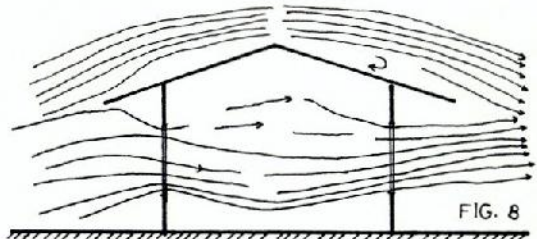


FIG. 8

FIG. 7: TREES HELP IN AUGMENTING AIR MOTION IN THE INTERIOR OF BUILDING.
 FIG. 8: ROOF OVER-HANG ENHANCES AIR MOTION IN THE LIVING ZONE INDOORS.

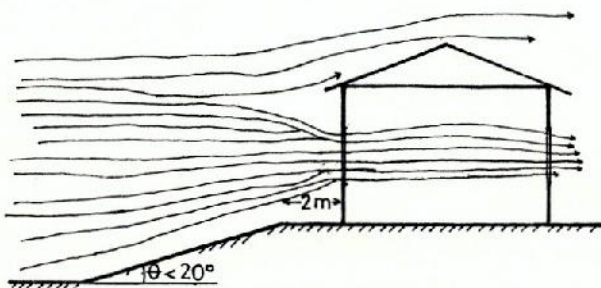


FIG. 9: BUILDING LOCATED ON AN EARTH MOUND HAS ENHANCED AIR MOTION INDOORS.

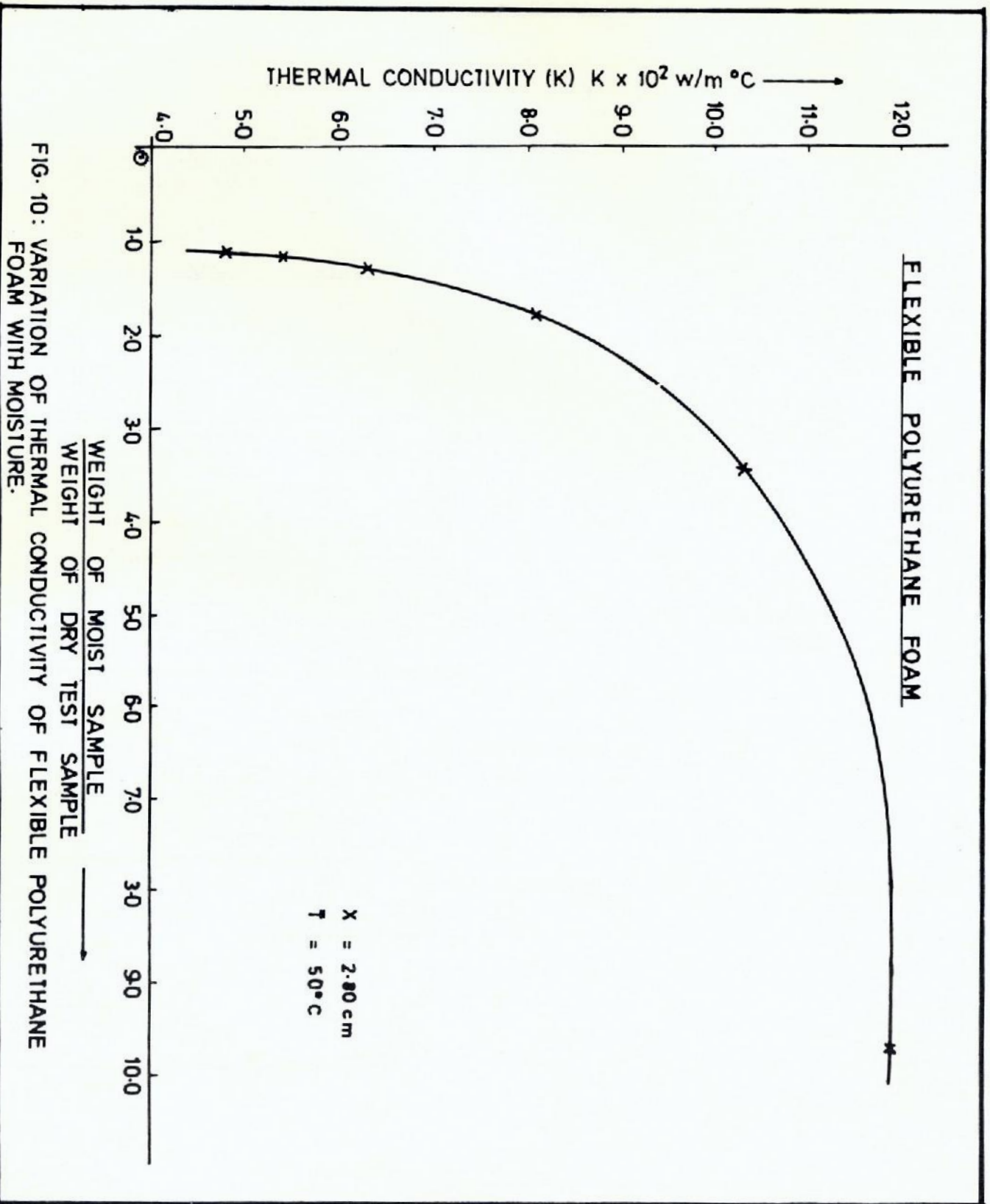


FIG. 10: VARIATION OF THERMAL CONDUCTIVITY OF FLEXIBLE POLYURETHANE FOAM WITH MOISTURE.

TABLE 6
THERMAL EVALUATION OF BUILDING AND INSULATION
MATERIALS AT MEAN TEMPERATURE OF 40°C

S.NO.	MATERIALS	THICKNESS CM	DENSITY GM/CC	THERMAL CONDUCTIVITY	
				K	W/M°C
1.	Fibreglas	2.8	0.077	0.032	
2.	Polystyrene	1.9	0.033	0.029	
3.	Rigid Polyurethane foam	4.7	0.039	-	
4.	Flexible Polyurethane foam	2.6	0.019	0.044	
5.	Nigerite Tile (Asbestos Cement)	1.32	1.5	0.240	
6.	Concrete (1:2:4) W/C = 0.6	3.48	2.3	1.061	
7.	Mortar (1:2)	3.86	2.2	0.484	
8.	Terrazo Tile	2.83	2.0	0.800	
9.	Marble (Cararra Marble)	1.97	-	1.718	
10.	Clay Brick (Oregon, Ikeja)	1.80	1.6	0.246	
11.	Wood	3.09	0.5	0.132	
12.	Ferro Cement (1,2) (2 Layers of wire mesh)	3.94	2.0	0.803	

TABLE 7
VARIATION OF THERMAL CONDUCTIVITIES OF SOME INSULATION
MATERIALS WITH MEAN TEMPERATURES

MATERIALS	FIBREGLAS	POLYSTYRENE	FLEXIBLE POLYURETHANE FOAM
THERMAL CONDUCTIVITY (K)	K (W/M°C)	K(W/M°C)	K (W/M°C)
MEAN TEMPERATURE T°C			
40	0.032	0.029	0.044
50	0.033	0.031	0.047
60	0.035	0.032	0.050
70	0.036	0.033	0.052
80	0.037	0.033	0.056
90	0.038	0.036	0.060
100	0.040	-	-
120	0.048	-	-

TABLE 8

VARIATION OF K-VALUE OF FLEXIBLE POLYURETHANE
FOAM MOISTURE AT MEAN TEMPERATURE OF 50°C

RATIO OF THE MOIST TO DRY WEIGHT OF SAMPLE	K-VALUE (W/M°C)
9.8	0.1188
3.5	0.1029
1.8	0.0812
1.3	0.0630
1.2	0.0540
1.1	0.0484

NB:

Weight of dry sample = 46.3 gms.

Sample thickness = 2.80 cm.

Note: Graphical representation is shown in Fig. 10.

(3) Hot Humid and Warm Humid:

Light-weight structures are satisfactory with some insulation on the east and west walls. Clay bricks also are preferred. Thickness of hollow concrete blocks should not be less than 15.0cm. Light colour and shading will improve thermal performance.

5.2 Roofs:

(1) Hot Dry Zone:

Heavy roof with a time lag of 6 to 8 hours is recommended. If galvanised iron or aluminium is used for the roof, a false ceiling is necessary and should be insulated. This is to keep in-door environment at comfortable temperature. Generally, the temperature of the ceiling underside should not be more than 4.5°C higher than the indoor air temperature for an acceptable roof system in the tropics - (Olufowobi, 1987) Roof should be painted with white or light colour to limit solar heat input.

(2) Temperate Dry, Hot and Warm Humid Zones:

Light-weight or medium heavy-weight insulated roof system is desirable. Roofs should be provided with false ceiling. Roofs should also be painted with white or light colour reflective surface to limit solar heat input.

6. Shading Devices:

Shading of windows or other glass areas from direct and diffuse solar radiations can be achieved by a large variety of sun control devices. These can be broadly

classified into two categories:

1. Internal Shading;
2. External Shading.

Internal Shading: Internal shading devices include venetian blinds, curtains etc. They are generally used to control daylight and glare. They also provide some relief against solar heat. They are not effective in this, however, as about 49 per cent of solar radiation still enters a conditioned space, when the glazing is provided with an internal venetian blind shading.

External shading: External shading devices provide the most effective means of reducing solar heat gains through fenestration. External sun control can give as much as 90 per cent reduction in solar heat gain when compared with ordinary single glass. This is so, because the sun's rays are neutralised before they come in contact with the glazing - hence most of the heat is dissipated externally. External shading may be permanent or retractable. Its design, installation and operation call into play the judgement and creativity of individual architect. The effectiveness of the shading device depends on its ability to eliminate direct solar radiation and glare, the retention of visibility and daylighting and the drastic reduction of the energy used by the air-conditioning equipment. External shading includes overhangs, wide variety of louvres, and horizontal projections provided by balconies. Natural sun-breakers such as plants and trees are also useful in low-rise buildings.

Another form of shading device is the use of special glass. Two main categories of solar control glasses are available. They are (a) the absorbing and (b) the

reflecting types. The typical absorbing type glass with about 50 per cent absorbing capacity, when installed as the glazing material, can prevent about 35 per cent of incident solar radiation from entering the internal space. Reflecting type glass materials is even more effective as a solar control glass as it can keep out over 60 per cent of solar heat from the conditioned space when used. The disadvantages of these special glasses are, however, that (a) they are expensive (b) they reduce amount of natural lighting available indoors. This implies more artificial lighting and hence higher electricity bills.

7. Landscaping:

Landscape design elements such as trees, flowers, hedges, earth mounds and other similar features have a pronounced effect on the flow of wind around

them. Their layout, in relation to the building, has an important bearing on air movement indoors. Air motion in a house may be enhanced or decreased depending on the height of landscape elements used and their distance from the building - (Chand and Komolafe, 1984). Care should therefore, be taken in the planting of hedges as they, sometimes, could retard air movement indoors. Hedges planted in the windward side of the building should be at a distance of about 20 times the hedge height. However, air motion in the leeward part may be enhanced by planting a low hedge at a distance of about 2 metres from the building. Buildings located at the edge of a mound with slopes less than 20° have their air motion indoors enhanced. Air movement indoors can be further increased with increase in height of the mound.

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THERMAL PERFORMANCE OF TRADITIONAL AND SANDCRETE BUILDINGS

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ABSTRACT

An investigation of the thermal performance of mud and sandcrete buildings in Ile-Ife during the dry and wet seasons revealed that the mud or traditional building has a better thermal performance than the sandcrete building which would require mechanical ventilation/cooling in order to maintain the minimum thermal comfort level within the building.

INTRODUCTION

An estimate of energy demand in the future is a necessary pre-requisite for identifying supply options that need to be put in place to meet anticipated demand. A number of analytical methodologies and models have been developed for estimating household (residential) energy demand (1,2). In many developing countries, a significant fraction of household energy demand is satisfied by the "non-commercial" fuels (wood, animal dung, agricultural wastes, etc.) and reliable data on quantity and price of the two

types of fuels, whenever they are traded, are usually not available in most developing countries. For many developing countries, the non-commercial energy constitute a large share of fuel consumed within the household⁽²⁾ especially the rural areas as shown in Table 1. Eventhough the rural households do not pay money for non-commercial fuels, they actually pay in terms of time allocation which they could have used for more productive activities. Commercial fuels are mostly consumed in the urban areas of developing countries but the quantities and type consumed depend on household income and the price of various fuels. Hence, the upper income group often consumes more of commercial fuel, especially electricity, because of higher stock of appliances (air conditioners, refridgerators, etc.) penetration in this group as shown in Table 2. Therefore, the household energy demand in developing countries has not lent itself easily to standard analytical techniques often used in energy systems analysis in more developed nations⁽³⁾.

Table 1 The structure of Non-Commercial Energy in some Selected Developing countries

Country	1971 ¹⁾		1981 ¹⁾	
	Non-commercial energy as a % of total energy consumption	Household share of non-commercial energy consumption %	Non-commercial energy as a % of total energy consumption	Household share of non-commercial energy consumption %
Venezuela	24	78	13	89
Peru	24	81	20	83
Bangladesh	NA	NA	60	96
Indonesia	77	97	57	96
Kenya	85	97	83	96
Nigeria	92	99	73	99

NA: Not available

1): Data from ref. 2

The high cost of energy consumption in buildings has reached an alarming proportion and in anticipation of the proposed government decision to remove oil subsidy, the cost of energy is bound to escalate further. Studies on the energy consumption for the mid-seventies show that most of the industrialized countries squander a large amount of previous energy (oil, gas, coal) for low-grade thermal processes. Table 3 and Figure 1 show that up to fifty percent of the electricity production is used for residential buildings. Over half of energy consumption in the building sector is consumed in space cooling in the urban and semi-urban centres where the imported western building designs are energy intensive. The space cooling is

caused by losses or gains due to heat transfer and by air movement due to infiltration and/or controlled ventilation. As houses were made tighter to reduce losses, especially in the hot arid region, the maintenance of acceptable indoor air quality begins to be an issue of concern. In view of the government's emphasis on rural development, the use of local materials plus the ever dwindling foreign reserves and purchasing power of the masses, the need for detailed study of the thermal performance of our local materials becomes pertinent in order to reduce the energy consumption — the full cost of which they cannot afford to pay.

Table 2 Income and Price Elasticities of Household Energy Demand in some Developing Countries.

Area and country	Fuel Type	Income elasticity	Price elasticity
1 India*			
Urban	commercial and non-commercial included	0.9158	-0.9324
Rural		0.7617	-1.1523
2 Pakistan			
Urban	commercial	0.8	N/A
Urban	non-commercial	-0.2	N/A
Rural	commercial	1.0	N/A
Rural	non-commercial	0.5	N/A
3 The Sudan			
Urban	commercial	1.2	N/A
Urban	non-commercial	0.5	N/A
Rural	commercial	0.8	N/A
Rural	non-commercial	0.8	N/A
4 Indonesia			
Urban (Java-Madura)	Kerosine	0.712	-0.43
Rural (Java-Madura)		0.83	-0.52
5 Kenya			
Urban (Nairobi)	commercial	0.557	N/A

FIG 1 GRAPHICAL REPRESENTATION OF THE STRUCTURE OF ELECTRICITY CONSUMPTION IN NIGERIA (1964-1980)

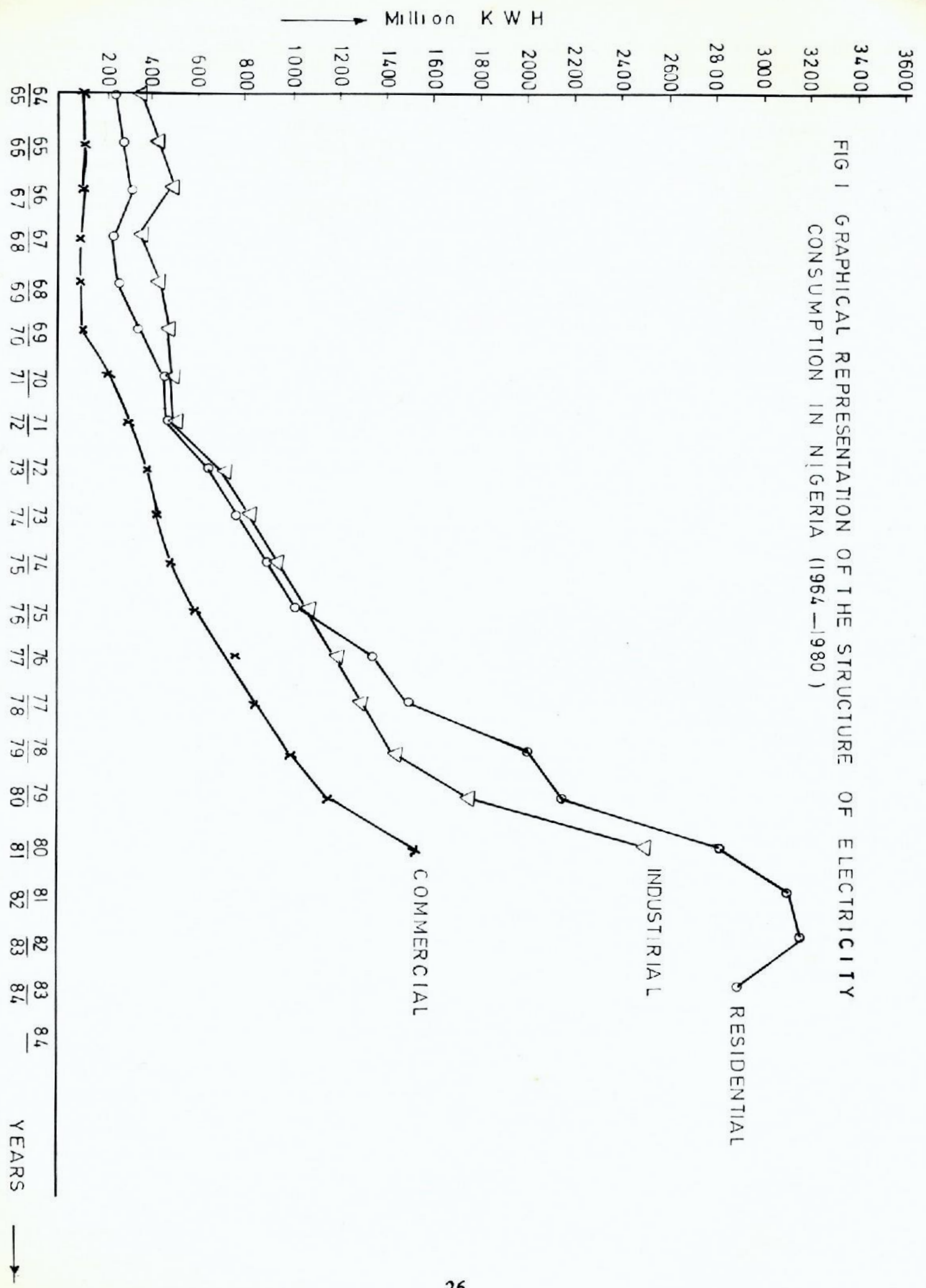


Table 3 The Structure of Electricity Consumption in Nigeria (in Million KWH)

Year	Residential	% of Energy	Commercial	% of Energy	Industrial	% of Energy
1964/65	256	34	112	14.9	384	51.1
1965/66	288	34	127	15	432	51
1966/67	311	32.6	141	14.8	503	52.67
1967/68	239	33.3	102	14.3	376	52.4
1968/69	259	32.7	100	12.6	434	54.7
1969/70	333	36.1	101	10.9	489	52.9
1970/71	445	30.8	243	21.2	459	40
1971/72	471	34.5	301	22	594	43.5
1972/73	634	36.8	391	22.7	729	42.3
1973/74	758	37.1	448	21.9	839	41
1974/75	895	38.4	498	21.36	939	40.27
1975/76	1014	37.5	597	22.1	1096	40.5
1976/77	1357	40.8	771	23.18	1198	36.0
1977/78	2201	41.1	824	22.8	1306	36.1
1978/79	2200	47.16	1003	21.5	1462	31.34
1979/80	2127	42.0	1166	23	1773	34
1980/81	2898	42.0	1517	22	2484	36
1981/82	3105.8	55.2				
1982/83	3135.7	53.0				
1983/84	2861.0	42.0				

Source: NEPA, Lagos

The rate of coolness which can be stored and retrieved in the building structure depends on the density, specific heat and thermal conductivity of the material, convective heat transfer coefficient and the ratio of the heat transfer area to the volume of the thermal storage element. In practice, the selection of the building materials and dimensions are based primarily on the structural and space utilization considerations and not solely on the thermal storage needs for passive cooling. In view of the space allocation and the relative humidity of the air blowing into the building in the hot afternoon weather which could be a source of discomfort to the occupants, the convective heat transfer coefficient with respect to the internal surfaces is often limited. The amount of coolness or thermal energy which can be stored and retrieved in the building mass of many conventional building designs on a daily cycle is limited while experience in the old traditional buildings in the hot regions indicate that walls made of local lateritic materials play the role of regular storage of coolness.

Structural materials of buildings are the most commonly used material for the storage of thermal energy but other materials such as water, pebbles and phase changing compounds are common in the middle-east⁽³⁾. The building structure is cooled at night – internally by circulating the night ambient air through the building and externally by allowing the outside surfaces to loose heat to the air by convection and to the clear sky by thermal radiation. During the day, the cooled internal surfaces provide

lower mean radiant temperature and help provide thermal comfort at higher air temperatures. According to Bahadori⁽⁴⁾, the internal surface temperatures may also be reduced by other methods. The lowest mean radiant temperature of the internal surfaces can be achieved in adobe and unpainted brick structures by keeping the internal surfaces moist and allowing them to cool evaporatively. Various methods which have been devised to condition the air within the buildings include the wind towers and domed roofs with holes in their crowns to increase the air circulation.

The purpose of this study is to compare the thermal comfort level in selected traditional and modern/conventional sandcrete buildings and to theoretically determine the energy consumption from the obtained data.

HEAT FLOW THROUGH WALLS/BUILDING ELEMENTS

In order to determine the thermal comfort level within any building, the process of heat transfer through the building elements by conduction, convection and radiation must be considered since the process of heating or cooling implies a transfer of thermal energy from one region to another by virtue of an existing temperature difference. In conduction heat flow, energy is transmitted by direct molecular communication with appreciable displacement of

molecules. The following three types of conduction are generally recognised.

- (a) **Transient or Unsteady State:** In this case, the rate of heat flow and temperature vary with time. This is partially the situation in most part of the country.
- (b) **Steady State:-** The temperature as well as heat flow rate do not vary with time. Such a state is hardly achieved in practice except for theoretical modelling.
- (c) **Periodic Heat Conduction:-** The periodic variation of temperature and heat is a common phenomenon and close to what exists in practice in all the climatic zones of the country i.e. – The temperature variation of the outside environment during a twenty four hour cycle is sinusoidal. The periodic variation of the outside temperature results in periodic temperature distribution and heat flow through the elements of a building structure. Periodic heat flow is of importance in air-conditioning instrumentation and process control. Convection is the process of energy transport by the combined action of heat conduction, energy storage and mixing motion which results in convective currents that are set up and are crucial factor in achieving natural ventilation. Radiation is the process by which heat flows from a body at a higher temperature to a body at a lower temperature when the bodies are separated in space – depending on the nature of the surface. In practice, the surface of building element like a wall or roof is in contact with environmental air on its either side. In this layer of air, convective currents are set up so that there exists a convective resistance. These surface resistances set up a temperature drop at the surface – hence the need for sol-air measurement. For a typical solid mud wall shown in Figure 2

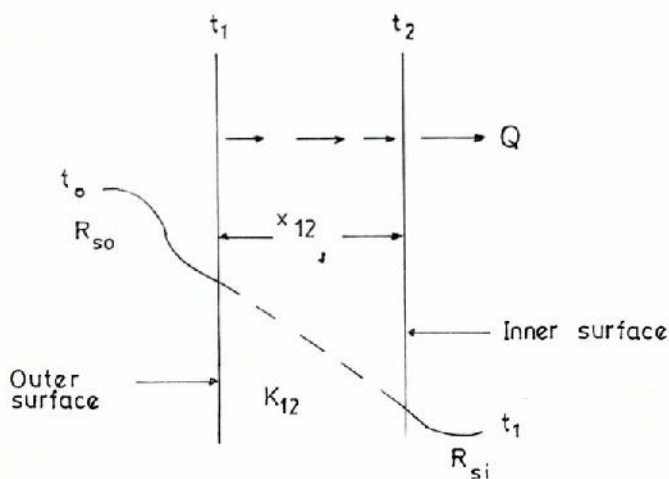


Fig. 2: Heat Transfer Through a Solid Wall

Figure 2: Heat Transfer Through a Solid Wall

The heat transfer due to both convection and radiation put together at the surfaces is given by the expression.

$$Q = \frac{(t_i - t_1)}{\frac{1}{A(h_{ri} + h_{ci})}} = h_{si} A (t_i - t_1) \dots (1)$$

Where h_{si} = Surface conductance at the inner surface

$$(W/m^2 \text{ } ^\circ C)$$

$$= (h_{ri} + h_{ci})$$

h_{ri} = Radiative heat transfer co-efficient at the inner surface ($W/m^2 \text{ } ^\circ C$)

h_{ci} = Convective heat transfer co-efficient at the inner surface ($W/m^2 \text{ } ^\circ C$)

If 'U', is the overall heat transfer co-efficient of the system or thermal transmittance, then

$$Q = UA (t_i - t_o) \dots (2)$$

where

$$UA = \frac{1}{\frac{1}{h_{si}A} + \frac{x_{12}}{k_{12}A} + \frac{1}{h_{so}A}} \dots (3)$$

The surface resistances are quite prone to variations of environmental conditions. Air movement and inside temperatures often affect the values of h_{si} . Excessive air movement over the surface – typified of the situation during harmattan, tends to increase h_{si} . An Radiative heat transfer depends on roughness, colour and emissivity of the building material surfaces while excessive wind speed increases the value of h_{so} . Exposure of the surface and its orientation all affect the h_{so} values. In general, the surface resistance R_s is a function of the radiative heat transfer coefficient, h_r , the convective heat transfer coefficient, h_c and the emissivity factor, E, and it is given by equation

$$R_s = \frac{1}{E h_r + h_c} \dots (4)$$

The outside surface resistances for walls are computed on the assumption that wind speed at two-thirds of those at the roof surfaces are appropriate. Solar radiation intensity on any wall may be obtained from the radiation data on any horizontal surface⁽⁵⁾

$$I_{ji} = R_{bji} I_{bh} + \frac{1}{2} I_{dh} + \frac{1}{2} \rho_{gr} I_h \dots (5)$$

where subscripts b and d refer to the beam and diffuse components, I the solar radiation and h to the horizontal surface.

R_{bji} can be determined from the knowledge of the sun angles

$$I_h = K_T I_{oh} \dots \dots \dots (6)$$

$$K_T = (a + b \cos w (t-12)) K_T \dots \dots \dots (7)$$

$$I_{oh} = I_{sc} \left(\frac{+ 0.33 \cos (360N)}{365} \right) \cos Q_z \dots \dots (8)$$

$$a = 0.409 + 0.5016 \sin (w_s - 60) \dots \dots \dots (9)$$

$$b = 0.6607 - 0.4767 \sin (w_s - 60) \dots \dots \dots (10)$$

$$w = \frac{2\lambda}{24} \text{ OR } 15^\circ/h \dots \dots \dots (11)$$

The ratio of diffuse to total radiation on a horizontal surface can be obtained from^(5,6).

$$\frac{I_{dh}}{I_h} = 1 - 0.249k_T \text{ for } K_T = 0.35 \dots \dots \dots (12)$$

$$\frac{I_{dh}}{I_h} = 1.557 - 1.84 k_T \text{ for } 0.35 k_T = 0.75 \dots (13)$$

$$\frac{I_{dh}}{I_h} = 0.177 \text{ for } k_T = 0.75 \dots \dots \dots (14)$$

Radiation and convection take place across the air space within the sandcrete walls or blocks, hence can be treated as media with thermal resistances and such depend on the surface emissivity, thickness, direction of heat flow, inclination of airspaces, temperature conditions and whether ventilated or not. The air gap resistance of the sandcrete block incorporates three components – the interface resistances shown dotted in Figure 3 – and the resistance of the thickness of the solid concrete portions. Therefore, the total resistance is given by the relationship:

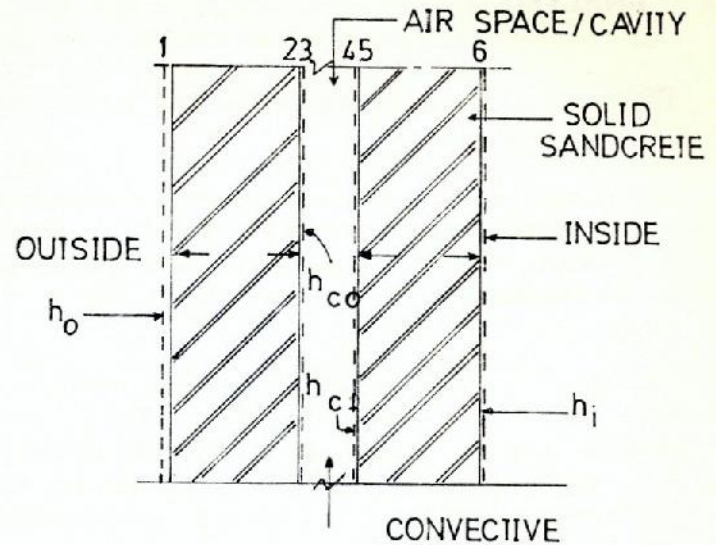


Fig. 3: Heat Transfer Through a Block Wall

Figure 3 : Heat Transfer Through a Block wall

$$R_{total} = R_i + R_{12} + R_a + R_{56} + R_o$$

$$= \frac{1}{h_{si}A} + \frac{x_{12}}{k_{12}A} + \frac{x_{56}}{R_a + K_{56}A} + \frac{1}{h_{so}A} \dots \dots (15)$$

Where R_a is the air space resistance.

When a pitched roof is combined with a flat ceiling, the thermal transmittance per unit area of a ceiling should be assessed by determining the thermal resistance of the sloping portion, R_s , (inclined surface to outside) which should be computed by adding the thermal resistance of the material, R_m , including the air-space resistance, R_{ar} , to the outside surface resistance, R_{so} , such that

$$R_s = R_{so} + R_m + R_{ar} \dots \dots \dots (16)$$

Similarly, the R_s for the flat ceilings should be calculated and added to the thermal resistances of the loft space, R_{sp} , the ceiling, R_{ce} and that of the inside surface, R_{si} . The thermal transmittance, U, can now be equated as

$$UA = \frac{1}{R_s \cos \alpha + R_{sp} + R_{ce} + R_{si}} \dots \dots (17)$$

ANALYSIS OF THERMAL PROPERTIES OF BUILDING TYPES A AND B

TYPE A

The walls were constructed of sandcrete blocks which is a physical mixture of sand, cement and water in varying proportions. The thermal conductivity values vary between $0.88 \text{ W/m}^\circ\text{C}$ and $1.40 \text{ W/m}^\circ\text{C}$ depending on the ~~pre-mix~~ sand cement ratio and the degree of compaction or density.

Corrugated asbestos roofing sheets having a k value of about $0.6 \text{ W/m}^\circ\text{C}$ were used with 13mm timber boarding. The external and internal surface conductance values were 22.8 and $9.5 \text{ W/m}^2^\circ\text{C}$ respectively. The windows were glazed with plain glass, an average emissivity value (low temperature radiation) of about 0.90 was assumed. The heat input through glazed windows could be calculated by using appropriate equations depending on the total surface area, the degree and angle of solar radiation.

$$Q_r = k_f I_G A_g \dots\dots\dots (18)$$

where

Q_r = Alternating heat input due to solar radiation

k_f = Alternating solar gain factor

I_G = Alternating global irradiance on vertical surface

A_g = Exposed glazed area (m^2)

TYPE B

The wallings were of mud; which essentially composed of clay and the thermal conductivity varies between $0.50 \text{ W/m}^\circ\text{C}$ and $0.90 \text{ W/m}^\circ\text{C}$ usually depending on the thickness and the degree/method of compaction. Aluminium roofing materials which

normally have a reflectivity (solar radiation) value of about 0.8 when new, were used. However, the reflectivity value of this material decreases rapidly with age and/or weather/degree of exposure. The ceiling was constructed with dry raffia palm which is a natural insulator having average thermal conductivity values of between 0.124 and $0.207 \text{ W/m}^\circ\text{C}$. The small/narrow windows were constructed of timber/wood.

EXPERIMENTAL TECHNIQUES

Building and Climatological Survey: The sandcrete building (thereafter referred to as Type A) indicated in Figure 4 was completed recently for the post graduate school at Obafemi Awolowo University while the mud building (thereafter referred to as Type B) shown in Figure 5 is an old residential building located at the centre of Ile-Ife town which lies along latitude 07.28°N and longitude 04.33°E in the warm-humid region of Nigeria. A typical data on the two buildings is shown on Table 4. The air-conditioners shown in the Figure were switched off during experimental periods.

Various instruments were used to measure the environmental parameters such as the air velocity, solar radiation, in-door and out-door temperatures, external and internal roof and wall temperatures and other parameters. Measurements were taken over a long period but the indoor temperatures were measured in an East-facing room in each building.

Data Collection: Relevant data about the weather conditions in Ile-Ife (a typical result is shown in Table 5) were collected with various equipments loaned from the Geography Department and the meteorological centre. The daily sunshine hours were recorded at two-hourly intervals over a three-month period using the sun-shine recorder while a bimetallic actionograph was also used briefly to collect the daily solar radiation. A self recording rain gauge was installed for recording the rainfall and the air velocity readings in the rooms were carried out with the aid of an anemometer.



Figure 4 "Type A Building



Fig 5 "Type B" Building

TABLE 4: BASIC DATA ON BUILDING TYPES A AND B

Type	Room Size (m)	Window Size (m)	Ventilation	Walls and Finishes	Roof
A	6.0 x 3.3 x 3.0	1.50 x 1.20	Cross ventilation when windows are opened. Air-conditioning available	225mm thick sandcrete wall, plastered and painted internally and externally	Asbestos cement sheets and 13mm timber boarding
B	5.7 x 3.3 x 3.0	0.7 x 0.4	Cross ventilation when windows are opened	300mm thick mud-wall. Not plastered nor painted internally and externally	Corrugated iron sheets and Raffia palm ceiling

TABLE 5

WEATHER CONDITION IN ILE-IFE IN MARCH 1987

Day	mm Rainfall	0900GMT		Relative Humidity %		Vapour Pressure (mb)		1500GMT		Sunshine Hours
		W.B.T.	D.B.T.	0900GMT	1500GMT	0900GMT	1500GMT	W.B.T.	D.B.T.	
1	0.0	22.5	26.0	73.0	34.0	24.5	20.3	24.0	36.0	0.0
2	0.0	22.5	27.0	66.0	26.5	23.6	16.5	23.0	37.5	6.8
3	0.0	24.0	25.5	88.0	37.0	28.5	22.5	25.0	36.5	7.0
4	0.0	24.0	27.0	68.0	37.5	25.2	23.5	25.5	37.0	8.0
5	0.0	25.0	29.0	71.0	34.5	28.5	25.0	26.0	37.0	7.3
6	0.0	25.5	28.5	77.5	43.5	30.2	26.6	26.5	36.5	6.8
7	14.0	25.5	28.5	77.5	40.0	30.2	25.7	26.5	37.5	6.8
8	0.0	24.5	26.5	84.0	43.0	29.2	25.6	26.0	36.0	7.5
9	0.0	25.5	26.5	92.0	60.0	32.0	27.8	25.5	31.5	3.5
10	3.5	24.0	26.5	80.5	50.5	28.0	25.4	25.0	33.0	5.5
11	0.0	23.0	26.5	73.0	46.0	25.4	24.5	25.0	34.0	5.8
12	0.0	25.0	29.0	71.0	49.0	28.5	26.9	26.0	34.5	7.8
13	0.0	25.0	29.0	71.0	49.5	28.5	27.8	26.5	35.0	7.0
14	0.7	25.0	29.0	71.0	51.0	28.5	27.3	26.0	34.0	7.5
15	0.0	25.5	29.0	75.0	58.0	30.0	28.5	26.0	32.5	0.8
16	0.0	24.5	26.5	84.0	65.0	29.2	27.7	25.0	30.0	0.0
17	0.0	24.5	28.0	74.0	48.5	28.0	25.0	25.0	33.5	5.5
18	1.1	25.0	28.5	74.0	51.0	28.8	27.3	26.0	34.0	4.5
19	0.0	25.0	30.0	65.0	43.5	27.7	26.6	26.5	36.5	6.8
20	10.5	25.5	27.0	88.0	42.0	31.5	26.2	26.5	37.0	6.7
21	2.5	23.5	25.5	85.0	70.0	27.8	26.6	24.0	28.0	0.0
22	0.0	25.0	27.0	85.0	60.5	30.0	28.8	26.0	32.0	4.0
23	0.0	25.0	27.5	81.0	60.0	29.6	27.8	25.5	31.5	6.0
24	0.0	25.0	27.0	85.0	50.5	30.0	25.4	25.0	33.0	8.5
25	0.0	23.5	26.5	77.0	49.0	26.6	26.9	26.0	34.5	2.8
26	0.0	25.0	28.0	77.5	51.0	29.4	27.3	26.0	34.0	1.0
27	4.2	24.5	28.5	71.0	48.5	27.5	25.0	25.0	33.5	3.0
28	3.5	25.0	25.5	96.0	85.0	31.5	30.0	25.0	27.0	0.0
29	0.0	24.0	27.5	74.0	67.0	27.0	29.2	26.0	31.5	5.0
30	0.0	23.5	27.0	73.0	65.0	26.0	27.7	25.0	30.0	0.0
31	0.0	23.5	26.0	80.0	48.5	27.0	25.8	25.5	34.0	6.0
mm	40.0	758.5	849.5	2408.0	1565.5	878.4	807.2	790.5	1048.5	147.9
mean	1.29	24.5	27.4	77.7	50.5	28.3	26.0	25.5	33.8	4.9

THERMAL PROPERTIES OF SANDCRETE AND MUD BUILDING ELEMENTS

Sandcrete is a physical mixture of sand, cement and water in varying proportions. The thermal conductivity values may vary between $0.68 \text{ W/m}^{\circ\text{C}}$ and $1.40 \text{ W/m}^{\circ\text{C}}$ depending on the pre-mix sand/cement ratio and the degree of compaction OR density.

Mud is essentially composed of clay and the thermal conductivity varies between $0.50 \text{ W/m}^{\circ\text{C}}$ and $0.80 \text{ W/m}^{\circ\text{C}}$ depending on the thickness and the degree/method of compaction.

EXPERIMENTAL RESULT AND DISCUSSION

The experimental results for the two building types are presented in table 6 and Figures 6 and 7. The indoor temperature curve for the buildings is sinusoidal, confirming Badori's mathematical deductions (7) and indicating that the building elements have thermal storage capacity to store the heat as the out-door temperature rises from about 0400h, reaching its peak of about $37^{\circ\text{C}}$ at 14.00h before the gradual decline to a minimum of $24.3^{\circ\text{C}}$ at 0300hr. The buildings emit the stored heat between 2400hr and 0400hr

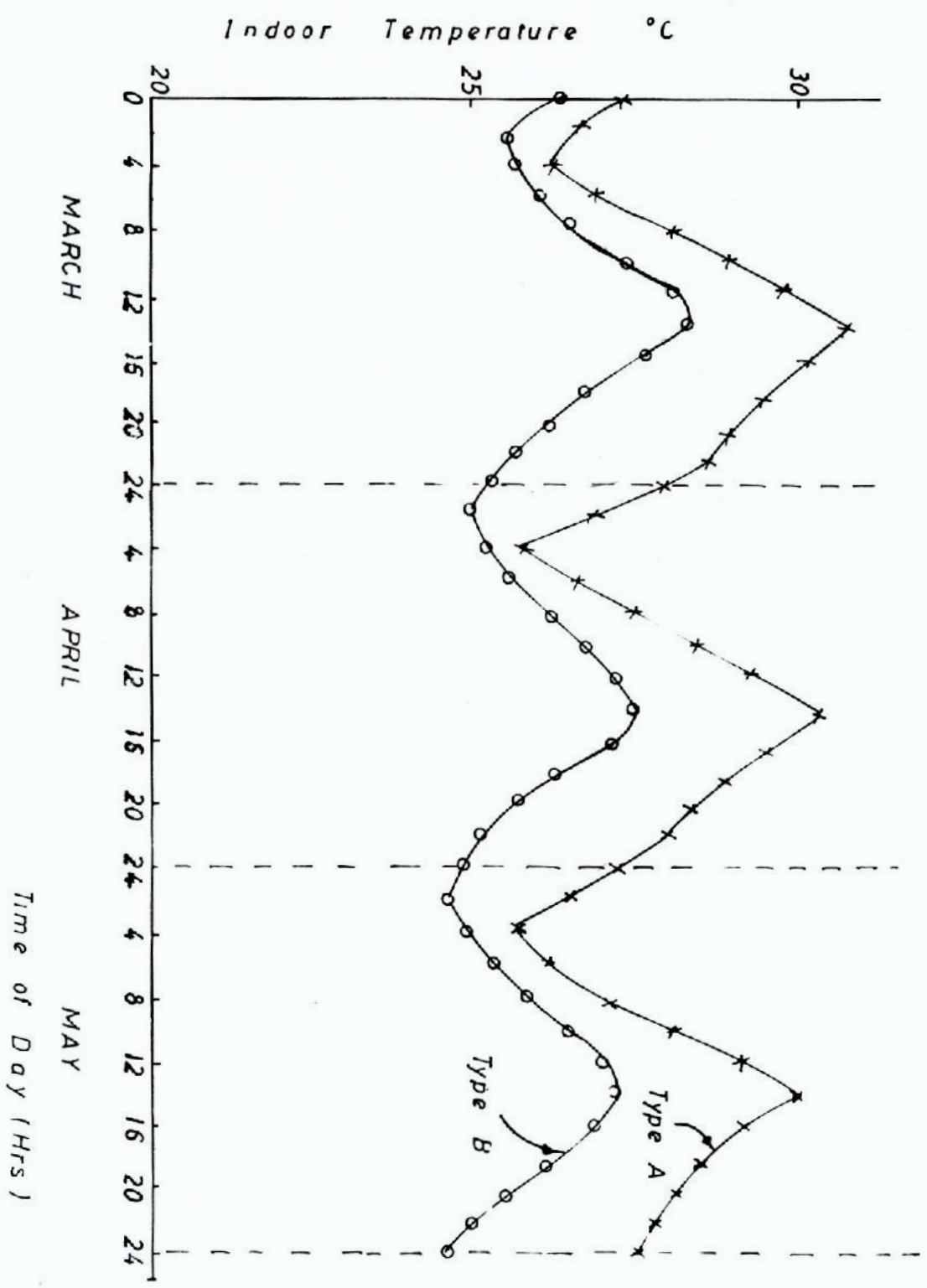


FIG COMPARISON OF MEAN MEASURED INDOOR TEMPERATURES FOR TYPES A & B BUILDING

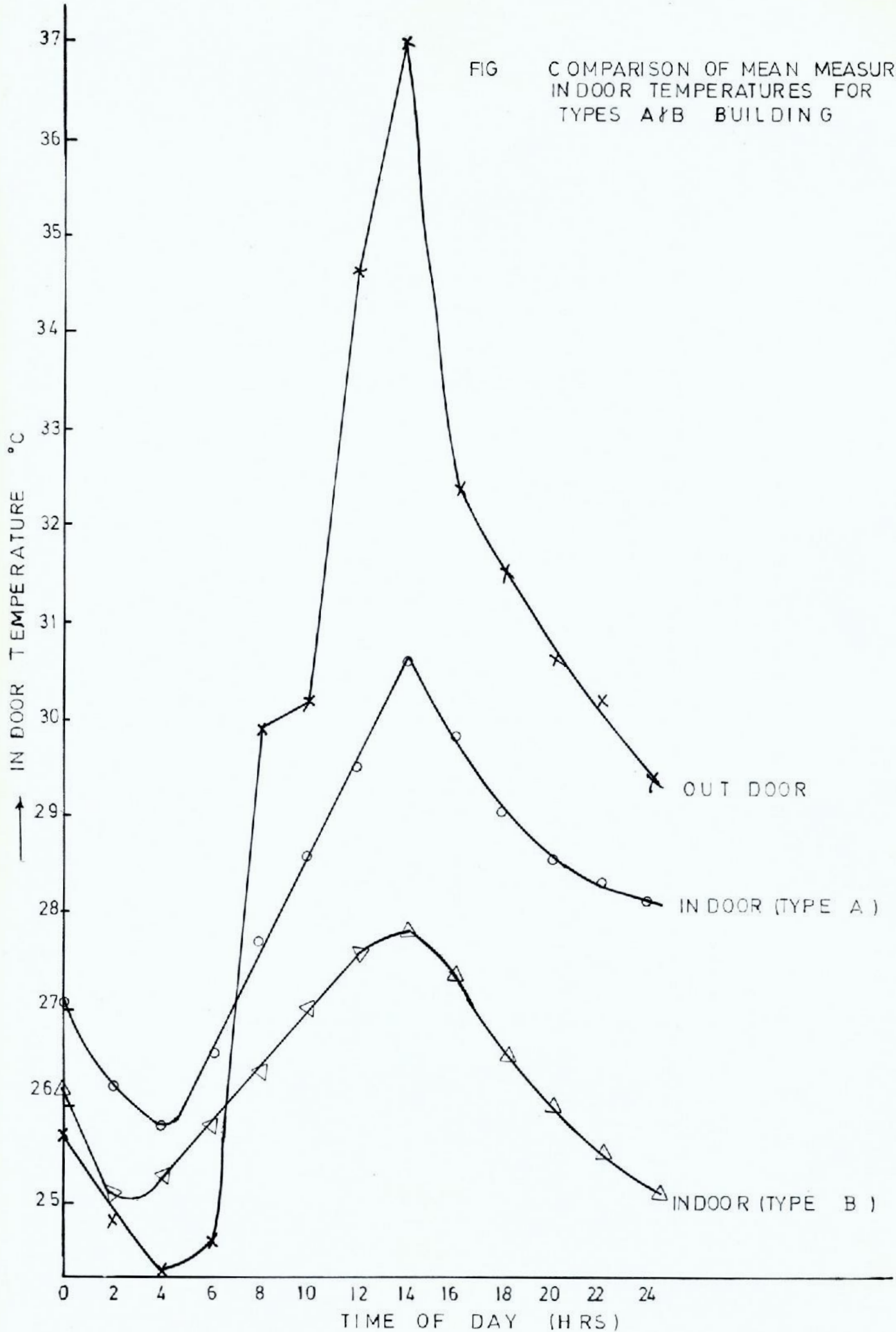


TABLE 6: MEAN VALUES OF DATA ON SANDCRETE BUILDING (TYPE A)

Serial	Time of	INDOOR					OUTDOOR				
		Indoor Temp °C	W.B.T.°C	D.B.T. °C	G.T. °C	Air Velocity (m/s)	Outdoor Temp. °C	W.B.T. °C	D.B.T. °C	G.T. °C	Air Velocity (m/s)
1.	0	27.0	26.7	27.0	27.2	1.40	25.7	24.7	25.8	25.9	2.70
2.	2	26.2	26.1	27.2	27.4	1.35	24.8	24.5	25.6	25.7	2.60
3.	4	25.7	25.3	26.5	26.8	1.35	24.3	23.4	24.7	24.9	2.50
4.	6	26.5	25.5	27.6	27.7	1.30	25.2	24.3	25.5	25.6	2.30
5.	8	27.7	27.6	28.0	28.2	1.25	29.8	28.5	30.2	30.5	2.00
6.	10	28.6	28.2	30.1	30.2	1.00	30.2	29.1	30.6	30.7	1.50
7.	12	29.5	29.1	31.0	31.3	0.80	34.6	30.0	31.2	31.3	1.20
8.	14	30.6	29.8	33.6	33.8	0.40	37.0	32.5	33.7	33.9	1.00
9.	16	29.8	28.2	32.6	32.7	1.00	32.3	31.7	32.6	32.9	1.30
10.	18	29.1	27.6	31.4	31.8	1.10	31.5	30.3	31.3	31.5	1.50
11.	20	28.5	27.5	31.2	31.4	1.20	30.6	29.6	30.1	30.2	1.70
12.	22	28.3	27.0	31.0	31.1	1.30	30.2	28.7	29.6	29.7	2.00
13.	24	28.1	26.4	30.5	30.7	1.40	29.3	27.6	29.4	29.6	2.20

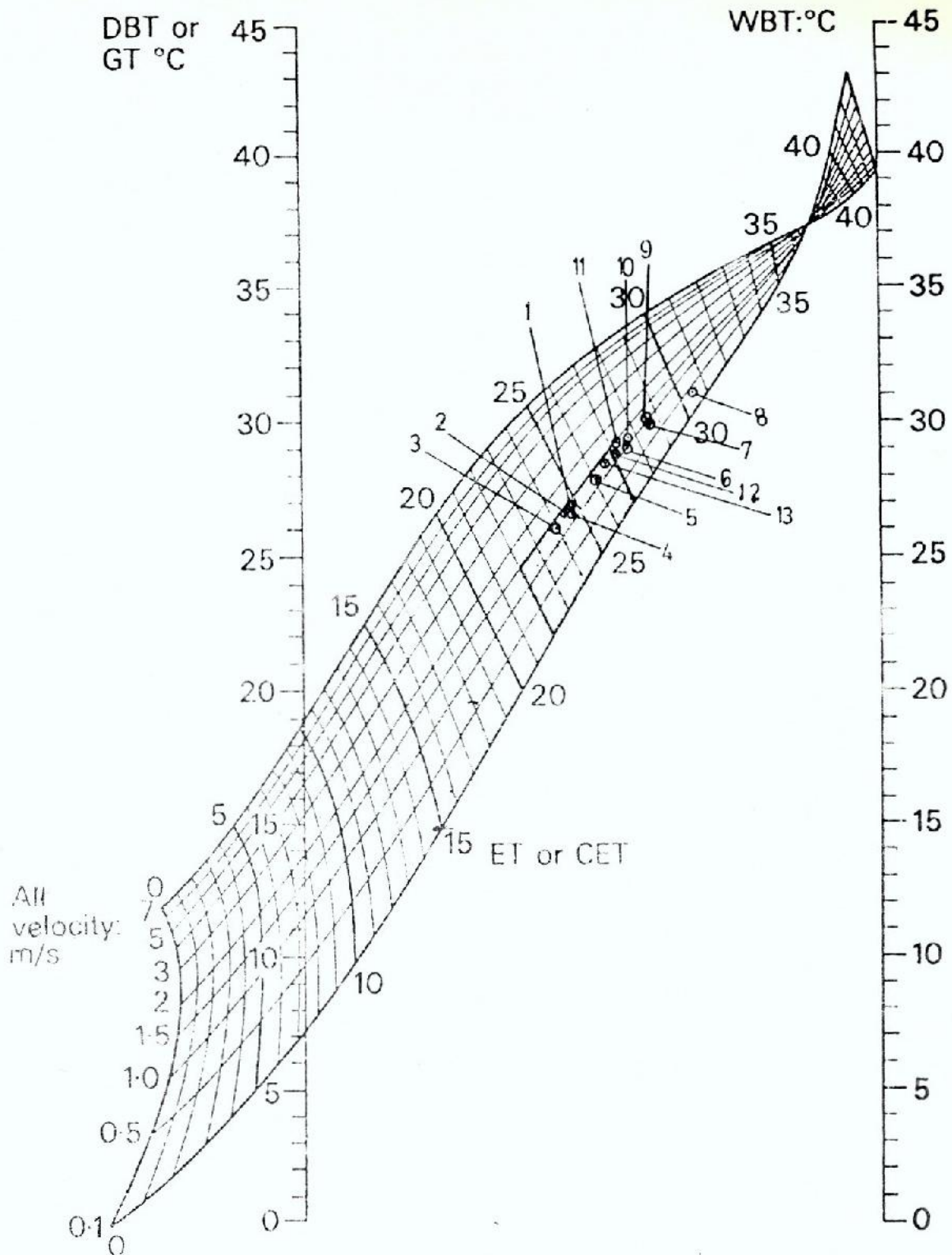


Figure 8: Effective Temperature Nomogram For Persons Wearing Normal Business Clothing (1clo.) in "Type A" Building.

-Comfort Zone is represented by the shaded area.

Source: Bedford, T. "Environmental warmth and its measurement", 1940/1961.

when the outside temperature falls below the indoor temperature. It could be inferred from Figures 6 & 7 and Table 6 that the structural materials of the buildings store thermal energy. The structures are cooled internally at night by circulating the ambient air through the building, and externally by allowing the outside surfaces loose heat to the air by convection and to the sky by thermal radiation. The "light

weight" sandcrete buildings dissipate most of the stored heat faster at night than building Type B resulting in lower mean radiant temperature than maintained during the period of higher insolation and help provide thermal comfort at higher air temperature when the outside temperature falls. It can also be inferred from the figures and tables that the structural elements of building Type B have better

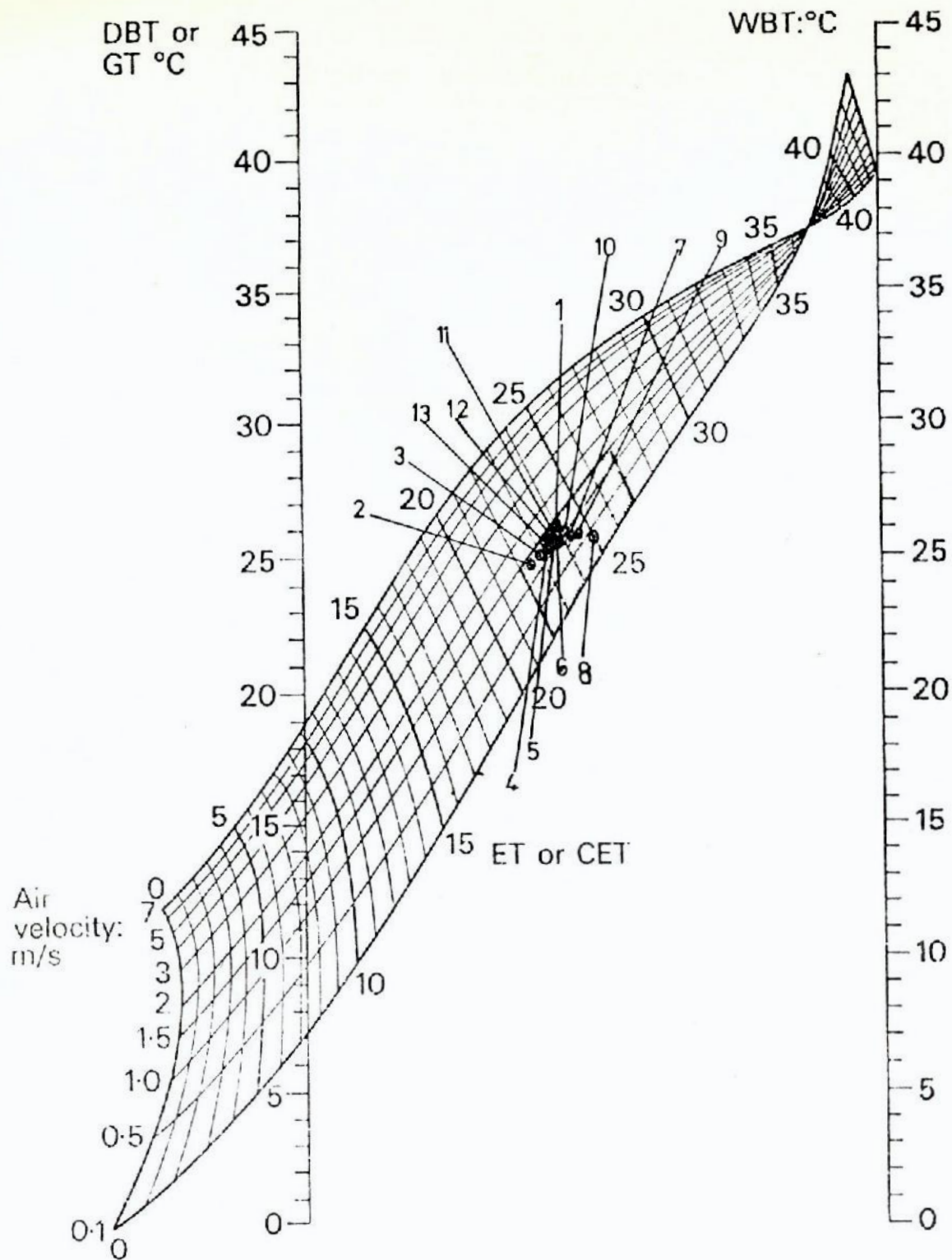


Figure 9: Effective Temperature Nomogram For Persons Wearing Normal Business Clothing (1clo.) In "Type B" Building. -Comfort Zone is represented by the shaded area.

Source: Bedford, T. "Environmental warmth and its measurement," 1940/1961.

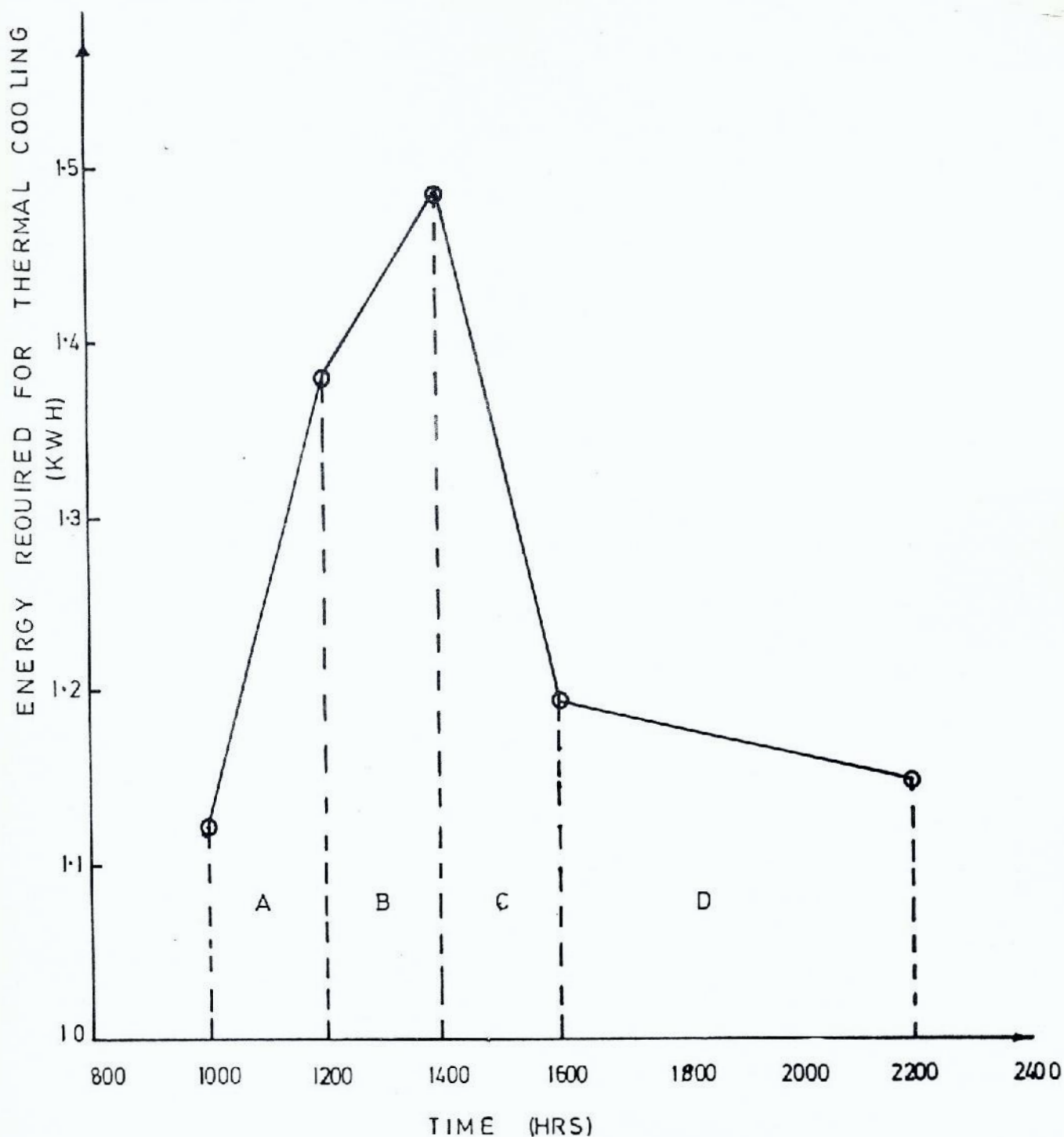
storage capacity, ensuring lower mean temperature than building Type A during the period of high insolation and hence providing better thermal comfort through passive cooling during the hot periods because of adequate time lag or buffer period.

THERMAL COMFORT

The obtained experimental data was used to determine the thermal comfort level in each building type

by using the idea of the corrected effective temperature (CET) established from the dry bulls temperature, d_{bt} , wet bulb temperature, wb_t , and air monogram for persons wearing normal business clothing as described by Bedford (8). The comfort zone lies between 22°C and 27°C C.E.T. and an air velocity of 0.1 and 1.5 m/s. The thermal comfort level on a two hourly basis plotted serially from one to thirteen. Figure 8 shows that the thermal condi-

FIG. 10 GRAPHICAL REPRESENTATION OF ENERGY REQUIREMENT FOR THERMAL COOLING IN BUILDING TYPE A



tion in building Type A was comfortable between 0000h and 0800h and uncomfortable between 1000h and 2400h. The analysis of the questionnaire filled by the residents of this building agreed with the theoretical analysis. The results plotted on Figure 9 shows that building Type B was comfortable throughout the twenty four hour period and the occupants of the building confirmed the acceptability of the result in the questionnaire analysis.

ENERGY CONCEPT

In view of the analysed results which showed that thermal comfort level could only be maintained in building Type A if mechanical ventilation or air conditioners (active cooling) are provided, detailed theoretical analysis was carried out using the data collected on site and assumed data based on the equations deduced earlier. The total energy required

to maintain thermal comfort level in each room per day was estimated as 15.03kW and the two hourly energy requirement is shown graphically in Figure 10.

CONCLUSION AND RECOMMENDATION

The analysis of the obtained field results shows that the thermal performance of the traditional mud building is superior to that of the modern sandcrete building and that the conditions within the latter was

most uncomfortable at the period of higher insolation, thereby requiring active cooling 15.03kW per room. The energy conservation of mud building has been highlighted and it is hoped that the designers, architects, government and other decision making bodies will take advantage of the thermal properties of our local materials during their design specifications for domestic and rural housing-more so when it is now clear that an average Nigerian can hardly pay for the cost of energy consumed for domestic purposes.

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FIGURES

No.

- 1 Graphical representation of the Structure of Electricity Consumption in Nigeria (1964 – 1984)
- 2 Heat transfer through a solid wall
3. Heat transfer through a cavity wall
4. Experimental Sandcrete Building (Type A)
- 5 Experimental Mud Building (Type B)
- 6 Measured Indoor Temperature for Building Types A & B
- 7 Comparison of Mean Measured Indoor Temperature for Building Types A & B
- 8 Effective Temperature Monogram for Persons Wearing Normal Business Clothing (1 clo) in Type A Building.
- 9 Effective Temperature Monogram for Persons Wearing Normal Business Clothing (1 clo) in Type B Building
- 10 Graphical Representation of Energy Requirement for Cooling in a Room in Type A Building

TABLES

No.

- 1 The Structure of Non-Commercial Energy in Some Selected Developing Countries
Source: Ref (2)
- 2 Income and Price Elasticities of Household Energy Demand in some Developing Countries.
Source:
- 3 Electricity Consumption in Industrial, Commercial and Residential Sectors in Nigeria (1964 – 1984)
Primary Source:- NEPA
Secondary Source:- CBN
- 4 Basic Data on Building Types A and B
- 5 Typical Weather Condition in Ile-Ife (March) 1987
- 6 Mean Values of Data on Sandcrete Building (Type A)

LIST OF SYMBOLS

- a A constant defined by eqn. 9
- b A constant defined by eqn. 10
- c Specific heat of the building material ($J/kg^{\circ}C$)
- C_p, C_v Specific heat of air at constant pressure and constant volume ($J/Kg^{\circ}C$)
- D Wall thickness (cm)
- h Convection heat transfer coefficient ($W/m^2^{\circ}C$). Subscripts; i, inside walls; ic, ceiling; if, floor; o, the outside surfaces
- I Solar radiation intensity (W/M^2). Subscripts: bh, beam on a horizontal surface; dh, diffuse on the external surface of wall exposure j (north, east, south and west); jl, total radiation on external surface of wall exposure j; oh, extraterrestrial radiation on a horizontal surface.
- I_{sc} Solar constant ($1353 W/m^2$)
- K_T Mean monthly clearness index
- k Thermal conductivity of the construction material ($W/m^{\circ}C$)
- K_T Hourly clearness index
- N The day numbers ($N = 1$ for Jan. 1)
- R Thermal resistance ($m^2^{\circ}C/W$). For subscripts see definition given for h
- Rbjl Ratio of beam radiation on the external surface of the wall exposure j to that on the horizontal surface.
- t Time, seconds or hours
- Q_z The zenith angle
- P Density of construction materials (Kg/m^3)
- ρ_i, ρ_o Density of inside and outside air (Kg/m^3)
- P_{gr} Reflectivity of the ground surface
- Average Angular velocity of earth rotating around its axis, $15^{\circ}/h$.

NATURAL CONDITIONING AND THERMAL DESIGN FOR BUILDING FOR COMFORT IN DIFFERENT NIGERIAN CLIMATE ZONES.

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ABSTRACT:

This paper is based upon personal experience and research but draws, in the main, on work done with a team of consultants for the standard setting stage of the First I.D.A. Education Project in 1965. Although this is over twenty years ago, the proposals are still valid and relevant to our present day needs.

Three important areas are discussed:

1. Proposed 'comfort zones' for acclimatised people in Nigeria
2. The zoning of the country into areas where similar climatic conditions predominate.
3. Consideration of design and construction within the parameters of Thermal Storage, Air Movement and Solar Heat Control for each climatic zone.

These are illustrated in the form of drawings, tables and photographs at the end of the paper which are also shown as slides in the presentation.

The paper is concluded with a summary of suggested areas for further work.

1. INTRODUCTION

I believe that the reason why I have been asked to present this paper to you today is because I am known for my strong and unwavering support for the "design for climate" school of thought as being necessary to improve living and working conditions in modern Nigeria.

However, before I started to assemble this paper I went back through my own work and many other references after which I reflected upon why all the readily available technology, most of which has been in existence for the past twenty years or more, has been ignored by all but a few designers.

Part of the answer must be that the need for climate control, particularly in housing has not been recognised and in urban environments where over-crowding, dirt and burglars negate any open planning, the window air-conditioner, for those who can afford it, solves the problems.

Another factor is a deep rooted culture much of which lives on today as it was a long time ago and therefore significant changes in our buildings are very much dependant upon a cultural revolution which has yet to emerge in this country.

Also I do not think we can discount the ignorance displayed by designers, of elementary rules of construction in this climate, some of which were well understood by the forefathers. For example, who has remembered the pivoting roofs of Benin? In the 16th century these were employed to deflect the breeze into courtyard houses.

Experience has taught me that, on the whole, Nigeria enjoys a good climate, it could be described as equable having no extremes of heat and cold. In a rural environment natural controls can be used to create comfortable conditions but in urban areas artificial solutions have become a necessity.

However, the starting point of the problem lies not in the design and construction of buildings but in the response of the body to heat stress and we do not have very much statistical information to work on from Africa where living and working patterns are changing to conform with international norms.

Consequently, one has to start from assumptions based upon outside researchers such as Bedford (1948) and more recently Givoni (1969), Bedford (1948) and other researchers concluded that there is no doubt that both mental and physical activities are affected by high temperatures and that human activity depends upon a pleasant and invigorating environment. I am convinced that designers should work more towards this goal, and furthermore that they educate building users about their buildings and how to get the best out of them.

As the title of this paper infers, its scope does not include air-conditioning or other mechanical systems of cooling; although, relatively unsophisticated methods such as fans to create air movement or evaporative coolers to reduce temperature in hot-dry climates are, I believe, necessary and cheap adjuncts to natural conditioning.

2. PROPOSED COMFORT ZONES FOR ACCLIMATISED PEOPLE IN NIGERIA

The human body responds to heat and cold by regulatory senses which control body heat loss through evaporation, radiation and convection.

The apparent range of this response varies between clothed and unclothed persons, (whether or not they are acclimatised), the rate of their metabolism, and their mental state. Many of these and other contributory factors are difficult or almost impossible to measure or quantify. For practical purposes however the nearest approximation of body response to climate can be judged by its reaction to a combination of air movement, air temperature, and radiant heat, either direct or indirect from the sun or from other sources.

It should be noted that air temperature alone cannot be taken as an index of comfort since, for instance, a high temperature may be considered comfortable if not accompanied by a high humidity or high wind movement both of which if taken into account would produce widely differing corrected effective temperatures, and might produce extremely uncomfortable conditions, the higher humidity by preventing heat loss by evaporation, and the higher wind speed by accelerating the effects of evaporation.

I think it has to be explained that Nigerians are not necessarily acclimatised in their own country if they move from one area to another. It is said that the adjustment period for a human body exposed to different climatic conditions is about 30 days (Manual of Tropical Housing & Building) and even then it may not be absolute so that when we move to Jos from Lagos, we must wear additional clothes particularly in the dry season. In other words, the two areas have different 'comfort zones'. From 1965 - 1967, I worked with the team of consultants employed by the Nigerian Government to establish standards for the design and construction of school buildings throughout the Federation (The First I.D.A. Education Project), and our first task was to estimate a comfortable range of temperatures or 'comfort zones' which would be acceptable to users in the various climates of Nigeria.

In the time available it was not possible to sample enough subjects to obtain their reactions to local climatic conditions, however the results of the

sampling were compared with evidence taken in other territories with similar climatic conditions and the resultant limits plotted on the 'Corrected Effective Temperature Scale'. This scale was developed from the 'Effective Temperature Scale produced by Houghton & Yaglou in 1923 which was later corrected to take account of radiation from the environment by Vernon & Warner in 1932.

The 'Corrected Effective Temperature' Scale or CET as it is known is still considered the most practical of the various thermal indices developed in the search for a complete scale. But it is only a guide.

Nigerian Meteorological records which have now been published in the Atlas of the Federal Republic of Nigeria First Edition 1979, (which I commend to the attention of anybody who has not seen it) were used in the computations for the 'Comfort Zones' here.

These zones were defined as follows:-

1. All areas excluding the Jos and Mambilla Plateaus 21°C (70°F) to 25.5°C (78°F) CET
2. Jos & Mambilla 18°C (65°F) to 24°C (75°F) CET

I should point out that I am using these figures only for purposes of this paper in the absence of more up-to-date statistics which are long overdue. This should embody a way of life and include clothing, age and sex, Body shape, State of health, eating habits and even skin colour as well as acclimatisation.

3. THE ZONING OF THE COUNTRY INTO AREAS WHERE SIMILAR CONDITIONS PREDOMINATE

Recently I obtained the NBRI Report No. 4 which was published, I believe, in 1986 and this refers to the IDA Project Report in which I was involved and to which I am referring in this paper. The NBRI report seeks to simplify and resolve for average consumption, the complex variables which influence the design and construction of buildings. Excellent as this is I think I should explain the thinking behind the IDA Report.

Ideally, and to facilitate standardization, we would have liked to have had similar standards for the whole of the country. However, since the climate of Nigeria varies quite considerably from the seaboard to the interior, this was not possible.

As the next step therefore, the climatologist on our team had to establish the various climatic zones where differences would affect building design and construction and to do this the climatic data of twenty-eight representative meteorological stations in the country were studied and used as a basis for demarcating the zones.

The object of having these zones was to achieve a graduated change in building design and construction which reflected the climatic variations throughout the country between the extremes of humid conditions in the South and dry conditions in the North.

It is well known that air movement and thermal storage have the most significant effects on building design and so had the largest influence on zoning procedure. For example, in a warm and humid climate, indoor comfort is dependent largely on the control of air movement and solar heat, and a building must cool quickly after sunset to give maximum night time comfort. On the other hand, in a hot and dry climate there is a considerable temperature variation between day and night.

In these areas it may become so hot during the day that a cooling breeze will turn into a hot, dry wind and create discomfort, but, depending on the number of people in a room and other heat sources, these conditions may be made use of to store the coolness of the night by closing doors and windows during the day, and by making the construction of a building such that it will be slow to heat up while reducing to a minimum the heat being allowed to penetrate through external openings.

There were other factors important enough to influence the zoning boundaries. For instance, the temperature moderating effects of higher ground and the stronger radiation experienced in upland areas made necessary certain modifications to the kind of building design required for the lower surrounding areas, and in the areas of the Niger Delta where the rainfall is high and spread throughout the year, covered circulation between separate buildings becomes a necessity.

Generally, boundaries for climatic zones follow the contours of the number of months that thermal storage may be used in the construction and the criterion for this was taken as being those months which have an average diurnal shade air temperature range of 11°C (20°F) or over.

The number of zones demarcated was 7 and to stress their function they were termed "Climate Building Zones". Zones 1 & 2 in the coastal belt of Nigeria have a period of up to 3 months only when thermal storage could be used and the difference in requirements between them was the amount of rainfall (over 150 rain days) which necessitated covered access, between buildings. The climate here can be described as warm and humid for most of the year. Zones 3 & 7 across the middle belt have a period of between 4 & 5 months when thermal storage could be used, the difference between the two being the upland location of Zone 7 which modified requirements. This climate is warm and humid for about half the year.

Zones 4 & 5 in Northern Nigeria have a period of between 6 & 8 months when thermal storage could be used, the difference between the two being the upland location of Zone 4.

Zone 6, across the Northern boundary of the country has a period of 9 months when thermal storage could be used. The climate of this zone and 4 & 5 is generally described as hot and dry. However, when we reached the point of specifying the standards for the various zones we found that it was necessary only to cover four basic types. The coastal Belt, The Middle Belt, the Northern Belt and the Upland Regions.

4. CONSIDERATION OF DESIGN AND CONSTRUCTION WITHIN THE PARAMETERS OF THERMAL STORAGE, AIR MOVEMENT AND SOLAR HEAT CONTROL

The performance standards for the construction had to be related to the "Comfort Zone" of the occupants of the buildings and the "climate building Zones" in which the buildings were situated. This involved studies of heat flow and thermal storage, air movement and solar heat control.

Design for the climate of the coastal zones was fairly straight-forward but the situation in the northern zones was complicated by the necessity to consider the period during the year when conditions could be similar to the coastal belt. I will revert to this problem later.

(i) *Thermal Storage.* Basically this had to be maximised in the northern zones where the climate is dry and the diurnal temperature range large enough. In the coastal areas however, the minimum storage capacity was required. Heat flow calculations were carried out for each zone to fix the parameter for thermal performance of the construction taking into account the air volumes and occupancies of rooms.

ii) *Air Movement.* During certain times of the year Nigeria is under the influence of two opposing wind systems, — the N.E. dry wind from the desert ('harmattan') and the S.W. moist wind from the Atlantic Ocean. The N.E. Wind is generally associated with the 'dry season' and the S.W. wind predominates in the 'wet season'. Since air movement over the body is required only during the warm/humid season it is the wind during this time that is of interest to the designer.

Wind directions for all months were mapped in order to establish for each location the prevail-

ing wind during the humid season. This was called the "design wind direction" and usually was found to be S.W. with instances of locations where westerly or even north westerly breezes dominated.

In effect this meant that window openings facing due south to obtain the minimum sun-load would be 45° off the wind direction or more in some cases. However, it was found from wind tunnel tests carried out on models that buildings with large shading projections on their elevations; for instance those consisting of extended structural piers and roof overhangs, were extremely tolerant in their orientation to the breeze when these projections occurred on the "inlet" side of the building (the side which is facing the breeze). The tests showed that this profile will retain useful air flow patterns and velocities in rooms even when orientated to as much as 70 degrees from the wind direction. On the other hand, it was found that an elevation without projections facing the breeze is more critical in its orientation, and its flow characteristics begin to deteriorate when it is orientated 30 degrees or more from the wind. In setting standards for the orientation of buildings, we gave the maximum flexibility to the designer and the tests enabled standards to be set accordingly.

In every zone it was necessary to make provision for good breeze penetration of the building. This can only be ensured by single banked planning which entails designing buildings with rooms arranged in single rows with windows in both external walls and not consisting of rooms on either side of an enclosed corridor, also the spaces between the buildings had to be sufficient to ensure the maintenance of cross-ventilation. The standard on this was based on the results of wind tunnel tests of airflow around model buildings carried out by the Texas Engineering Experiment Station.

- (iii) **Solar Heat Control.** It is necessary to control the penetration of windows and other openings by direct solar radiation and the effects of diffuse and sky radiation, also the transmission of solar heat through unshaded walls and roofs.

The shading of windows and walls were calculated from shadow angles derived from solar charts. These charts were reproduced for every meteorological centre in Nigeria approximating to four latitudes 6,8,10 and 12 degrees North and on them we plotted the periods when the CET was expected to exceed the comfort zone in that particular area. From the resulting diagrams it is possible to see the minimum period of time throughout the year during which exclusion of solar radiation is essential. In some instances, this gave the designer more flexibility,

in the orientation of his buildings - particularly in upland regions where the CET for long periods in the mornings and late afternoons are lower than the comfort zone.

The over-riding standard which we established however, was that in all zones windows should be shaded from the direct rays of the sun during working hours.

Solar heat transmission through unshaded portions of the structure is dependent upon the solar reflection value of the outside surface and the transmittance value of the structure and the coefficient of absorptivity of the surface when used in the heat flow calculations in establishing the thermal performance of various constructions proposed.

A factor was established called the "solar heat factor" which was derived from the heat flow in B.T.U./hr./sq.ft equal to a 45°C (8°F) increase in ceiling temperature over ambient air temperature, - a maximum suggested by O. Koenigsberger and Robert Lynn in their book "Roofs in the Warm Humid Tropics".

The maximum heat flow permitted was calculated as $11.4 \text{ BTU/hr./sq.ft}$ and expressed as a percentage of the maximum value of solar radiation received, which in Nigeria may be assumed as $285 \text{ BTU/sq.ft./hr.}$, giving a value for the factor of 4% - the allowable maximum ratio of solar heat entering a room.

This was used as performance standard for roofs in the coastal zones and took into account discolorations of the roof surface so prevalent in the humid tropics particularly in the case of asbestos cement.

In all other zones where external openings might be closed during the daytime for significant lengths of time during the year, we had to give consideration to the heating effect which solar radiation has on indoor air. A detailed study of this suggested that the maximum allowable solar heat factor should be reduced to 3% for the buildings in these zones.

- (iv) **The Northern Belt.** The climate in this zone is complicated by apparently contradictory requirements. For instance, to facilitate cross-ventilation during the humid season, large external openings and extended planning are desirable. Good performance during the dry season, however, requires smaller openings and compact planning. In order to resolve these questions a study was made of the thermal performance of a typical classroom in a typical block.

The classroom was chosen because of its high density of occupation. The most important objectives in the thermal design of this room were:-

First, the maximisation in surface area of surrounding elements having high thermal capacity.

Second, the minimisation of daytime heat entry.

And, third, the construction of external walls and roofs so as to have the correct time-lag of heat transmission.

Against these it had to be remembered that in the humid season the most important objective is to provide large well-placed inlet and outlet openings to assist cross-ventilation.

A synthesis of these requirements was helped by the fact that there is a S.W. prevailing wind during the humid season in Northern Nigeria and the air-flow studies of the model classroom block we did, confirmed that on the outlet side of the room, in other words, the North elevation in most cases, openings could be placed at high level only, provided they were large enough. This enabled a considerable extra area of wall to be gained which would improve dry season thermal storage characteristics.

Advantage was taken of the fact that during the dry, sunny weather of the hot dry season, satisfactory lighting can be obtained with smaller external openings than during the humid season, thus movable opaque insulated panels were introduced into the inlets. Since these would be closed during the daytime in the hot dry season, the amount of heat entering the room at that time would be reduced. The use of insulated opening panels allows openings to remain large while glazing areas incorporated in the opening can be comparatively small.

Calculated predication of room air temperature during the hot dry season were made and it was concluded from these that a classroom designed on the principles outlined, with its walls and roof constructed correctly, would perform satisfactorily during the hot dry season.

This led to a type of construction which was known as "heavy construction" which, related to an external wall or roof, was a term used to denote the fact that it had a long time lag, usually 8 hours or over.

It has been established (Bruckmayer) that a long time lag may be obtained in a wall or roof by using a composite construction consisting of a light insulating layer outside and a heavy dense layer inside. In fact, a performance similar in many respects may be obtained from a 300mm wall of solid masonry combined with one consisting of 50mm of a material such as expanded polystyrene. This fact is of importance in Northern Nigeria where cement and aggregates for concrete are expensive.

The parameter for the performance of "heavy construction" is the "time constant" which is a measure of thermal response which may be calculated directly from the materials and construction used. A time constant giving a time lag of 8 hours was used for external elements of appropriate rooms in parts of the country where thermal storage was of significance. Time constant factors elsewhere could be kept to a much lower figure, in the region of three to four hours.

The success of the construction proposed for the hot/dry/warm/humid climate depends, of course, on the building being used correctly. During the hot dry season, when the shade temperature exceeds the maximum 35°C (95°F) it is advisable to close the major openings to the rooms both occupied and unoccupied at around 10.00 am in order to keep them cool. Apertures may be opened as soon as the inside air temperature exceeds that outside which is usually about 8.00 or 9.00 p.m.

At least half the openings should remain open throughout the night for full effectiveness for the technique and for this reason we recommended the use of security protection on those windows to be left open.

Having said that windows should be kept closed for long periods during the day, it should not be forgotten that for hygienic reasons there had to be some ventilation, and we reckoned that this could be limited to 5 air changes per hour for a full classroom which would prevent excessive heat transmission from the outside. The method which we proposed for regulating the airflow at these times was to keep the size of such inlet openings as small as possible.

(v) **Presentation of the Comfort Standards**

Having completed what we considered to be the most important areas of research to enable standards of design and construction to be established the next stage was to set out the standards in such a way that they would be easy

to assimilate, at the same time providing sufficient flexibility for the individual designer to offer a solution out of a range of possibilities.

We were wary of insisting upon too much standardisation of components in view of the co-ordination problems throughout the country and the capacity of the construction industry and this policy led us away from the temptation of offering complete design recipes. Instead, we relied on the laying down of mandatory standards backed by some "deemed to satisfy solutions" and as an appendix to the standards we provided the necessary information for designers to work out their own solutions such as the application of methods of checking solar screens and investigations carried out on local brickwork in order to assess its compatibility with the 'standards'. A study in local brickwork was carried out by my office for projects on which we were acting in an executive capacity, and an interest in this material re-vitalised a dying craft in the area and improved the standard of manufacture at a time before proper clay industries had been established.

As far as possible these standards were related to the building elements, each element being considered in terms of air-movement, thermal storage requirements and solar heat control to provide an integrated solution suitable for the particular "climate building zone".

It should be remembered that these so-called comfort standards had to be related in particular to the planning and construction standards as we expected designers to take them into account at every stage of the design process of the buildings.

My own office, acting in an executive capacity, prepared a brief from the 'comfort standards' for the particular localities where they were involved. This provided a quick visual reference for checking design and construction.

(vi) Daylighting & Colour

Daylighting and Colour have an important influence on the thermal performance of buildings but at the time of this report, not enough was known about these factors in the tropics and I believe that some additional work still needs to be done, although, Givoni and O. Koenigsberger have published more information recently.

However I will mention some of the salient points in the IDA report: Generally, the total daylighting reaching a point in a room is the sum of the following components:

- a) Direct sunlight component – the sunlight entering an opening.
- b) The sky component – the light received directly from the sky.
- c) The externally reflected component – the light received after reflection from the ground, buildings and other surfaces.
- d) The internally reflected component – the light received after being reflected from surfaces inside the room.

In evaluating natural daylighting for IDA buildings it had to be assumed that the main objective was to exclude as much solar radiation as possible which would, of course, conflict with the daylight requirement.

We held discussions with specialists on the particular problem of daylighting in the tropics but it was impossible to be definite about any requirements partly because the design conditions of the sky in Nigeria are not known and therefore it is impossible to make any calculations of the daylight components reaching the room.

Hot-dry Climates

We were able to ascertain that in a hot-dry climate accompanied by cloudless skies the brightness of the light source at mid-day could be as low as 500 foot-lamberts. However, the reflectance from other sources near the ground is considerable and assuming a ground reflectance of 20% and a perpendicular sky illumination of 10,000 lumens/sq. ft. Under these circumstances the externally reflected component is of over-riding importance in daylight calculations.

Hot-Humid Climates

It has been estimated that the frequently overcast skies associated with hot-humid climates can be very dull, down to 250 feet-lamberts or less. If the cloud cover is thin the sky can be very bright giving rise to high radiant heat values. Under these circumstances sunshading devices which exclude direct sunlight only, are ineffectual against glare and heat. To partly overcome this we decided to use the recommendations put forward for schools in (what was then) Northern Rhodesia in 1961 which give a minimum angle of cut off to the eaves from the nearest desk to the window of 45 degrees.

We concluded that there could be sufficient reflected daylight during the greater part of the time that the school rooms are in use, but accepted that at certain times supplementary artificial lighting would have to be used.

Colour

We made some suggestions about colour and more particularly in connection with obtaining satisfactory solar heat factors when considering external colour schemes or where we were relying upon the interiors of the classrooms to provide a reflective surface to enhance the lighting from the small areas of glazing proposed.

5. SUGGESTED AREAS FOR FURTHER WORK

- (i) I believe that the present 'ad hoc' approach to the design of our less prestigious buildings which are nevertheless important, such as housing is not contributing to the health and efficiency of the population.
- (ii) We need statistical information on the reactions of people in the built environment in the various climates of Nigeria in order to establish comfort zones upon which criteria can be based for the design and construction of buildings to suit various functional needs.
- (iii) Many of the standards proposed in this paper are theoretical only and many buildings were built employing them, however, we need to make a detailed investigation on whether they performed as designed and whether the thermal conditions were acceptable to users. Also comparisons need to be made with 'ad hoc' and traditional forms.
- (iv) More work is required on solar radiation in Nigeria and finally
- (v) The application of natural conditioning must be examined for urban areas in the light of noise levels, atmospheric pollution and security.

ILLUSTRATIONS

FIG. 1 **Body Heat Loss.** This diagram constructed from the research work of Houghton shows the degree of heat loss under varying humidities for working subjects. It illustrates the significance of evaporative loss in bodily adjustments in high temperature.

FIG. 2 **Effective Temperature Chart.** This shows the comfort zone proposed for Plateau region (blue) and other regions (red) compared with that proposed by O. Koenigsberger

FIG. 3 **Equatorial Comfort Index.** Graph constructed from subjective sampling giving Climatic Optimum Temperature (G. Webb).

FIG. 4 **Solar/Comfort Chart for Jos.** This illustrates the use of the solar chart to show the period during the year when the comfort zone is exceeded (the overheated period).

FIG. 5 **Nigeria — Climate Building Zones.** This illustrates the seven zones proposed which for the purposes of construction standards were re-grouped into four zones.

Zone 1 & 2	Coastal Belt
Zone 3	Middle Belt
Zone 4 & 7	Upland Regions
Zone 5 & 6	Northern Belt

Note however that the months of thermal storage vary.

FIG. 6 **IDA Project — Location Check.** Basic data provided before proceeding to design and construction. Indicates Climatic Building Zone, Solar/Comfort Chart, Design wind, relative solar time.

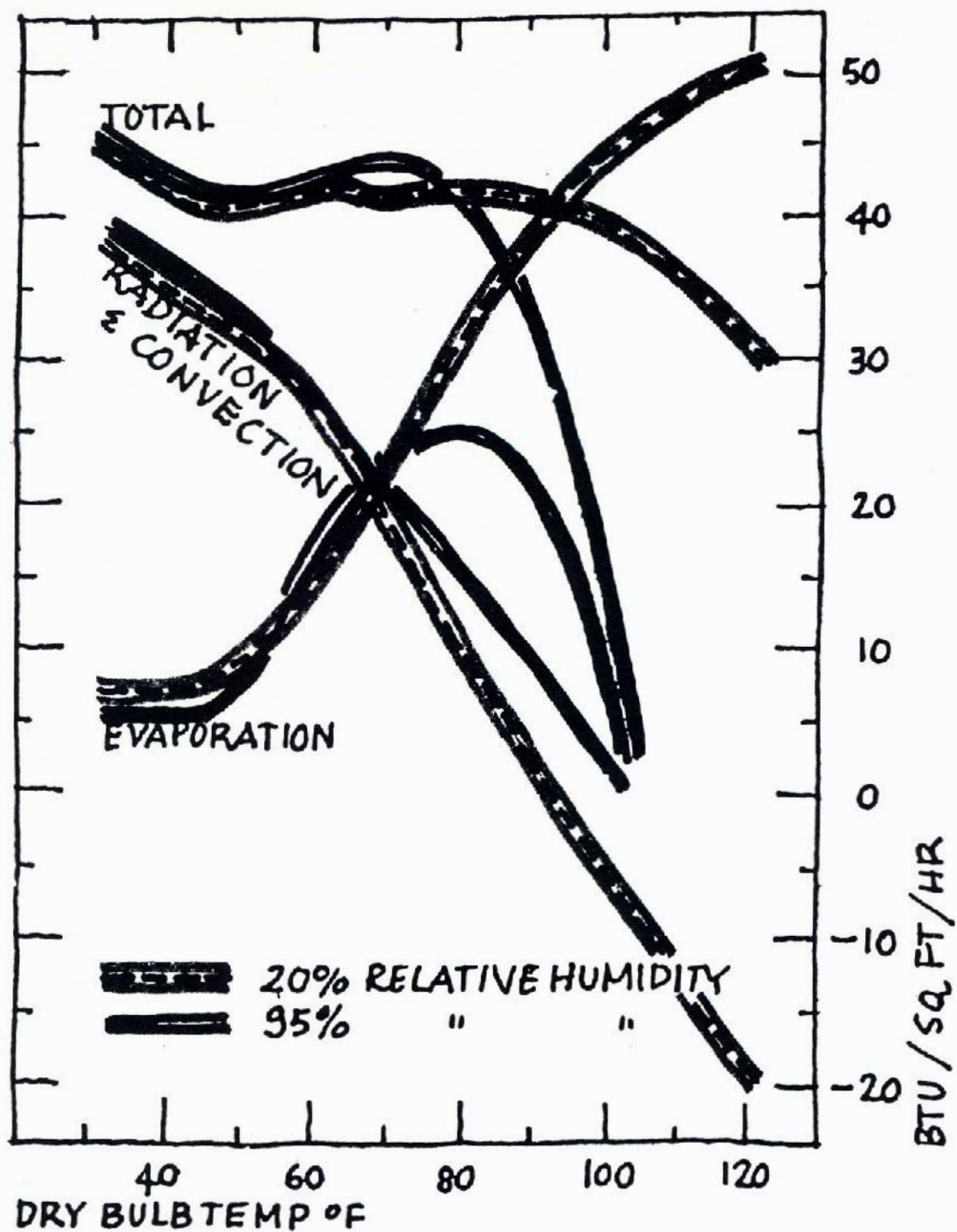
FIG. 7 **IDA Project — Site Layout Check.** Orientation of inlet walls of buildings to wind direction. 70° angle gives reduced air flow if the elevation is flat.

- FIG. 8 **IDA Project -- Site Layout Check.** Building spacing for unimpeded breeze distribution for different building heights and profiles
- FIG. 9 **Air-Flow Around Buildings.** Texas Engineering Experiment Station wind tunnel tests on buildings of various profiles (Tests 2 & 4).
- FIG. 10, 11, 12, **Housing at Warri.** Planning indicates application of IDA standards (Godwin & Hopwood)
- FIG. 13 **IDA Project -- Site Layout Check.** Obstructions to breeze flow and provision of covered ways.
- FIG. 14 **IDA Project -- Planning Design Check.** Room and Corridor/verandah arrangement. Double banking of rooms along a central corridor not permitted.
- FIG. 15 **IDA Project -- Planning & Design Check.** Permitted reduction of window opening in inlet walls on plan.
- FIG. 16 **IDA Project -- Planning & Design Check.** Sizes and disposition of windows on inlet and outlet walls—Example for Northern Belt (Zones 5 & 6)
- FIG. 17 **IDA Project -- Planning & Design Check.** Ceiling heights. The height between the ceiling and a ceiling fan should not be less than 750mm for efficient operation.
- FIG. 18 **IDA Project -- Planning & Design Check.** These illustrate the amount of overhang (shown in feet) for various overhangs in Zones 5 & 6 for external walls 10'0" (3m) high with projectivity plan construction 6'0" (1.8m) centres. The most economical orientation for openings is N/5.
- FIG. 19 **IDA Project -- Planning / Design Check.** Sky glare cut-off and solar heat factor on shaded walls.
- FIG. 20 **Secondary School -- Maiduguri** Photograph illustrates IDA Proposals (Zone 5 & 6)
1. Planning for breeze
 2. Sunshading
 3. Cavity wall construction on west wall using light coloured local brick
 4. Solid panels in windows
- (Godwin & Hopwood)
- FIG. 21 **IDA Project -- Construction Check.** Floors in Zones 5 & 6 need to be of dense material to take advantage of the 'fly-wheel' effect of day and night temperatures.
- FIG. 22, 23 **IDA Project -- Construction Check.** Deemed to satisfy constructions meeting the requirements for Heat flow (solar heat factor) Transmittance ('U' value). Time lag expressed as the 'Time Constant' which is a factor not the actual hours. Note requirements for 'heavy' and 'light' constructions depending upon the function of the building space.
- FIG. 24 **IDA Project -- Construction Check.** Internal walls in Zones 5 & 6 need to be of dense material. In other zones they should be as light as possible.
- FIG. 25 **Offices in Lagos -- Roof Construction.** Comparison of the thermal properties of a concrete slab and a lightweight insulated roof on the same building, measured simultaneously. (Godwin & Hopwood)

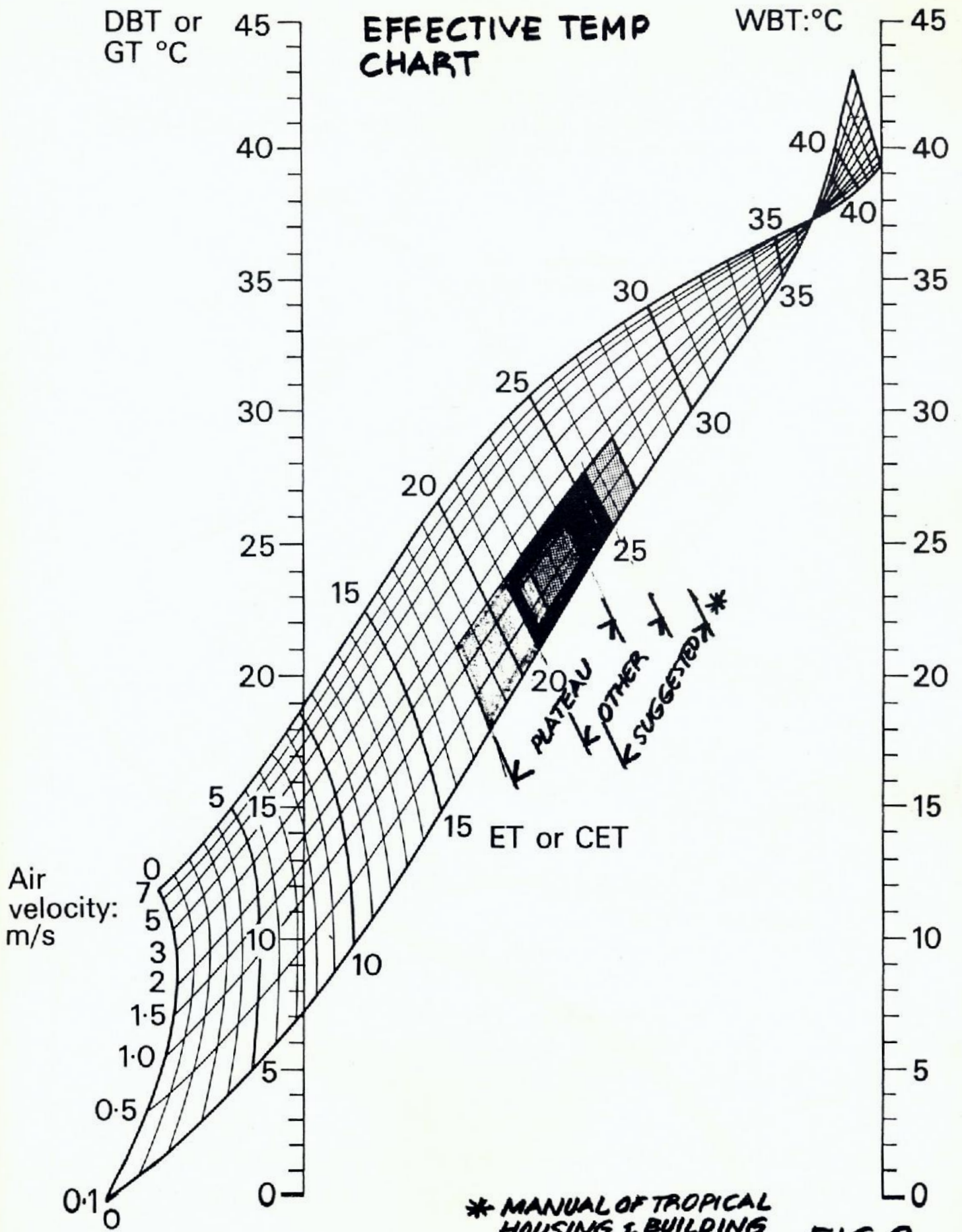
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BODY HEAT LOSS



BODY HEAT LOSSES OF CLOTHED SUBJECTS WORKING UNDER VARYING TEMPERATURES & HUMIDITY (AFTER HOUGHTEN 1929 & 1931)



* MANUAL OF TROPICAL HOUSING & BUILDING

FIG. 2

PERCENTAGE OF SUBJECTS
FREE FROM THERMAL DISCOMFORT

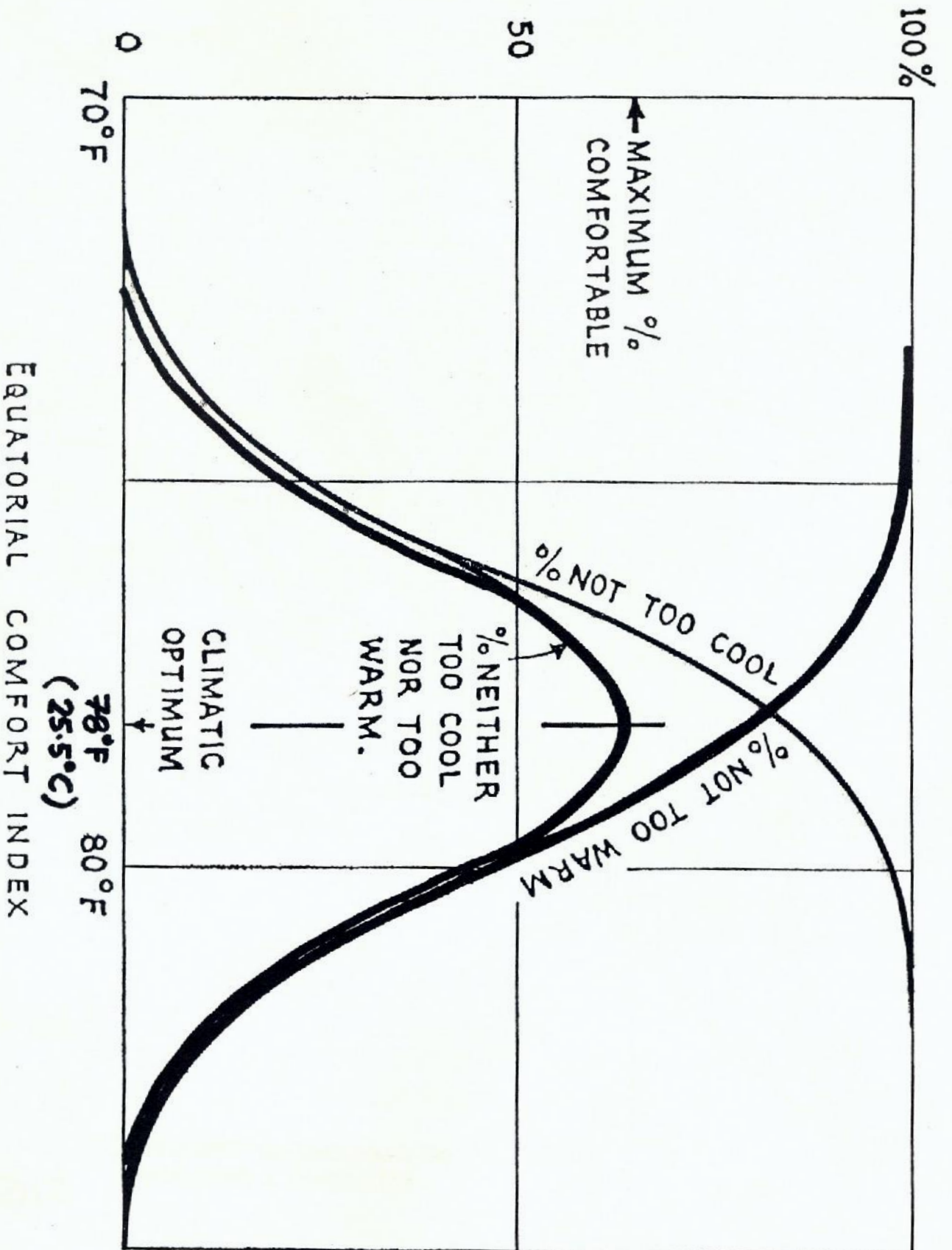
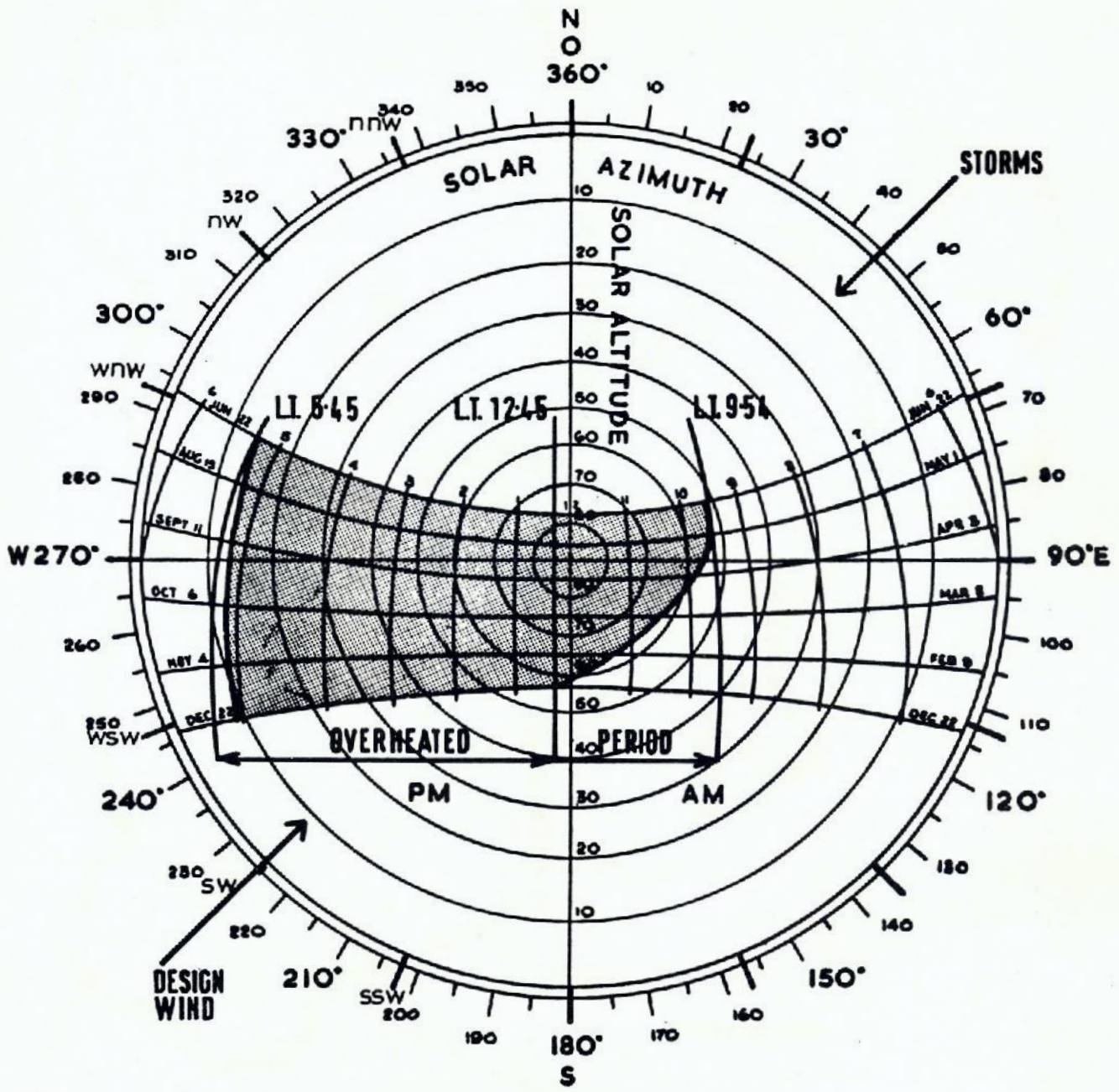


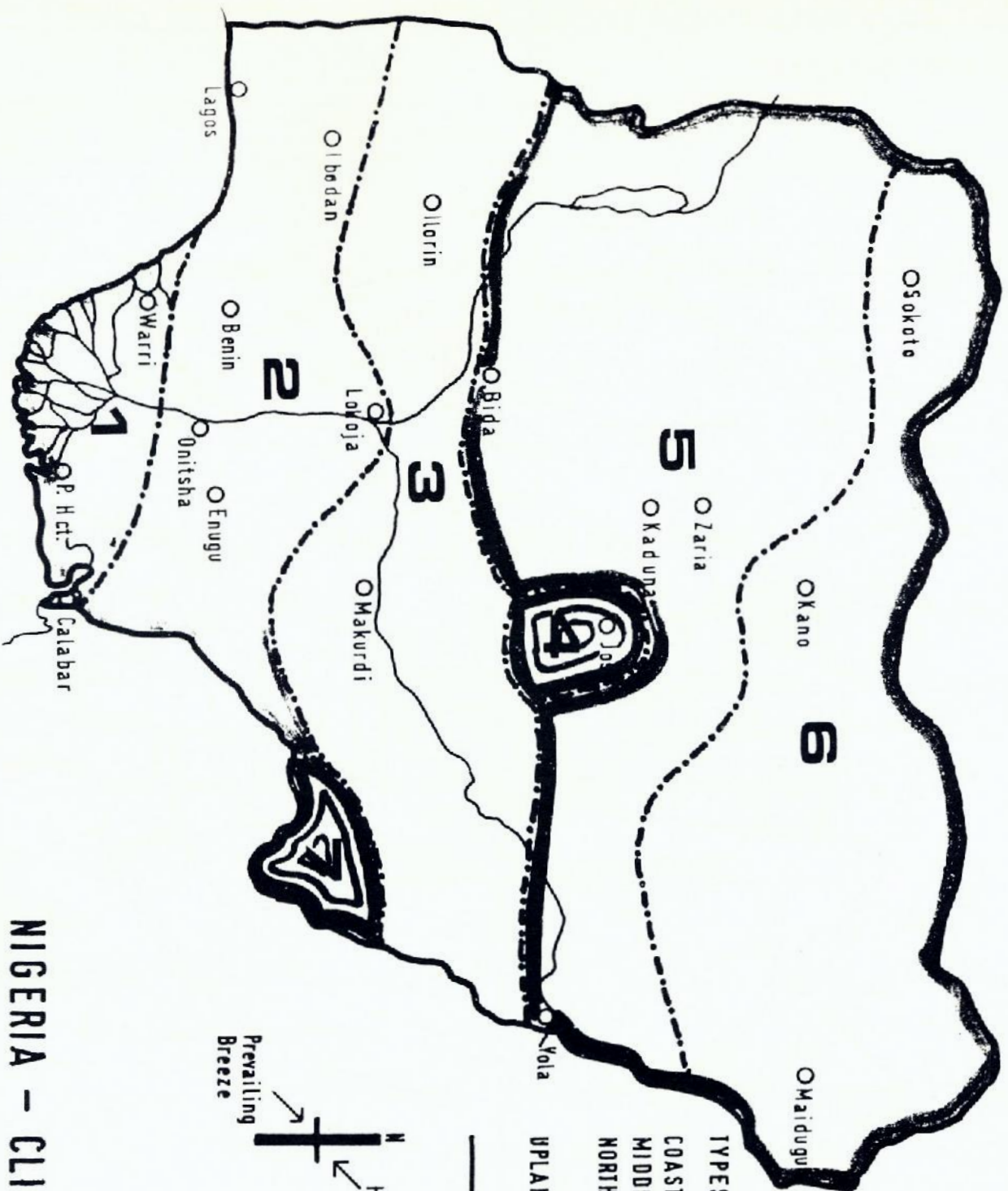
FIGURE 3. Comfort graph for men resident in Singapore.

FIG 3



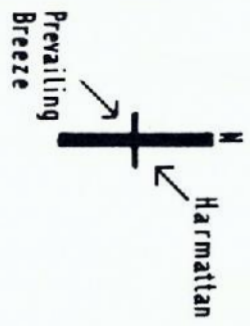
SOLAR/COMFORT CHART FOR JOS
 ZONE 4 LAT. 9°45'N LONG. 8°52'E HGHT. 4233 FT.

FIG 4



TYPES OF CLIMATE

CLIMATE TYPE	CLIMATE ZONES	Months of Thermal Coverage
COASTAL BELT	ZONES 1 & 2	0-3
MIDDLE BELT	ZONE 3	4-5
NORTHERN BELT	ZONE 5	6-8
UPLAND REGIONS	ZONE 4	9
	ZONE 6	6-8
	ZONE 7	4-5

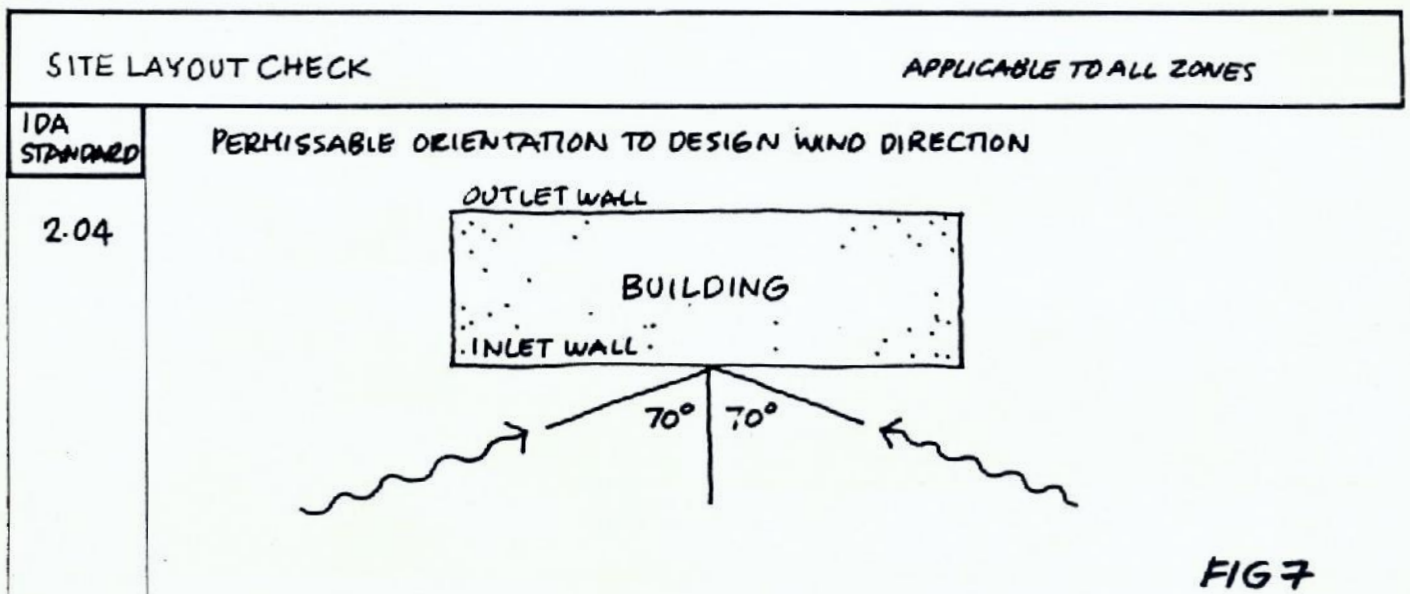


NIGERIA - CLIMATE/BUILDING ZONES

FIG 5

IDA EDUCATION PROJECT CLIMATIC REQUIREMENTS FOR DESIGN & CONSTRUCTION

LOCATION CHECK						
G+H NO	IDA NO	LOCATION	ZONE	COMFORT CHART NO	DESIGN WIND	LOCAL TIME AHEAD OF SOLAR TIME
308	154	MAIDUGURI	6	17	SW	+ 7 MINS
309	142	YOLA	5	28	WNW	+ 10 MINS
310	135	MUBI	5	28	SW	+ 7 MINS
311	146	GOMBE	5	28	WSW	+ 16 MINS
312	123	MAIDUGURI	6	17	SW	+ 7 MINS
313	143	YOLA	5	28	WNW	+ 10 MINS
314	155	MAIDUGURI	6	17	SW	+ 7 MINS
325	2	LAGOS	2	15	SW	+ 46 MINS
						FIG 6



10.01

BUILDING SPACING FOR BREEZE

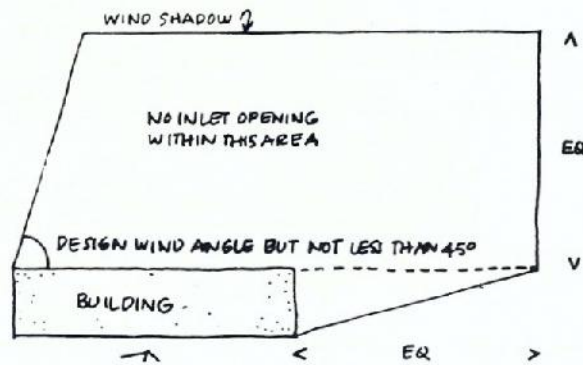
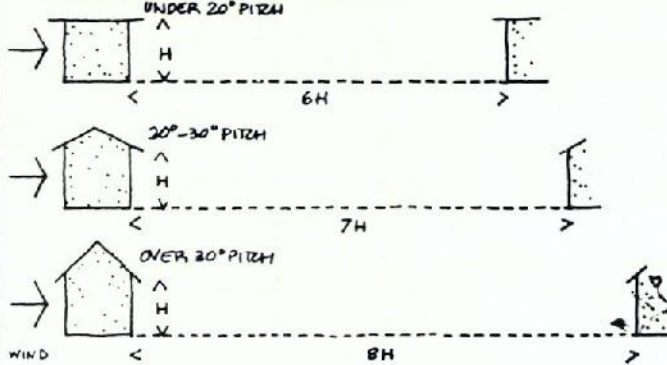
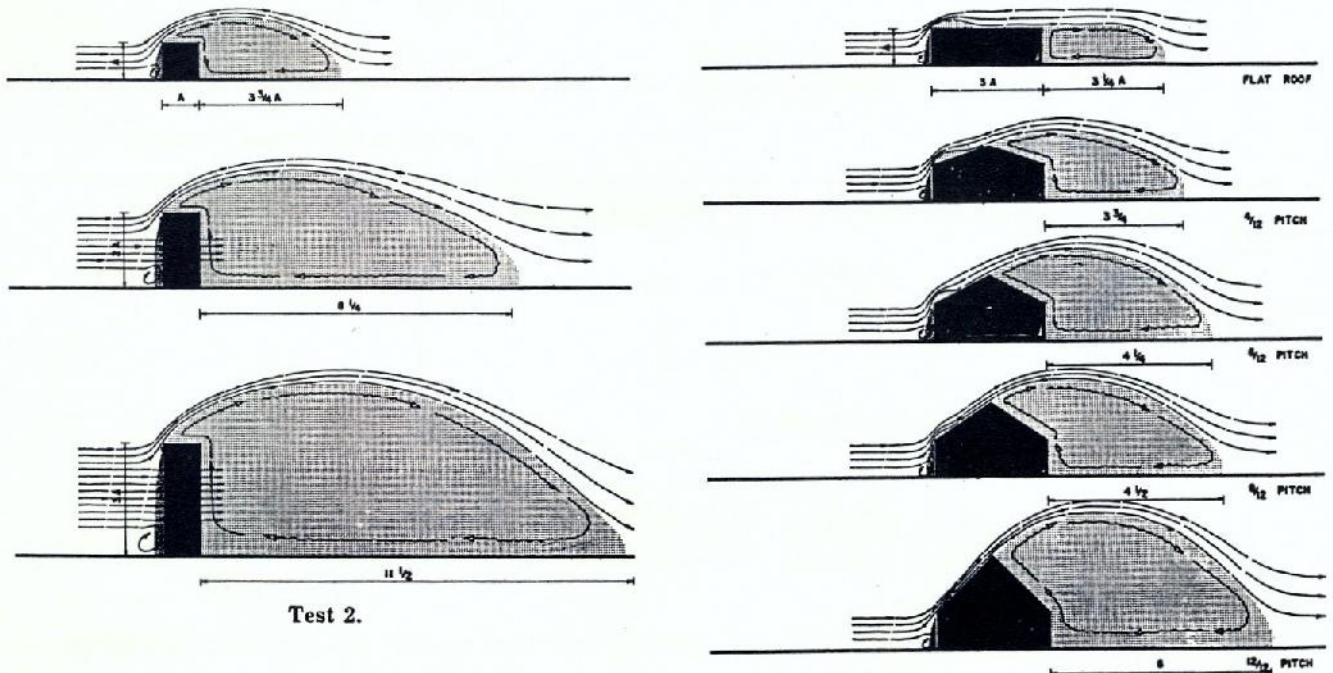


FIG 8

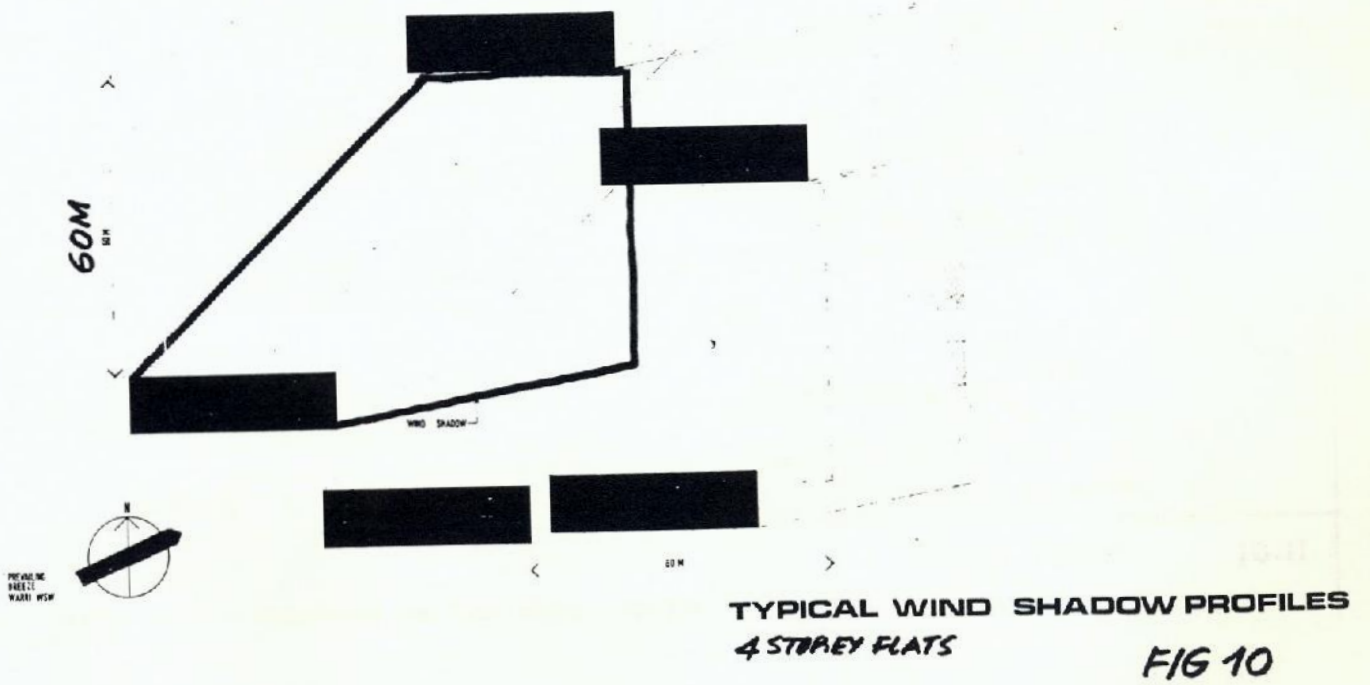
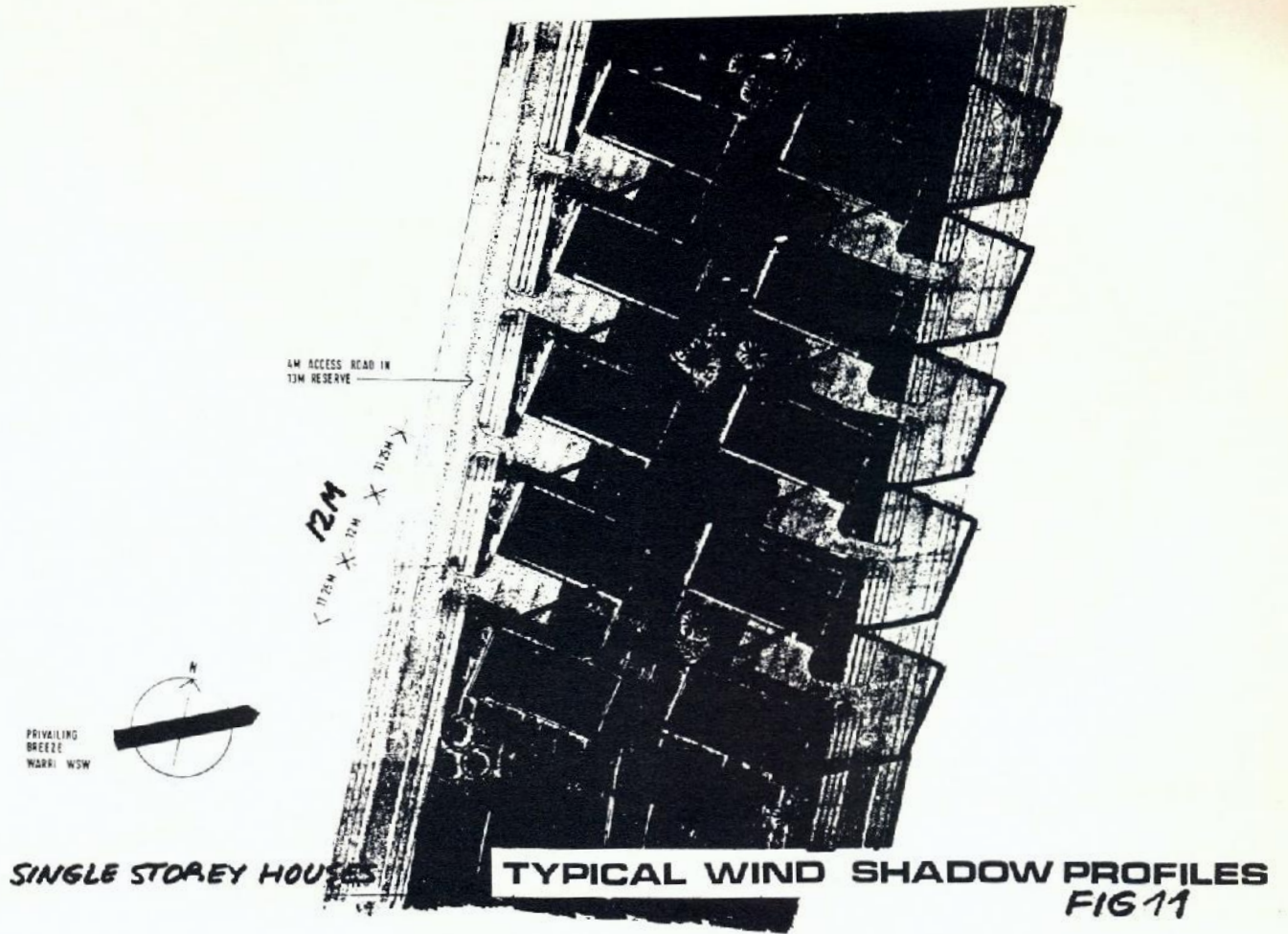
6

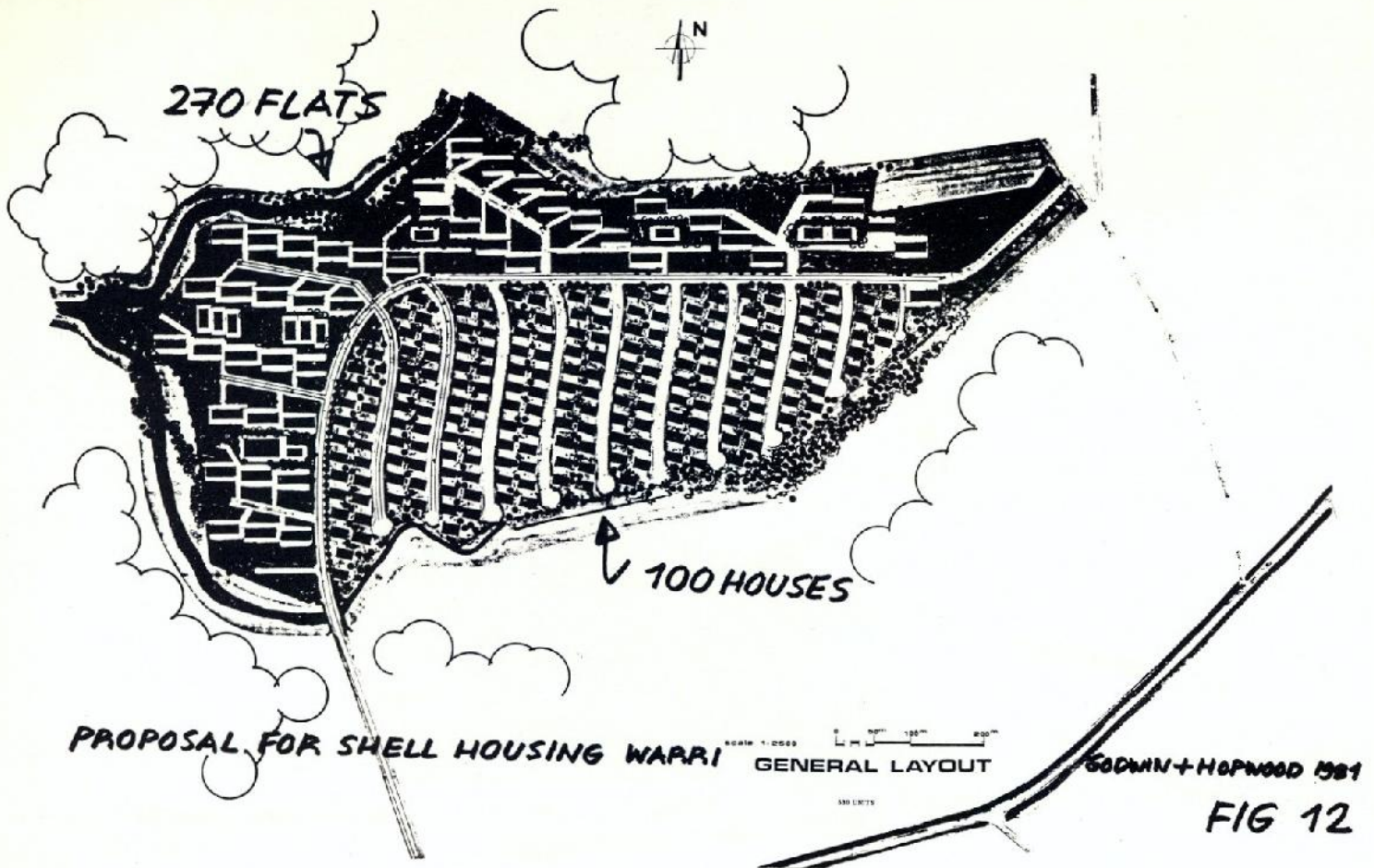
TEXAS ENGINEERING EXPERIMENT STATION NATURAL AIR FLOW



Test 4.

FIG 9





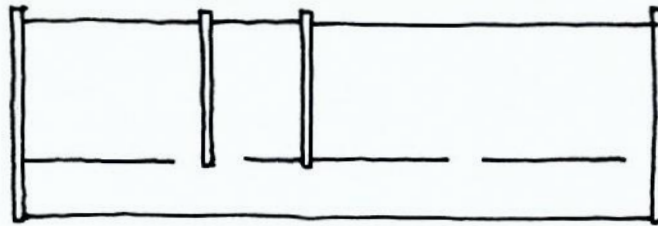
SITE LAYOUT CHECK		APPLICABLE TO ALL ZONES
IDA STANDARD	BOUNDARY & SCREEN WALLS	N.B. OVER 80% VOID NO RESTRICTION
10.02	<p>80% - 50% VOID</p> <p>4H</p>	
	<p>50% - 30% VOID</p> <p>6H</p>	
	<p>UNDER 30% VOID</p> <p>8H</p> <p>WALL < > BUILDING</p>	
11.01	COVERED WAYS CIRCULATION BETWEEN BLOCKS NEED NOT BE COVERED	

FIG 13

IDA
STANDARD

1.01

SINGLE BANKING OF ROOMS ONLY PERMITTED



EXCEPT STORES & W.C. SUBJECT TO STANDARD 2.11

FIG 14

2.08

MIN LENGTH OF OPENINGS ON PLAN & MAX LENGTH OF INTERRUPTION

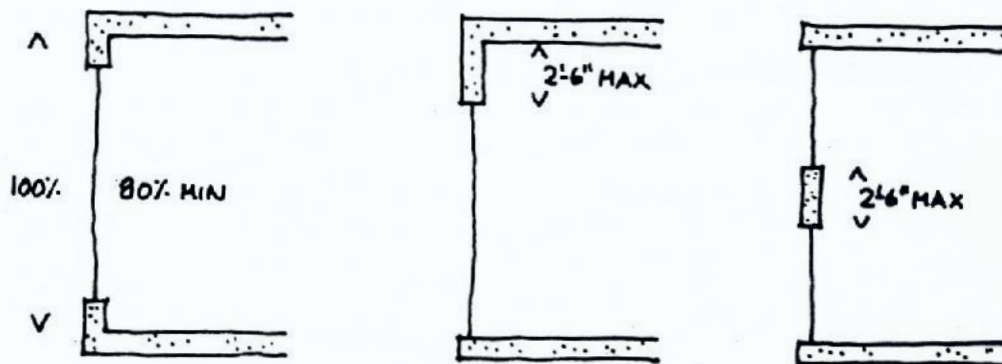


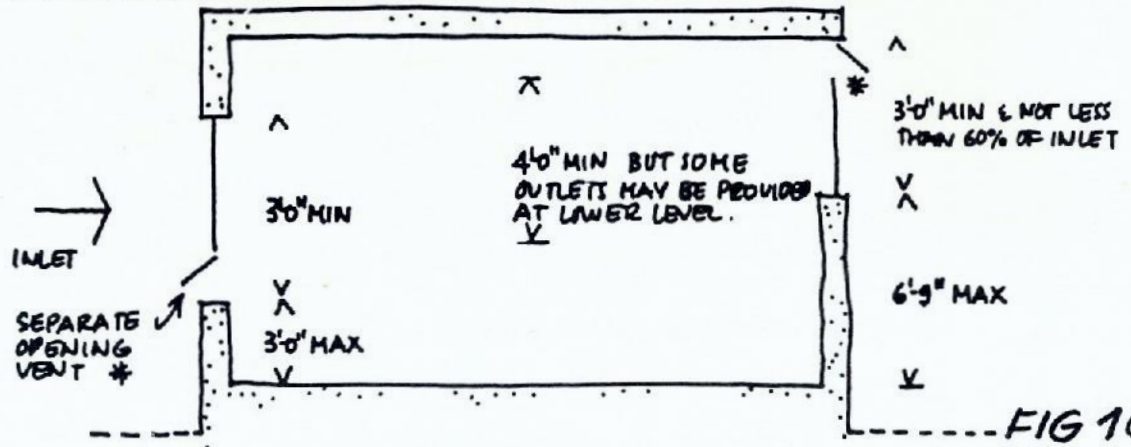
FIG 15

IDA
STANDARD

- 2.05
- 2.06
- 2.07
- 2.09
- 2.10

DISPOSITION OF GLASS & OPENINGS &
PROVISION OF SPECIAL VENTS
(ALL VENTS MUST CLOSE TIGHTLY)

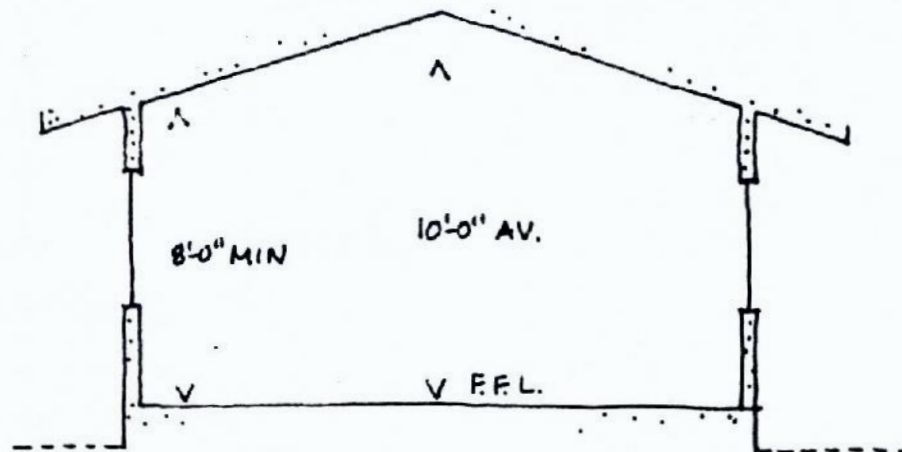
* TO BE PROVIDED AT RATE OF
72" / ADULT & 48" / PUPIL



- 5.03
- 9.01

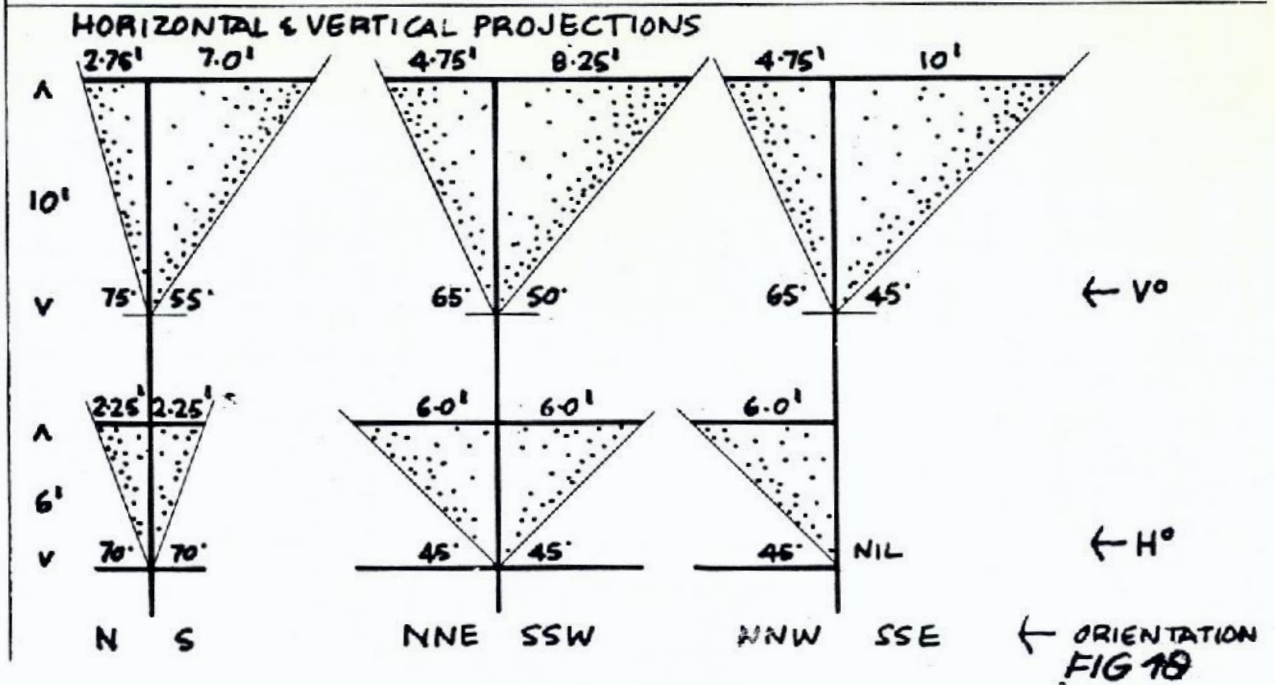
CEILING HEIGHTS OF HABITABLE ROOMS

N.B. CHECK OPERATING HEIGHTS FOR FANS IF PROVIDED

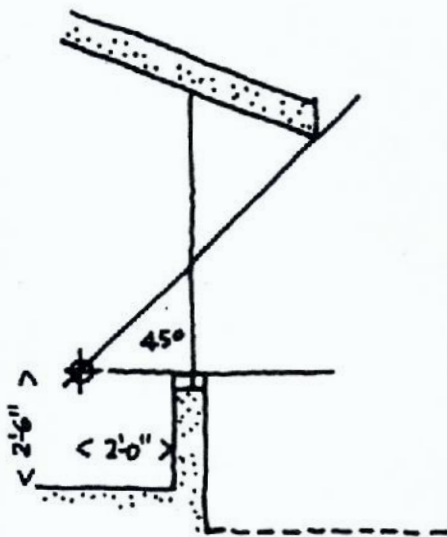


G+H 9/67

FIG 17

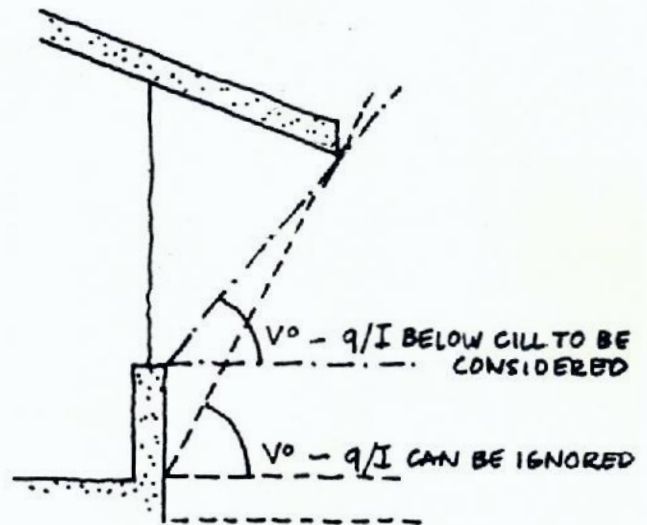


2.03
3.03



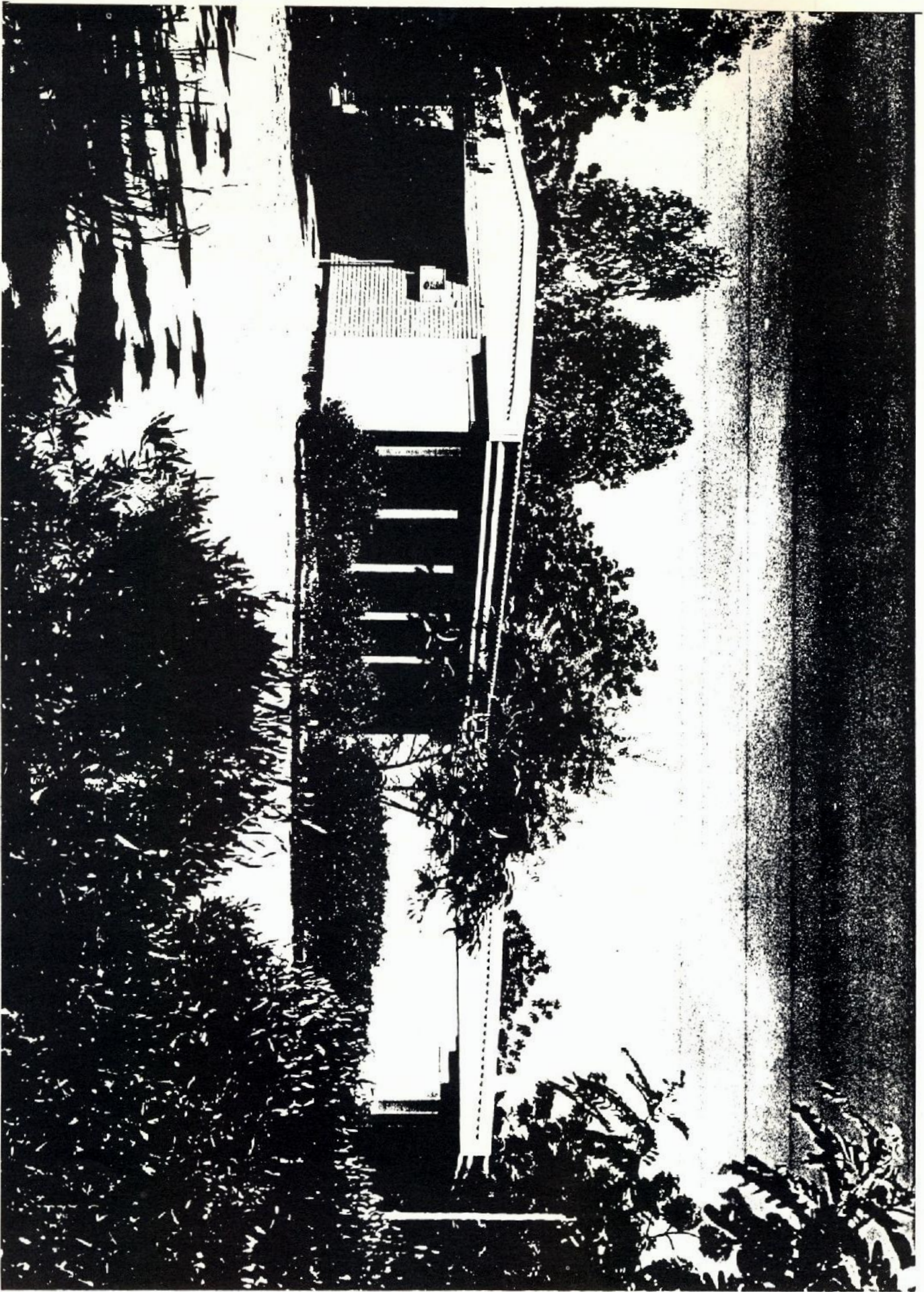
VISUAL CUT OFF - MINIMUM
(GLARE & SKY RADIATION)

G+H 9/67



SOLAR HEAT FACTOR q/I

FIG 19



SECONDARY SCHOOL - MAIDUGURI

FIG 20

IDA
STANDARD

ELEMENT 'B' WORK TO TOP OF GROUND FL. FINISH

7.01

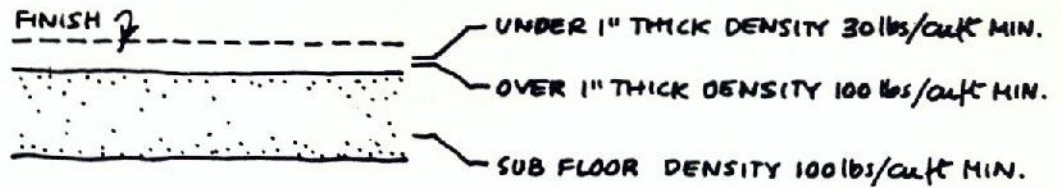


FIG 21 A

5.01
5.02

ELEMENT 'D' ROOF

CHARACTERISTICS REQUIRED	SOLAR HEAT FACTOR (SHF)	TRANSMITTANCE 'U'	TIME CONST. HRS
BEDROOMS, DORMITORIES & NON-DOMESTIC KITCHENS	3% MAX.	0.15 MAX.	10 MAX.
ALL OTHER ROOMS	3% MAX.	0.15 MAX.	25 MIN.
PROPOSED CONSTRUCTION FIG. 6.10			
36 	2.8%	0.14	25.0
37 AS ABOVE BUT 3" SOIL CEMENT 1:12	2.7%	0.13	25.0
38 	2.5%	0.11	29.3
41 AS ABOVE BUT 2 1/2" SOIL CEMENT	2.8%	0.12	30.0

21 B

CONSTRUCTION CHECK

ZONES 5 & 6

IDA STANDARD	ROOF	PROPOSED CONSTRUCTION FIG 6.10	SOLAR HEAT FACTOR q/I	TRANSMITTANCE 'U'	TIME CONST. HRS
5.01 5.02		<p>20 CORR. AL. GREEN FINISH CAVITY UNVENTILATED 1/2" FIBERBOARD 1" POLYSTYRENE</p>	3.0%	0.13	10 or UNDER
		32 AS ABOVE BUT PLAIN ALUMINIUM	2.4%	0.12	"
		<p>21 CORR. AL. GREEN FINISH CAVITY UNVENTILATED 1" POLYSTYRENE AL. FOIL</p>	3.0%	0.13	"
		33 AS ABOVE BUT PLAIN ALUMINIUM	2.4%	0.12	"
		<p>23 AS 21 BUT GAP VARIES</p>	2.8%	0.12	"
		34 AS ABOVE BUT PLAIN ALUMINIUM	2.2%	0.11	"

FIG 22

3.01
3.02

ELEMENT 'F' EXTERNAL WALLS (F3)

CHARACTERISTICS REQUIRED	SOLAR HEAT FACTOR q/I	TRANSMITTANCE 'U'	TIME CONST. HRS.
BEDROOMS, DORMITORIES & NON-DOMESTIC KITCHENS	4% MAX	0.50 MAX	10 MAX.
ALL OTHER ROOMS	4% MAX	0.35 MAX	25 MIN.
PROPOSED CONSTRUCTION FIG. 8.9			
<p>8 OUT IN HOLLOW BLOCK 40% VOID MIN. MIN SOLAR REFLECTIVITY 50% MUNSEL 7.60 CAVITY 1" 4" SOLID BLOCK</p>			
<p>9 OUT IN 12" LATERITE OR SOIL/CEMENT 1:12 MIN. MIN SOLAR REFLECTIVITY 50% MUNSEL 7.60</p>			

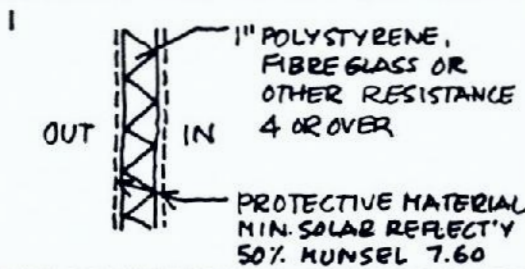
FIG 23

CONSTRUCTION CHECK

ZONES 5 & 6

IDA STANDARD

EXT. WALLS (F4)

4.01	CHARACTERISTICS REQUIRED	SOLAR HEAT FACTOR Q/I	TRANSMITTANCE 'U'	TIME CONST. HRS
	OPENING PANELS ALL ROOMS	3.0%	0.20	
	PROPOSED CONSTRUCTION FIG. 6.9.			
	 <p>1" POLYSTYRENE, FIBRE GLASS OR OTHER RESISTANCE 4 OR OVER</p> <p>PROTECTIVE MATERIAL MIN. SOLAR REFLECT'Y 50% KUNSEL 7.60</p>			

CONSTRUCTION CHECK

ZONES 5 & 6

IDA STANDARD

ELEMENT 'G' INTERNAL WALLS

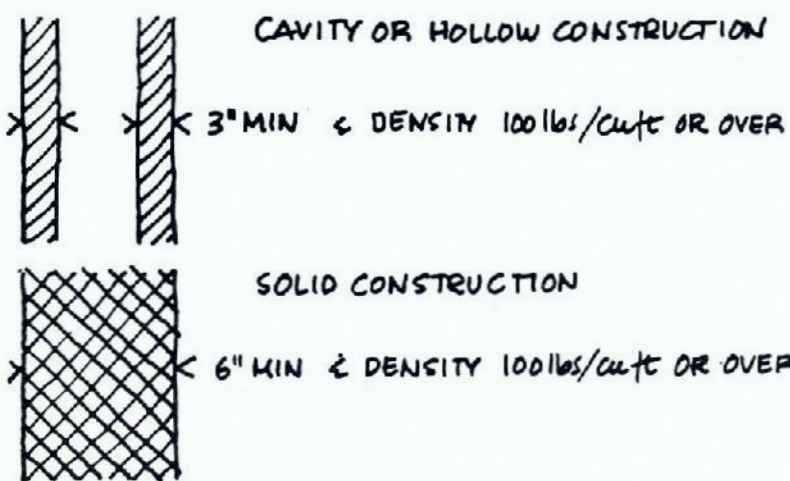
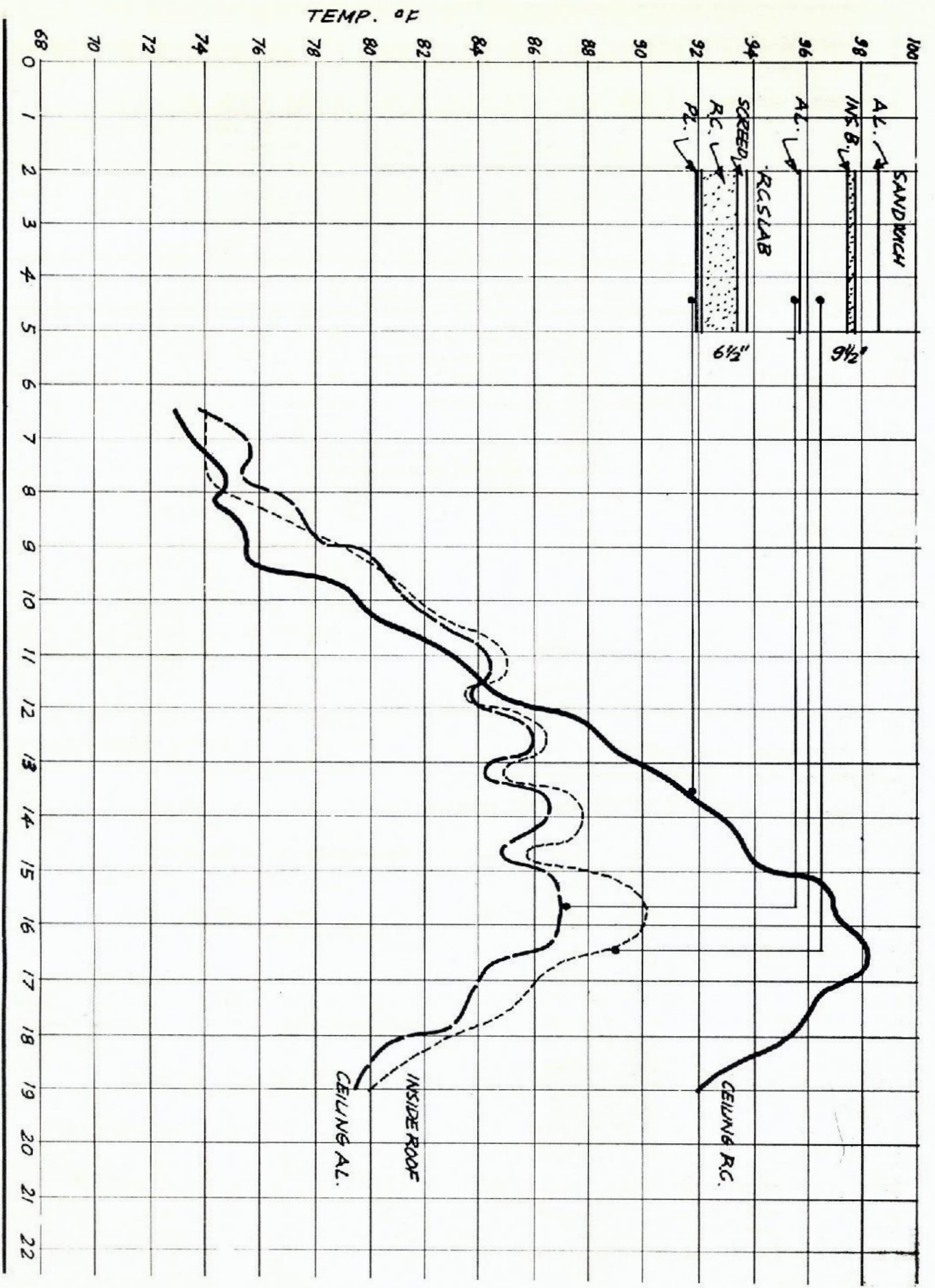
6.01	 <p>CAVITY OR HOLLOW CONSTRUCTION</p> <p>3" MIN & DENSITY 100 lbs/cu ft OR OVER</p> <p>SOLID CONSTRUCTION</p> <p>6" MIN & DENSITY 100 lbs/cu ft OR OVER</p>
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FIG 24

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THEMAL DESIGN OF BUILDINGS FOR COMFORT IN DIFFERENT NIGERIAN CLIMATE ZONES

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INTRODUCTION

An intended goal through the erection of buildings is to avert or reduce the level of problems imposed by the elements of physical environment with the view to gaining human comfort. This includes of course, thermal comfort which can only be achieved if adequate considerations are made during the planning and designing stages of buildings. Thermal problems emanate from the heat produced from solar radiation which is either received in or conducted into the buildings, from the heat produced by human body, cooking fire and through the use of electrical appliances.

Under normal circumstances, the human body produces heat through the basal and muscular metabolism. It utilizes 20% and gives out the rest 80% of the heat¹ it produces. It means therefore that in order to maintain the normal body temperature which is 36.5°C or 37°C, the human body must have to enjoy a sort of thermal comfort. In terms of definition, it should be understood as an optimum temperature that favours an effective temperature regulatory process that should take place in the human body with the view to achieving the normal functionality of the systems of human physiology. Now at any time of the day, if the temperature of the immediate surrounding fails to favour this process, problems are developed and the human body reacts accordingly. As a follow up, the following symptoms; sweating, headache, abnormal circulation of the blood, uneasiness, concentration failure, etc² are then registered. With this background, this paper intends to discuss certain aspects of thermal problems and then make some recommendations that could be considered for design parameters in buildings.

THE PROBLEMS

Thermal problems being experienced as of now will be viewed in two main areas. The first is the one arising from the lack of thermal comfort in buildings while the other one will be arising from some attempts made to achieve the thermal comfort. These will be treated precisely thus:

- (a) When the indoors become uncomfortably hot, the inhabitants decide to sit on the balcony,

loggia, verandah and in the courtyards to enjoy the cool air in the evenings particularly; But unfortunately this is not a solution because the mosquitoes force them back into the room they were forced out by the heat. Now associated to this is the fact that they cannot sleep comfortably enough to be productive. At the same time during the day in the offices and institutional buildings where brainwork is involved the level of performance remains low.

- (b) The compact layout system of buildings in the hot-dry zone which is supposed to be a solution to achieving thermal comfort has some discrepancies which can be viewed as follows: The failure to receive some amount of direct solar radiation in some parts of the buildings and cross-ventilation which is the main source of reducing damp, the growth of mould, etc. and additionally increasing the amount of fresh air needed in the rooms, constitute a poor hygienic situation.

With consideration to the above, it is quite apparent that the failure to achieve thermal comfort is due to lack of proper application of certain principles of planning and designing of our buildings.

RECOMMENDATIONS

Measures needed for achieving thermal comfort in buildings will be discussed in the following areas: Choice of site and landscape duties, orientational layout of buildings, architectural design aid, architectural design skill, choice of colour, building material, constructions for the exterior wall, roof and windows.

(a) Choice of Site and Landscaping Duties

The choice of the building site and measures to improve the existing landscape remain transparently very important. This involves the avoidance of siting buildings on hill-sides or valleys which could impede the process of cross-ventilation. In the warm-humid zone, the walling-round of buildings which has been the practice should be discouraged. Though this measure has security implication and legally defines the plot size, it obstructs the intended process of cross-ventilation. In the hot-dry zone, in which

the Northern part of the country lies, the construction of walls round the buildings is recommendable only if their function is restricted to obstructing the dusty wind blowing into the buildings. However, the existing landscape should be improved by planting grasses and trees that could create shades, particularly at window areas and give enough water vapour into the surrounding air with the view to reducing the immediate atmospheric – and the indoor temperature.

In addition to this, trees do help to reduce wind speed and filter the dust contained in the air or carried by the wind. The grasses form a vegetative cover and help to reduce the wind erosion and dust contained in the air. Trees and shrubs also absorb the sun rays, and consequently, help to reduce the reradiation process that could have increased the atmospheric and indoor temperature.

(b) Orientational Layout of the Buildings

The layout of the buildings should be handled with the view to achieving a proper orientation. This involves making the shorter side of the building to face the East and West in order to reduce the volume of solar radiation which the exterior walls could absorb, and consequently, the rate of transmittance of heat into the buildings.

(c) Architectural Design Aid

This design aid includes mainly the assessment of the vertical and horizontal angle of incidence. This involves calculating the angular inclination of the sun in relation to the geographical location of the buildings in question.³ The result of this exercise influences the decision on the usage of sun-breakers in the form of additive and subtractive elements on the buildings that should reflect the vertical or horizontal shading functions.

(d) Architectural Design Skill

This involves creating proper building forms and proper interior partitioning with the view to avoiding conventional or double banking system that creates barrier for cross-ventilation. The building forms or the layout form of the buildings should also give consideration to the creation of courtyards. In the hot-dry zone where the intensity of solar radiation is higher than what it is in the warm humid zone, the smaller the courtyards the more effective the shading that the buildings will create for themselves. Nevertheless, in this process, the theory of safe distance between two exterior walls of two different buildings or flats with openable windows should not be neglected so that some social and technical problems can be averted. However, though the intensity of the solar radiation in the warm-humid zone is not as acute as it is in the hot-dry zone because of the existence of high humidity and vegetative cover that reduces reradiation process from the ground, the idea of creating courtyard in the buildings should remain valid. Not-

withstanding, it has to be remarked that during the design and construction stages, proper drainage for the possible accumulation of rain water in the courtyards should be considered.

(e) Choice of Colour for the Outside of the Exterior Walls

The use of bright colours for the outside of the exterior walls is recommended in view of the fact that they have higher reflective ability. Table 1 shows the rate of reflection and absorption of solar radiation by the colours of the different materials

ABSORPTION/REFLECTION COEFFICIENTS OF SOME BUILDING MATERIALS

Table 1:

Materials	SOLAR RADIATION	
	Absorption	Reflection
White wash	21%	79%
Bright aluminium	30%	70%
Yellow colour	48%	52%
Dark aluminium	63%	37%
Bright red	65%	35%
Light green	73%	27%
Black colour	97%	3%
Concrete	70%	30%
Fire clay bricks – red	70%	30%
White asbestos – cement	50%	50%
Copper sheeting	64%	36%
Red Roofing tiles	70%	30%
Aluminium foil	39%	61%
Asphalt	95%	5%
Plaster	81%	9%

Source: Geog Lippsmaier – Building in the Tropics
Published by Callwey Verlag Minchen 1969, Pages
71/73.

(f) Choice of Building Materials

This is very necessary as the rate of conductivity depends on the density of respective materials. The higher the density, the higher the conductivity and the lower the conductivity, the better insulator the materials is.⁵ Since the conductances of materials cannot be added, one has to rely on the resistances. The air to air resistance of materials which is the reciprocal of the air to air transmittance of heat or the U-value can be calculated and added together in the case of composite constructions. However,

U-value is equal to $1/R_a$. R_a is equal to $1/f_i + R_b + 1/f_o$ whereby $1/f_i$ is equal to the internal resistance, R_b is the main body resistance and $1/f_o$ is the external resistance of the used material⁶. With this background, it is hereby recommended that the U-value of the constructions of the perimeter walls and the roofs should be calculated with the view to establishing the usage of the right building materials needed for achieving thermal comfort. Tables 2 and 3 contain different building materials and their rate of conductivity, resistivity and U-value

Table 2:

CONDUCTIVITY AND RESISTIVITY OF SOME MATERIALS

	conductivity k W/mdegC	resistivity 1/k mdegC/W
Asbestos: loose	0.034	29.40
sprayed	0.046	21.75
Asbestos cement sheet: light	0.216	4.63
average	0.360	2.78
dense	0.576	1.74
Asphalt	0.576	1.74
Brickwork commons: light	0.806	1.24
average	1.210	0.83
dense	1.470	0.68
in lightweight bricks	0.374	2.68
in engineering bricks	1.150	0.87
Concrete: ordinary, dense	1.440	0.69
clinker aggregate	0.403	2.48
expanded clay aggregate	0.345	2.90
foamed slag aggregate	0.245	4.08
Cork slab: natural	0.043	23.20
regranulated, baked	0.039	25.60
Eel grass blanket	0.043	23.20
Glass-wool: quilt	0.034	29.40
blanket	0.042	23.80
Mineral wool: felt	0.037	27.00
rigid slab	0.049	20.40
Onozote (expanded ebonite)	0.029	34.50
Plasterboard, gypsum	0.159	6.33
Plastering: gypsum	0.461	2.17
vermiculite	0.201	4.98
Plywood	0.138	7.25
Polystyrene foam slab	0.033	30.30
Rendering, sand-cement	0.532	1.88
Stone: granite	2.920	0.34
limestone	1.530	0.65
sandstone	1.295	0.77
Strawboard	0.093	10.75
Timber: softwood	0.138	7.25
hardwood	0.160	6.25

		conductivity k W/mdegC	resistivity 1/k mdegC/W
Wood chipboard		0.108	9.26
Wood fibre softboard		0.065	15.38
Wood wool slab:	light	0.082	12.20
	dense	0.115	8.70
Metals:	lead	34	0.0294
	cast-iron	50	0.0200
	steel	58	0.0172
	bronze	64	0.0156
	zinc	110	0.0091
	aluminium	220	0.0045
	copper	350	0.0029
	silver	407	0.0024
Air		0.026	38.45
Water		0.580	1.72

Source: Koenigsberger/Ingersoll/Mayhew/Szokolay Manual Tropical housing and Building. Part 1, page 285.

Table 3:

TRANSMITTANCE (U-VALUE) OF SOME CONSTRUCTIONS (IN W/M²DEGC)

Type of 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:			1.13
	100 mm aerated concrete blocks		1.30

Type of construction

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	
+ 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	
+ 13 mm timber boarding	7.95
+ 50 mm straw or wood wool slab	2.16
+ 25 mm quilt on 13 mm boarding	1.25
	0.85
Corrugated iron sheets or tiles on battens	
+ plaster ceiling	8.52
	3.18
Tiles or slates on boarding and felt with plaster ceiling	
	1.70
Aluminium deck, 13 mm fibreboard with two layers bituminous felt	
Aluminium deck, 50 mm straw or wood wool slab	2.16
	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 screed (in lieu of normal):	

Source: Koenigsberger/Ingersoll/Mayhew/Szokolay Manual Tropical Housing. Part 1, page 287.

(g) Choice of Construction for the Exterior Walls

There are two main recommended types of constructions for the exterior walls; the single massive – and the multilayered walls. The single massive wall is the type constructed with a homogenous material as reflected by Fig. 1 while multi-layered wall can be described as a composite wall because it consists of two or more different walling material-layers with or without cavity space. Now a multi-layered wall which consists of a solid part and a heat insulating material as reflected by Fig. 2 has a remarkable disadvantage. This is because placing the insulating material either on the outer or inner side of the solid wall will not favour the process of heat dissipation as

such. However it could be placed on the outside of the exterior wall if the heat gained in such buildings will not be much and more also, if the process of cross-ventilation is adequately considered. The second type of a multi-layered wall consists of an outer solid wall, a ventilated cavity and an inner solid wall as reflected by Fig. 3. The third type of multi-layered wall as reflected by Fig. 4 consists of an outer shell as cladding or panelling element, air space and a solid part. On the whole the usage of a single massive mud wall, because of its poor conductive ability, the double walling system and the cladded or panelled walls which enclose ventilated cavity or air spaces will be recommended here as being more ideal.

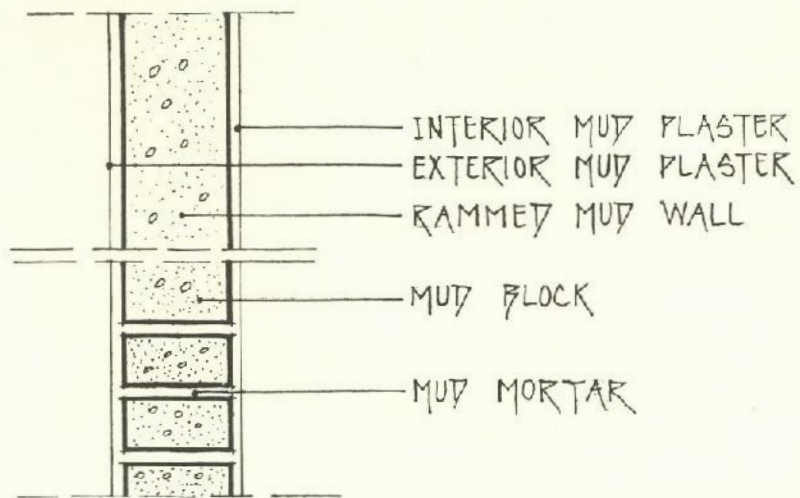


FIG 1

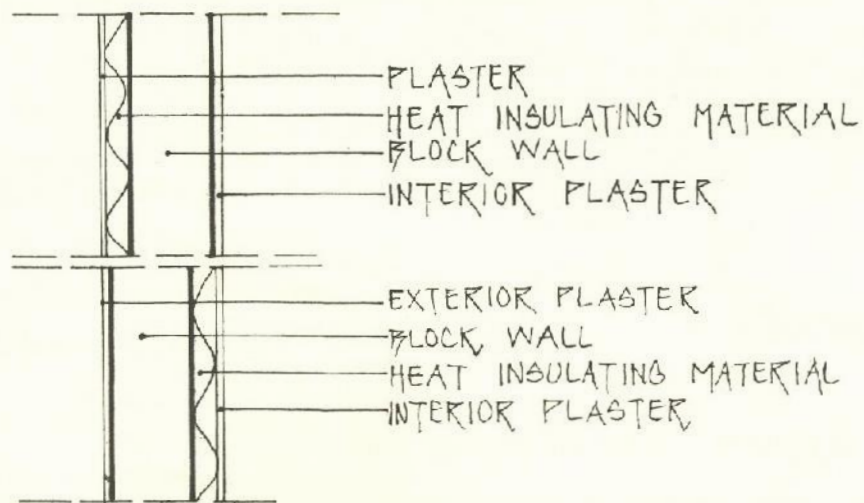


FIG 2

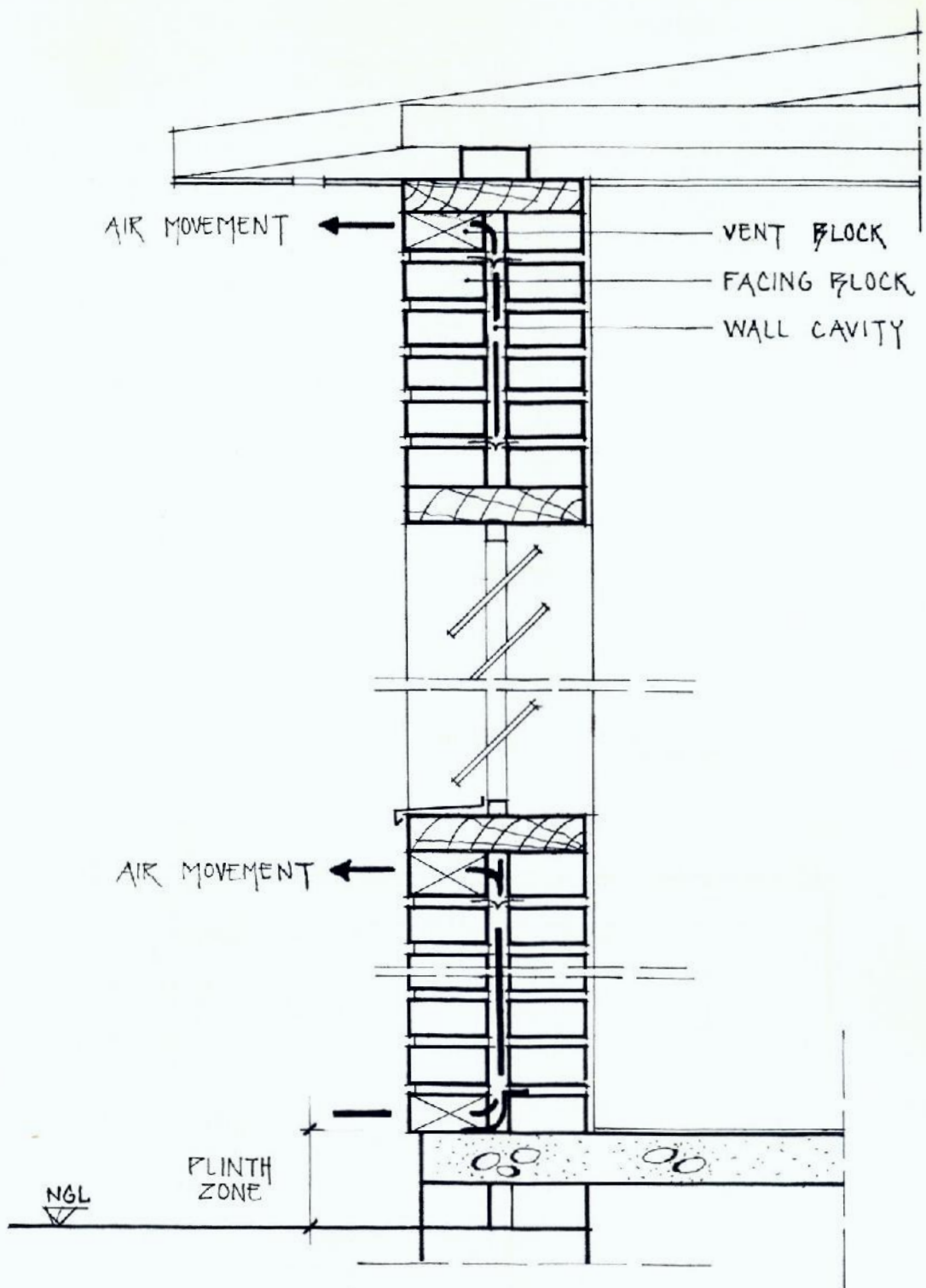


FIG 3

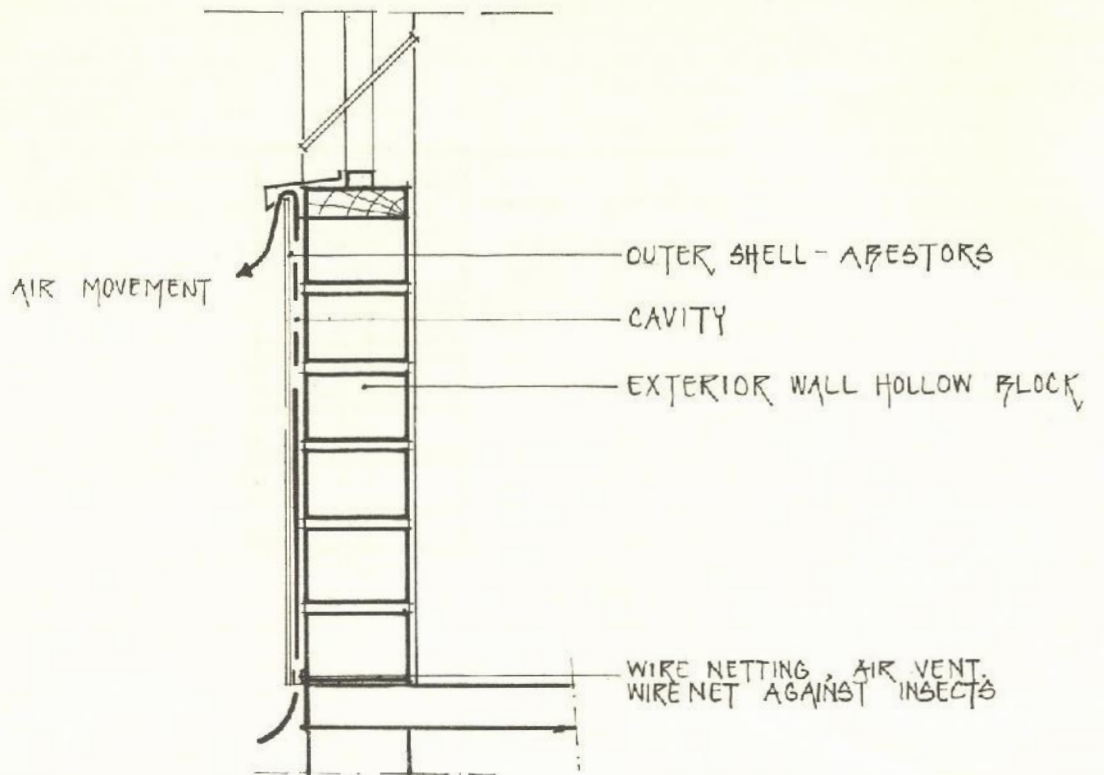


FIG. 4

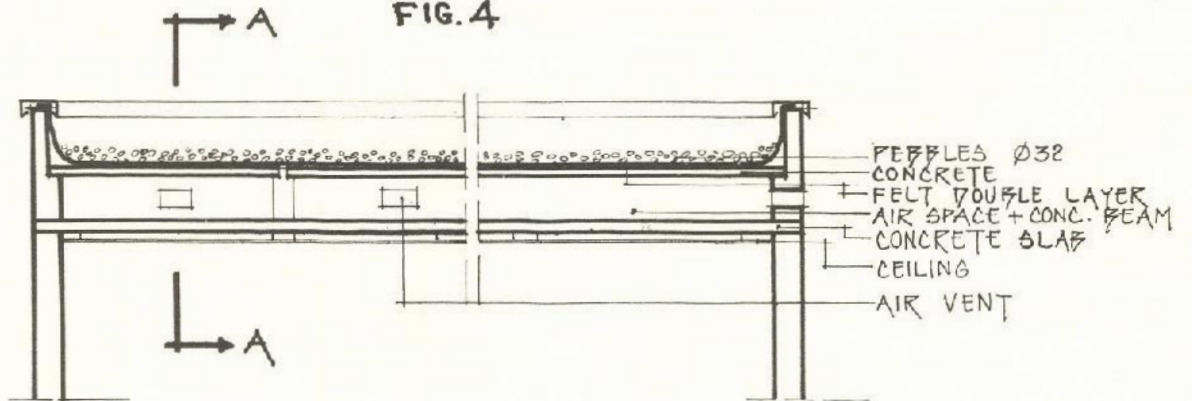


FIG 5

SECTION A-A

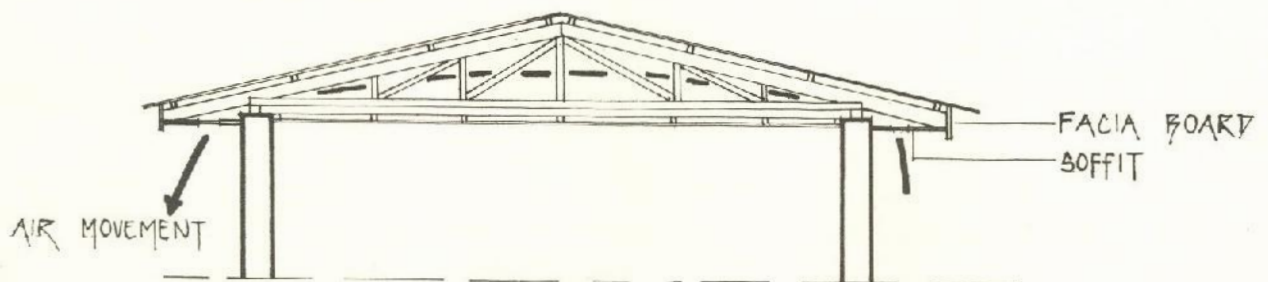


FIG 6

(h) Choice of Construction for the Roof

In view of the fact that the roof receives the greater amount of solar radiation and consequently highest heat load, its construction should be given an utmost attention. In order to achieve that minimum indoor temperature that is conducive to human comfort, the followings will be recommended: Due to the fact that modern roofing materials are heat conductive, both the flat and pitched roof constructions as reflected by Figs. 5 and 6 should have at least two layers with the view to creating roof-space for air circulation needed for the reduction of the rate of inflow of heat. However, a continual usage of the traditional mono-layered roof construction system which seems to be effective because of the low conductive ability of the mud or thatch materials should be encouraged. While advising that in the hot-dry and warm-humid areas the roof ceilings could be of light materials, in Jos region where the outdoor temperature could be as cold as between -2°C and 5°C in the months of October to February, the opposite will be the case. The fact is that the buildings with the traditional style of roof construction which involves the use of pitched roof terminated with massive flooring for the ceiling are warmer and cooler than the others during the cold and hot periods respectively.

(i) Choice of Construction and Material for Windows

In order to achieve thermal comfort in buildings, considerations should also be extended to the construction and the type of materials that should be used for the windows. One of the materials mainly used presently is glass, which varies. The normal single-glass compared to the coated glass with nickel or gold or to a combined normal and coated has little resistance to heat flow into or out of buildings. This can be substantiated by the relevant information in Table 4

Table 4

Type of Glass	Thick-ness in	% of Solar Radiation Distribution on Glazed Window Opening		
		Absorbed	Reflec-ted	Trans-mitted
Single glazing	3	11	7	82
Double glazing	2x3	15	9	76
Double glazing	2x6.5	17	10	73
Single bronze glass	6.5	50	18	44
Double glazing				
a) 1 x bronze glass	2x6.5	55	8	37
1 x Normal glass	2x6.5	55	8	37
b) 1 x Normal glass				
1 x Nickel flashed inside	2.3	52	23	25
c) 1 x Normal glass				
1 x Gold flashed inside	2x6	29	47	24

Source: Georg Lippsmaier – Building in the Tropics. Page 143.

Now apart from the fact that windows have the functions of allowing contact with nature in terms of day-light and fresh air, it allows also some amount of sun rays which are necessary for hygienic purpose. In view of the above, the followings will be recommended.

- The use of a wooden window shutter is advisable for the fact that wood is a bad conductor of heat.
- Double glazing is advisable for the fact that cavity between the two sheets of glass does not allow inward and outward heat flow.
- If the glazing will be of single sheet, the use of small window-openings will be advisable particularly in the hot-dry regions. However, this is contrary to what should be applicable in the warm-humid zone where large window openings will be recommended for easy heat dissipation processes.
- In order to make the rate of air movement in terms of cross-ventilation controllable, the use of horizontal louvres is advisable.
- Finally, the window-openings should be located on the opposite sides of the exterior walls⁷ and the sills should be about 90cm above the floor-finish in order to achieve excellent cross-ventilation.

CONCLUSION

The recommended measures described in the areas of site planning, design principles, choice of constructions and materials in this paper should be seen as a guide to achieving thermal comfort in our buildings. In other words, they should become policies in terms of forming part of the building by-laws that should be considered when approving plans of buildings for construction. Due to the fact that achieving thermal comfort in our buildings is very important, an effective application of the items mentioned above is therefore very important.

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“DESIGN CONSIDERATIONS FOR NATURAL VENTILATION IN NIGERIAN BUILDINGS”

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INTRODUCTION

Despite the increasing amount of mechanical ventilation and air conditioning being used in our buildings today, the greatest portion of our everyday buildings, and particularly our houses, still rely on natural means of ventilation. Our buildings can and should be designed to take maximum advantage of natural ventilation since nature's air supply is free, especially in our country where the supply of power to generate these mechanical means is not reliable.

Good ventilation is worth working for, yet, there is a serious lack of positive information concerning the design of buildings for utilizing natural ventilation for hot weather (dry season) cooling. *This paper is a presentation of some basic design considerations.*

Man's energy and health depend, in large measure, on the direct effects of his environment. The physical environment consists many elements in a complex relationship which can be described as the environmental constituents such as: light, sound, space, animate and climate (Fitch, 1948). They all act directly upon the human body.

Man strives for the point at which minimum expenditure of energy is needed to adjust himself to his environment. Conditions under which man succeeds in doing so can be defined as the "Comfort Zone", wherein most of his energy is freed for productivity.

The four main variables affecting human comfort are air temperature, humidity, radiation and air movement. There are two ways of evaluating these climatic effects on man: One way is to describe the negative effects and these can be expressed in the form of stress, pain, disease and death. The second way is in terms of the conditions in which man's productivity, health, mental and physical energy are at highest efficiency (Olgay, 1963).

Some writers regard sunstroke or heatstroke as the upper temperature limit for man's existence and the freezing point as the lower limit (Markham, 1947). The ideal air temperature may be taken to be midway between these extremes (70°F). Furthermore, the desirable comfort zone lies between 30% and 60%

relative humidity; care must then be taken to check for all poorly ventilated cooler areas for condensation, corrosion, mould-deterioration and discolouration. Radiation effect on inside surfaces can be used, to an extent, to balance higher and lower air temperatures.

Controlling any of these variables, by mechanical or other means, enables us to adjust human comfort to some extent. But in the absence of temperature, humidity and radiation controls, especially here in the tropical climate where we depend entirely on natural means for hot weather cooling, the only controllable factor with which to obtain comfort is air movement. Air movement affects body cooling. It does not decrease the temperature, especially in tropical region, but causes a cooling sensation due to heat loss by convection and due to increased evaporation from the body. As velocity of air movement increases, the upper comfort limit is raised.

As will be explained later in this text, it can be said that the normal comfort conditions precede architecture, underline architecture, and affect both architecture and engineering.

2.0 ANALYSIS OF AIR MOVEMENT

2.1 Characteristics of Air Flow

Air is caused to move by two natural phenomena, first by pressure differences, and second by temperature differences which really result in pressure difference. Air flows from high pressure to low pressure regions, and hot air rises. Air will flow through a low structure by temperature difference alone, but in hot weather its cooling effect is negligible compared to that caused by even a very light breeze setting up pressure differences around the structure. (Labour Department, 1948).

2.1.1 Pressure Difference

The fundamental question is, though simple, where do the pressure differences exist when the wind envelopes a building? Naturally, the air tends to flow into the building at the high pressure regions and out of the building at the low pressure regions, (Fig. 1 a & b). Therefore, all that is needed to allow the air to flow through the building is – to locate openings in

the high pressure walls, to let it in, and in low pressure walls to let it out. In order to produce a cooling effect on the occupants of the building, especially in tropical weather, the air movement must be within the living zone of the building around the occupants' bodies; for, simply providing openings does not necessarily allow the air to flow within the living zone.

2.2 Air Flow Pattern

In order to have a desirable air flow in the living zone of a building, we should therefore, consider the effect of the geometry of the buildings on the air flow patterns within them. There are two factors which determine the pattern, they are:

- (i) the location of inlets; and
- (ii) the type of inlets.

2.2.1 Location of Inlets

Fig. 2 shows what effect the location of the inlet has on the air pattern. Fig 2 (a) shows that with the opening located symmetrically, there exists equal pressures on both sides of the opening causing the air to flow straight into the building. Fig. 2(b) shows that when the opening is not located symmetrically, the pressures on the two sides of the opening are unequal, causing the air to enter the opening diagonally.

The foregoing principles were in consideration of the location of a simple void in a solid surface as an inlet opening. This was applied by the Texas Engineering Experiment Station in 1950, and the result is shown in the following diagrams: Fig 3(a) The air flow pattern was slightly downward and into the living zone on a bungalow building. Fig. 3(b) further examines the performance on the same room but now located on the top floor of a two level building. The resulting air flow pattern observed is definitely away from the living zone and toward the ceiling. Fig. 3(c) curiously locates the room on the middle floor of a three level building, the air pattern would again be in the living zone of the room.

All these variations in air pattern were caused by the inequality of pressures above and below the inlet openings as a result of their location in regard to the proportion of solid wall surface around them.

The effect of the inertia of the air entering the inlet openings causes it to flow upward and across the ceiling regardless of the location of the outlet opening and continue across the ceiling until it reaches the immediate vicinity of the outlet. Fig. 4 (a) (b) & (c).

2.2.2 Types of Inlet

Fig. 5 now takes into consideration, the type of openings. There are many types of windows in the market which when used for inlet openings in buildings result in a variety of air patterns. This is as a

result of a principle that when the position of the outlets is fixed, but the inlets are placed at high, medium and low positions, the pattern of the flow will vary. We can then conclude here that the placement of the *inlets* governs the flow pattern within a structure and this can be regulated not only by the position but also by the arrangement and type of inlets.

2.2.3 Size of Inlet versus Size of Outlet

The significance of air speed cannot be overlooked especially when designing for the maximum utilization of natural ventilation for hot weather cooling. "In regard to the theoretical efficiency of openings, the greatest volume of air flow" or, in other words, the greatest number of air changes per sq. cm. of total opening, "is acquired when the inlet and outlet are equal in size" (A.S.H.V.E., 1951).

One popular misconception of the proper sizing of openings is the practice of putting extremely large openings toward the breeze with the idea of "scooping" the air into the room, along with a strip of small openings on the opposite side of the room to allow for cross ventilation. Actually, the reverse is the case, because maximum air speeds within a building are acquired when the outlet is larger than the inlet as shown in Fig. 6(a)&(b).

The conclusions to be drawn here are as follows:

1. The location and type of inlet determine the air flow pattern through a building.
2. The location and type of outlets have little to do with the air flow pattern except for the size of the outlet compared to the inlet size.
3. In order to acquire the most effective air movement from the natural wind forces for hot weather cooling, abrupt changes in direction of the air movement within a building should be kept to a minimum

3.0 DESIGN PROBLEMS AND CHALLENGES

There are a number of architectural and site planning problems in the design consideration for natural ventilation, which need reasonable good solutions. from a broader perspective — and that is, analysing ventilation problems as they affect types of buildings. For example, as between residential buildings and office, school, hospital, commercial or industrial buildings. While comfort in the residential building is a day-and-night problem, in the office or the school, it is a day-time problem. Thus, from that point of view, the latter is simpler.

Pursuing this subject further, and more broadly, in residential buildings, we must bear in mind that such houses in Nigeria have three kinds of living areas: indoor, completely outdoor, and indoor-outdoor by way of terrace, loggia, corridor, verandah or balcony.

The latter two are much more basically important in the tropics than in temperate region. The temperate-based architects are likely to ignore this fact. This is why in most tropical countries with a colonial history, architects from the temperate region have, by and large, created unsuitable buildings, because they imported their own experience and habits – suitable to the indigenes or not.

In Nigeria, living habit is something more than only physically and climatically important; psychologically and spiritually, the privacy, the quietude, the invitation to introspection, the sense of community – whether in a family or school or at place of work – these are important values.

Narrowing down to site planning problems, the question of location of buildings, their orientation, their spacing from each other, constitute the largest single creative useable or controllable item in the whole range of natural factors. The three constituent factors are sun, breeze and view; the detail of this is left for scientists and the engineers to tackle.

To make it more comprehensive the following are questions for which scientists and engineers must provide good answers through further research:

1. How does one best promote natural convection, particularly when there is no breeze available? In other words, what is the minimum satisfactory ceiling height under various conditions, various types of buildings and why? Allied to this is another question – Assuming no appreciable air ventilation, are the customary supplemental high windows of real value? The theory is that the warm air rises, and escapes through these windows. Is this useful, and does the blanket of warm air at the top of the room which would exist without such upper windows, constitute any actual detriment to comfort conditions?
2. Optimum building construction characteristics seem to differ depending on whether a building is air conditioned or not. When not air conditioned, and in a humid climate (as in most parts of Nigeria) with good breeze, a very open construction seems desirable where walls of fixed louvres only might seem ideal. If later on this building is to be air conditioned, a quite different construction would be required. Is there any answer to this dilemma?
3. Cavity walls are assumed to be effective in blocking heat transmission. However, this we rarely do, why? What space is needed to activate convection within them? How much are our local materials useful for this purpose especially here where day and night temperatures don't differ much.
4. Where there is enough air movement, buildings can be economically designed with rooms on either side of a single corridor. Here then, ventilation can be attained across the corridor by louvres or sash, in the two corridor walls. The disadvantage of this system in offices and school buildings is transmission of noise between rooms, and from corridor to either room. How can we solve this problem?
5. The last question is in two fold. Given the requirements of lighting for a particular building, what should be the dimensions of the windows? Given a window width and height, what should be the penetration and spread of a given daylight factor for interior parts of Nigerian buildings?

4.0 DESIGN GUIDING PRINCIPLES

To expantiate further on the earlier conviction that 'comfort conditions precede architecture, underline . . .', there are four variables to work with. The interplay of the four variables (elements) can lead us to a more accurate approach to the problem at hand. These elements can be arranged in the following order:

Climate;
Biology;
Technology;
Architecture (Olgay, 1963).

The first step towards the solution is a survey of the climatic elements at strategic locations in the country. The second, to analyse the bioclimatic impacts on man, and to classify his needs. Third, to seek methods and means to satisfy those needs with technological solutions. And last, to find out how those solutions can be adopted and synthesised to architectural expressions.

Attaining solutions to the enumerated design problems and challenges is by far beyond what an architect, only, can achieve on his draughting table. There are a lot that precede it. There is the need for a data bank for a compendium of basic data and information, or a handbook like those existing in other fields like medicine, pharmacy, etc.

Most practitioners or individuals can-not afford the time and/or expense to find and assemble meteorological and climatological data and put them into readily usable form. This can only be done by government aided research institutes.

The prime object of design in tropical climate is to provide free air movement through building and to prevent the temperature of its inside surfaces rising above shade temperature.

The Nigerian architects must therefore be infused with the following three cardinal geometric principles for consideration in the design for natural ventilation in Nigerian buildings.

First: *ORIENTATION* – To obtain the greatest benefit from air movement on days when there is only a slight breeze, orientation in its prevailing direction is a first consideration, though this must be balanced against the optimum shade provided by the normal (usual) north-south orientation. Orientation should take cognisance of two conditions:

- (a) *Inlet Variation* – Fig. 7 shows the effect of certain inlet variations on the air flow pattern through a particular room. Fig. 7(a) depicts the natural air flow pattern through the room with one simple opening for an inlet. Fig. 7(b) shows what happens when another simple opening is created at the ceiling to accomplish this. To achieve the desired total air pattern, it is therefore necessary to introduce turning vanes of some sort into the main inlet to direct the main air stream back into the living zone as shown in Fig. 7(c).
- (b) *Orientation for Sun* – Additional consideration should be given to the orientation of building and groups of buildings on the basis of solar radiation. This orientation means the relatively best position of a surface in regard to insolation. Insolation (the sun's heat) is important for its positive effects in the temperate and cold regions and its negativity in the tropical regions. With the aid of the "Bioclimatic Chart" (Olgyay, 1963), the year can be divided into "underheated" and "overheated" periods. In the underheated period, the most radiation will be sought and in the overheated, the least radiation.

Building should be as open as possible. Dead air pockets on plan, as well as in section, should be avoided. Walls and ceiling should be shaded from the sun so that they are not heated much, if at all, above shade air temperature – roof and wall surfaces exposed to the sun should be white so as to reflect its heat. The standard Stevenson screen (a well ventilated modern box with a double top and double-louvred sides the whole painted white) used by meteorologists to house thermometers for measuring shade temperatures, provides an admirable model, so often, does the traditional native house.

Second: *LANDSCAPING* – Figures 8 and 9 show some of the effects of landscaping on the air flow within a building. Fig. 8 shows how high hedges (shrubs) may be used to create differences in pressure and cause air to flow through a building oriented with a solid wall into the wind which would otherwise be without airflow because of equal pressures at the two window walls. This suggests that buildings do not necessarily have to be oriented perfectly to the wind if privacy problems interfere.

Fig. 9 shows the effect of variations in a hedge and tree arrangement. With the hedge located leeward of the tree as shown in the upper diagram, the air flow is deflected over the building creating a low pressure

region in front which causes the air to flow through the building slowly in the opposite direction to the wind. But with the hedge and tree arrangement reversed as shown in Fig. 9(b), the air flow is restored to the ground causing it to flow forward through the building in the usual manner.

Third: *SHADING MASKS* (Olgyay, 1963) – Lines, planes or objects with defined characteristics; geometrical forms in their projected diagrams are termed "shading masks". Horizontal overhangs, vertical fins, egg crates, or any other geometrical shading devices will fall into "shading mask" categories. These devices act as sun-shades and sometimes permit windows to be kept open for ventilation when it is raining but, where the main source of light, and radiant heat, is the sky, they give little protection. The view of the sky, thereof in addition, needs to be screened by louvres and similar means, or by judicious planting. Low-caved verandahs are frequently used, but these have turned out to make it too dark inside. The excessive ceiling heights (4.0m and more) formally favoured in the tropics are being abandoned as the fact becomes more widely known that a high ceiling in a multi-storey building makes no contribution to thermal comfort.

5.0 CONCLUSION

Ventilation is needed in Nigeria for not less than 85 per cent of the year. Features such as screening, louvres, jalousies and grills are useful to admit air flow and to provide protection against the sun. Since the strongest thermal impacts occur in the region prevention of the sun from directly striking the walls during dry season through the use of roof overhangs must be provided. Furthermore, a ventilated double roof is desirable where the upper roof provides protection from the sun. Shading trees should be high-branching so that they do not interfere with breezes. Low vegetation should be kept away from houses so as not to block air movement. E-W cross ventilation is essential.

Beyond this, it would seem that such questions raised in this text, or better ones, would need research on three levels:

- to gain better understanding and make better use of natural conditions;
- to produce further improvement of existing simple devices for ameliorating heat as generated from the sun; and
- provision of a data bank for a compendium of basic data and information with a view to producing a handbook.

Actually, if the above can be accomplished, significant and happy contribution would have been made towards attaining the desired conditions of livability.

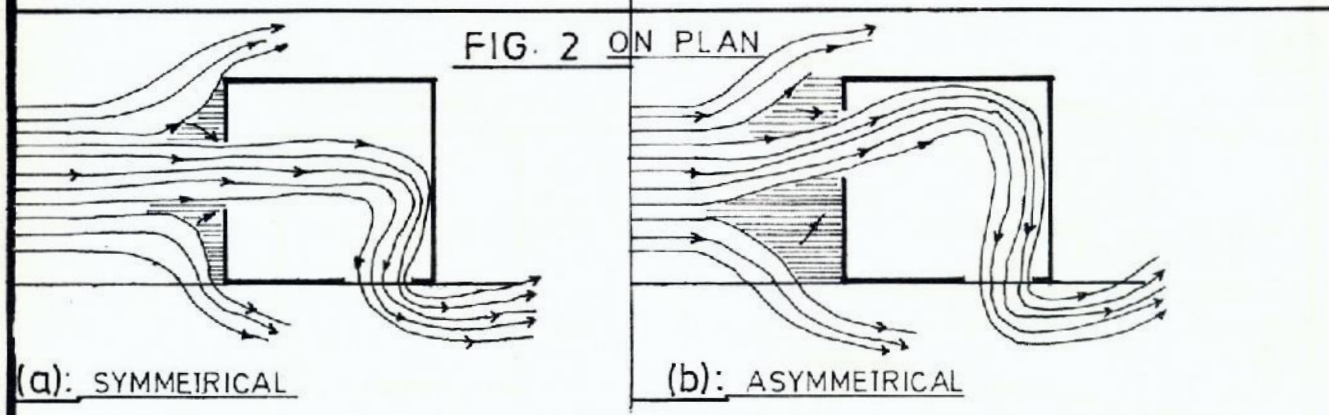
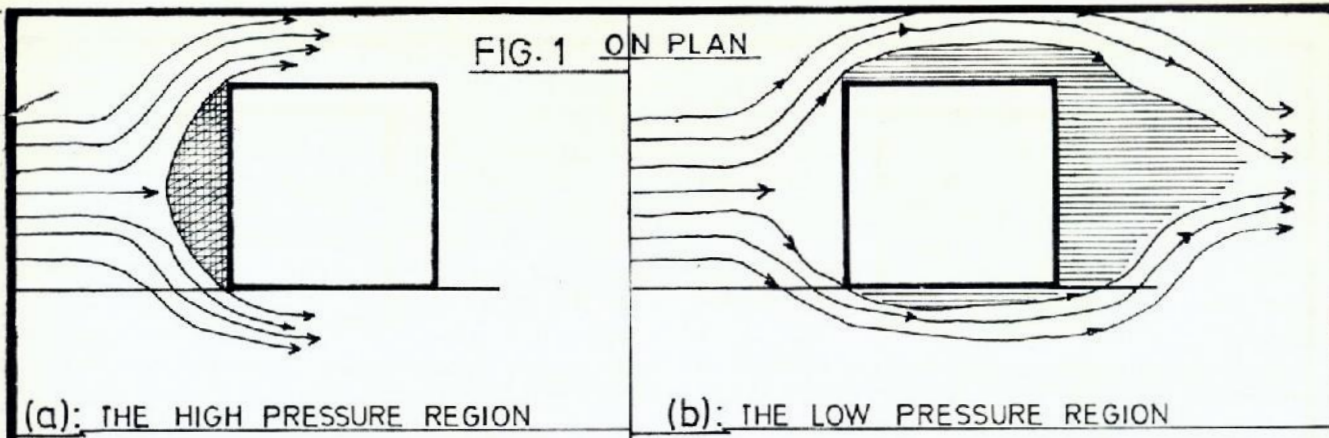
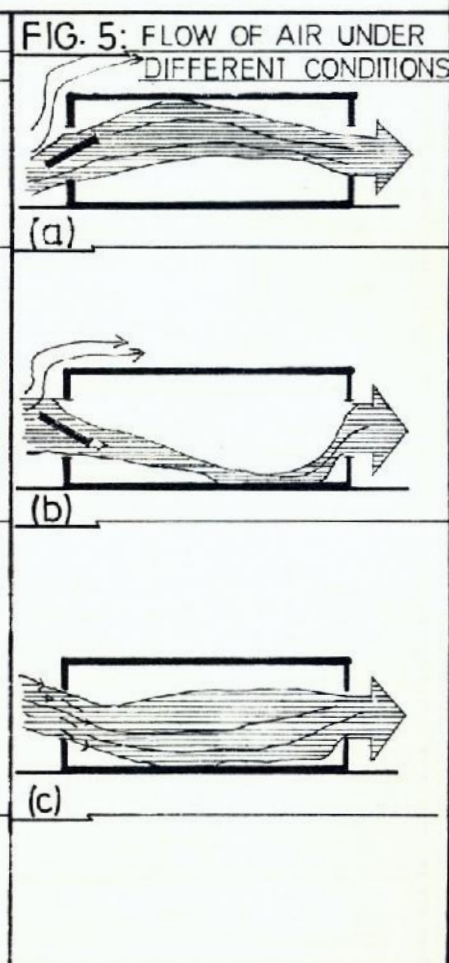
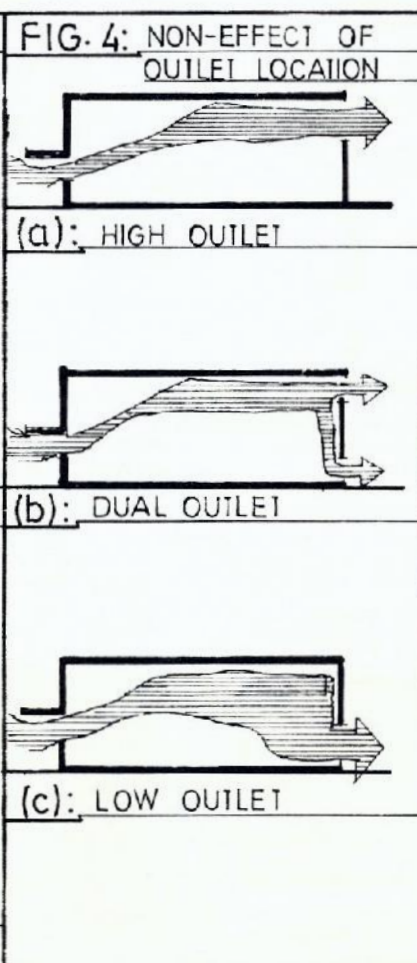
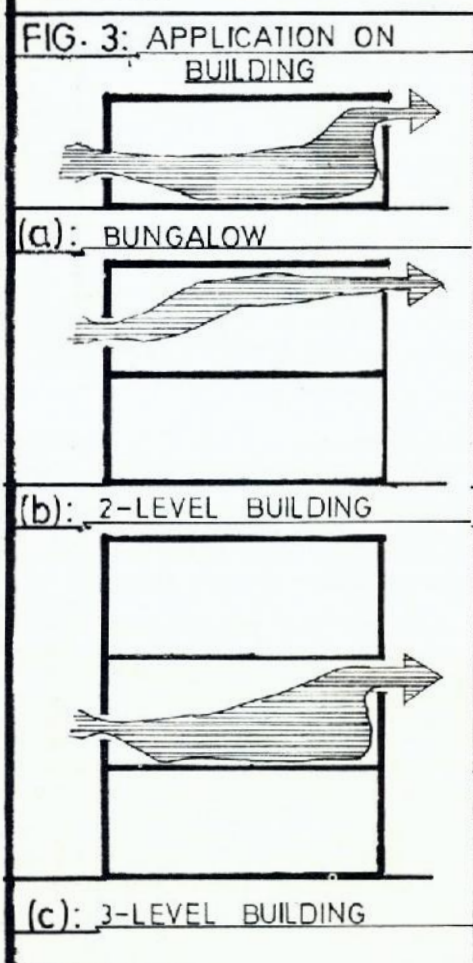
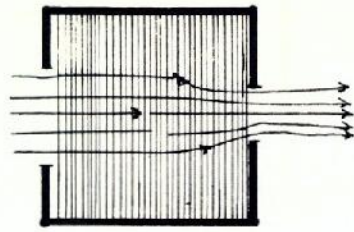
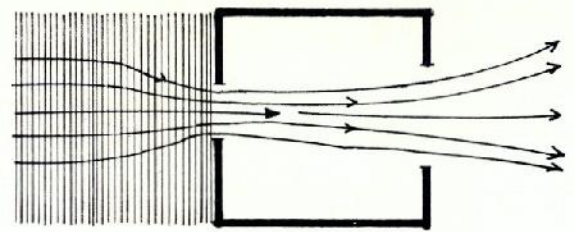


FIG. 2: EFFECT OF LOCATION OF THE INLET ON AIR PATTERN





(a): LARGE INLET, SMALL OUTLET



(b): SMALL INLET, LARGE OUTLET

FIG. 6: SIZE OF INLET VS. SIZE OF OUTLET

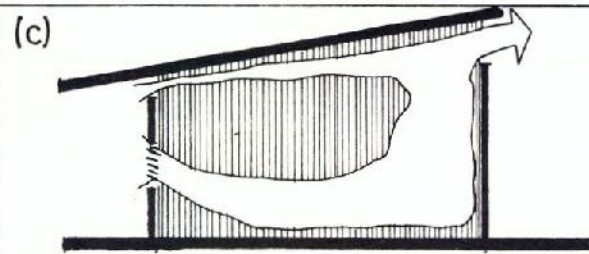
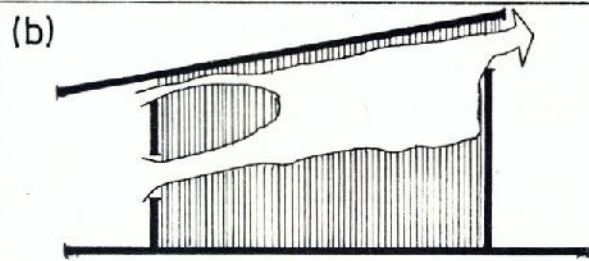
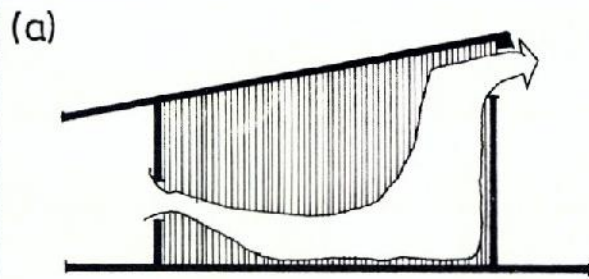


FIG. 7: INLET VARIATIONS ON AIR FLOW PATTERNS

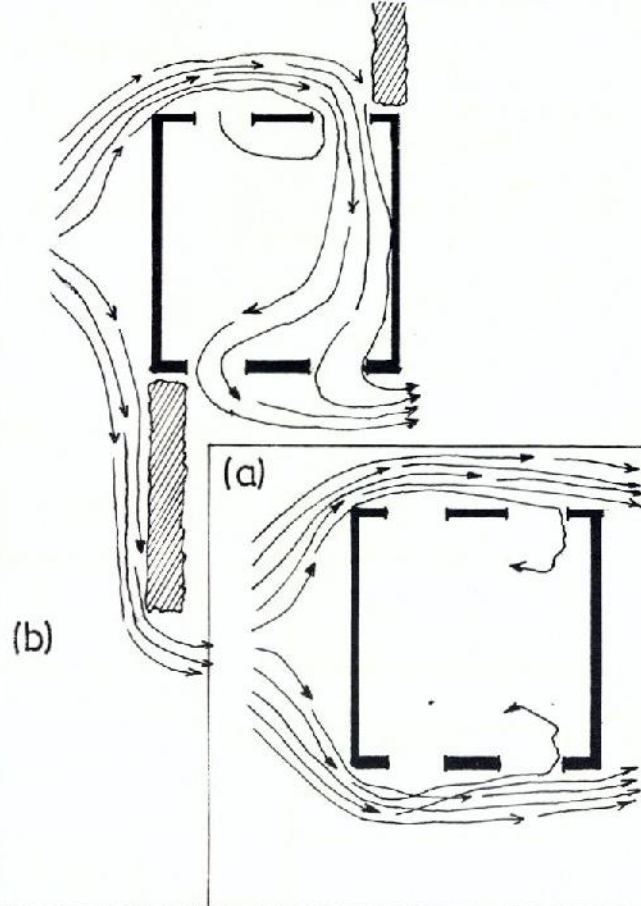


FIG. 8: EFFECT OF HIGH HEDGES

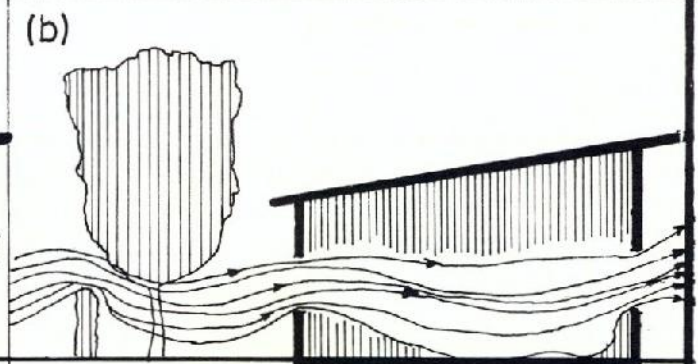
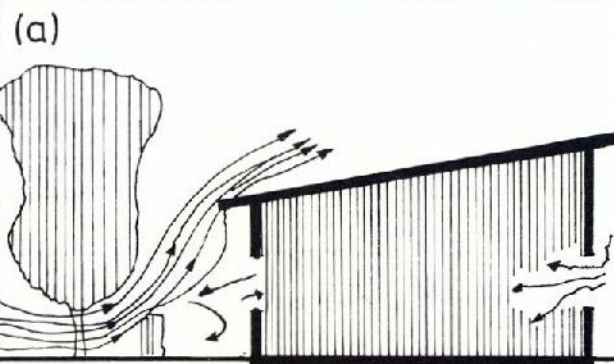


FIG. 9: EFFECT OF VARIATIONS IN A HEDGE AND TREE ARRANGEMENT

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THE NEED FOR ROOF INSULATION IN A WARM CLIMATE

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ABSTRACT

Uncontrolled heat gains through roofs have a pronounced influence on indoor thermal conditions. Warm ceilings usually contribute to the overheating of a building interior in a warm humid climate, consequently leading to the thermal discomfort of occupants or resulting in a high cooling load in an air-conditioned interior.

This paper deals with the analysis of heat flow through the roof/ceiling combination with and without insulation. Calculated results show the influence of ceiling insulation on the ceiling temperature and also on the total heat flow into an interior through the bounding structures.

INTRODUCTION

The human body maintains its thermal equilibrium with the environment by means of heat exchanges, involving, evaporation, convection and radiation. In warm environment, the proportion of heat exchanges by the body through radiation alone is up to 55% (convection 15%; evaporation 30%).

The environmental factor which influences the contribution of radiation to thermal comfort is the mean radiant temperature (m.r.t.). The mean radiant temperature is a measure of the thermal conditions of the internal surfaces of a room. When the body is surrounded by surfaces cooler than the skin temperature, it will lose heat and if the surfaces are hotter it will gain radiant heat. Thus, the presence of any warm surface, much warmer than the skin temperature is undesirable for thermal comfort. The exposure of external walls and roofs to the outdoor air and solar radiation makes their internal surfaces prone to overheating. Therefore, when designing walls and roofs, one of several performance requirements to be considered is their thermal performance; that is their effectiveness in maintaining the temperature of internal surfaces at the desirable value.

The roof in particular, due to its position in a building, is more exposed to solar radiation than any other surface. Consequently, it is expected that the greatest proportion of heat flow into an interior comes in through the roof. The roof system must be designed

to offer a high resistance to heat flow.

A simple analysis of heat flow into an interior would show the relative contributions of heat flow through the roof and through each of the walls on the North, South, East and West orientations to the total heat flow.

1. Floor area is 6m x 4m = 24m²
2. South window area = 4.4m²
3. North window area = 4.4m²
4. South wall area = 13.6m²
5. North wall area = 13.6m²
6. West wall area = 12m²
7. East wall area = 12m²
8. 15° pitched roof of area 24.85m²

ANALYSIS WEATHER DATA

A period of high heat stress is chosen for the analysis. The climatic conditions are for May 30. The locations of the hypothetical interior is on latitude 9°N. The analysis weather data are recorded in Table 1.

SOL-AIR TEMPERATURE FOR VARIOUS SURFACES

The thermal flow through a building structure is due to the combination of the heating effect of solar radiation and the effect of outside warm air. The sol-air temperature indicates the overall effect of the two thermal sources. The sol-air temperature T_s is given by the following equation

$$T_s = T_o + \frac{\alpha I}{f_o}$$

where

- T_s = Sol-air temperature in °C
- T_o = Outside air temperature in °C
- α = absorbance of the surface
- I = Solar radiation intensity in W/m²
- f_o = outside surface conductance in W/m² degC

α is 0.75 for asbestos cement roofing material and is 0.65 for walls.

The calculated sol-air temperatures for the roof and wall surfaces are in Table 2.

U-VALUES OF STRUCTURES

Each wall is constructed of sandcrete blocks and the U-value is $2.2 \text{ W/m}^2 \text{ deg. C}$.

For 5mm corrugated asbestos cement sheet over 5mm asbestos ceiling sheets (uninsulated), the U-value is $2.31 \text{ W/m}^2 \text{ deg. C}$. The same roof when insulated using 25mm fibre glass, U-value is $0.88 \text{ W/m}^2 \text{ deg. C}$.

HOURLY HEAT FLOW THROUGH VARIOUS BUILDING STRUCTURES

Heat flow through a wall or the roof at any hour is given by the equation below.

$$Q = AU (T_s - T_i)$$

where Q is the total heat flow through the surface in Watts.

- A is the total surface area of structure in m^2
- U is the U-value of structure in $\text{W/m}^2 \text{ deg. C}$.
- T_s is the sol-air temperature in $^\circ\text{C}$.
- T_i is the internal air temperature in $^\circ\text{C}$

For this theoretical analysis for which no measurements are carried out the internal air temperature is taken to be the same as the external air temperature where the interior is adequately ventilated.

The values of the hourly heat flow into the interior through the roof and each of the four walls are separately given in Tables 3 and the values of the total hourly heat flow into the interior through all the structures are given in Table 4. Here the roof is not insulated.

An observation of Table 4 shows that: first, the peak of the total heat flow occurs between 10.00 and 14.00hr. and in particular the maximum occurs at about 12noon. Secondly the greatest proportion of the maximum total heat flow is contributed by the roof. Thirdly the greatest proportion of the total heat flow between the hours of 08.00 and 16.00 is contributed by the roof. Fourthly, the maximum heat flow through the roof occurs at 12noon.

TOTAL HOURLY HEAT FLOW INTO THE INTERIOR WHEN THE ROOF IS INSULATED.

The values of the total heat flow into the interior when the roof is insulated are contained in Table 5. Insulation is not applied on any of the four walls. The benefits of applying insulation on the roof can be inferred from the reduced heat flow values in the Table. These benefits are

- i) The peak values of the heat flow through the roof are considerably reduced. A reduction of 62% is achieved in each value of the hourly heat flow through the insulated roof.
- ii) Large reductions are achieved in the values of total hourly heat flow through all the structures in to the interior. The maximum total heat flow at 12noon is reduced by over 50 per cent (50.5%).

TEMPERATURE OF CEILING UNDERSIDE

The influence of roof insulation on the temperature of the ceiling inner surface is illustrated in fig. 1. The ceiling temperature is considerably lowered when the roof is insulated. At noon, the difference in the temperatures of the uninsulated ceiling and the insulated ceiling is about 6°C . The hot uninsulated ceiling is a source of radiant heat to occupants and inner surfaces of walls. The effect of any increase in ceiling temperature is a rise in the mean radiant temperature of the interior and which in turn results in the increase of the effective temperature thereby tilting the thermal comfort scale.

CONCLUSIONS

This paper has drawn attention to the advantages that can be derived from insulating roofs in a warm humid climate.

During the day time the temperature of an uninsulated ceiling is far higher than those of walls, indoor air temperature and floor. The hot ceiling thus becomes a source of radiant heat into the internal environment. Furthermore, when the roof is insulated, the cooling load in an air-conditioned room is greatly reduced. Though, no cost comparison has been done, it is expected that the reduction in cooling load will yield some savings in the initial costs of airconditioning plant and its running cost.

Table 1: Analysis Weather Data

Solar Radiation Intensity on Surface W/m^2

Time of day (hr)	Outdoor air temp. ($^{\circ}C$)	Roof	South Wall	North Wall	East Wall	West Wall
07.00	24.8	150	30	230	530	30
08.00	25.9	355	35	265	635	35
09.00	26.9	575	45	275	595	45
10.00	28.1	730	50	275	450	50
11.00	29.0	785	55	275	275	55
12.00	30.1	877	57	277	57	57
13.00	31.1	785	55	275	55	275
14.00	31.7	720	50	280	50	460
15.00	32.1	545	45	275	45	595
16.00	32.1	335	35	255	35	635
17.00	31.7	150	30	230	30	530

Table 2; Sol-air Temperatures for Roof and Walls

Sol-air Temperature $t_{sa} = t_o + \frac{I}{h_{so}}$

Time of day (hr)	Outdoor air Temp. ($^{\circ}C$)	Roof	South Wall	North Wall	East Wall	West Wall
07.00	24.8	30.4	25.8	32.3	42.0	25.8
08.00	25.9	39.2	27.0	34.5	46.5	27.0
09.00	26.9	48.5	28.4	35.8	46.2	28.4
10.00	28.1	55.5	29.7	37.0	42.7	29.7
11.00	29.0	58.4	30.8	37.9	37.9	30.8
12.00	30.1	63.0	32.0	39.1	32.0	32.0
13.00	31.1	60.5	32.9	40.0	32.9	40.0
14.00	31.7	58.7	33.3	40.8	33.3	46.7
15.00	32.1	52.5	33.6	41.0	33.6	51.4
16.00	32.1	44.7	33.2	40.4	33.2	52.7
17.00	31.7	37.3	32.7	39.2	32.7	48.9

Table 3a: Hourly Heat Flow Through the Roof (Uninsulated)

Time of day (hr)	Indoor air Temp. T_i ($^{\circ}\text{C}$)	T_s ($^{\circ}\text{C}$)	$T_s - T_i$ ($^{\circ}\text{C}$)	U ($\text{W}/\text{m}^2 \text{degC}$)	A (m^2)	Q (Watts)
07.00	24.8	30.4	5.6	2.31	24.85	321.5
08.00	25.9	39.2	13.3			763.5
09.00	26.9	48.5	21.6			1239.9
10.00	28.1	55.5	27.4			1572.9
11.00	29.0	58.4	29.4			1687.7
12.00	30.1	63.0	32.9			1888.6
13.00	31.1	60.5	29.4			1687.7
14.00	31.7	58.7	27.0			1549.9
15.00	32.1	52.5	20.4			1171.0
16.00	32.1	44.7	12.6			723.3
17.00	31.7	37.3	5.6			321.5

Table 3b: Hourly heat flow through the South Wall

Time of day (hr)	Indoor air temp T_i ($^{\circ}\text{C}$)	T_s ($^{\circ}\text{C}$)	$T_s - T_i$ ($^{\circ}\text{C}$)	U ($\text{W}/\text{m}^2 \text{degC}$)	A (m^2)	Q (Watts)
07.00	24.8	25.8	1.0	2.2	13.6	29.9
08.00	25.9	27.0	1.1			32.9
09.00	26.9	28.4	1.5			44.9
10.00	28.1	29.7	1.6			47.9
11.00	29.1	30.8	1.7			50.9
12.00	30.1	32.0	1.9			56.8
13.00	31.1	32.9	1.8			53.9
14.00	31.7	33.3	1.6			47.9
15.00	32.1	33.6	1.5			44.9
16.00	32.1	33.2	1.1			32.9
17.00	31.7	32.7	1.0			29.9

Table 3c: Hourly heat flow through the North Facing Wall

Time of day (hr)	Indoor air temp. T_i ($^{\circ}\text{C}$)	T_s ($^{\circ}\text{C}$)	$T_s - T_i$ ($^{\circ}\text{C}$)	U ($\text{W}/\text{m}^2 \text{degC}$)	A (m^2)	Q (Watts)
07.00	24.8	32.3	7.5	2.2	13.6	224.4
08.00	25.9	34.5	8.6			257.3
09.00	26.9	35.8	8.9			266.3
10.00	28.1	37.0	8.9			266.3
11.00	29.0	37.9	8.9			266.3
12.00	30.1	39.1	9.0			269.3
13.00	31.1	40.0	8.9			266.3
14.00	31.7	40.8	9.1			272.3
15.00	32.1	41.0	8.9			266.3
16.00	32.1	40.4	8.3			248.3
17.00	31.7	39.2	7.5			224.4

Table 3d: Hourly Heat flow through the East Facing Wall

Time of day (hr)	Indoor air Temp. T_i ($^{\circ}\text{C}$)	T_s ($^{\circ}\text{C}$)	$T_s - T_i$ ($^{\circ}\text{C}$)	U ($\text{W}/\text{m}^2\text{degC}$)	A (M^2)	Q (Watts)
07.00	24.8	42.0	17.2	2.2	12.0	454.1
08.00	25.9	46.5	20.6			543.8
09.00	26.9	46.2	19.3			509.5
10.00	28.1	42.7	14.6			385.4
11.00	29.0	37.9	8.9			235.0
12.00	30.1	32.0	1.9			50.2
13.00	31.1	32.9	1.8			47.5
14.00	31.7	33.3	1.6			42.2
15.00	32.1	33.6	1.5			39.6
16.00	32.1	33.2	1.1			29.0
17.00	31.7	32.7	1.0			26.4

Table 3e — Hourly Heat flow through the West Facing Wall

Time of day (hr.)	Indoor air temp. T_i ($^{\circ}\text{C}$)	T_s ($^{\circ}\text{C}$)	$T_s - T_i$ ($^{\circ}\text{C}$)	U ($\text{W}/\text{m}^2\text{degC}$)	A (m^2)	Q (Watts)
07.00	24.8	25.8	1.0	2.2	12	26.4
08.00	25.9	27.0	1.1			29.0
09.00	26.9	28.4	1.5			39.6
10.00	28.1	29.7	1.6			42.2
11.00	29.0	30.8	1.8			47.5
12.00	30.1	32.0	1.9			50.2
13.00	31.1	40.0	8.9			235.0
14.00	31.7	46.7	15.0			396.0
15.00	32.1	51.4	19.3			509.5
16.00	32.1	52.7	20.6			543.8
17.00	31.7	48.9	17.2			454.1

TABLE 4: TOTAL HOURLY HEAT FLOW INTO THE INTERIOR, WHEN ROOF IS NOT INSULATED

Time of Day/ Surface	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
Roof	321.5	763.5	1239.9	1572.9	1687.7	1888.6	1687.7	1549.9	1171.0	723.3	321.5
South Wall	29.9	32.9	44.9	47.9	50.8	56.8	53.9	47.9	44.9	32.9	29.9
North Wall	224.4	257.3	266.3	266.3	266.3	269.3	266.3	272.3	266.3	249.3	224.4
East Wall	545.1	543.8	509.5	385.4	235.0	50.2	47.5	42.2	39.6	29.0	26.4
West Wall	26.4	29.0	39.6	42.2	47.5	50.2	235.0	396.0	509.5	543.8	454.1
Total Heat flow (Watts)	1056.3	1626.5	2100.2	2287.4	2315.1	2315.1	2290.4	2308.3	2031.3	1577.3	1056.3

TABLE 5: TOTAL HOURLY HEAT FLOW INTO THE INTERIOR, WHEN ROOF IS INSULATED

Time of day/ Surface	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
Roof	290.8	472.4	599.2	642.9	719.5	642.9	590.00	446.1	275.5
South Wall	32.9	44.9	47.9	50.9	56.8	53.9	47.9	44.9	32.9
North Wall	257.3	266.3	266.3	266.3	269.3	266.3	272.3	266.3	248.3
East Wall	543.3	509.5	385.4	235.0	50.2	47.5	42.2	39.6	29.0
West Wall	29.0	39.6	42.2	47.5	50.2	235.0	396.0	509.5	543.8
Total Heat flow (Watts)	1153.8	1332.7	1341.0	1242.8	1146.0	1245.6	1348.8	1306.5	1129.5

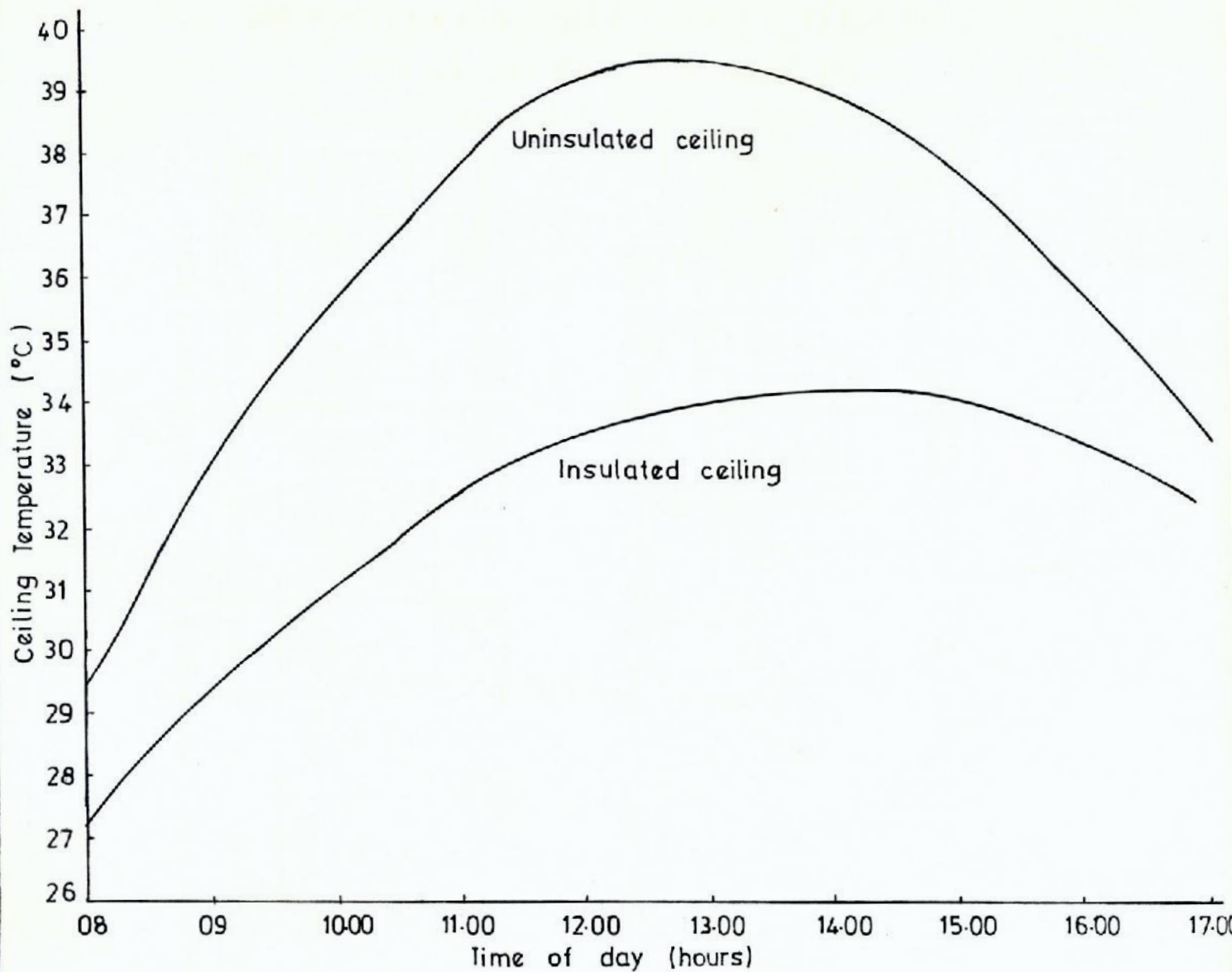


Fig. 1: Effect of Insulation on the temperature of ceiling inner surface

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VENTILATION, AIR MOVEMENT IN BUILDING, AIR QUALITY. “A Case Study of Nigerian Climate”

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ABSTRACT

Investigations were carried out within the climatic zones of Nigeria by studying various environs, taking measurements of comfort parameters and heat transfer through the building elements/structures. These investigations revealed that natural controls can be achieved as a result of careful planning, choice of materials plus the application of certain design features and forms to enhance natural but adequate supply of fresh air, convective and physiological cooling. Adequate controls of air quality is also achieved - especially in the hot-dry climate where hostile weather conditions and the diurnal temperature range imposed some design constraints on the provision of adequate ventilation and the maintenance of a comfort level day and night. Residential buildings should be orientated in the N.E and S.W directions in zones A and B respectively to enhance adequate/maximum natural cooling. There is an urgent need for recommended environment conservation measures that will contribute significantly to energy conservation. The thermal comfort zone lies between 25°C and 29°C and depends on the relative humidity and air movement.

1.0 INTRODUCTION

Ventilation, air movement and the air quality in buildings are mostly controlled mechanically in the western world where advance technology is at its peak. Considering the present economic situation in many third world countries which are plagued with acute shortage of foreign exchange and balance of payment problems, it has dawned on us that the days of unrestricted importation are over and that the use of natural controls and the application of intermediate technology where appropriate are the ideal solutions.

2.0 CLIMATIC ZONES

In order to develop efficient and economical design concepts, the climatic variations in Nigeria is analysed. The country is situated between Latitude 4 and 14 degrees North of the equator and Longitude 2 and 15 degrees East of the Meridian. It is bounded in the North by Niger Republic and South by the Atlantic Ocean. The climate in the country is a transitional

one, lying between the dryness of the desert of the north and high humidity of the Atlantic coast in the south, hence, the country enjoys a tropical climate with marked wet and dry seasons. The intensity of the wet season decreases as one moves away from the coast while the marked seasons are associated with the prevalence of the moist Maritime South Westerly Monsoon from the Atlantic Ocean and the dry dust-laden continental North Easterly wind from the Sahara desert. The point of convergence of the two air masses is the Inter Tropical Convergence Zone, generally known as the ITCZ. The fluctuating positioning of this zone marks the sequence of weather types found in Nigeria.

2.1 Wind

Winds are mostly gentle to moderate except at the approach of rainstorm when high velocity and at times destructive winds are experienced. The overall modal wind speed is between one and two metres per second. The dominant winds are southerly, south-westerly and westerly at stations south of the ITCZ while the northerly, easterly and north-easterly winds are dominant in the north of this position.

2.2 Seasonal Variations

Rainfall is seasonal in character with marked wet and dry seasons. Rainfall intensity decreases from the coast to the interior both in amount and in distribution, ranging annually from about 2800mm in the south to about 530mm in the north. The length of the rainy season ranges from 9-11 months in the coastal areas of the south to less than 3 months in the extreme north. The seasonal variations can be attributed to the positioning of the ITCZ. Seasonal variations in the length of day is very minimal with a probable maximum sunshine hours of between 10 and 12 hours. The presence of cloud cover reduces the actual totals of incident solar radiation received to about 55% of the maximum possible.

2.3 Relative Humidity (R.H.)

These vary from about 90 per cent to about 15 per

cent in the south and north respectively. The highest and lowest values being recorded at around 0600 and 1400 hours respectively.

2.4 Climate Classification

A study by the IDA Education Project (1970)^[1] divided Nigeria into seven zones but the boundaries were not necessarily divided into climate zones. Thornthwaite and Mather^[2] classified Nigeria into five climatic zones; perhumid, humid, moist humid, dry subhumid and semi-arid, based on the moisture index of Nigeria. Broadly, Nigeria can be divided into four climatic zones^[3], hot-dry; temperate dry, hot humid and warm humid as depicted in Figure 1. These could be further reduced to two because the boundaries of each zone will overlap, substantiating the reasons for the overlap in design concepts in the various zones.

2.4.1 Dry Hot

The zone covers the wide areas of dry region in the far north of the country. This region is dry, with annual maximum and minimum temperature of between 30–40°C and 20–25°C respectively in the dry and wet seasons. The relative humidity varies between 35 to 45 percent during the dry season and between 70 to 80 percent during the wet season. The hot dry wind is in the north-east direction during the dry season and the thermal wind with a lot of dust storm prevails in the south-west direction during the rainy season. Strong and direct solar radiation characterises the day-time period because of the low cloud cover except during sand-storms, which also result in reduced visibility.

2.4.2 Temperate Dry

The zone comprises the Upland and Plateau areas of the country. The maximum temperature range is between 25°C and 33°C during the dry season and a mean minimum range of between 18°C and 25°C during the harmattan and wet seasons. The relative humidity range and wind direction are similar to what obtain in the dry hot zone but the incidence of sand-storm is minimal.

2.4.3 Hot Humid

The zone covers part of the Middle-Belt and part of the southern regions. Mean maximum temperature range in dry season is between 30°C and 38°C while the mean minimum range recorded in wet season is between 25°C and 30°C. The wind direction and the relative humidity are same as in the temperate and hot-dry zone, but heavy rainfalls are recorded during the wet season. High radiant heat values, overcast sky and glare problems are common features.

2.4.4 Warm Humid

The warm humid zone extends from Latitude 4.5°N southwards to the sea. The mean maximum temperature range is between 28°C and 33°C in the dry season and between 21°C and 26°C during the wet

season. This zone is characterised by a south westerly wind and high intensity rainfall in the wet season. Sky conditions are the same as in the hot humid zone.

2.5 Thermal Comfort

Human comfort level indoor is dependent on the dry bulb temperature (t_{db}), relative humidity (R_H), air velocity (V_a) and radiation from surfaces (X_r). These parameters could be controlled to an optimum degree in each zone by careful planning, design and choice of local materials to ensure thermal comfort through natural controls. The analysis in Section 2.4 shows that for thermal comfort analysis, the zones can be re-grouped further hence Hot Dry and Temperate Dry zones are grouped as Zone A while Hot Humid and Warm Humid will be classified as Zone B.

3.0 ANALYSIS OF FACTORS AFFECTING VENTILATION AND AIR MOVEMENTS

Adequate building ventilation is primarily dependent on building design, choice of materials, topography/morphology and climatology. The additional factors which may play limited role in the adequacy of building ventilation are the building types, density and the dilution of CO₂ concentration.

3.1 Natural Ventilation

Air movement through a building shell is a combination of viscous and turbulent flows through openings and cracks^[4]. The former is proportional to the pressure difference over the envelope whereas the latter often varies with the square root of the pressure difference. Hence the different mechanisms that are primarily responsible for the natural air-flow in the building are the wind pressure, bouyant forces and a combination of these two factors.

3.1.1 Flow Due to Wind

Ventilation wind forces are affected by the average wind velocity, the prevailing direction and the local obstructions; but the quality of air forced through ventilation inlet opening by wind, Q_r , which is a function of the effectiveness of opening, A_e , and the velocity, V_w , can be expressed mathematically as

$$Q_r = K_o \delta m A_e V_w \quad (1)$$

where K_o and δm are metric factor and effectiveness of openings respectively. Wind flows will provide a velocity pressure field around the buildings and the pressure fields could be characterised roughly by regions of over-pressure (OP) on the facades parallel to the air-stream—the wind-ward sides or by under pressure (UP) on the facades parallel to the air stream on the lee-ward side of the building. Such pressures could be proportional to the dynamic pressure in the undisturbed wind stream⁽⁴⁾ and could be expressed as

$$P_w = \frac{1}{2} \rho_a (y, T) \times V_w^2 (y) \times \delta k (y) \quad (2)$$

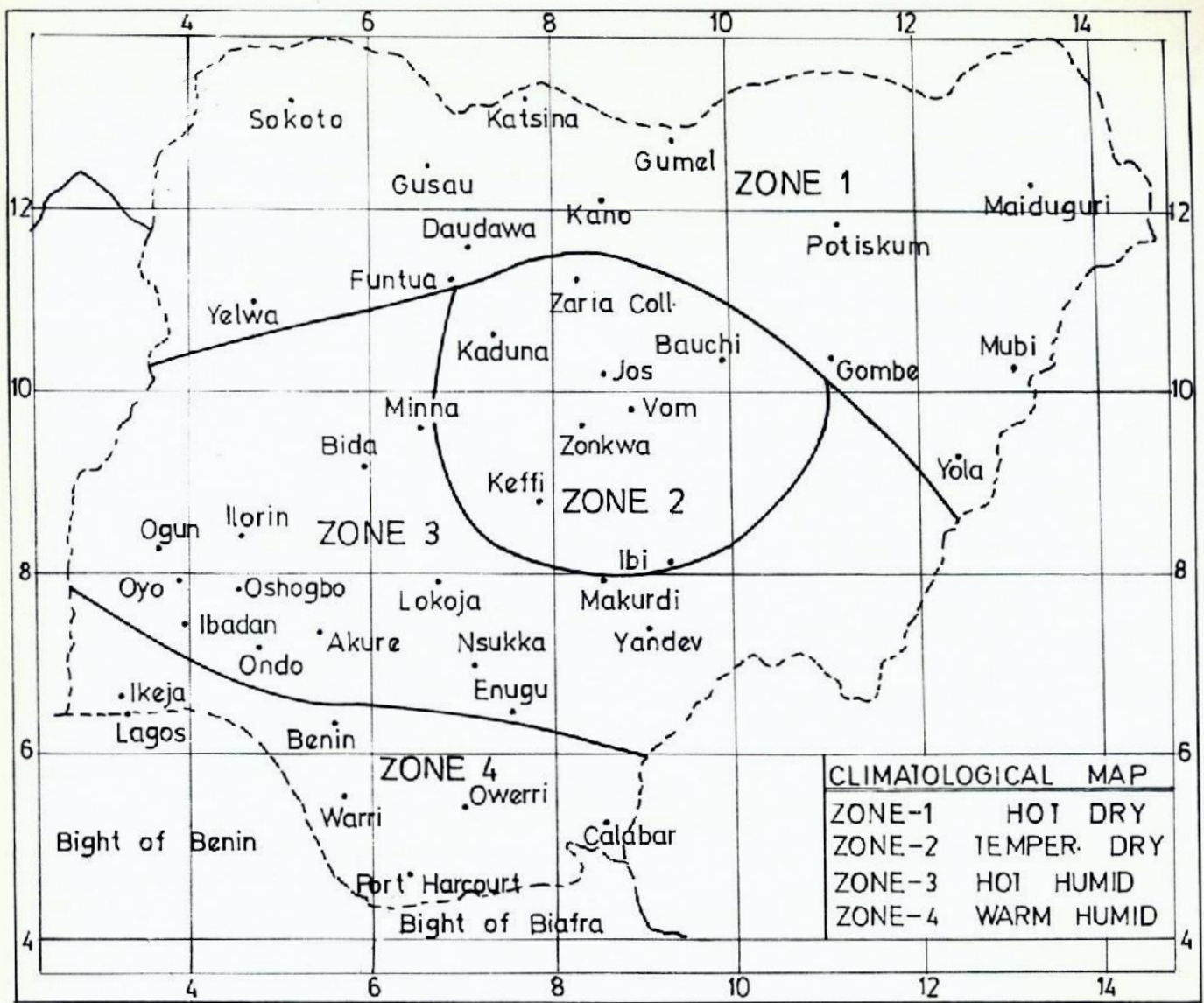


FIG. 1: CLIMATOLOGICAL MAP OF NIGERIA.

SOURCE: NIGERIAN BUILDING AND ROAD RESEARCH INSTITUTE

ZONE 1 & ZONE 2 = ZONE A

ZONE 3 & ZONE 4 = ZONE B

where P_w , P_a , y and Ok are wind pressure, air density, height of building and coefficient respectively. But the vertical profile of the mean wind in the atmospheric boundary layer often depends primarily on the surface roughness as influenced by terrain and shows an increasing velocity with height above ground. Apart from the wind-ward and the lee-ward sides of the building, the pressures on the other sides would either be positive or negative depending on the wind angles and the shape of the building. For simplicity, it may be assumed that the static pressures over building surfaces are almost proportional to the velocity head of the undisturbed air stream, but for the detailed analysis, the variations of static pressure with height at building surface is less than the variations in velocity pressure of the oncoming flow. Such velocity head will vary with the building type, shape, orientation, external features, size, position and controls of openings and the wind direction. Internal pressure will affect pressure difference across walls or roof and the resulting infiltration. Such pressures inside the building as a result of wind forces will also depend on the resistances of openings and cracks and their locations relative to wind direction.

3.1.2 Thermal Forces

These are responsible for the positive or negative internal pressure within the building, depending on whether or not the temperature within such a building is greater or less than that outside. When thermal forces act alone neutral pressure level (NPL) will exist, when there is no pressure difference between the outside and the inside. At all other levels, the theoretical pressure difference, P_t , will depend on a atmospheric pressure, P_a , distance between the NPL, h_{NPL} and the effective chimney height, h_e , difference between the absolute air temperature of the inside, T_i , and the outside air, T_o , respectively in such a way that

$$P_t = K_p P_a y (1/T_o - 1/T_i) \quad (3)$$

where K_p is a constant. In the same manner, the pressure gradients between inside and outside the building, which arising from a change in air densities ($\rho_o - \rho_i$) due to temperature difference between the ambient air and air inside the building can also be simply equated as

$$\rho_s = g(\rho_o - \rho_i) (y - y_{NPL}) \dots \dots \dots (4)$$

where g is the gravitational acceleration and y_{NPL} is the height of building facade where the interior pressure equals the exterior. The influence of thermal forces is crucial in high-rise building design and it is usual to assume that infiltrations will be uniformly distributed over the building shell, but for complex buildings, the effect of stairwells, elevator shaft, ducts, chimney and internal partitions must be considered[4]. It must be appreciated however that the universal stack effect systems are natural function caused by differences in air pressure and thermal layering in all buildings – whether operating under

natural or mechanical systems.

3.1.3 Combined Wind and Thermal Bouyancy

The flow due to each mechanism is not additive since the flow rates are not linearly proportional to the pressure differences. The actual flow is less than the summation of the two forces acting separately but when such forces are equal, then, the total value is about thirty three percent greater than the value of each acting separately.

3.2 Energy Demand:— Building Planning

Though building orientation and its relationship to site planning and building design have substantial influence on the end-use energy consumption of building, the commercial buildings in most Nigerian cities have their windows/openings orientated towards the streets without considering the energy implications. If only the planning authorities are energy conscious in the planning of our streets, roads and other facilities, they should have taken cognizance of the energy implication of their layouts. Basic decisions are being taken in landscape planning and designs that demonstrate lack of consciousness of the implications of energy consumption in the initial construction and the continuous maintenance of landscape projects. Proper orientation of our buildings is one of the most effective ways to lower energy use. The naturally-lit, naturally-ventilated office has a primary energy consumption almost one-third less than the air conditioned, artificially-lit office. Most measures which conserve energy consume other scarce resources with the possible exception of better husbandry. If the optimum use of all resources is to be made, resources devoted to energy conservation must be cost-effectively applied while the principles of cost-effectiveness analysis for such decisions in the public and private sectors must be well established.

4.0 THERMAL COMFORT: IMPLICATION OF BUILDING CONCEPT

Building concepts in Nigeria are influenced by religion, culture, climate, tradition socio-economic and security factors, while the type of building materials are dictated by geography and the historical background of each area. The design concepts in the country have gone through three distinct eras; pre-colonial, colonial and post-colonial with each era leaving its impact on planning, plan form, choice of materials and other criteria. Traditional building concepts were used during the pre-colonial era while the western architecture dominated the colonial and post colonial era with the latter culminating in a totally unsuitable building forms and architecture. The bungalow type traditional buildings still suffice in the rural areas where more than eighty percent of the population dwells. Though multi-storey/framed structures are now dominating the commercial areas of the city centres, the bungalows “face-me-I-face-you” Swahili type of Houses still dominate the main design concepts in all residential area. The essence of architecture is the form that is given to space, the order that it establishes for human and their physical surroundings. The major impact of a house form resides in its spatial quality rather than

solely on the materials that make up the walls or roof. A house must be understood both as a personal and a cultural expression - both as home and habitat. For clarity, the analysis of air flows, ventilation and air quality would be approached from two angles, traditional and conventional.

4.1 Traditional Buildings

4.1.1 Planform/Layout

The planform/layout in the hot-dry/temperate dry zones is influenced mainly by the Islamic architecture/Hausa culture and the reality of the harsh climatic weather. The curvi-linear pyramidal and the rectilinear are the dominant planforms of construction while the open, semi-open and the double courtyard planning featured prominently in the local designs. Buildings are often grouped together for mutual shading while the courtyards are planted with tree and shrubs. The compound and the courtyard layouts characterise the planform in the hot/warm humid zones. The planform emanated partly from the Portuguese/Christians/Brazilian influence in the southern part of the country and the common culture with the mild weather. The room layout within the compound system varies from the one depicted in Figure 2 to typical design where two rows of rooms are separated by a common corridor. The compound has always been regarded as the hearth of the Nigerian family community and modern planners have accepted it as the cornerstone of any development. Most activity happens in the compound, serving as the play room, kitchen, dining room, living room, garden, relaxation spot, gossip forum, patio-all together in one flexible space - the family social centre. Traditional buildings are orientated by trial and error in the direction of the wind with little regard being given to sun exclusion.

4.1.2 Walls and Openings

Mud walls with the thickness between 300mm and 400mm with few windows that open into the courtyard characterise the traditional designs in Zone A. Many external walls are devoid of windows partly to reduce the external heat flow into the building and mainly to guarantee the privacy of the wives whose rooms/apartments are

often located close to the back of the building, shielded away from the visitors, as depicted on Figure 3. The mud walls are sometimes reinforced with agricultural materials. Light weight walling materials such as bamboo, timber, lateric materials, etc. shown in Figure 4 are used in Zone B where the daily swing of outdoor temperature is minimal and where the ambient temperature hardly exceeds the body temperature. Most buildings have large window openings but some have small window openings for security reasons.

4.1.3 Roof Design

The two typical roof designs commonly used in Zone A are the "flat" mud roof shown in Figure 5 (experimental building) and the conical/pyramidal thatched roof. The flat mud roof which is commonly used due to the low rainfall is constructed with puddled mud

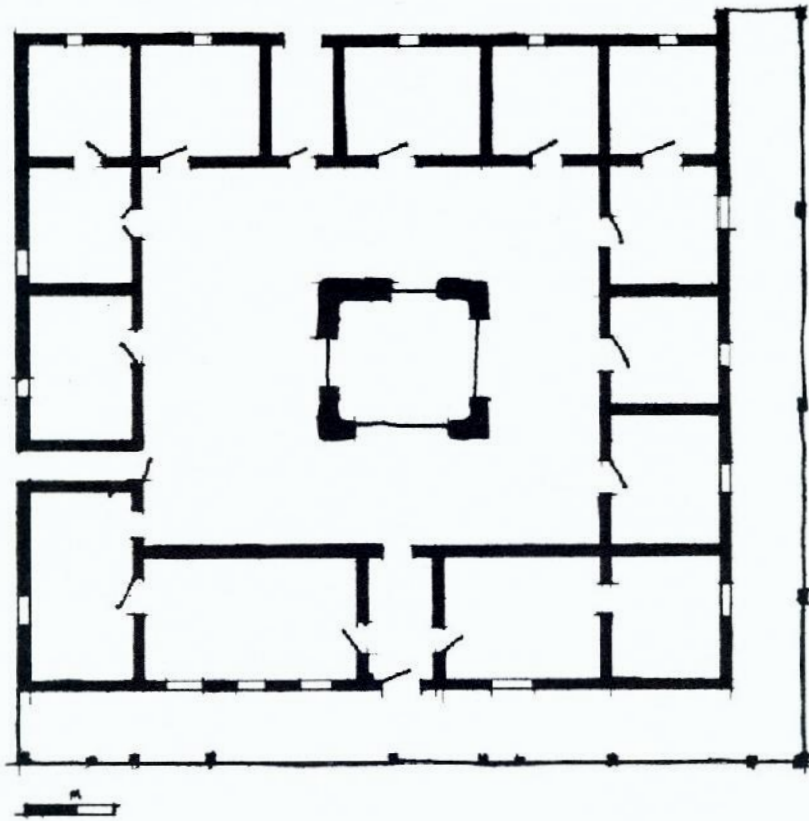
reinforced with dry tree branches or straws and finished with water resistant solution before finally covered with wild grass and similar locally available agricultural materials. The design of the conical thatched roofs consists of roofing materials such as reeds or woven grasses laid on wooden rafters and purlins. Pitched roofs with ceilings are commonly used in Zone B to enhance maximum rainwater collection and drainage. Such roofs are covered with either woven thatch, palm leaves and similar agricultural materials, recently, with corrugated iron sheets.

4.2 Analysis of Thermal Implication

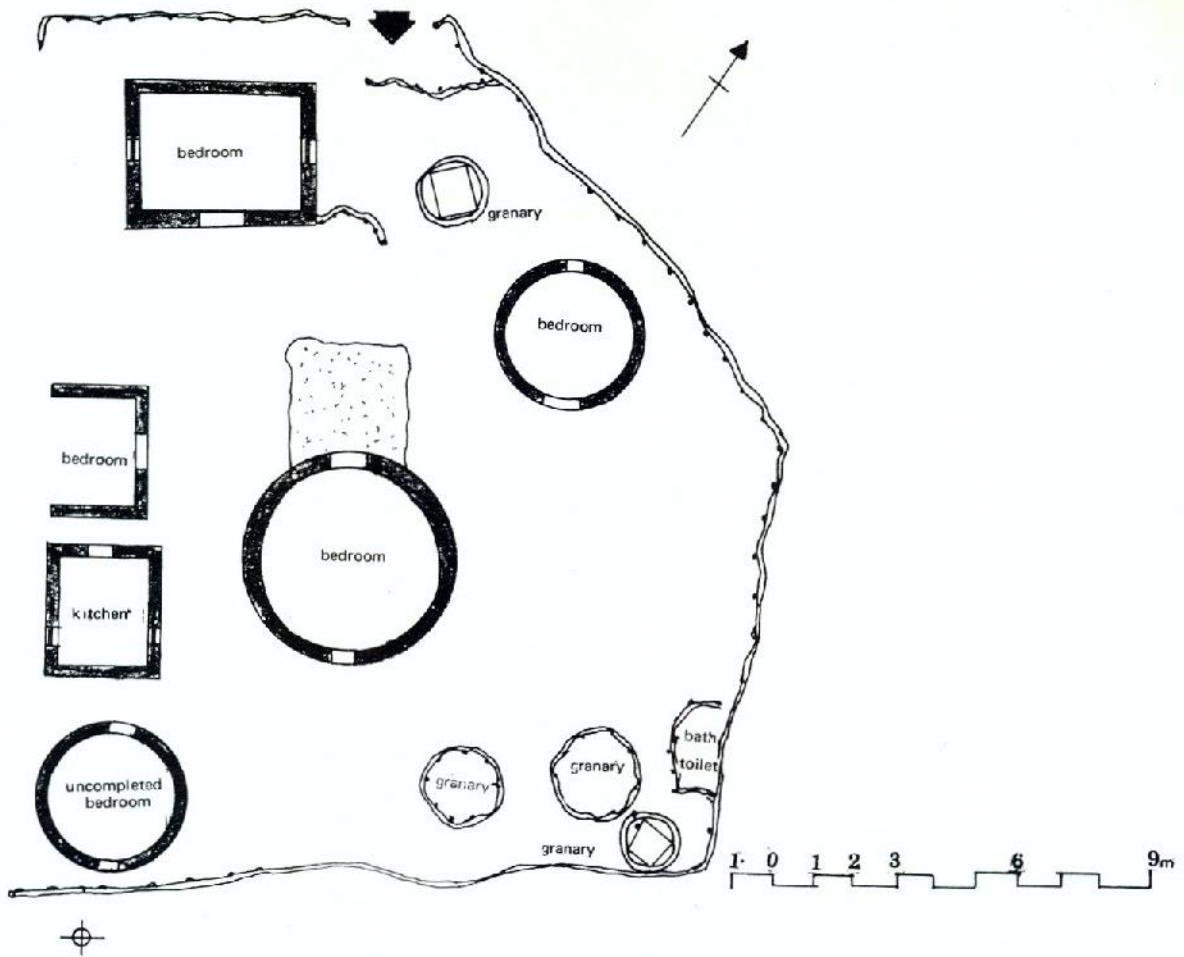
Daily and seasonal thermal exchange between sites, structures and the ambient atmosphere results in a continuous process of vertical air-flow, both gravitational - cool and levitational - warm actions. The velocities vary according to the pressure differences created between the upper and lower layers. This movement is generated by the heating and cooling of surfaces in the rural and urban areas and is omnipresent in the vertical cavities and roof-spaces in all buildings. The thermal properties of the materials in contact with the boundary layers of air, determine the rate of heat transfer and consequent rate of flow. Urbanisation often complicates the velocity and direction of air motion while the basic determining parameters are orientation, morphology, ground surface texture, plantings, materials exposed to radiation, the population/building density and the type of activities in the urban cities. The rural areas are also affected by morphology and thermal characteristics of materials.

4.2.1 Traditional Design Concept

Courtyards are modifiers of microclimate which help to maintain air circulation through convective currents. At night, cool damp air would be formed at ground level and slowly sweeping into the rooms, as indicated in Figures 5, thus making them cool enough to be comfortable for a good part of the next day. The courtyards also act as a buffer against the noise from the streets, keep dust and sand out of habitable rooms, reduce direct solar radiation on wall and provide shade. The courtyard design promotes better air movement and enhances better natural lighting within the building. Thermal and airflow behaviour are conceptualised in traditional internal courtyard design. In double courtyards, building morphology and orientation further affect the heating and cooling of surfaces with consequential effect on airflow patterns as shown in Figure 6 while external courtyards aimed at privacy, do not effect thermal regulation in the core of the building. The orientation of site and buildings are crucial parameters while the choice and thickness of materials with the types of planting will affect the radiation performance and hence the quality and volume of air in motion. The plan to height ratio of the courtyard is also a significant parameter in determining the quality of cold air entrapped in the courtyard. The analysis of air flow pattern in courtyards is dealt with in another paper. In Zone A, the planted trees/shrubs provide a valuable cooling effect through provision of shade, absorption of part of the incident solar energy in the photosynthesis process, reflection of part of



PLAN OF A COMPOUND IN ZONE B



Floor Plan of a Compound In Hot-Humid Zone

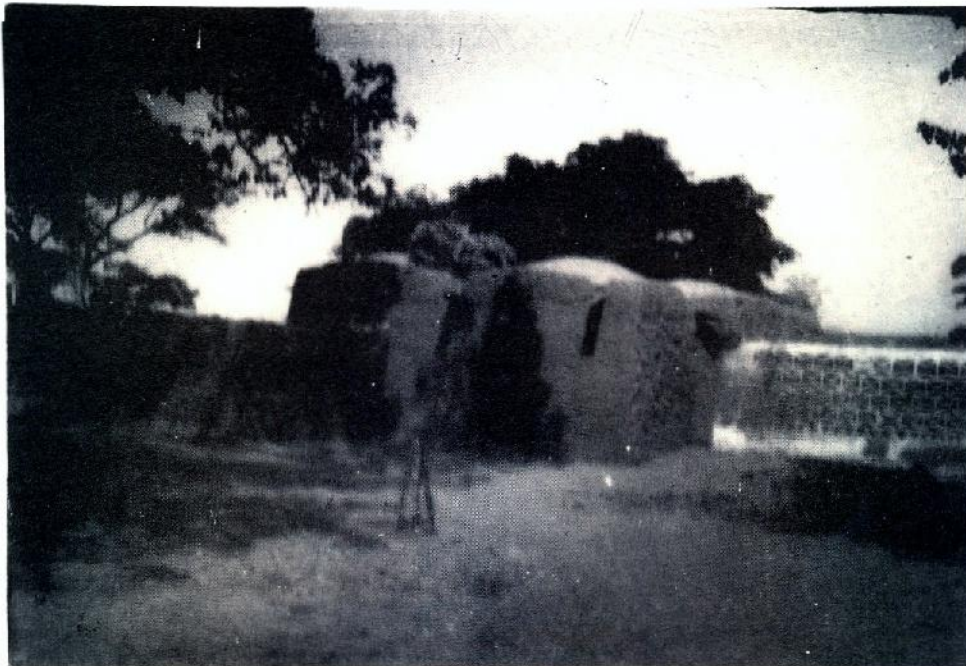


Figure 3: Typical Traditional/Experimental Building in Zone A

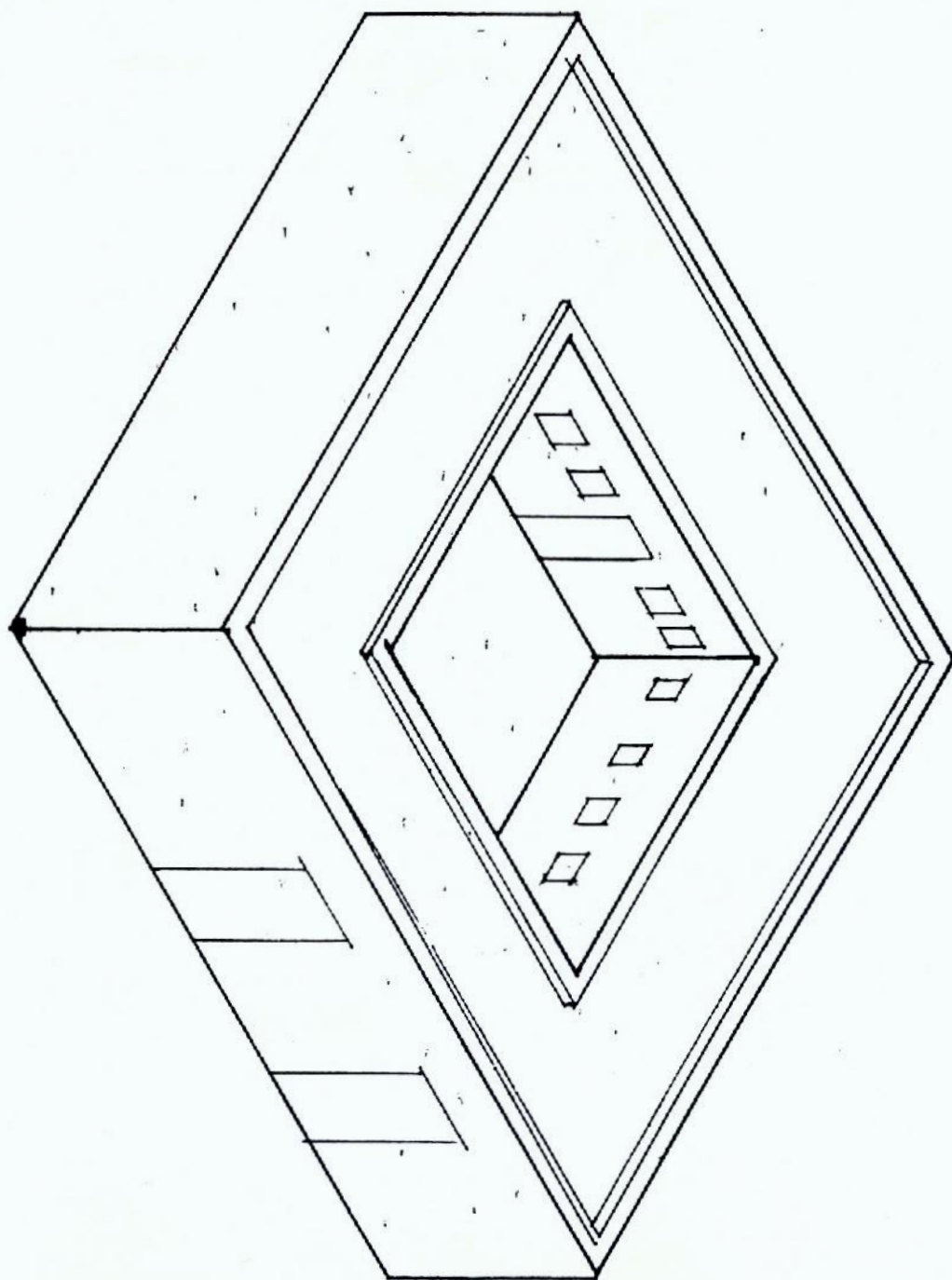
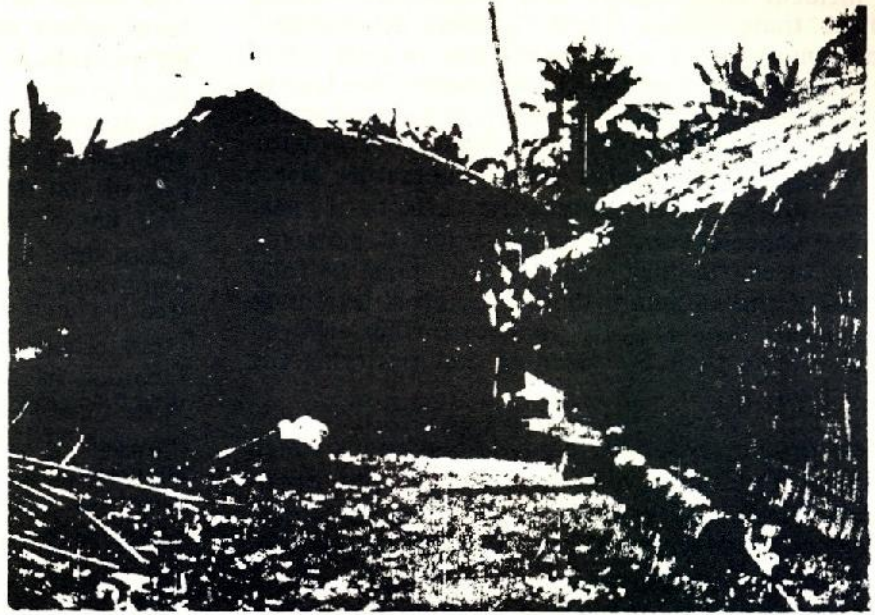


Figure 3^A; Typical Traditional Building Layout in Zone A.

(a)



(b)



(c)



Figure 4
Typical Traditional
Experimental
Building in Zone B

the incident solar energy and evaporative cooling through transpiration. Their "cooling mechanism" become more active with the increase in solar intensity while disregarding the use of plants often lead to increasing air temperature at micro and macro scales. Temperature above unprotected hard surface materials is significantly higher than temperature above planted areas. The cumulative effect of heat absorbed especially in the city centres – generally referred to as "the heat island effect" must be fully analysed if the minimum thermal comfort level is to be achieved. They are also used for further environmental effects such as screening and purifying the polluted air.

In view of the favourable climatic conditions which encourage outdoor living in Zone B, the open-staggered layout adopted enhanced adequate air circulation and cross ventilation. Thermal and airflow behaviour are conceptualised in traditional open/semi-open courtyard design and their use maximises and remains a constant source of cooling.

The thick mud walls having a thermal conductance ranging from $0.5 \text{ W/m}^{\circ}\text{C}$ to $0.8 \text{ W/m}^{\circ}\text{C}$ depending on thickness, degree of compaction, grain size and the source of the earth; have high heat storage capacity which ensures that the building remains cool during the hottest part of the day and retains heat during the wet season. Figures 6 and 7 show the result of typical measurements carried out in traditional mud buildings in zones A & B which indicate that the thick walls absorbed the daily solar heat loads rather than immediately transmitting them to the interior of the building. The stored heat is later released to both the interior and the exterior of the building during the cool night hours; hence the walls could be regarded as insulators and reservoirs of heat. Since the rate of coolness which can be stored and retrieved in the building structure depends on the properties of the storage materials such as density, thickness, specific heat and thermal conductivity: convective heat transfer, area to the volume of the thermal storage element, the thick and heavy earth walls used in these dwellings (Zone A) have the capacity to store coolness for several days. The small openings on walls in Zone A are located at high levels in order to reduce the amount of dust and heat gain into the building. These openings which sometimes open into the courtyard are hardly needed by the occupants except for occasional lighting and ventilation. The small openings which characterise the design features in the two zones, undoubtedly for security reasons, are responsible for poor lighting and ventilation and might be a source of health hazard during an outbreak of epidemics.

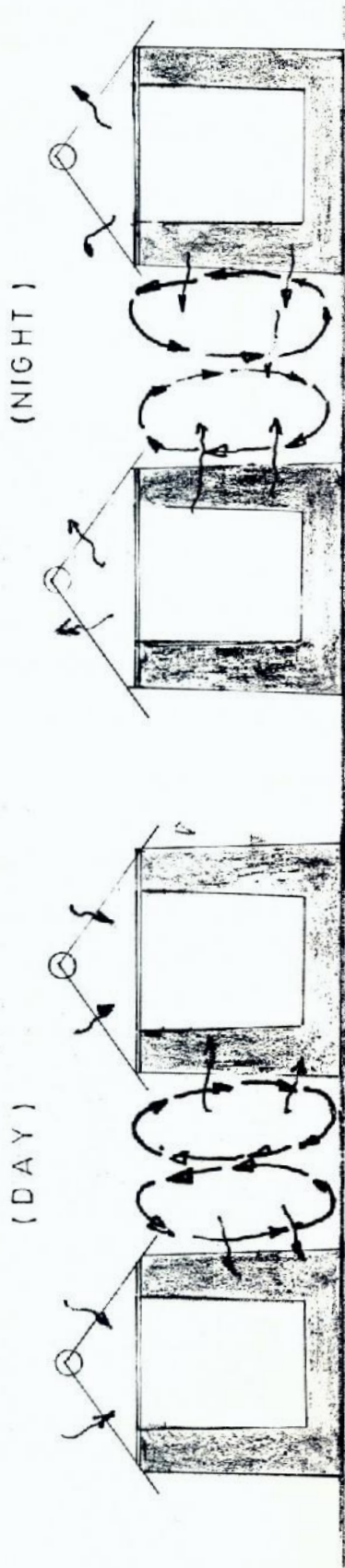
Results show that the thermal performance of the mud roof is better than the mud walls because of the high insulating values of the wild grass. The thermal mass of such roofs, acting as a thermal control, undoubtedly contribute to the control of heat transmittance. Other roof designs incorporate manually operated openings which are operated only at night when the outside temperature is lower than that inside. Such a device aids quick heat emission.

The design of the conical thatched roof reduces the total surface area exposed to solar radiation while the air pockets in the woven reeds reduce the thermal conductivity. These raffia and grasses have longitudinal fibres; the grass has a tough outer skin layer and a soft or hollow interior, however along the centre-line of the raffia blade, there is a thick tough wood web; hence these materials are both heterogeneous and anisotropic and they passively produce comfortably conditioned residential spaces – being cool in hot weather and warm in cold weather. The thermal conductivity of dry elephant grass cross-grain was recorded as being between $0.115 \text{ W/m}^{\circ}\text{C}$ – $0.163 \text{ W/m}^{\circ}\text{C}$ while that of dry Vaffia palm cross grain is between $0.124 \text{ W/m}^{\circ}\text{C}$ – $0.207 \text{ W/m}^{\circ}\text{C}$. These analyses indicate that the traditional building materials have low thermal conductivities and hence provide adequate thermal comfort level indoor.

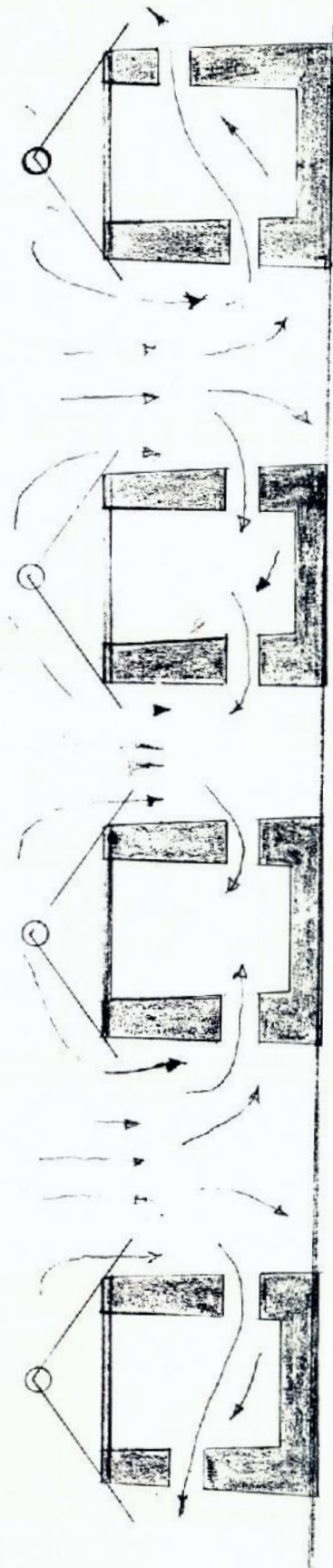
In Zone B however, light building materials are used which emit heat quickly. This, combined with high ventilation rate, ensure the required thermal comfort level. The two extreme designs in these two zones confirm the objectives of thermal controls in buildings i.e. – "To prevent heat gain and maximise heat loss in hot conditions and to even out temperature variations in warm conditions". These objectives were achieved by structural rather than by mechanical controls.

4.3 Conventional Design

The choice of design, planform and material depend on the function of the building such as residential, industrial and commercial, private or public. Basically, most of the residential planforms in all the zones are a reflection of the cultural religion and other factors enumerated in section 4.0. The commercial buildings in the principal cities are a close replica of the western ideas. Courtyard designs, planted with shrubs are adopted in some governmental buildings (because there is no land restrictions) with a view to achieving cross-ventilation and vegetative cooling but the objectives are hardly achieved because the windows and doors are hardly kept open to enhance air movements cross ventilation. Private developers whose main objective is to maximise their returns often disregard the use of plants and this has negative effects on the micro and macro scales. The conventional buildings in Zone B are staggered like the traditional design to enhance maximum ventilation where this could be achieved but those in Zone A are hardly grouped together for mutual shading. The current energy conscious design in the latter zone is such that the kitchens, stores, pantries, etc. are located by external walls to reduce the heat gains into the core of the building where the bedrooms are located. A North East and a South West building orientation is favoured for residential buildings in Zone A and B respectively while a North-West orientation is often adopted for commercial buildings. In many cases, various forms of solar shadings are used to reduce heat gains via solar insolation as depicted in figure 8.



(a) TYPICAL AIRFLOW PATTERN IN COURTYARDS (NO OPENINGS)



(b) TYPICAL AIRFLOW PATTERN IN COURTYARD (WITH OPENINGS)

FIG. TYPICAL TEMPERATURE MEASUREMENT FOR ROOF, WALL AND INDOOR OF A TRADITIONAL MUD HOUSE IN ZONE B.

ZONE B

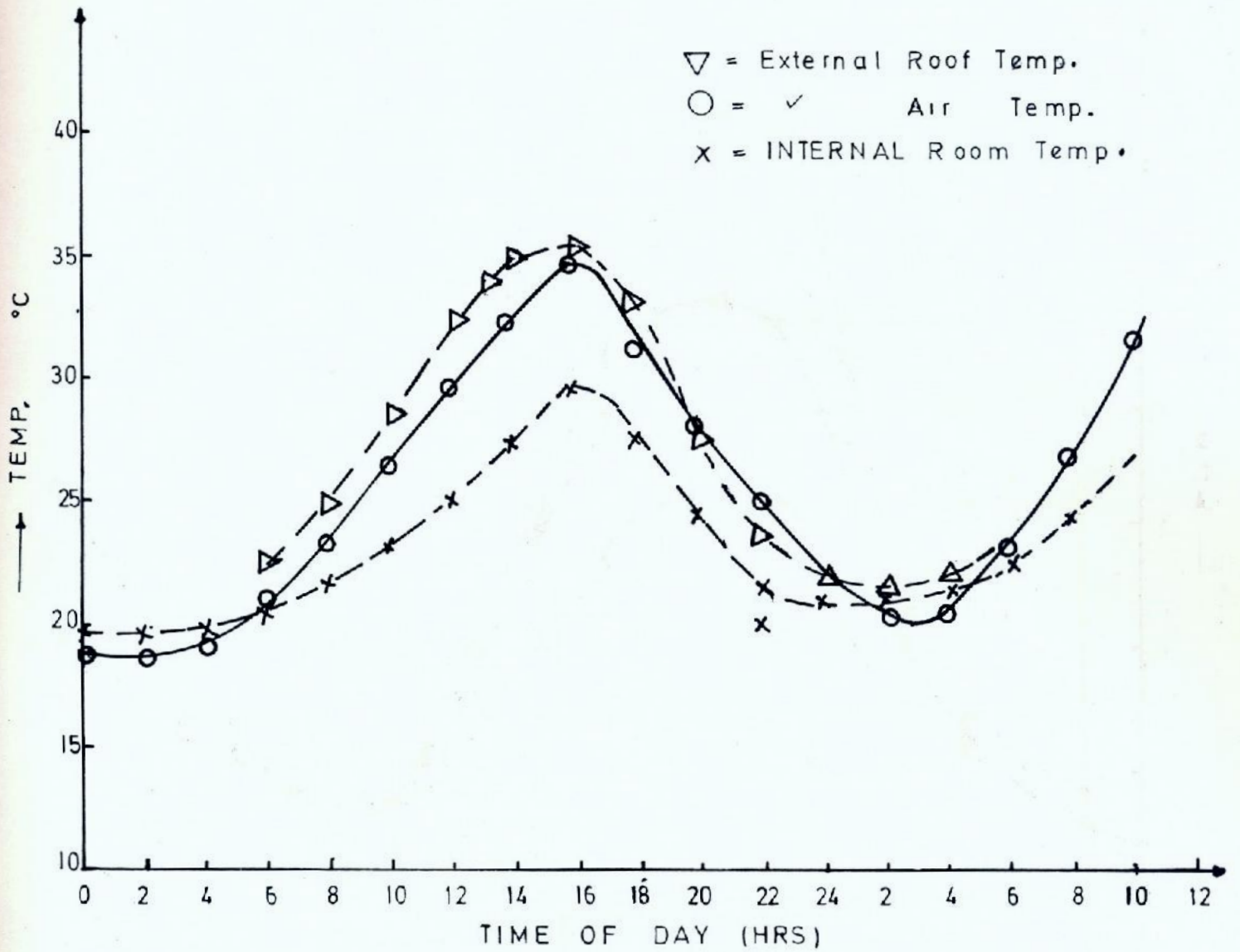
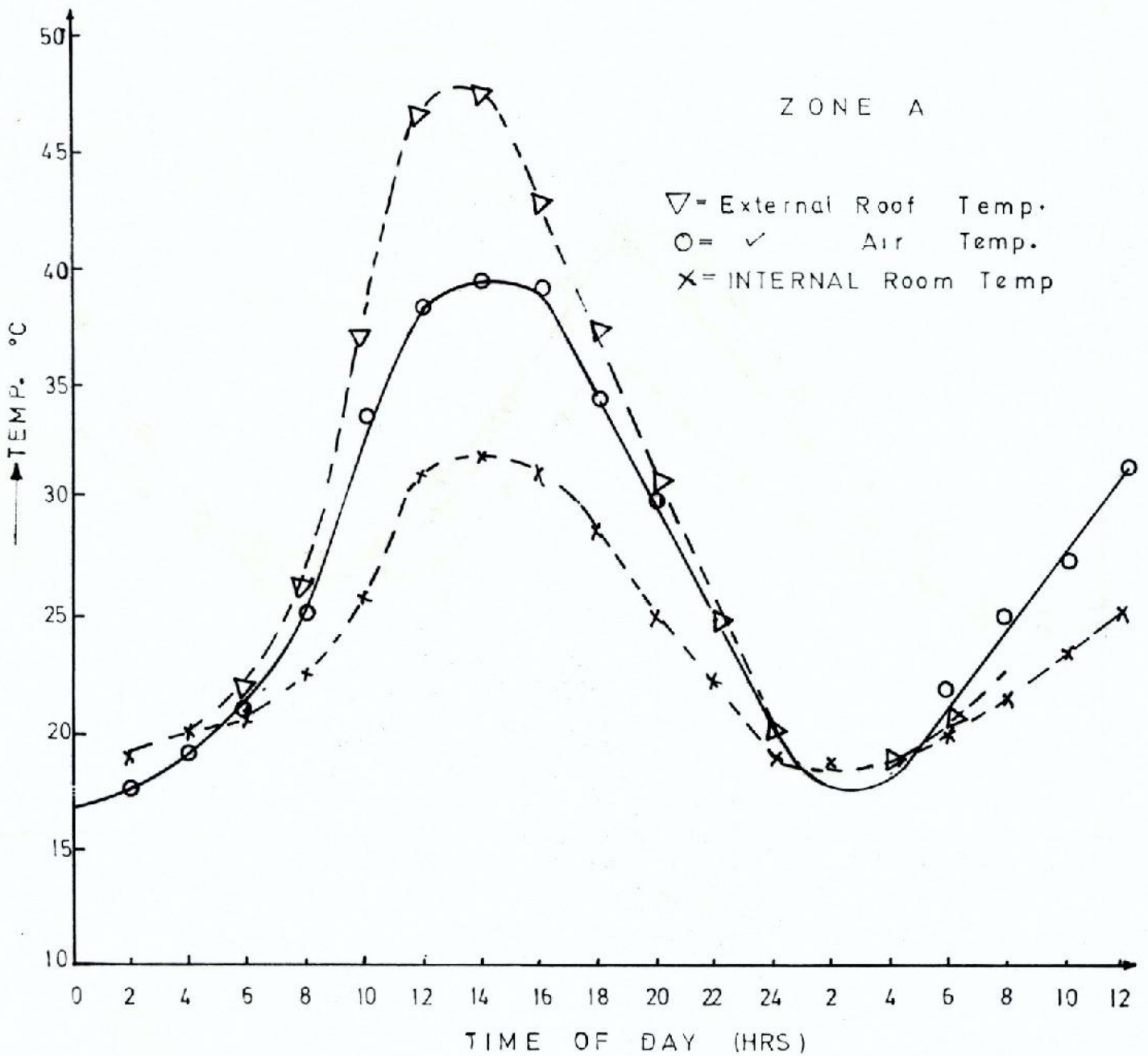


FIG. TYPICAL TEMPERATURE MEASUREMENTS FOR ROOF, WALL AND INDOOR OF A TRADITIONAL MUD HOUSE IN ZONE A.



4.3.2 Walls and Openings

Sandcrete blocks and burnt bricks

Sandcrete blocks and burnt bricks are used in the two zones but very thick up to (1.5m) and cavity wallings are adopted in modern residential buildings in Zone A. In some designs, the ground floor levels are constructed of thick sandcrete walls while the upper floor wallings are made of light weight materials such as aluminium which are polished externally for maximum solar reflection of about 0.9. The ground floor of such buildings store coolness for many hours hence they are designed as living rooms, kitchen, pantries, etc. for day usage while the light weight floor houses the bedrooms since most of the heat gained during the day would be dissipated before the early hours of the morning. Though large windows are typified of the old designs in both zones, most of the current designs in Zone A have narrow windows (with close fitting shutters) located at high levels and well recessed with solar shadings in order to reduce solar gains and dust. For adequate ventilation however, the ratio of openings to floor areas is often stipulated at about forty five percent to compensate for the reduction in openings resulting from using mosquito nets on windows and doors.

4.3.3. Roof Design

The roof designs are a reflection of the traditional building designs though new locally developed roofing materials with high thermal capacity are now employed. Cast in-situ concrete roofs are finished with bitumen felt and special stones which act as solar reflectors while well ventilated double roof design is gaining favour in Zone A.

4.3.4 Analysis

The choice of planform/layout of conventional buildings especially residential and governmental buildings, should be such that energy conservation is taken into consideration at conceptualized state in order to reduce the amount of energy expended on mechanical ventilation and air conditioning. The hollow sandcrete blocks which are mainly used in construction have thermal conductivity values of between $0.88\text{W/m}^{\circ}\text{C}$ and $1.35\text{W/m}^{\circ}\text{C}$ depending on the mix ratio and the degree of compaction while the trapped air pockets act as buffer against heat transfer into the building. The thermal performance of sandcrete blocks is less than that for mud, the latter can only be used for bungalows or a storey building because of its low crushing strength when it is not stabilized with cement. Though the results revealed that buildings with thick-heavy weight/heavy weight with cavity wallings in Zone A have better thermal performance than light weight materials, their usage should be confined to few storey heights because of the excessive dead load imposed on the foundation. As lower solar insolation prevailed in Zone B, the combination of light weight structures and high ventilation rates through the size and distribution of openings ensured the minimum thermal comfort.

Most of the conventional – locally produced roofing materials have low thermal conductivities, ranging between $0.35\text{W/m}^{\circ}\text{C}$ for Super Seven to $0.87\text{W/m}^{\circ}\text{C}$ for terracete roofing sheets. The thermal conductivities of other locally produced roofing materials fall within the quoted range.

High-rise were not studied in detail but the analysis of the thermal performance in multi-storey buildings is complex. Since most of the high-rise are located in fully urbanised city centres, negative modifying effects are encountered. In view of the fact that the vertical profile of the mean wind velocity in the atmospheric roughness as influenced by terrain – showing increasing velocity with height above ground, the surrounding buildings would deflect the wind, thereby starving the lower floors of natural ventilation while the wind pressures on the upper floor might be excessive.

4.5 Thermal Comfort Level

The survey carried out amongst various classes of people in some cities in the two zones (Abuja, Kaduna, Jos, Kano, Ikot Epene, Ile-Ife, Umuohia and Lagos) show that the comfort level of an individual is dependent on zone, the season and the type of activities carried out, but the relative humidity and air movement detailed in Tables 3 and 4 are considered as the crucial parameters. The analysis showed a common average thermal comfort zone of between 25°C and 29°C in all the climatic zones.

5.0 CONCLUSIONS AND RECOMMENDATIONS

- 5.1 The results show that traditional materials used for housing in the two zones have capacity to store coolness.
- 5.2 Traditional building materials have low thermal conductivities and hence provide better comfort indoors.
- 5.3. The thermal comfort zone lies between 25°C and 29°C and depends on the relative humidity and air movement.
- 5.4 The diurnal temperature ranges between 15°C and 7°C in Zones A and B respectively.
- 5.5 The courtyard design acts as a modifier of the environment and should form the basis for modern building designs.
- 5.6 Structural controls built into the buildings system reduce the amount of energy consumed and the total reliance on mechanical controls.
- 5.7 Residential buildings should be orientated in the N.E and S.W directions in zones A and B respectively for maximum/adequate natural cooling.
- 5.8 Energy consumption in buildings can be reduced appreciably by careful planning/planform and choice of materials.

Figure 8^A

Building Design with
attria-analysed in
Figure 5A

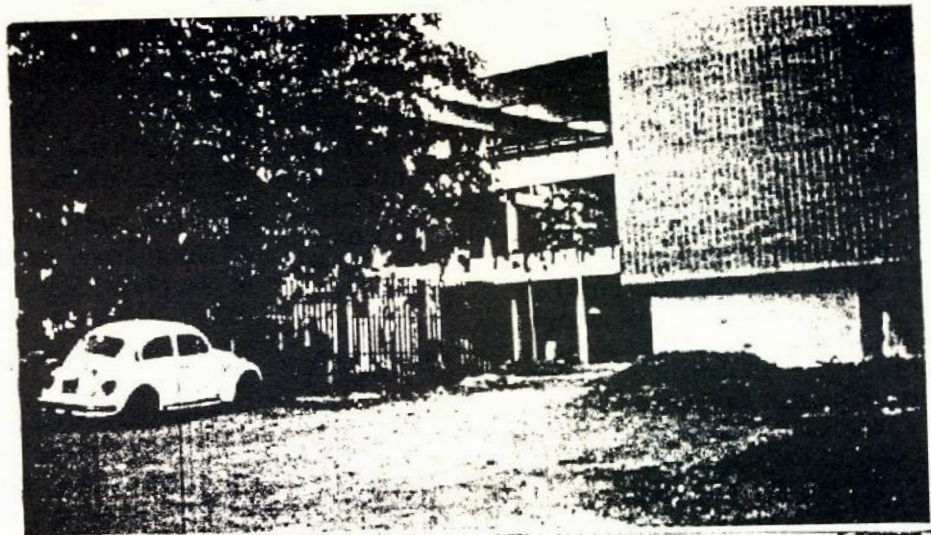


Figure 8^B

Modern Building
Designed for
Passive Cooling
in Zone B.

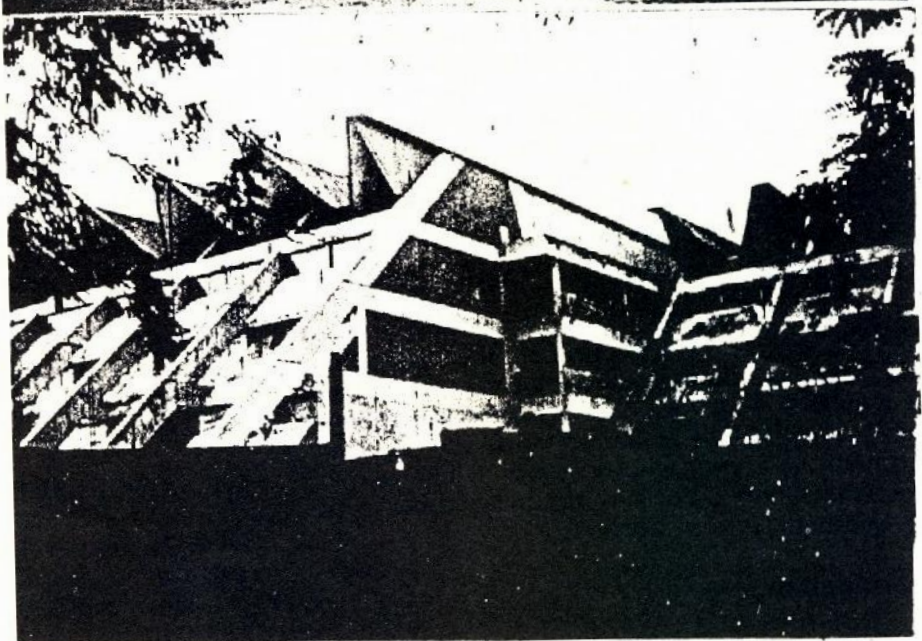


Figure 8^C

Shading device in
modern building

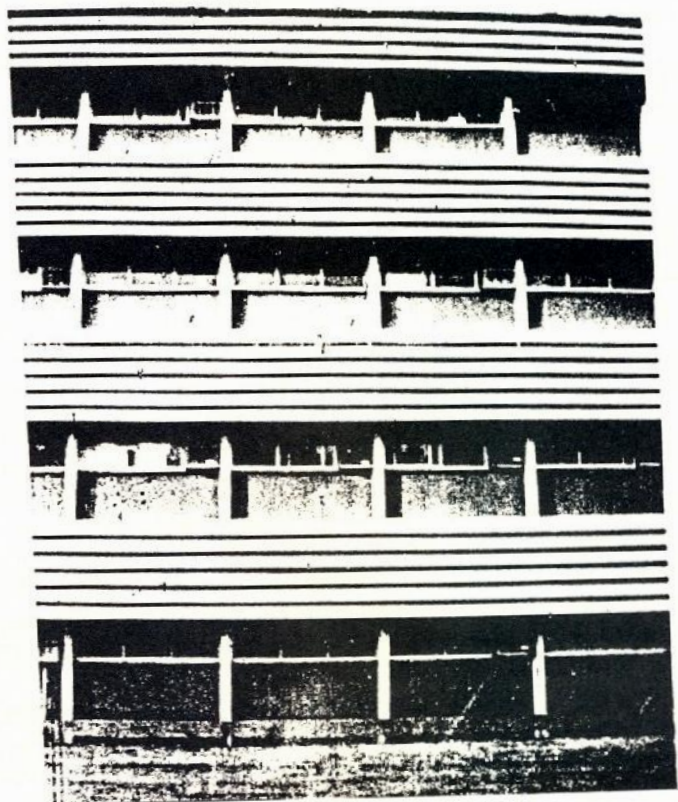


Table 1: Climatic Classification

ZONE	Mean Dry Bulb Temperature Range °C		Diurnal Range C	% Relative Humidity dry season	Average Height Above Sea Level (m)	Rainfall (mm)	Wind Directions		Desirable Building Orientation	Desirable orientation for Bung—allows/one Storey Building
	Dry Season °C	Wet Season °C					Dry Season	Wet Season		
ZONE A										
Hot Dry	35 (30–40)	(20–25)	15	45	300	530–1000	N.E	S.W	N.S	N.E
Temperate Dry zone	30 (25–33)	(18–25)	10	50	300	1070–1400	N.E	S.W	N.S	N.E
ZONE B										
Hot Humid	33 (30–35)	(25–30)	07	50–80	100–300	1180–1790	S.W	S.W.	N.S.	S.W.
Warm Humid	30 (28–33)	(21–26)	07	70–100	100	1190–2890	S.W.	S.W.	N.S.	S.W.

Table 2: Experimental Data on Traditional Building — Zone B

Time of Day (Hrs)	INDOOR					OUTDOOR				
	Indoor Temp :C	W.B.T. °C	D.B.T. °C	G.T. °C	Air Velocity (m/s)	Outdoor Temp °C	W.B.T. °C	D.B.T. °C	G.T. °C	Air Velocity (m/s)
0	26.5	26.3	26.6	26.7	1.35	25.7	24.6	26.0	26.2	2.45
2	25.5	25.0	25.5	25.5	1.30	25.0	24.2	25.6	25.9	2.40
4	25.6	25.1	25.6	25.9	1.30	26.2	23.8	24.9	24.9	2.10
6	25.9	25.2	25.9	26.0	1.25	26.9	24.6	25.8	25.4	2.00
8	26.5	25.3	26.1	26.2	1.20	27.5	25.0	26.1	26.5	1.90
10	27.4	25.5	26.4	26.3	0.90	28.9	27.2	28.6	28.6	1.40
12	28.1	25.7	26.5	26.5	0.75	31.0	30.5	31.7	32.0	1.10
14	28.3	25.9	26.6	26.6	0.35	33.0	31.5	32.9	33.0	0.90
16	27.7	25.5	26.8	27.0	0.65	31.7	30.6	32.1	32.2	1.10
18	26.7	25.2	26.9	27.1	1.00	30.5	29.6	31.0	31.1	1.40
20	26.3	24.8	27.1	27.2	0.90	28.4	28.6	29.8	30.4	1.50
22	26.0	24.6	27.3	27.3	1.00	27.9	28.0	28.8	28.9	1.80
24	25.5	24.5	27.4	27.4	1.30	26.8	26.9	27.5	27.8	2.10

W.B.T. — Wet Bulb Temperature
 O.B.T. — Dry Bulb Temperature
 G.T. — Globe Temperature

- 5.9 Adequate shading devices should be introduced in commercial building design in order to reduce solar gains and hence the cooling load.
- 5.10 Energy optimization can be achieved through landscape architecture.
- 5.11 There is an urgent need for recommended environment conservation measures that will contribute significantly to energy conservation.
- 5.12 The architects and government should recommend and probably enforce the use of proven local building materials. The government should take the lead by ensuring that local building materials are used for governmental projects.

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DEVELOPING PARAMETERS FOR THE DESIGN OF LOW COST HOUSES FOR THERMAL COMFORT IN NIGERIA

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ABSTRACT

In describing a building as 'low cost', it is meant that not only the construction cost is low, but the maintenance cost as well as the running cost in terms of energy demand are also expected to be reasonably low.

This paper presents the results of the analysis of the influence of prevailing climate on buildings and goes further to use these results in proposing a general design concept for a building whose internal environment is to be controlled by passive means in order to achieve some level of thermal comfort. Further analysis leads to the proposal of design specifications for (i) the U-values of walls and roofs, (ii) sizes of windows for adequate air movement and (iii) the dimensions of horizontal shading devices.

INTRODUCTION

The primary function of a domestic building is to provide shelter from rain and spells of extreme heat or cold, minimal privacy and for the safe storage of possessions. In providing shelter from heat or cold it is conceived that the building will ensure a pleasant internal environment in comparison to outdoor conditions. In essence, the building should not merely give shelter from unpleasant external climate but should furthermore be a means of controlling the external environment. It should function as a modifier of an unpleasant environment.

The operational concept of low cost housing covers the construction cost, the maintenance cost and the energy demand cost. Assuming that the construction and maintenance costs have been appropriately handled to achieve the low cost concept, how is low electric energy demand achieved through building design? The answer to this question is in designing buildings for thermal comfort through passive means or fabric control. The objective is to eliminate or reduce to the minimum the use of mechanical controls (requiring electricity) such as air-conditioners and fans.

Thermal comfort inside a building depends on the combined effect of (i) air temperature (ii) relative humidity (iii) air velocity (iv) mean radiant temperature. In a building, that is adequately opened to the outside through windows and doors, air temperature

and relative humidity are not significantly modified by the building envelope; their outdoor values are nearly the same as the internal values. Air velocity, that is, air speed and distribution indoor, is partially controlled by the building envelope; the mean radiant temperature is completely determined by the building envelope. In essence, passive control of internal environment should be geared basically at how we can achieve, through building design, the optimum air distribution indoor and an appropriate mean radiant temperature as dictated by the conditions for thermal comfort.

The process of evolving standards for building design in respect of thermal comfort can be carried out in two stages, thus:- the climatic analysis stage and elements specification stage.

CLIMATIC ANALYSIS

This step essentially entails gathering and processing climatic data in order to arrive at an overall design concept with respect to the thermal performance of the building and its elements in qualitative terms. Knowing the objectives to be achieved, design guidelines are recommended concerning building layout, spacing, air movement, openings in buildings, physical nature of walls and roofs.

Using a method developed by C. Mahoney⁽¹⁾ to analyse the climatic data for fourteen Nigerian towns spread over the country, the following design guidelines emerge. From the results obtained, the design parameters fit into two climatic zones. They are the Warm humid zone (from the coast up to latitude 9°N) and the Intermediate zone (9°N - 14°N) - this is between the warm humid zone and the hot dry zone of the sahara.

1. Warm Humid Zone (4°N to 9°N)

i) Layout

Open elongated plan shapes with a single row of rooms to allow cross-ventilation. Long elevations of buildings are to face the North and South; that is, the long axis is on the East-West direction.

ii) Spacing

Open spacing for breeze penetration; staggered layout of buildings to overcome the problem of shadow effect.

- iii) **Air-movement**
Buildings with single, banked rooms to ensure permanent provision for air movement.
 - iv) **Position of Openings**
Windows should preferably be positioned on the North and South walls and to be at body height.
 - v) **Size of Openings**
Medium size openings occupying 25–40% of wall area are recommended for towns within latitudes 7°N and 9°N .
Large openings occupying 40–80% of wall area are recommended for towns below latitude 7°N .
 - vi) **Protection of Openings**
Provision of shading device on openings to exclude direct sunlight penetration.
 - vii) **Walls**
Both external and internal walls should be light with low thermal capacity.
 - viii) **Roofs**
A light roof with good insulation is ideal. On the other hand, a light roof with highly reflective surface is equally effective.
2. **Intermediate Zone (9°N – 14°N)**
- i) **Layout**
The same as for the warm humid zone.
 - ii) **Spacing**
Open spacing for breeze penetration; staggered layout of buildings to overcome the problem of shadow effect: Exception is Jos area where compact layout of buildings is appropriate.
 - iii) **Air Movement**
Single banked buildings to ensure permanent provision for air movement. Exception is Jos area where buildings with double banked rooms are recommended.

- iv) **Position of Openings**
Windows are to be positioned on the North and South walls and at body height.
- v) **Size of Openings**
Small openings occupying 15–25% of wall area.
- vi) **Protection of Openings**
Provision of shading device on openings to exclude direct sunlight penetration.
- vii) **Walls**
External walls should be light material of low thermal capacity while internal walls should be heavy with high thermal capacity.
- viii) **Roofs**
Either a heavy roof with high thermal capacity or a light roof having good resistive insulation above the ceiling.

SPECIFICATIONS FOR BUILDING ELEMENTS

The preceding stage develops design parameters in qualitative terms from which a sketch design can be obtained. The next step is to develop precise specifications in quantitative terms for the following building elements: They are

- Roofs
- Walls
- Windows
- Shading devices.

Roofs

The roof can contribute significantly to overheating in a building, if it is not properly designed to control excessive heat flow. From the results of a theoretical investigation of the thermal performance of common roof system in Nigeria⁽²⁾ the following roofs are recognised to prevent overheating of the ceiling. See table 1

Table 1: Thermally acceptable roof systems

Material of roof deck	Horizontal ceiling material	U-value of roof W/m ² deg. °C
5mm corrugated asbestos cement sheets	25mm fibre glass on 13mm fibre board	0.72
As above	25mm fibre glass on 13mm timber board	0.84
As above	25mm fibre glass on 5mm asbestos cement sheets	0.88
9mm corrugated fibre cement sheets	25mm fibre glass on 13mm fibre cement sheet	0.84
as above	25mm fibre glass on 13mm fibre board	0.71
0.8mm corrugated galvanised iron sheets	25mm fibre glass on 13mm fibre board	0.73
As above	25mm. fibre glass on 5mm asbestos cement sheet	0.89
As above	25mm. polyurethane foam slab on 13mm fibre board	0.52
As above	25mm polyurethane foam slab on 5mm asbestos cement sheets	0.60
0.8mm corrugated aluminium	13mm fibre board	1.5
As above	25mm rockwool on 13mm timber board	0.70
As above	25mm rockwool on 5mm. asbestos sheet	0.70

The above list is not exhaustive. Some other combinations of roofing material, insulation and ceiling materials could also perform satisfactorily in their heat flow control. In general, with the exception of aluminium roofing sheets, all other roofing materials require insulating materials, placed above the ceiling, in order to adequately control solar heat flow.

Walls

The climatic analysis indicates that lightweight materials are required for the external walls. The relevant parameter that determines the thermal performance of a wall is its U-value or thermal transmittance. Knowing the standard U-value will lead to the design of a wall that is thermally suitable. If the wall is not to be a source of overheating to the building interior and the occupants then its surface temperature should not be excessively higher than the internal air temperature or the normal skin temperature.

Analysis of steady heat flow through a wall from outside to the room interior yields the following equation.

$$t_{ws} - t_i = \frac{U}{h_{si}} (t_{sa} - t_i) \quad (1)$$

where

t_{ws} is the temperature of internal surface of wall in °C

t_i is the temperature of indoor air in °C

U is the air-to-air thermal transmittance or U-value of wall in W/m² deg. °C

t_{sa} is the sol-air temperature on the external surface of wall in °C.

h_{si} is the internal surface conductance in W/m² °C

The sol-air temperature, t_{sa} is obtained from the equation below,

$$t_{sa} = t_o + \frac{I\alpha}{h_{so}} \quad (2)$$

where

t_o is the outdoor air temperature in $^{\circ}\text{C}$

I is the intensity of direct solar radiation in W/m^2 ,

α is the absorptivity of wall material.

h_{so} is the wall external surface conductance in $\text{W}/\text{m}^2 \text{ deg C}$.

To allow for convenience of design and construction, uniform U-value standard should be adopted for all external walls regardless of their orientation.

Deduction of the U-value standard is based on the requirement that the temperature of the internal surface of wall should not be higher than the normal skin temperature of 34°C . Therefore, the limit of the internal surface temperature of wall, t_{ws} is set at 34°C .

Consider a wall on the West elevation of a building located in Lagos; at 4p.m. on a day in March the temperature of the outdoor air is 31°C . The Intensity of solar radiation I on the vertical wall is $700\text{W}/\text{m}^2$. The absorptivity of the wall material is 0.65. The external surface conductance h_{so} is $20\text{W}/\text{m}^2 \text{ }^{\circ}\text{C}$. Using these data in equation 2 the, sol-air temperature t_{sa} , on the external surface of wall is 53.8°C .

From equation 1,

$$U = \frac{h_{si}(t_{ws}-t_i)}{(t_{sa}-t_i)}$$

$t_{sa}=53.8^{\circ}\text{C}$; $t_i = 31^{\circ}\text{C}$; $t_{ws} = 34^{\circ}\text{C}$; $h_{si} = 8.12\text{W}/\text{m}^2 \text{ deg C}$ U-value is $1.1\text{W}/\text{m}^2 \text{ deg. C}$.

It thus appears that a U-value of $1.1\text{W}/\text{m}^2 \text{ deg.C}$ has emerged from the simple analysis, as a first step in the process of evolving performance specifications in respect of the thermal behaviour of walling materials. Actual field trials and measurements are required to corroborate the result of the theoretical analysis; Table 2 shows the U-values of some common walling materials.

Table 2: U-value of some wall constructions

	Construction	U-value $\text{W}/\text{m}^2 \text{ deg C}$
1)	100mm (4") sandcrete hollow block + 15mm lightweight plaster internally	2.52
2)	150mm (6") sandcrete hollow block + 15mm lightweight plaster internally	2.45
3.)	220mm (9") sandcrete hollow block with 15mm plaster internally and externally	2.17
4)	220mm (9") solid brickwall, unplastered	2.30
5)	220mm (9") solid brickwall with 15mm plaster on inside surface	2.10
6)	220mm (9") solid brickwall with 15mm plaster on external and internal surfaces	2.00
Prefabricated materials		
7)	5mm asbestos-cement corrugated sheet	5.30
8)	Double skin 5mm asbestos-cement with 25mm glass-fibre insulation in between	1.10

Windows

The purpose of ventilating a building in a warm and humid climate is to provide high air movement for physiological body cooling rather than the removal of excess heat from the building. Under warm, humid conditions, air speeds below $0.1\text{m}/\text{sec}$ usually result in a feeling of stuffiness and stagnation of the air, whereas high air speeds will be most effective in aiding body cooling by evaporation. In high humidities (above 85%), the cooling effect is restricted by the high vapour pressure, preventing evaporation, but high air speeds above $1.5\text{m}/\text{sec}$ will remove this restriction.

In designing windows for air movement, the essential design parameters are, window size, location of windows on walls, and orientation of openings.

Window Size: Wind tunnel tests on building models, carried out at the Central Building Research Institute, Indian(3) showed the following results concerning window size and sill height.

- (i) Any increase in the window width beyond a value $2/3$ of the room width gives an insignificant improvement of the room air distribution.
- (ii) Any increase in the window height above 1.1m has a very small effect on the air movement in the normally occupied zone.
- (iii) The indoor air speed increases with the increase of the window area up to 25% of floor area, beyond which air speed is more or less independent of the area of window.
- (iv) To derive maximum air movement in the normally occupied zone, the sill height must be kept at 0.9m above the floor.
- (v) in general, the sill height must be kept at about 85% of the height of the plane at which maximum air movement is desired.

In order to estimate the size of windows suitable for optimum air movement in a building, a knowledge of the outdoor wind speed is required. Table 3 shows the design wind speed for Ikeja in March. The average of mean wind speeds for five years is taken as the design wind speed outdoor.

Table 3: Values of mean outdoor wind speed for Ikeja: Month is March.

Year	Wind Speed m/sec
1971	3.1
1972	3.0
1973	2.7
1974	3.2
1975	3.2
Average	3.04 Design wind speed

The desired indoor wind speed is determined from table 4. The information in table 4 is extracted from the effective temperature monogram (1, pg. 54). From the knowledge of the outdoor wind speed and the desired indoor wind speed, the size of the window, as a percentage of the floor area is determined from fig. 1.

Table 4: Desired wind speed for comfort (based on effective temperature 26°C)

Dry bulb Temperature °C	Relative Humidity %	Desired wind speed m/sec
34	45	1.50
32	65	3.50
32	60	3.00
32	55	2.00
31	80	3.00
31	75	2.50
31	70	2.00
31	65	1.50
31	60	1.40
31	55	0.80
30	75	1.70
30	70	1.25
30	65	0.75
30	60	0.50

Location and Orientation of windows: Studies carried out by B. Givoni (4) resulted in the following observations concerning the performance of windows with respect to their orientation and location on walls.

- i) In a room with windows in opposite walls, optimum air distribution is obtained when the wind is oblique at an angle 45° to the inlet window
- ii) If the windows are located in adjacent walls, optimum air distribution is obtained when the wind is incident normally on the window.

For sun exclusion the preferred orientation is the North-South direction. In the Southern part of Nigeria, the wind direction is predominantly South-West. Thus, for a room, having windows on opposite walls, the most favourable orientations for air movement and sun exclusion coincide. In the Northern part of Nigeria, the wind direction is also South-West for most of the year except in November, December, January, February and March when the wind direction is North-East. That, notwithstanding, the favourable orientation for air penetration is still North-South, for windows on opposite walls; this agrees with the orientation for sun exclusion.

Where for some reasons the windows cannot be placed on opposite walls but on adjacent walls, then priority should be given to the preferred direction for air penetration over that for sun exclusion. Inlet windows should thus be the South-West.

Shading Device

Prevention of sun penetration through windows can be achieved by the use of shading devices. Blinds, either internal or external are less efficient than fixed

external devices which may be vertical or horizontal projections over windows. It has been established by Givoni and Hofman(5) that horizontal shading is more effective than a vertical one. Horizontal projections cast shadows over windows by cutting off the sun's rays. The height of the vertical shadow cast over a window depends on the extent of the horizontal projection. It is possible to design a projection that will completely shade a window during some hours of the day when sun penetration need to be prevented. A recent study carried out by the author(6) included a table of shading device dimensions as determined by the window height, period when shading is desired, and orientation of the window wall. An extract of this table is table 5 showing the extent of the horizontal projection that will completely shade a window of specific height and facing any of the eight cardinal directions. The limit of window height is 1.1m according to the requirement for effective air distribution in a room.

CONCLUSIONS

The climatic analysis procedure yields broad design parameters from which sketch designs can be obtained.

Roofs need to be insulated to make them effective against the transmission of solar radiation unto the ceiling underside, and maximum U-value of $0.9\text{W/m}^2\text{degC}$ is suggested for the roof construction. A roof decked with aluminium sheets may not require insulation.

Thermal performance of walls is specified by the value of the thermal transmittance (U-value). An optimum U-value of $1.1\text{W/m}^2\text{deg.C}$. is recommended for the external wall.

The most favourable orientation for windows regarding sun exclusion and effective air distribution is the North-South axis, for rooms having windows on opposite walls. If windows are located on adjacent walls, the best orientation for wind penetration takes precedence over that for sun exclusion, which in any case, can be achieved by the use of shading devices over such windows.

Horizontal projections or ledges, of appropriate dimensions, above windows will serve to shade windows from solar radiation.

Table 5: Horizontal Shading Device Specification.

Orientation	Period of Shading	Window Height (Metre)	Extent of Projection (Metre)
North	10a.m. - 4p.m.	0.5	0.3
		0.7	0.4
		1.1	0.6
North-East	10a.m. - 1p.m.	0.5	0.3
		0.7	0.4
		1.1	0.6
East	10a.m. - 12noon	0.5	0.3
		0.7	0.4
		1.1	0.6
South-East	10.a.m. - 2p.m.	0.5	0.3
		0.7	0.4
		0.1	0.6
South	10a.m. - 4p.m.	0.5	0.35
		0.7	0.5
		1.1	0.8
South-West	11a.m. - 4p.m.	0.5	0.4
		0.7	0.6
		1.1	0.9
West	12noon - 4p.m.	0.5	0.8
		0.7	1.1
		-	-
North-West	11a.m. - 4p.m.	0.5	0.7
		0.7	1.0
		-	-

(shaded area; comfort zone)

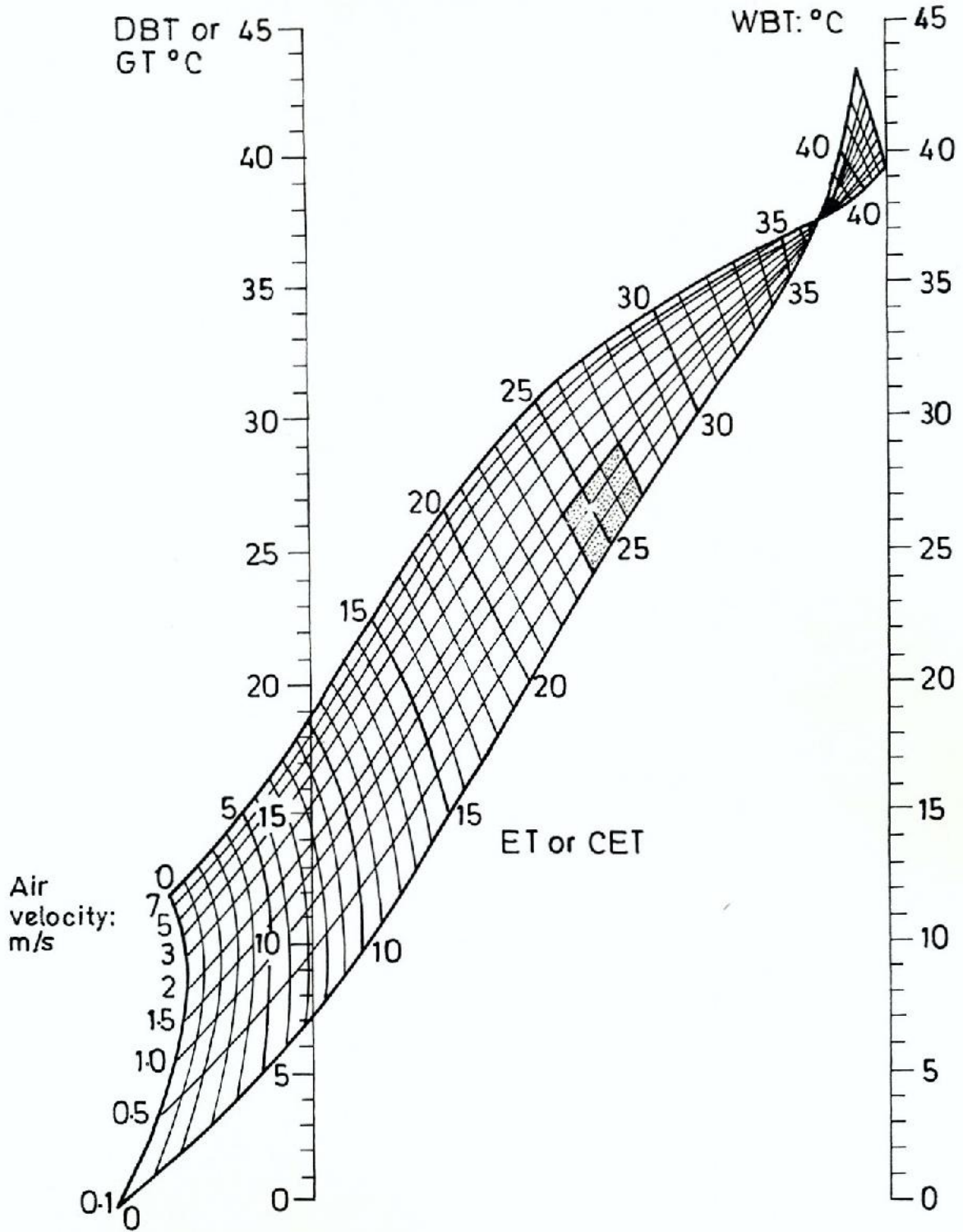


Fig. 1: Effective temperature nomogram for persons wearing normal business clothing (1 clo.)

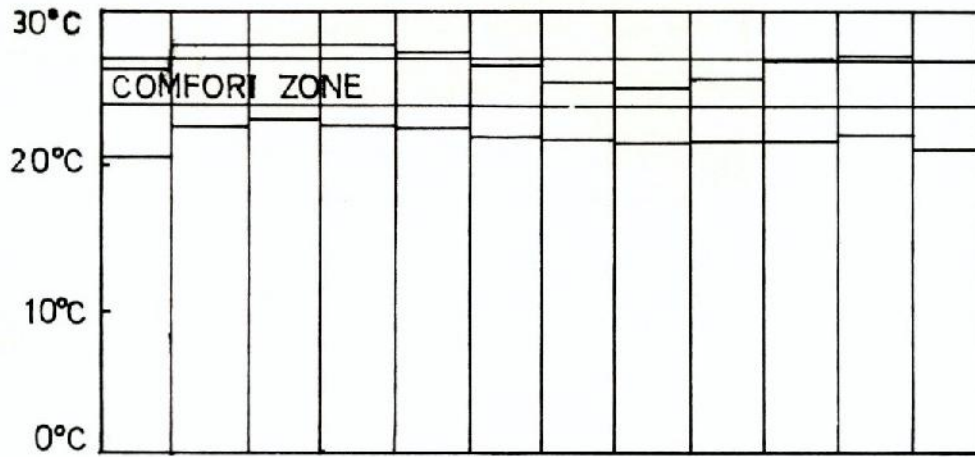


Fig. 2: Effective Temperature (ET) histogram (IBADAN)

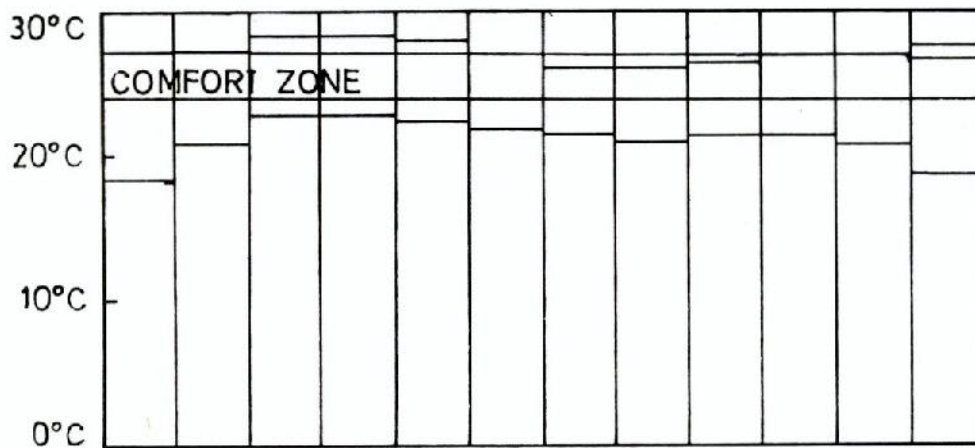


Fig. 3: ET histogram (ILORIN)

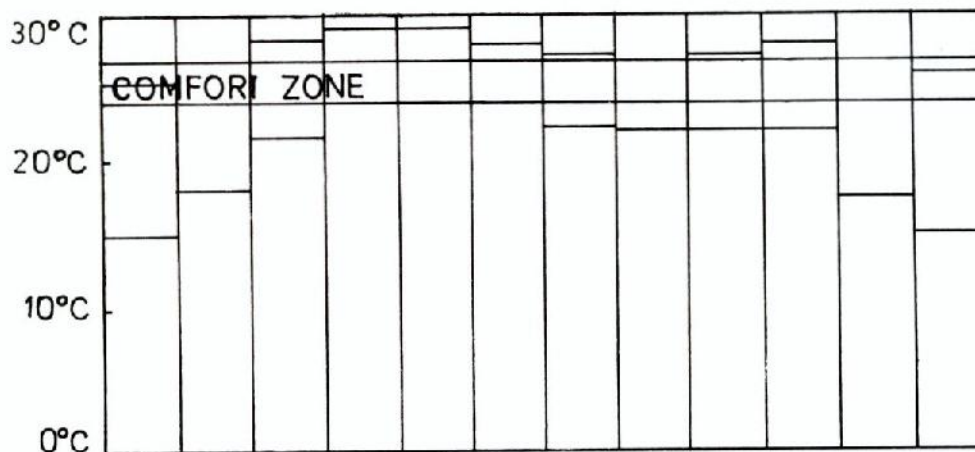


Fig. 4: ET histogram (YOLA)

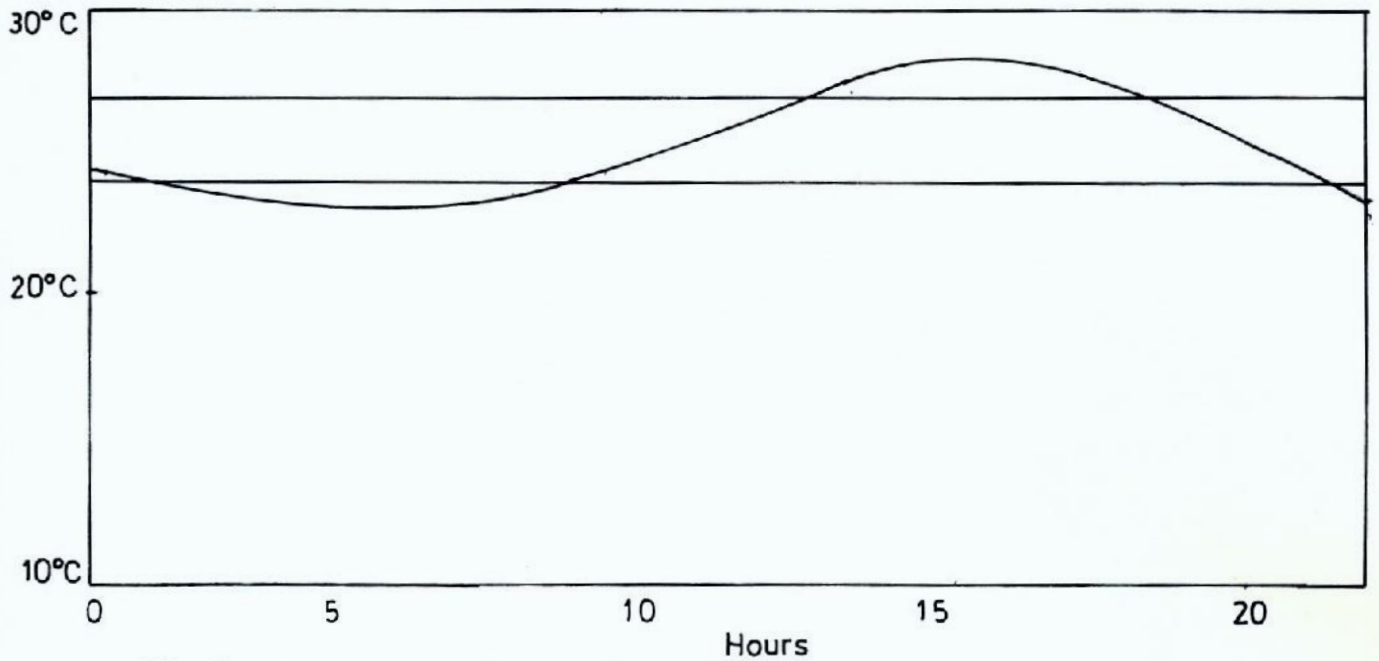
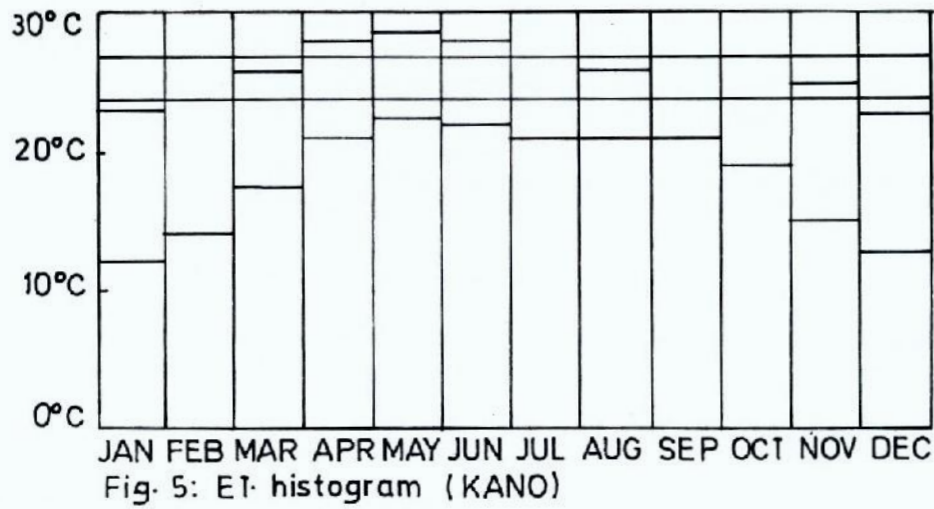


Fig. 6: ET Curve for March-IBADAN

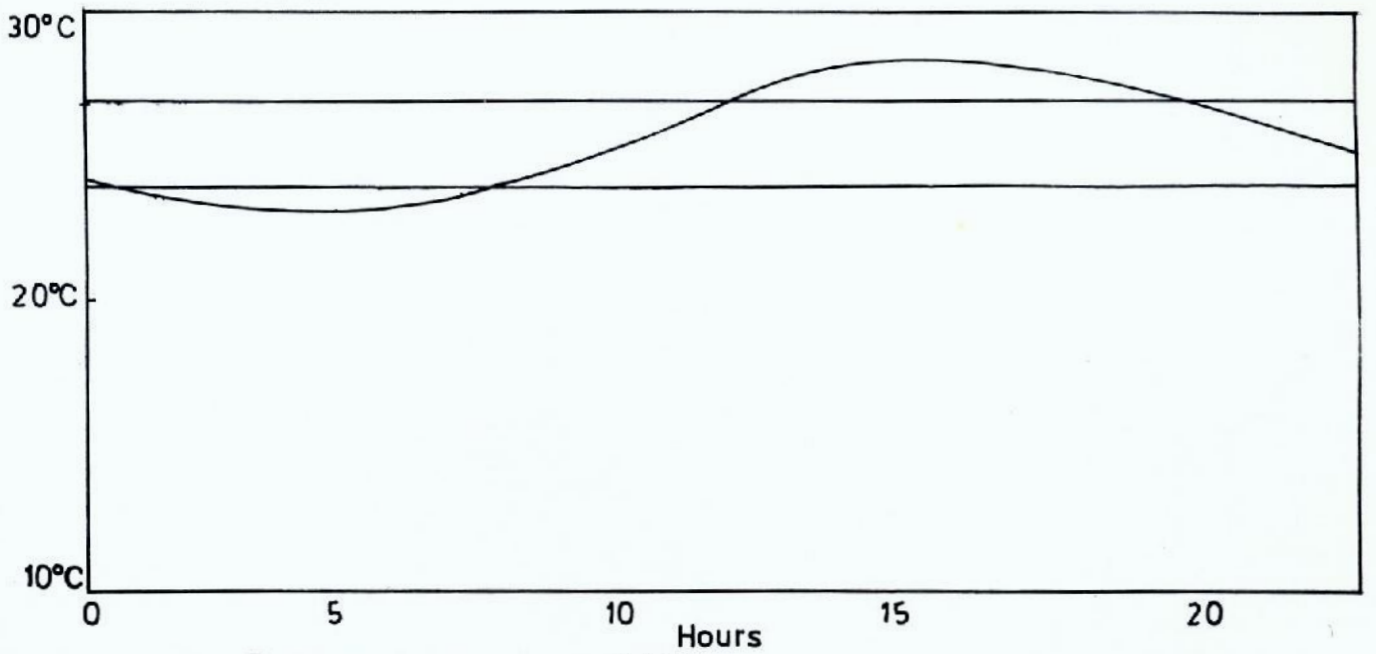


Fig. 7: ET Curve for June-KANO

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DESIGN FOR SHADING DEVICES FOR THE CONTROL OF SOLAR HEAT GAIN THROUGH WINDOWS IN TROPICAL BUILDING

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ABSTRACT:

The current trend in architectural development is the use of large expanse of glass in office and residential buildings as fenestrations for ventilation, daylight and outside view. Since glass transmits solar radiation, this results in considerable heat gain inside the buildings in tropical climates with high solar radiation intensity. Extensive glazing, therefore, calls for judicious sun control. In the passive design of energy efficient buildings, this is achieved by the provision of shading devices to prevent excessive heat flow into the living space indoor.

In this presentation, building design criteria are defined for solar control as a means of improving the thermal comfort environment. The concepts of shadow angles, horizontal and vertical shadow throws, and solar shade-cum-protractor methods are applied to the determination of shapes and sizes of louvres for external shading of windows.

1. INTRODUCTION:

The heat gain of a building can be categorized into heat received through the ingress of fresh air, heat generated by the occupants, lights, fans and other electrical appliances, and, the sensible heat gain due to heat flow through building fabrics such as roofs, walls, windows and doors. The sensible heat gain causes a noticeable change in the air temperature. All building materials exposed to the sun will absorb solar heat to a greater or lesser degree depending on their absorptivities for solar radiation. However, a judicious selection of building components, optimum orientation of building layout and provision of adequate glazing area will make energy conservation inside a building possible (1, 2).

1.1 Direct Solar Heat Gains through Windows:

Glass is used for aesthetic by designers of modern buildings without taking the greenhouse effect into consideration. When direct solar radiation falls on a sheet of glass, a part of it is reflected, absorbed and transmitted. The reflectance, absorptance and transmittance of glass to solar radiation depend on the angle of incidence of the solar beam on the glass.

In the tropics, an ingress of solar radiation will contribute to discomfort. The effect of uncontrolled solar heat gains through windows on the indoor air temperature of dwellings on a typical warm day is to make the maximum indoor temperature exceed the maximum outdoor air temperature when the window is unshaded. That is, there is an increase in the mean radiant temperature experienced. Visual discomfort due to glare is also experienced. Direct sun penetration is possible during the early morning hours and late afternoon hours if the windows are unshaded (3-5).

In an office building, the fenestration areas vary from 15 to 40%. The maximum glass area is limited by considerations like space. Windows are generally provided in walls of buildings for daylight, outside views and ventilation. In accomplishing these, there is need to maintain air flow through the building for ventilation, admit controlled levels of diffused daylight into the building and take care not to block views out of the windows. A compromise has to be made between the percentage maximum of glass area and the amount of shading (1, 5). The function of shading is to reduce the solar heat gained through openings.

1. The Greenhouse effect: The phenomenon whereby glass, like most translucent materials, transmits solar or short-wave radiation directly in varying degrees, depending on the nature and colour of the glass, but is opaque to long-wave radiation emitted from heat sources internally (3).

A study of climatic data for Nigeria shows that March, April, May, September and October are possibly the months when the greatest relief from solar heat gains is required. For example, possible sunshine hours in Lagos is about 7 hours in April and in Katsina it is above 9 hours from October to February (6, 7).

2. SHADING DEVICES:

Shading devices are used to reduce the solar heat gained through glasses. Various materials and geometries have been suggested: movable or fixed shading devices such as horizontal and vertical elements placed above or at the sides of the windows in a direction perpendicular to its plane. Louvres and plants can also be positioned in front of the windows to partly or fully block the direct solar radiation. A wide variety of sun control devices are available for shading windows from the direct and diffuse radiations.

Basically, there are four different methods of shading, viz: the use of special glasses and glazing materials, double glazing, internal shading and external shading. Table 1 gives the relative efficacies of the materials (1, 2, 6, 8 - 10).

2.1 Types of Shading Devices:

(a) **Internal shading devices:** These are used for reducing glare and heat from windows. Examples are curtains, movable blinds, venetian blinds, etc. They are very effective in cutting off the sun's glare. However, they impede air movement and outside views in non-airconditioned buildings. They should perform their functions effectively without cutting off daylight excessively. The effective utilisation of daylight will considerably reduce energy consumption for most of the day.

Table 1: RELATIVE EFFICACIES OF DIFFERENT METHODS OF SHADING

METHOD OF SHADING	DESCRIPTION OF FENESTRATION	SOLAR HEAT GAIN EXPRESSED AS PERCENTAGE OF THAT THROUGH CLEAR GLASS
	Corrugated polymethyl methacrylate sheets (a) Clear (b) Flat, white (translucent)	100 89
	Glass fibre sheets with plastic binder, TRANSLUCENT (corrugated) (new) (a) Clear (b) Green	83 75
SPECIAL GLASSES AND GLAZING MATERIALS	Heat - absorbing glasses (tinted laminated safety glasses) (a) Light tint (b) Dark tint	80 49
	Heat-reflecting glasses (thin metallic films deposited between laminates) Medium tint.	29
	Ordinary clear glass (solar transmittance 0.86) both sides	86
	Heat-absorbing glass (solar transmittance 0.46) outside and ordinary glass (solar transmittance 0.80) inside	56
DOUBLE GLAZING	Heat-reflecting glass (solar transmittance (0.11) outside and ordinary glass inside with air space ventilated to outside	17
	Ordinary glass both sides and white venetian blind in-between	33

METHOD OF SHADING	DESCRIPTION OF FENESTRATION	SOLAR HEAT GAIN EXPRESSED AS PERCENTAGE OF THAT THROUGH CLEAR GLASS
INTERNAL SHADING	(a) Net curtain with folds	75
	(b) Heavy curtain with white lining with folds	35
	(c) White roller blind	36
	(d) Black roller blind	68
	(e) Venetian blinds (closed)	43
	(i) White (ii) Black	75
EXTERNAL SHADING	Awings, louvres, etc., completely shading glass and allowing free air movement	20

(b) **External Shading Devices:** These are the most effective means of reducing solar heat gain through fenestration. External shading intercepts solar heat before it reaches the glass. It has the added advantage that it prevents the surface temperatures of the glass from rising unduly. Examples are louvres sun breakers, verandah and balconies. Fixed or movable overhang used as sun breakers can be selected by using a procedure based on the solar noon profile angles (4). Obstructions such as trees and herbs are also very effective.

(c) Different types of glasses are generally used for glazing windows. Double glasses, heat absorbing and reflecting glasses, and painted glasses can be used as shading devices.

2.2 Thermal Performance of Shading Devices:

The effectiveness of shading devices is evaluated from their performance given in terms of their shade factor.

Shade factor is defined as the ratio of heat transmitted through the device to that through the same area of plain glass sheet. Table 2 shows the measured values of the shade factors, U-values and increase in cost for various types of shading devices. The calculations are based on a heat gain factor of 40 kcal/hrm^2 (46.52 W/m^2) through glazed windows.

The shade factor used for unconditioned building should not exceed 0.5 and for conditioned building 0.3. Several combinations of both internal and external shading are used to obtain the required shade factor. Table 2 can be used to work out the type of shading devices required. External shading should exceed 50% from the point of view of energy conservation. Internal shading by venetian blinds and no external shading is sufficient to meet the requirements of 0.5 shade factor.

Table 2: THERMAL PERFORMANCE OF SHADING DEVICES

NAME OF THE MATERIAL (1)	U-VALUES Kcal/hr. °C m ² (2)	SHADE FACTORS FOR DIFFERENT PERCENTAGE OF EXTERNAL SHADING					PERCENTAGE INCREASE IN COST IN COMPARISON WITH PLAIN GLASS SHEET WINDOWS (8)
		0% (3)	25% (4)	50% (5)	75% (6)	100% (7)	
SINGLE GLAZING:							
Plain glass sheet	4.50	1.0	0.76	0.57	0.37	0.26	16.00
Heat absorbing glass	4.00	0.45	0.38	0.26	0.21	0.16	
DOUBLE GLAZING:							
Heat absorbing glass outside and plain glass inside	2.00	0.38	0.28	0.22	0.16	0.12	24.0
Plain glass outside and heat absorbing glass inside	2.00	0.32	0.20	0.16	0.12	0.09	24.0
Double plain glass sheet	2.25	0.65	0.54	0.40	0.28	0.18	16.0

NAME OF THE MATERIAL (1)	U-VALUES Kcal/hr.°C M ² (2)	SHADE FACTORS FOR DIFFERENT PERCENTAGE OF EXTERNAL SHADING					PERCENTAGE INCREASE IN COST IN COMPARISON WITH PLAIN GLASS SHEET WINDOWS (8)
		0% (3)	25% (4)	50% (5)	75% (6)	100% (7)	
INSIDE SHADING: Plain glass sheet outside and curtain inside (i) Light colour (ii) Dark colour	2.50	0.35 0.40	0.28 0.35	0.21 0.28	0.17 0.20	0.12 0.17	12.0
Plain glass sheet outside and venetian blind inside (i) Light colour (ii) Dark colour	2.8	0.35 0.40	0.27 0.34	0.21 0.27	0.16 0.20	0.11 0.16	62.0
Heat absorbing glass outside and curtain inside (i) Light colour (ii) Dark colour	2.20	0.22 0.25	0.18 0.22	0.14 0.19	0.10 0.15	0.07 0.10	28.0
Heat absorbing glass outside and venetian blind inside (i) Light colour (ii) Dark colour	2.40	0.24 0.28	0.20 0.23	0.16 0.19	0.12 0.15	0.09 0.12	28.0 78.0

$$1.163 \text{ W/m}^2 = 1.0 \text{ Kcal/hr. m}^2 \text{ } ^\circ\text{C}$$

3. DESIGN PRINCIPLES:

Planning in relation to the sun requires a thorough understanding of the motion of the sun through the sky throughout the year. Several methods exist for assessing sunlight and shade patterns in the interior of buildings (1,6-10). Many of these procedures are complicated and time consuming. To simplify the procedure and compliment the solar charts, tables of horizontal and vertical shadow angles, solar altitude and azimuth were prepared for every 2 degrees of Latitude for 1st and 15th of every month; and one day each including equinoxes and soltices for every latitude between 4° and 15° North. The sunrise and sunset times, duration of possible sunshine hours on horizontal (roofs) and vertical (walls), surfaces, the sun's change over time for vertical (walls) surfaces and shadow-throws for the design of louvres and shading devices are computed and put in a reference booklet¹ (6,7).

The solar chart with shadow angle protractor method is a versatile method for determining the shading device and its year-round performance. The extent of horizontal and/or vertical projections from the walls for given vertical and horizontal shadow angles, and openings dimensions can be read off directly with the aid of alignment charts. Once the size of the window and shadow angles are known, the louvres can be designed for effective solar control.

The vertical and horizontal shadow angles are used for shading on vertical surfaces. The vertical shadow-throw can only be downward, the horizontal shadow-throw can either be to the right (R) or to the left (L) defined with respect to the observer facing the wall.

The relation between the shadow throws and the corresponding shadow angles are expressed by the equations:

$$\begin{aligned} \tan H &= h \\ \tan V &= v \end{aligned}$$

where H and V are the horizontal and vertical shadow angles and h and v are the corresponding shadow throws. These relations can be used to determine shadow throws from shadow angles. The shadow

1. The tables of values for the various parameters are given in the publication: Climatological and Solar Data for Nigeria by J.O. Ojosu et al. (Ref. 6).

determine shadow throws from shadow angles. The shadow angle protractor (Fig. 3) is used with solar charts to determine shadow angles.

Fig. 1 shows the basic ways of shading: Horizontal, Vertical and inclined shades. Fig. 2 shows the geometric relations for shading on a vertical surface by a horizontal sunbreaker.

3.1 Design of Louvres for Shading Windows:

Louvres are very effective for external shading. There are three types of louvres horizontal, vertical and egg-crate. These are shown in Fig. 4. Several methods are practised by designers in determining the type, shape and size of effective external shading devices and louvers (4,6-12). Design examples are illustrated in the Appendix. With the help of these examples, good design for louvres can be worked out using the tables.

4. CONCLUSION:

Guidelines and examples are provided here for the design of shading devices. The designer is left entirely to decide the type and size of the desired shading

devices. The provision of the right type of shading devices installed at the optimum orientation, will reduce the ingress of direct sunlight and the amount of direct heat gains into the building.

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APPENDIX

DESIGN OF LOUVRES: - Illustrative examples.

*Note: All Tables used here are in the publication of Ref. 6.

Example 1:

A 1.5m high and 0.90m wide window situated on NW wall is to be fully shaded from direct sun rays with a horizontal louvre at Maiduguri. The louvre is to be fixed 15cm. above the window and the window panes are 30cm. behind the wall. To calculate the effective projection of the horizontal louvre on 16th May at 2.00 p.m. (see Fig. A.1)

Height of window	=	1.50m
Louvre level above top edge of the window	=	0.15m
Total vertical height to be shaded	=	1.65m
Vertical angle (ν) at 2.00 p.m. on 16th May at Maiduguri (Lat. 12°N) from Figs. A3 and Table 6.	=	64°

$$\begin{aligned} \text{Vertical shadow throw (Tan V)} &= 2.05 \\ \text{Now, to cover the louvre, Projection} &= 1.0\text{m} \\ \therefore \text{To cover 1.65m, the projection is} &= \frac{1.0 \times 1.65}{2.05} \\ &= 0.80\text{m.} \end{aligned}$$

Since the outer surface of the wall is 0.30m in front of the window panes. The required effective projection of louvre is $= 0.80 - 0.30 = .50\text{m}$. The horizontal louvre should extend sufficiently on either side of the width of the window for effective horizontal coverage as explained in example 2.

Example 2:

In the above example, what should be the minimum extension of the louvre beyond the window width, to just cover the window?

Using Solar Chart

From the solar chart for 12°N , using the shadow protractor the horizontal shadow angle at 2.00 p.m. on 16th May for a NW wall at Maiduguri (12°N) is about 27° . Therefore, the corresponding horizontal shadow throw is $\tan 27^\circ = 0.51$. The horizontal shadow length for a louvre projecting 0.80m (as calculated in example 1) $= 0.80 \times 0.51 = 0.41\text{m}$.

Using table

From table 6, the horizontal shadow throw at 2p.m. on 16th May for a NW wall at Maiduguri (12°N) is 0.52L. The horizontal shadow throw for a louvre projecting 0.80m in front of the window panes is $0.80 \times 0.52 = 0.416\text{m} = 0.42\text{m}$ approximately to the left.

The shadow cast by the louvre of the same length as the width of the window is a parallelogram (Fig. A. 1) representing a vertical section containing the window panes. In this case, although the shadow extends to the lower edge of the window, a triangular strip on the right side is left uncovered. To cover this also, the louvre should extend to at least 0.41m to the right beyond the width of the window.

Alternatively, a vertical louvre of the same width at the right can be used in conjunction with the horizontal louver.

Note 1: A window boxed in completely by two horizontal (above and below) and two vertical (left and right) louvers can be considered as provided with infinitely long louvres on all sides.

Note 2: An egg-crate louvre consisting of additional horizontal or vertical or both louvres in between, is often times adopted. Each member of this egg-crate louvre is now

required to cover only a part of the window. Hence their width can be reduced considerably than what they should be if intermediate louvres are not provided. But the economy derived from reducing the widths is offset by the necessity of providing the additional louvres. An egg-crate louvre is used mostly only to enhance the architectural effect.

Note 3: The designer of the louvre has first to decide which window or part of the window to cover for which period of the day, in which part of the year. On the basis of the above examples, the correct solution can be obtained from the different shadowthrows given, the solar charts and the shadow angle protractor. The tabulated values will also indicate, for which period of the day and the year the window will be fully or partly covered, as this is also a relevant consideration in the design.

INCLINED LOUVRES

It is possible to obtain additional shading coverage from the louvres inclined at different angles from the normal as tabulated in Table 7.

Example 3:

What is the vertical coverage for a horizontal louvre of width 0.92m (3ft.) when it is fixed:-

- normal to the wall
- inclined downwards through an angle of 40°

The wall is facing East at Zaria on 11°N Lat. The coverage at 10a.m. is to be calculated for April 16th. Refer to Table. 6

The vertical shadow throw at 10 a.m. on April 16th for a east facing wall is 1.73.

The corresponding vertical shadow angle is obtained from the formula $\tan V = v$. By referring to a table of natural tangents V is 60° approximately.

- Normal louvre

For a 0.305m (1ft) louvre the shadow cover is 0.53m (1.73ft)

For a 0.9m (3ft) louvre the shadow cover $= 3 \times 0.53$
 $= 1.59\text{m}$
 (Answer)

- Louvre inclined through 40° :

See Table 7 for the inclined louvres. In the column headed 60° for V(or H) and against the angle of inclination 40° is the entry 1.97.

For a 0.92m (3ft) louvre the vertical shadow cover $= 3 \times 0.601\text{m}$ ($3 \times 1.97\text{ft}$)
 $= 1.8\text{m}$ (Answer)

It is seen, that by inclining the louvre by 40° the shadow throw has been increased to 1.8m from 1.59m for a normal louvre i.e. the shadow cover is increased by 0.21m.

The same increase would have been realised if we had inclined the louvre by 20° only instead of 40° (see table). Obviously, the 20° inclination would suffice.

The maximum coverage would be obtained for 30° inclination; (using the table), the coverage would be $(3 \times 2\text{ft} = 6\text{ft}) = 3 \times 0.61\text{m} = 1.83\text{m}$.

This optimum angle (30°) for maximum coverage is the complement of the corresponding shadow angle (60°) for a normal louvre

Use of Shadow Protractor:

Example 4:

Use the shadow protractor to find the vertical and horizontal shadow angles and vertical and horizontal shadow throws, on a wall facing SE at 12°N Lat. at 8a.m. on April 16th.

Place the protractor, centre to centre, on the Solar Chart for 12°N Lat with its base line in the direction of the wall SW-NE and its central line in the direc-

tion to which the wall faces i.e. SE. Corresponding to the position of the sun at 8a.m. on April 16th as indicated in the chart, read the protractor for the horizontal shadow angle along the radial line passing through that position, and the vertical shadow angle along the curved line passing through that position.

The protractor readings as judged by the eye are as follows:

Horizontal shadow angle is about 49° on the side indicated left on the protractor. The vertical shadow angle is about 44°

The horizontal shadow throw	= $\tan 49^\circ$
	= 1.5L
	towards
	the left.
The vertical shadow throw	= $\tan 44^\circ =$
	0.97.

By referring to the shadow throw tables these values can be found to be nearly the same as what are tabulated.

COMMENT:

Fig. A.2 can be used to work out the length of the horizontal and vertical projections for various widths and heights of windows.

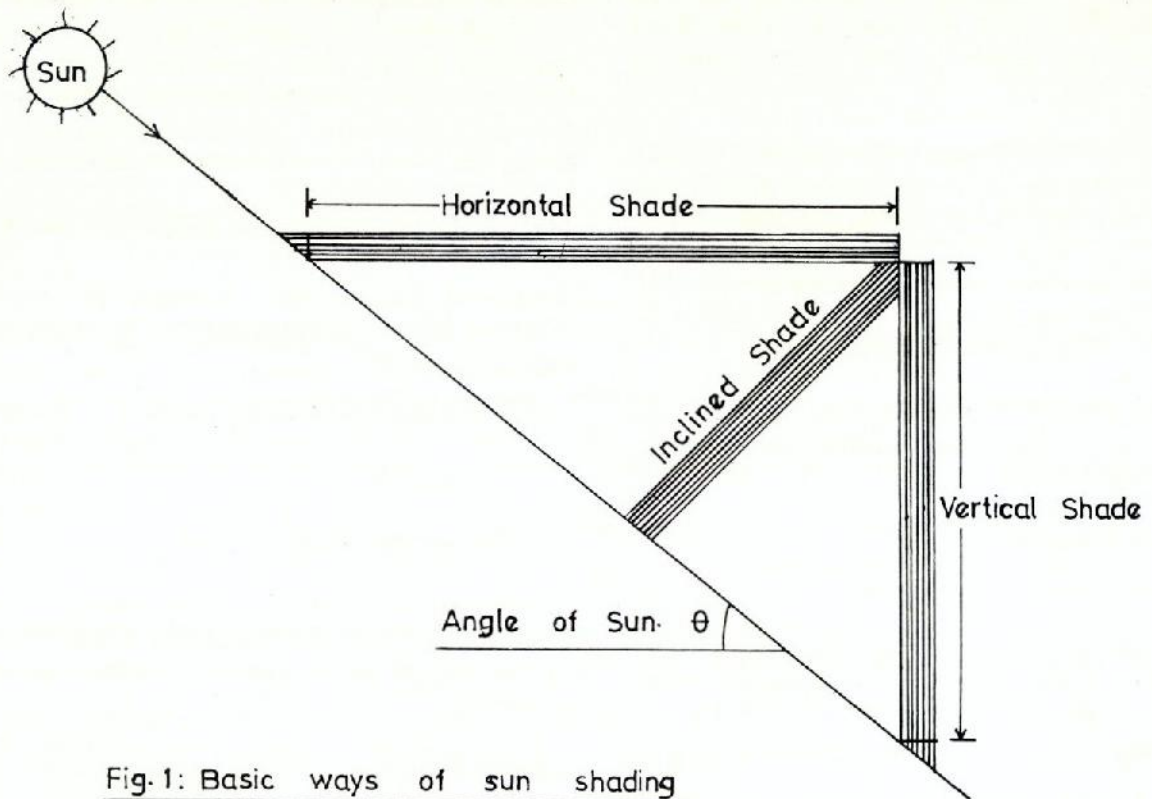
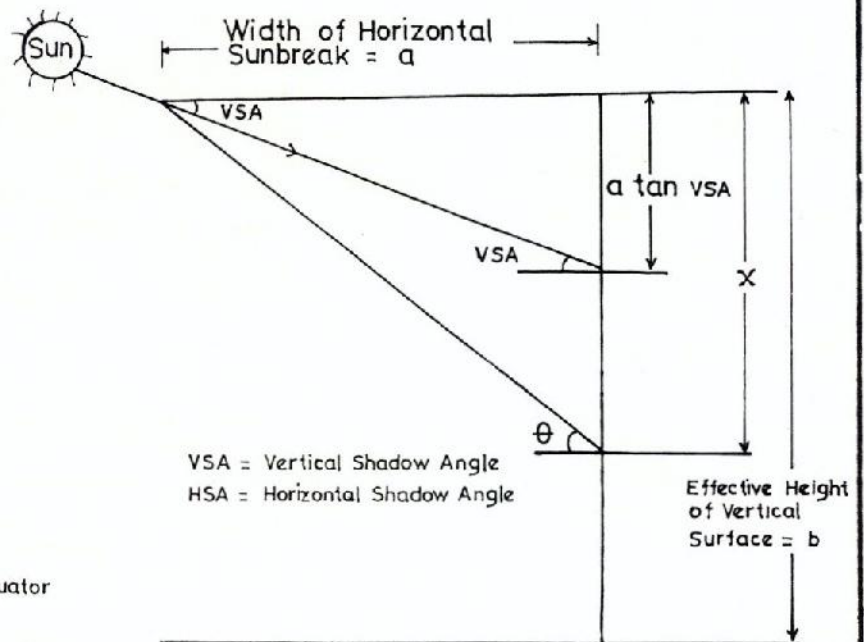
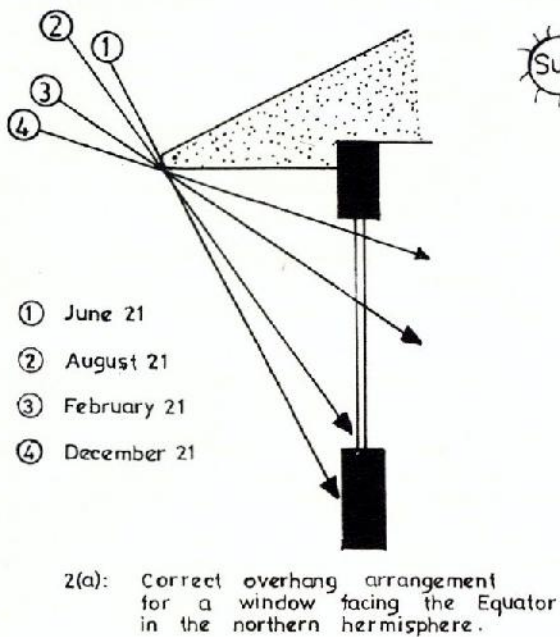
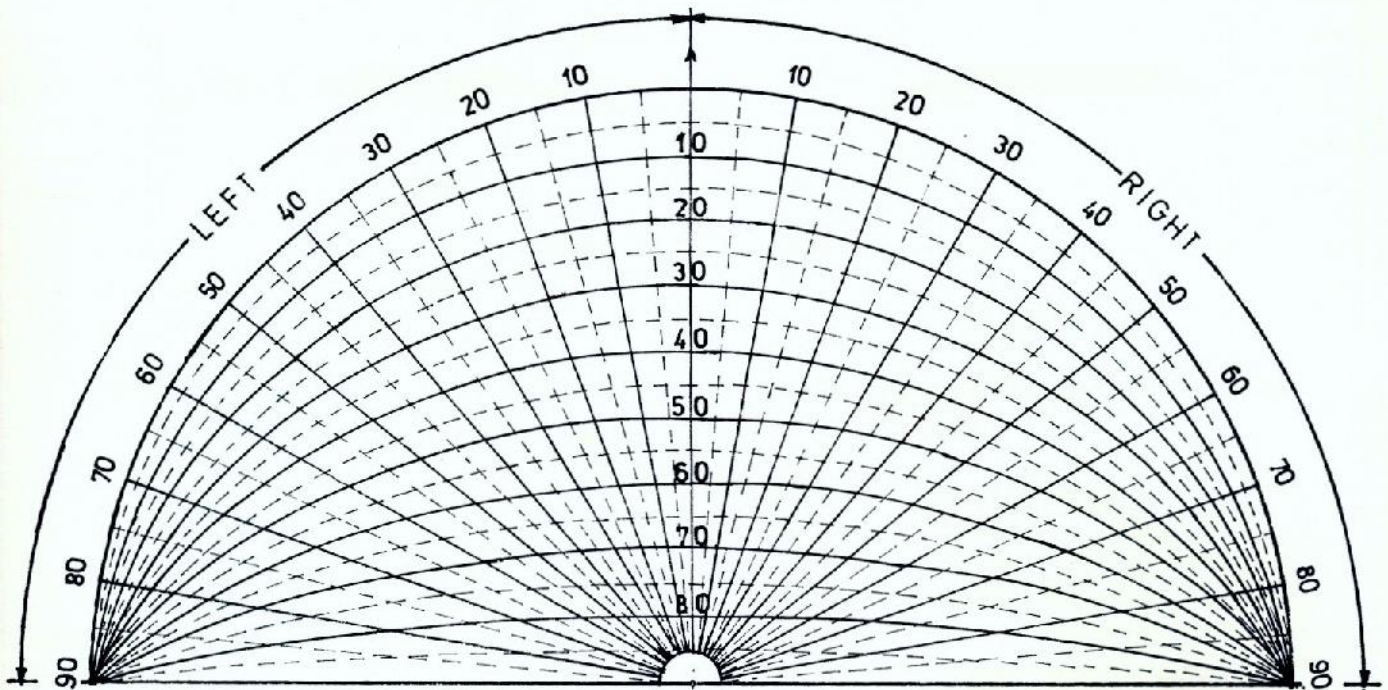


Fig. 1: Basic ways of sun shading



2(b): Geometric relations for shading of a vertical surface by a horizontal sunbreak.

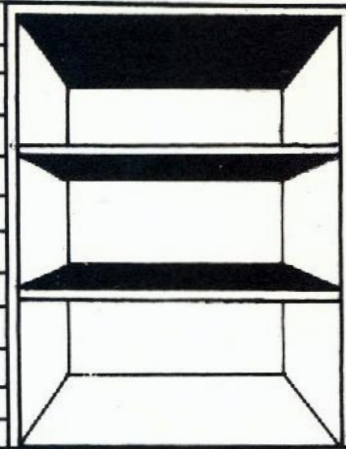
Fig. 2: Shading of a vertical surface by a horizontal sunbreak or overhang



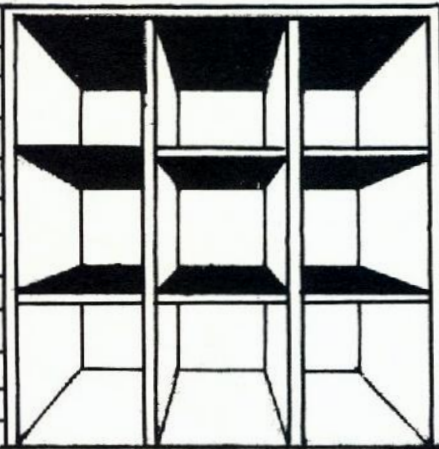
(FOR USE ON THE SOLAR CHART OF ANY LATITUDE)

PLACE CENTRE TO CENTRE WITH THE PROTRACTOR ON THE SIDE TO WHICH THE WALL FACES AND ITS BASE LINE ALONG THE WALL DIRECTION. READ THE HORIZONTAL SHADOW ANGLE ALONG THE RADIAL LINE AND THE VERTICAL SHADOW ANGLE ALONG THE CURVE PASSING THROUGH THE SUN'S POSITION AT THE TIME.

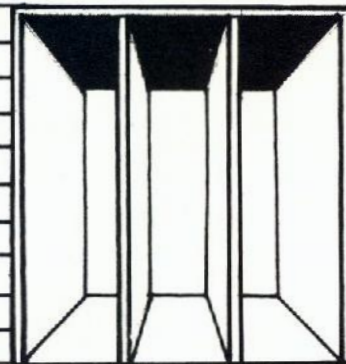
Fig. 3: SHADOW ANGLE PROTRACTOR



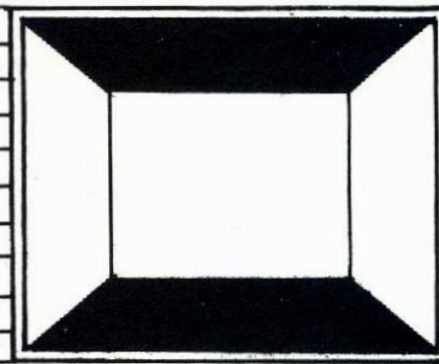
HORIZONTAL LOUVERS



COMBINATION OF HORIZONTAL
AND VERTICAL LOUVERS

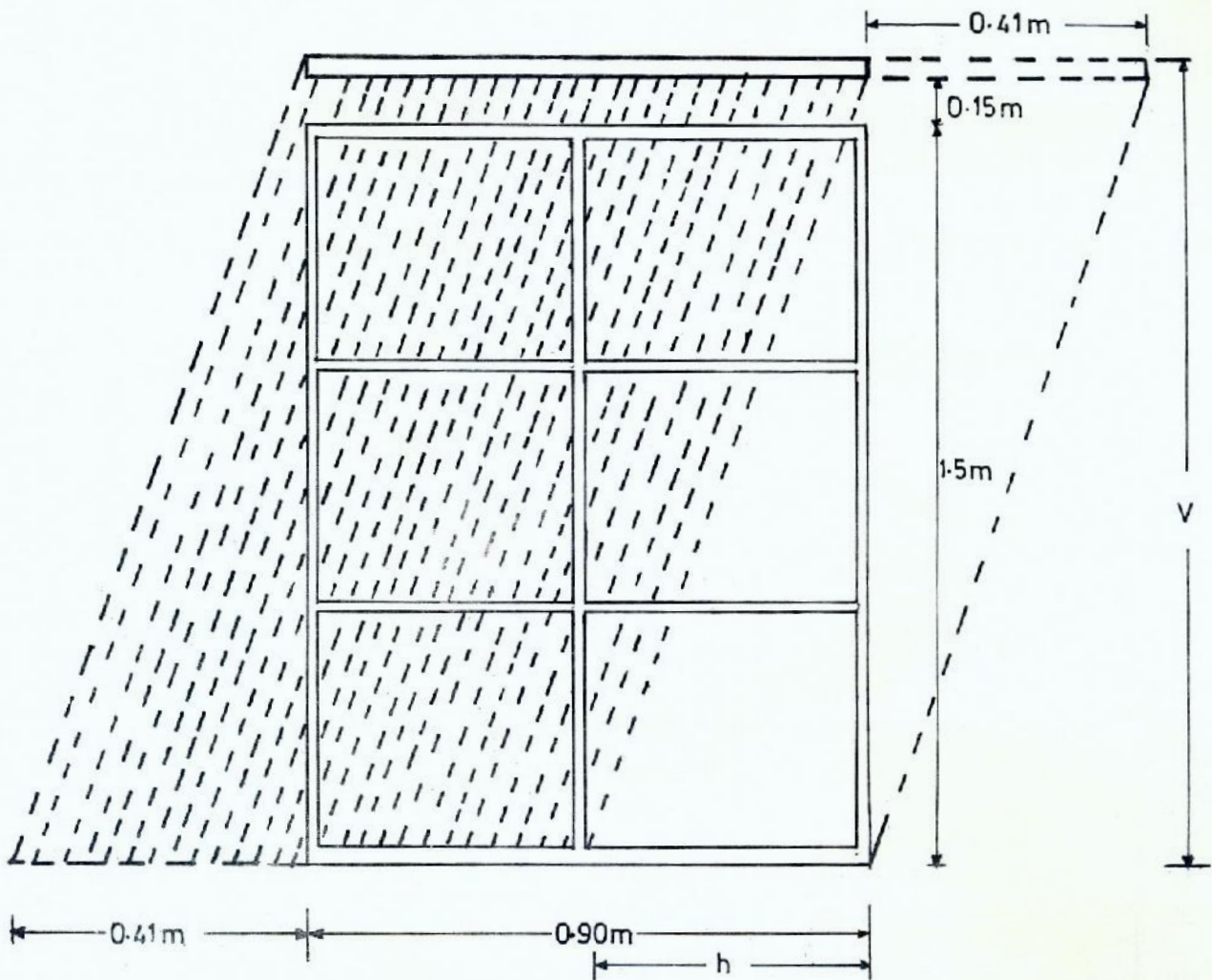


VERTICAL LOUVERS



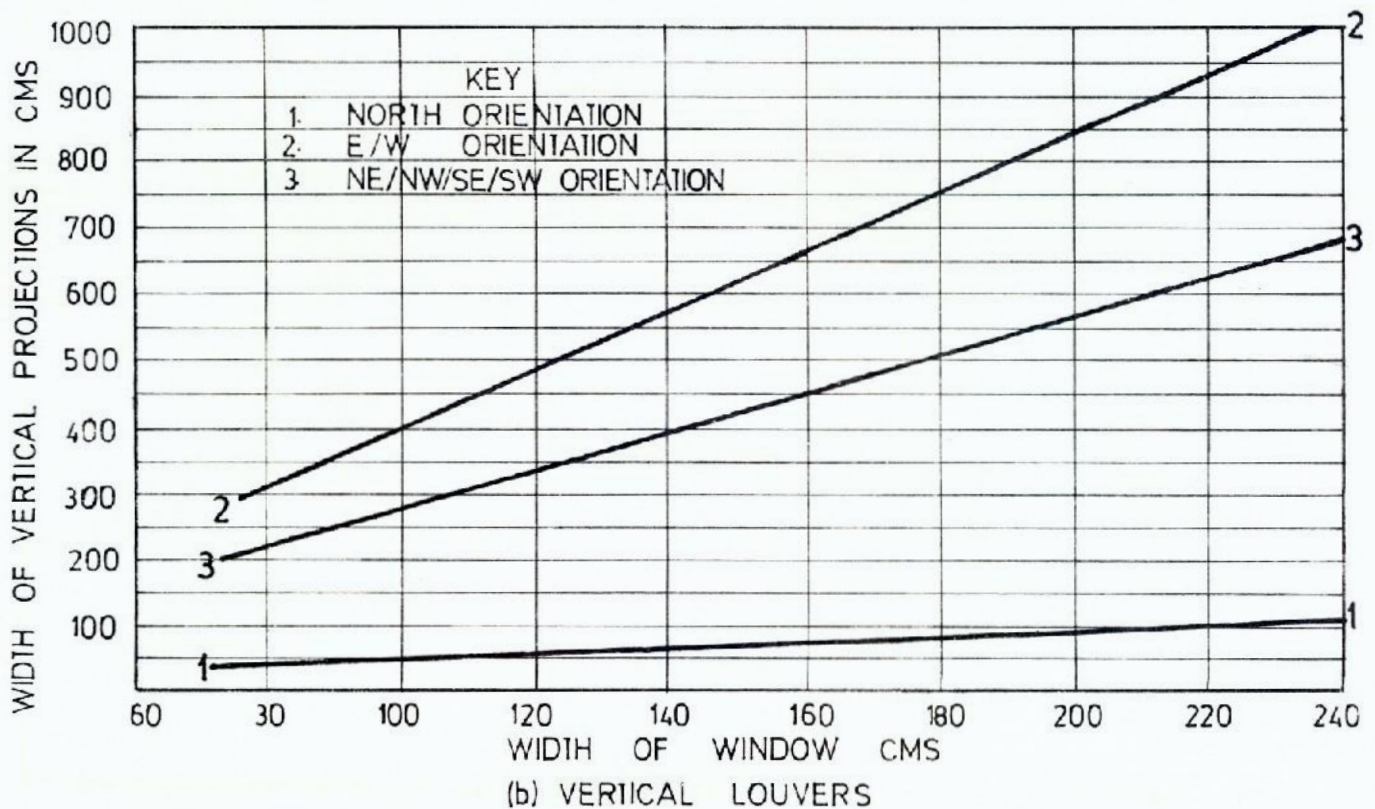
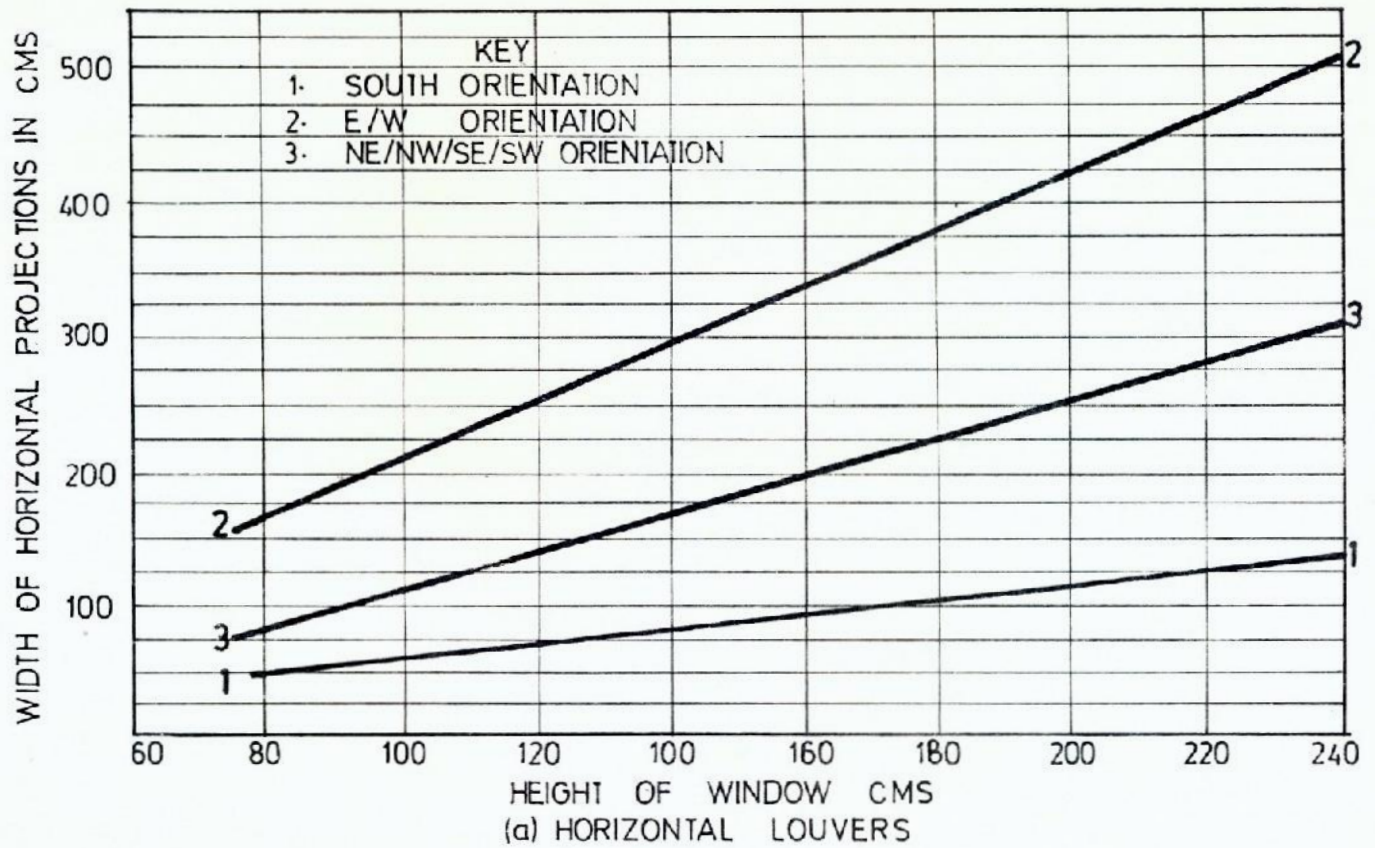
BOX TYPE LOUVER

FIG 4: TYPES OF LOUVERS



ILLUSTRATIVE EXAMPLE FOR THE
 CALCULATION OF LOUVER SIZE
 AT MAIDUGURI

FIG. A-1



GRAPHS FOR DESIGN OF LOUVERS

These values of projections are for 100% shading for other percentages of 50%, 25% etc a proportionate reduction should be made.

FIG. A2.

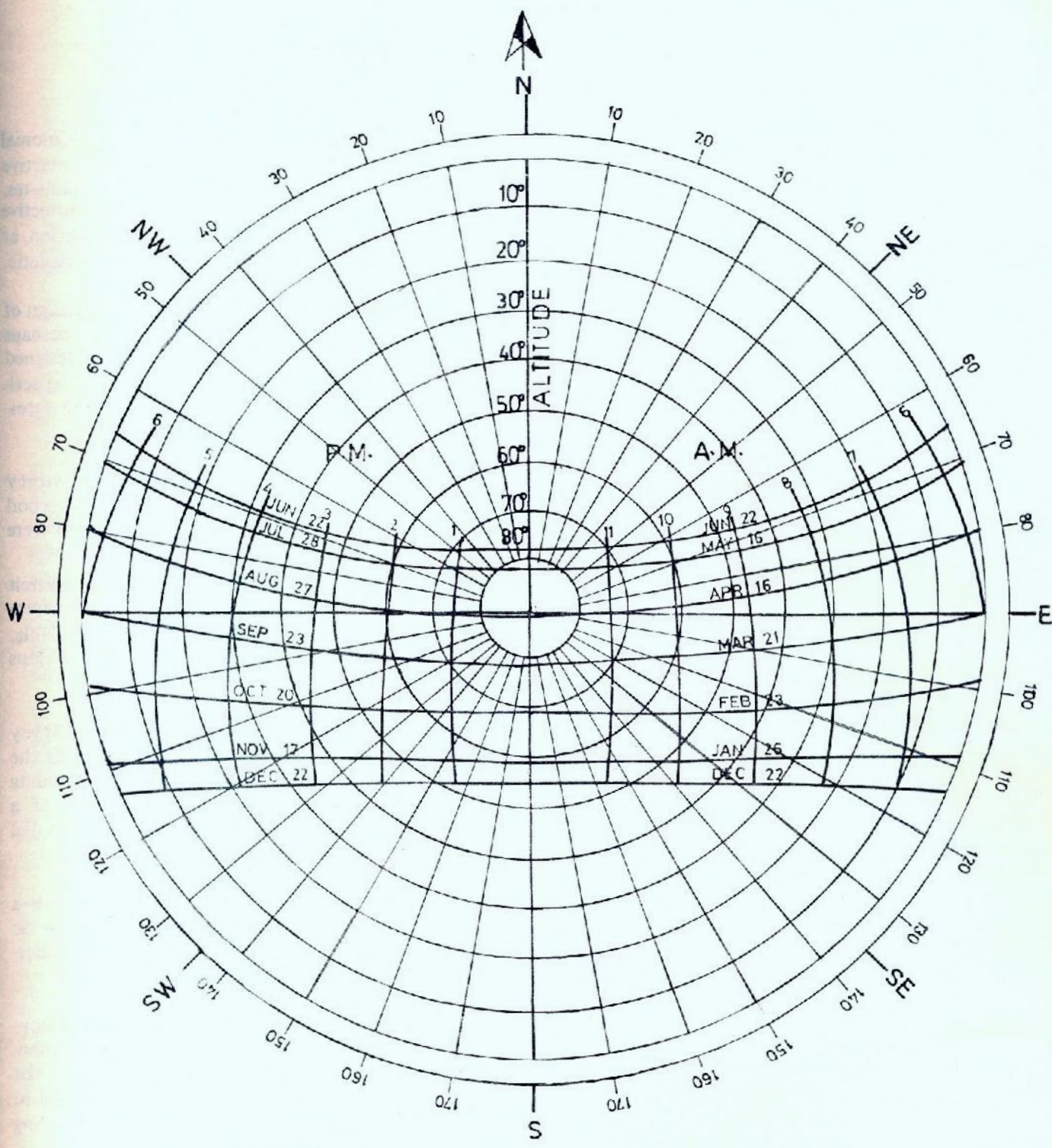


Fig. A-3: Solar Chart: LATITUDE 12° NORTH

SOLAR DATA FOR APPLICATION TO BUILDING DESIGNS IN NIGERIA.

Design of Solar Screens

JOHN GODWIN OBE FNIA FRIBA
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ABSTRACT:

This paper is concerned with the design and construction of solar screens to reduce solar heat gain in buildings. The subject is introduced by a historical survey followed by a discussion on the methods used to test the adequacy of solar control systems and a detailed explanation of the type adopted by the office of the writer.

This is followed by a case study of Bookshop House designed by Godwin & Hopwood.

1. INTRODUCTION

The effects of solar radiation on buildings and the use of it covers a very wide field. This paper however, is restricted to the design of one element of a building, namely screens, to protect openings in buildings from solar heat gain.

2. HISTORICAL BACKGROUND

Traditional design and construction has produced its own solutions within the constraints of the materials available and the overall response of people to their climatic environment.

In Southern Nigeria the necessity to provide large openings for increased air movement combined with the availability of light structural and cladding materials from the forests has produced appropriate forms including large overhangs which protect walls and openings from the sun as well as throwing off the torrential rains.

At the other extreme, in Northern Nigeria where timber is scarce, mud has been adopted as the main structural and cladding materials. Openings are reduced to a minimum to exclude the direct rays of the sun and a low rainfall has eliminated the need for large overhangs. The heavy structure soaks up the daytime heat releasing it to the interior at night when the air temperature drops. This, of course, is not ideal at some periods of the year but further discussion is outside the scope of this paper.

In the 19th Century, particularly in Southern Nigeria architectural influences from Europe and Europe via Brazil and India have produced new forms felt to be more similar to the life style of the users. Thus a type of architecture based on Mediterranean climates has

been introduced giving us the 'Brazilian' and 'Colonial' styles incorporating decorative and protective features which owe their existence to sunny climates. Thus, large overhangs, jalousies and other protective elements are employed to minimise solar radiation, at the same time producing a distinctive aesthetic.

After the Second World War the emphasis in design of buildings shifted from the traditional and perhaps grandiose to a more cost conscious exercise designed to cope with the tremendous increase in building activity prior to independence combined with the necessity for some degree of sophistication.

Buildings such as factories, hospitals or multi-storey office blocks could not be built of mud and wood although the lessons to be learnt from them were recognised.

Almost overnight therefore tropical building research came to the fore-front in order to fine tune principles of design for the climate within the budgets available. Solar radiation became a prime target and various design tools were proposed.

(i) **The Shade Dial.** This was developed by Olgyay (1955) from the sun dial idea. By adjusting the dial to the latitude of the proposed building location, and the light source, the tip of a shadow cast by a pin in the centre of the dial indicates the selected time and date.

The shade dial is used in conjunction with a model, both being tilted at the same angle so that the shadow cast by the light source indicates the desired time and date.

(ii) **The Heliodon & The Solar Scope.** These are more sophisticated instruments which can be manipulated to simulate sun direction at a particular time on a particular location, using a model to show the effectiveness of the sunshading proposed.

(iii) **The Solar Chart.** These are charts constructed from solar declination tables at any latitude desired. The Azimuth and altitude of the sun can be directly read off the chart by means of a protractor which is drawn to the same scale as the chart. By rotating the protractor on the chart to the orientation of the proposed building optimum angles for vertical and horizontal sun

shades can be ascertained. I will describe the use of this in more detail later as I consider this to be the most practical and easiest tool to use other than a computer programme which can of course produce instant print outs and drawings. Solar charts can be used in conjunction with other overlays to indicate radiation intensities etc.

In the absence of appropriate charts I constructed charts in 1955 from data collected from Nigerian Meteorological services. Unfortunately these are not in accordance with scales later internationally accepted.

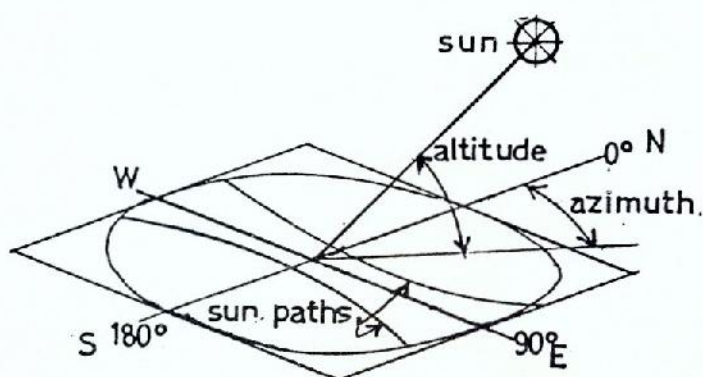
- (iv) **Shadow Angle Diagrams.** Developed by the West African Building Research Institute in the late 50's. These provide a good visual guide for the designer who does not want to go to the trouble of using the solar charts.

3. DESIGN OF SOLAR SCREENS USING SOLAR CHARTS & SHADOW ANGLE PROTRACTOR

It should be remembered that this design aid deals with the exclusion of *direct radiation* only and does not take account of reflected radiation, glare or ventilation patterns through the openings they protect and the required daylighting levels in the rooms.

Consideration also has to be given to the heat absorbed and re-radiated by the exposed surfaces of the screening device.

The following notes were written by me for the First IDA Education Project in 1965



declination of the sun
figure 1

The Solar Charts

The Solar charts are projections of the patterns of the sun at selected times of the year, on to a plane parallel with the horizon. The mid-point of the diagram represents the observer's position at the given latitude and the outer circle represents the horizon line.

The sun's paths, which are represented by a series of curved lines running from East to West, are constructed from solar *azimuth* and *altitude* angles at hourly intervals. From these it is possible to read off the declination of the sun at any time.

The azimuth is the angular distance measured clockwise from North and the altitude is read off by means of the concentric solar altitude circles — figure 1.

For example, the declination of the sun at latitude 4°N on 1 May and 13 August at an Azimuth of 76°E and an altitude of 29° — figure 2.

It should be remembered that the hourly times given are *solar time* which must be corrected to give *local time* and that North on the charts is *true North*.

We provided solar charts for 28 key locations in Nigeria in order that they could be used not only for reading off solar declination but, by superimposing the overheated period of the day on the chart for the particular area, it was possible to ascertain when sun shading was required. Thus Jos, although on a similar latitude to Yola which requires solar exclusion almost all day, needs shading only between 9.30 am and 5.30pm (solar time).

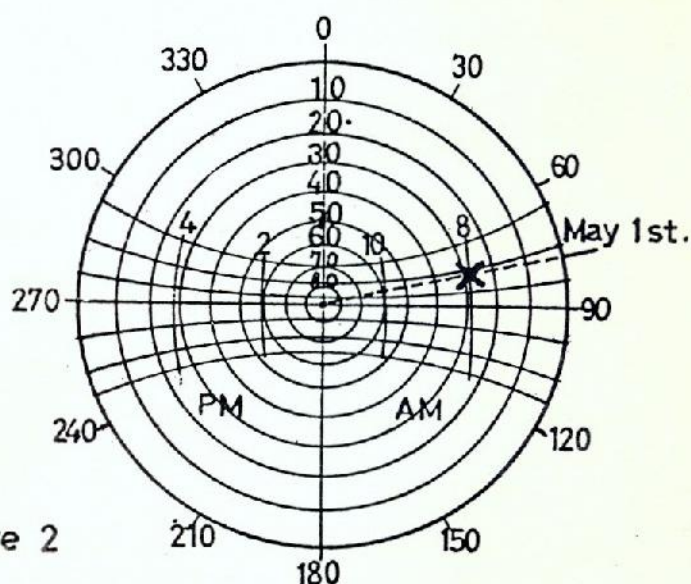


figure 2

The Shadow Angle Protractor

The shadow angle protractor is used in conjunction with the solar charts to determine the amounts of horizontal and vertical projections required to exclude direct sunlight for any orientation at a given latitude. The *baseline* represents the vertical surface to be shaded and the mid-point represents the observer's position. Fig. 3

The radial lines represent horizontal shadow angles

(H°) formed by *vertical projections*, and the curved lines (which are a function of solar declinations) represent *vertical shadow angles* (V°), formed by *horizontal projections*, normal to the observer's position. (Thus a vertical shadow angle of 70° represents a solar altitude of 55° at an azimuth of 300° or a solar altitude of 66° at an azimuth of 320° . It does not represent the altitude of the sun.)

The Protractor may be used for any solar chart of the same diameter and using the same solar altitude scale.

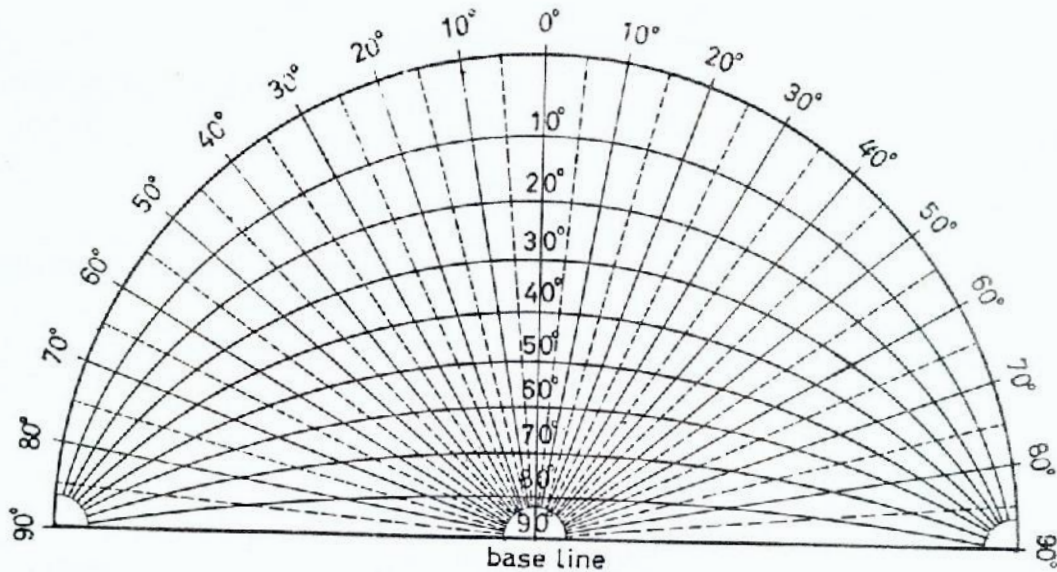
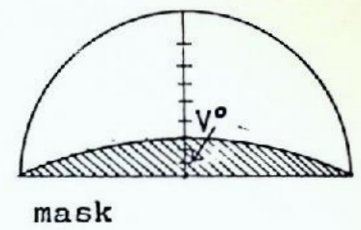
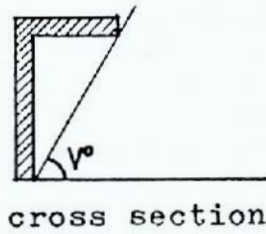


fig 3

Selected horizontal and vertical shadow angles produce *shading masks* and simple examples of these together with the projections which produce them are given below. Fig. 4

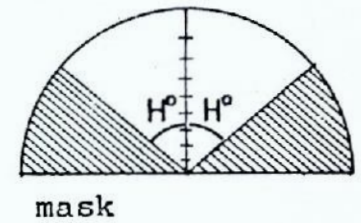
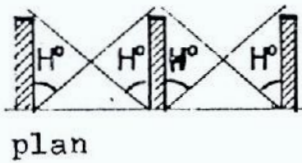
A. Shading mask produced by continuous horizontal projection

A



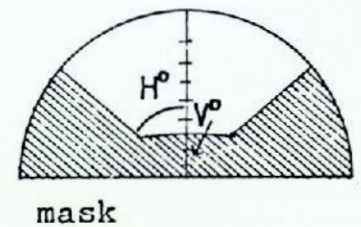
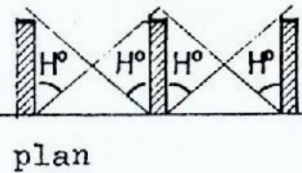
B. Shading mask produced by vertical projection

B



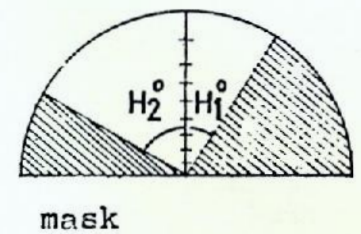
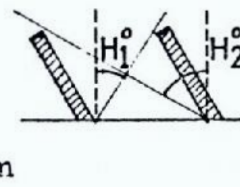
A+B combined to give shading mask produced by "eggcrate" screen

A+B



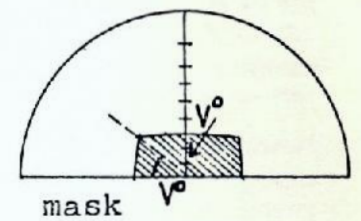
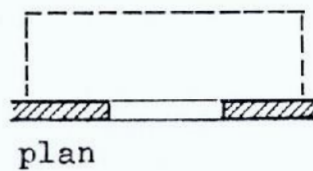
C. Shading mask produced by angled vertical screen

C



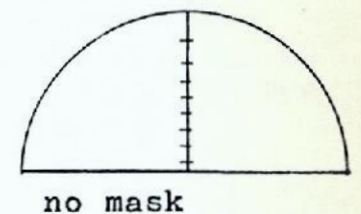
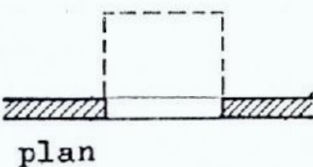
D. Non continuous horizontal projection produces limited shading mask

D



E. Non continuous horizontal projection without side laps gives no shading mask

E



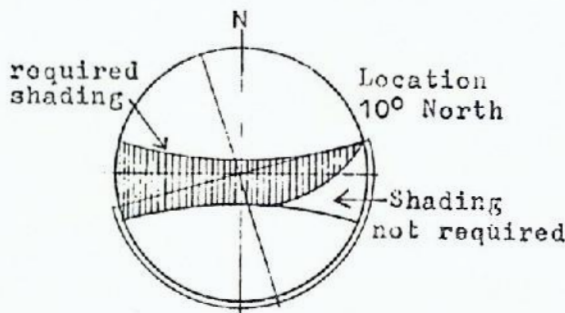
SHADING MASKS

4. PROGRAMME FOR DESIGN. FIG. 5

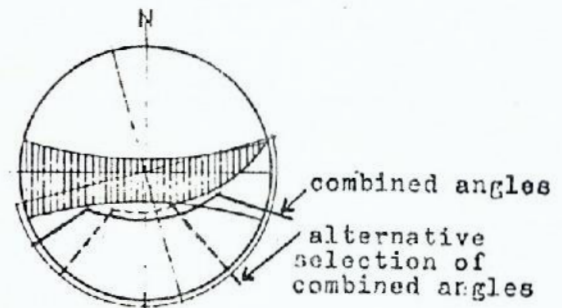
- Step a) Select the solar chart for the nearest location and latitude to the site under consideration.
- b) Place the shadow angle protractor over the mid-point of the chart and pivot it about this point until the base line is perpendicular to the required orientation.
- c) Select horizontal and vertical shadow angles to give shading required by reading off angles on the protractor where they coincide with the solar declination curves

on the solar chart. Note various combinations of the two angles may be chosen; for complete exclusion of sun on the surface to be protected the shading mask of the solar screen must lie outside the relevant solar declination curve.

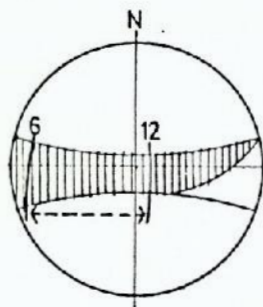
- d) Check the effects of correction from solar time to local time and check periods where complete solar exclusion is required.
- e) Check shadow angles required on other orientations.
- f) Select shading mask for each elevation.



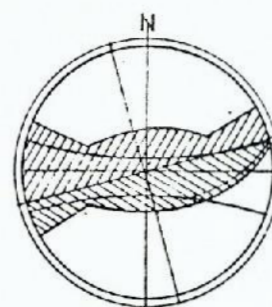
a & b) selected solar chart with protractor orientated



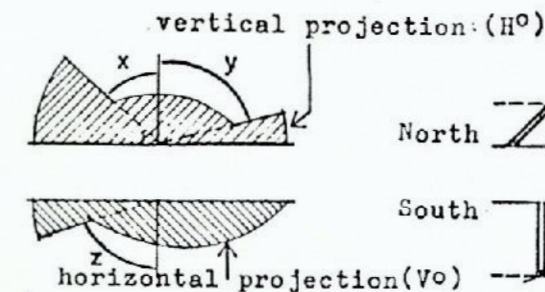
c) selection of shadow angles



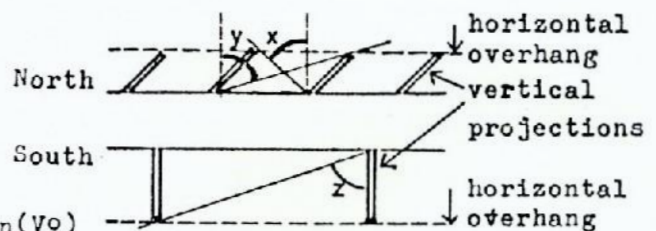
d) correction to local time



(e) final shadow angles



f) masks for North and South elevations



possible 'oggrate' solution to solar screen from masks

fia5

In connection with Step (d) above it will be noted that the difference between local standard time and solar time can be significant. Fig. 6.

Town	Approximate Longitude East		Reference Longitude East degrees	Time Difference Standard time minus Solar time minutes
	degrees	minutes		
Enugu	7	29	15	+ 30
Ibadan	3	54	15	+ 44
Kaduna	7	26	15	+ 30
Kano	8	32	15	+ 26
Lagos	3	24	15	+ 46
Port Harcourt	7	01	15	+ 32
Sokoto	5	16	15	+ 39
Zaria	7	48	15	+ 29
Maiduguri	12	35	15	+ 07
Yola	12	14	15	+ 10
Mubi	12	36	15	+ 07
Gombe	10	32	15	+ 16

Fig. 6

5. CASE STUDY — BOOKSHOP HOUSE, LAGOS

This building is a fourteen storey office block on Broad Street, Lagos and was completed in 1977. The structure is of reinforced concrete and finished with mosaic tiles and cast aluminium cladding panels. The windows and sunbreakers are in anodised aluminium.

Environmental Problems

Lagos lies approximately $6\frac{1}{2}^{\circ}$ North in the tropical zone and on the edge of the rain forest. Average temperatures and relative humidities vary little throughout the year ranging between $30^{\circ}\text{C} - 35^{\circ}\text{C}$ and 70% - 90% respectively. In these conditions a comfortable environment can be achieved naturally by reducing the solar heat load and exploiting the prevailing breeze, or artificially by air-conditioning.

In city conditions such as Lagos where high land values and site restrictions demand compact planning and the environment is noisy and dirty, it is necessary to adopt artificial cooling methods to produce comfortable conditions for the occupants of buildings.

Air-conditioning loads can be considerably reduced by proper insulation of the building fabric and protection of it from the direct rays of the sun. It is surprising however that this is frequently ignored, to the discomfort of the building occupants, when poor mechanical design, frequent breakdowns or power failures result in interruptions of the cooling system. Also a higher energy input and attendant costs result from unnecessarily high air-conditioning loads.

These were factors which were taken into consideration in the design of this office block.

Options for the reduction of the solar heat load

In principle, it was accepted that a reduction in solar heat load on the building was necessary and apart from the normal roof insulation it was a matter of evaluating various options for the external walls and fenestration.

The facades of the main tower block of the building for all practical purposes face North, East, South and West. It was decided to reduce fenestration to a minimum compatible with the internal appearance of the perimeter offices and the need to be able to see out. The window openings amount to 38% of the exterior facades which are constructed in reinforced concrete and faced in a light coloured mosaic tile.

With these basic factors given, the consulting engineers were requested to consider the following options relative to capital costs and air-conditioning running costs arising from the fenestration.

- Option 1. No protection, clear glass.
- Option 2. Various types of 'anti-sun' and other coloured or coated glasses with light coloured venetian blinds behind.
- Option 3. Externally applied sunshading designed to exclude all the sun's rays on North and South elevations and rays between 0900 hours and 1600 hours on East and West elevations.

In the first option, the solar heat reduction was taken as nil.

In the second option, ten types of glass were considered and it was found that a reduction of between 52% and 56% could be obtained. With the third option, however, a reduction of 85% could be obtained with dark bronze horizontal blades set at an angle of

17° In 1971 the cost of running a ton of airconditioning plant per annum at 75% capacity was US \$56.40 and the capital cost of the installed plant worked out at US \$1,000.00 per ton.

The peak air-conditioning load due to glazed areas and resultant capital and running costs are given below for the three options.

OPTION	REDUCTION IN SOLAR LOAD %	TONS OF A/C REQUIRED	CAPITAL COST US \$	RUNNING COST US \$ PER ANNUM
1	0	167	167,000	9419
2	52	80	80,000	
			20,443	(anti-sunglass)
			5,754	(venetian blinds)
			106,197	4521
3	85	25	25,000	
			42,129	
			67,129	1410

From these figures it was decided to accept the use of external sunshading and preliminary designs and specifications were prepared by the architects upon which tenders were obtained.

Sunbreaker Design

The design parameters prepared by the architects included the following criteria:

- The construction would be supported off the building structure at every floor level and should be strong enough to withstand wind gusts of up to 90mph.
- The material should be aluminium anodise to a depth of 20 microns Clear anodising was specified for the vertical members and bronze anodising for the horizontal blades. (This was done to give a more vertical emphasis to a rather squat tower and the bronze blades would not show dust and reflect about 10% less solar radiation at an angle of 17°)
- The leading edges of the horizontal blades should be at the same level on all facades.
- Standing and sitting eye levels should not be obstructed and therefore to achieve this, the total solar exclusion on East and West elevations was limited to the hours between 0900 and 1600. (office hours were from 0800 to 1700).

- Components for all facades should be standardised.

The 'shading masks' for each facade were derived from the solar chart for latitude 7°N using a matching shadow angle protractor, allowance being made for the difference between Solar Time and Nigerian Standard Time, which in Lagos is 46 mins ahead of Solar Time. The combination of vertical and horizontal angles derived are shown on Figure 7.

Sunbreaker Production Design

The production design was the result of a joint collaboration between the manufacturers and the architects. The final design is shown in Figure 8.

The following considerations were taken into account:-

- Material had to be provided in standard elements which involved a minimum of packing and transportation costs.
- If possible special extrusions were to be produced in Nigeria at Nigalex Limited but the maximum size of extrusion in any direction was restricted to 6" (150mm).
- The horizontal blades would be made up from flat sheet fitted to a profiled frame also of aluminium with the exposed leading edges anodised bronze to match the sheets.

- d) The method of fixing the horizontal blades of the vertical fins had to provide for angular adjustment to enable a similar blade size to be used on North and South elevations as well as East and West. Also location adjustment to enable blades to line through bay to bay independently of the vertical positioning of the fins.
- e) The support structure should be capable of reasonable adjustment to suit inaccurate builders work since the structural engineers would not permit holes to be left and fixing plates had to be cast in situ.
- f) Permissible tolerance for erection purposes were limited.
- g) Fenestration was designed to be inward opening for both cleaning of the windows and the sun-breakers from inside the building.

Erection Procedure

Erection of the sunbreakers on each facade was started as soon as the window fixing and mosaic tiling was completed.

The vertical centre lines of each fin were checked and adjustments made to suit the cantilever brackets which were fixed next to receive the cladding panels.

After the fins had been erected and checked for verticality and spacing the frames for the horizontal blades were inserted by means of a jig which had been pre-aligned with a fixed datum at each floor level. This ensured that the blades were in the correct location, horizontal and inclined at the specified

angle for that facade. The elliptical ends of the frames were locked in position by special bolts which slotted into continuous vertical channels formed in the extruded panels of the fins.

Next were fitted the pre-cut panels of Alucolux to complete the horizontal blades.

As the erection was completed the work was cleaned down and the scaffolding removed.

In-use Experience

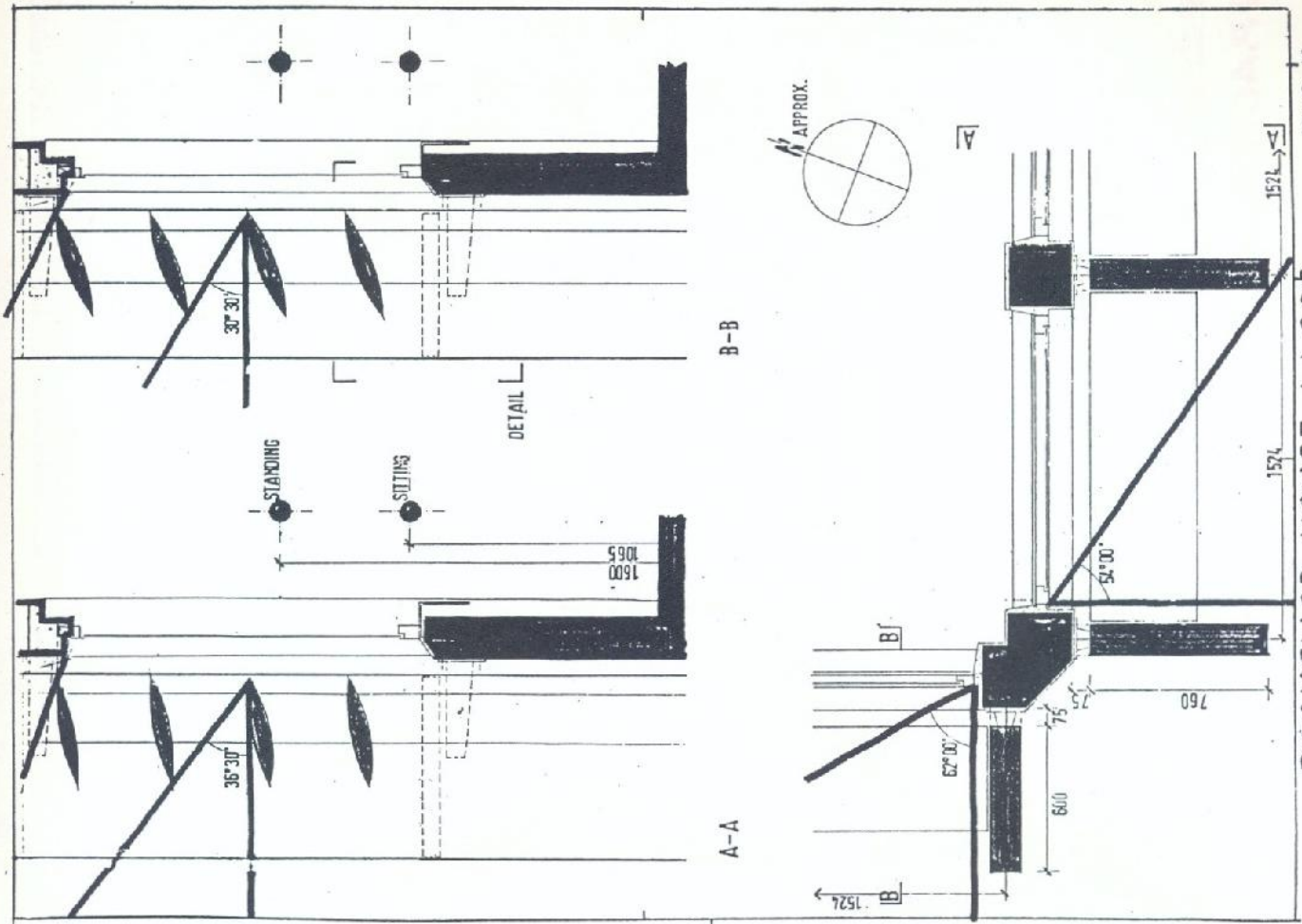
Between the date of completion and the writing of this paper the building has been in use for ten years. In this time the sunbreaker system has been found satisfactory apart from a few defective infill panels which became detached in high winds.

In periods when the air-conditioning has been out of commission the exclusion of solar radiation has greatly alleviated the discomfort which might otherwise become intolerable had there been no sunshading.

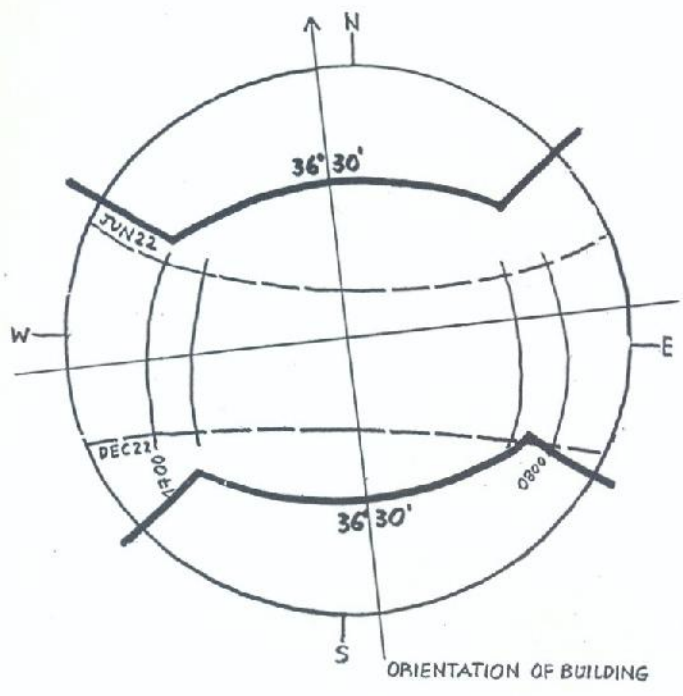
Building	“Bookshop House” Lagos
Owners	Bookshop House Limited
Architects	Godwin & Hopwood F/FNIA, F/FRIBA, A. A. Dipl, Lagos
Consulting Engineers	Stanley Consultants Ltd., USA
Quantity Surveyors	Tillyard & Partners, Lagos
Estate Management	Fox & Co. Lagos
General Contractors	G. Cappa Ltd., Lagos
Sunbreaker & Window	Alumaco, Lagos
Sub-Contractors	

ILLUSTRATIONS

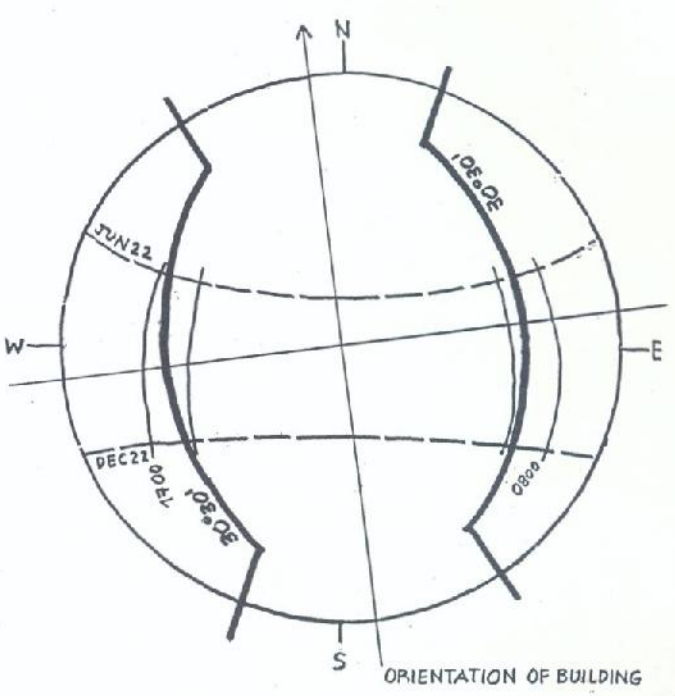
- Fig. 1 *Declination of the Sun.* Diagram illustrates relationship between Altitude and Azimuth (Text)
- Fig. 2. *The Solar Chart.* This example for Jos (10°N) also shows the period when direct sunlight should be avoided and openings protected as well as corrections from solar to local standard time.
- Fig. 3 *The Shadow Angle Protractor.* Used in conjunction with the solar chart to ascertain solar declination at any time for any orientation of the building. (Text)
- Fig. 4. *Shading Masks.* Shows protection given by some examples. Note that examples A & D are better if combined with a vertical element or by continuing the horizontal overhang.
- Fig. 5. *Procedure for Design.* Illustrates the design method in use in six steps.
- Fig. 6 *Local Standard Time & Solar Time.* The time adjustments to be made for some locations are tabulated. (Text)
- Fig. 7. *Bookshop House, Lagos.* Case study showing determination of horizontal and vertical shading masks on N/S and E/W orientations.
- Fig. 8. *Bookshop House, Lagos.* Case study showing design developed from Fig. 7.
- Fig. 9. *Traditional Building.* Illustrates 'light' construction in timber and palm fronds from Southern Nigeria and 'heavy' construction in mud from Northern Nigeria.
- Fig. 10. *Imported Building Design.* Examples of 'Brazilian' and 'Colonial' designs from Lagos, C1900
- Fig. 11. *Shade Dial.* Sun dial for use with models designed by Olgyay.
- Fig. 12. *Shadow Angle Diagrams.* A useful quick design tool for orientations N/S and E/W and specific times only produced by the West African Building Research Institute, Ghana. Note the depth of sunlight penetration on east/west orientations.
- Fig. 13. *Sunbreaker System, Ibadan.* The doors and the horizontal louvres combine to give complete protection while providing unimpeded ventilation. On cool days with the doors closed light is received from a single glazed window. (J. Godwin)
- Fig. 14. *Sunbreaker System, Lagos.* The vertical and horizontal system reduces sky glare and filters the light. The louvres reflect solar radiation away from the building and the timber construction reduces re-radiated heat. The materials are however difficult and expensive to maintain.
- Fig. 15 *Air Flow Patterns* Drawn from wind tunnel tests carried out by the Texas Engineering Experiment Station indicate how the height of openings and the adjustment of fenestration/sunbreakers influences air flow patterns.
- Fig. 16 *Primary School, Lagos.* Illustrating a combination of sunshading and ventilation employing permanent overhangs in conjunction with adjustable solid panels (windows). The glazing is fixed at high level. (Godwin & Hopwood)
- Fig. 17. *House, Kano.* Illustrating the complete screening from direct radiation of the main living quarters by walls and adjustable sunbreakers (Godwin & Hopwood)
- Fig. 18. *Bookshop House.* View of sunbreaker system taken of the S.W. corner of the office tower. The fact that there is a difference in depth of vertical elements and pitch of horizontal blades between elevations is hardly noticeable.



BOOKSHOP HOUSE LAGOS FIG 8

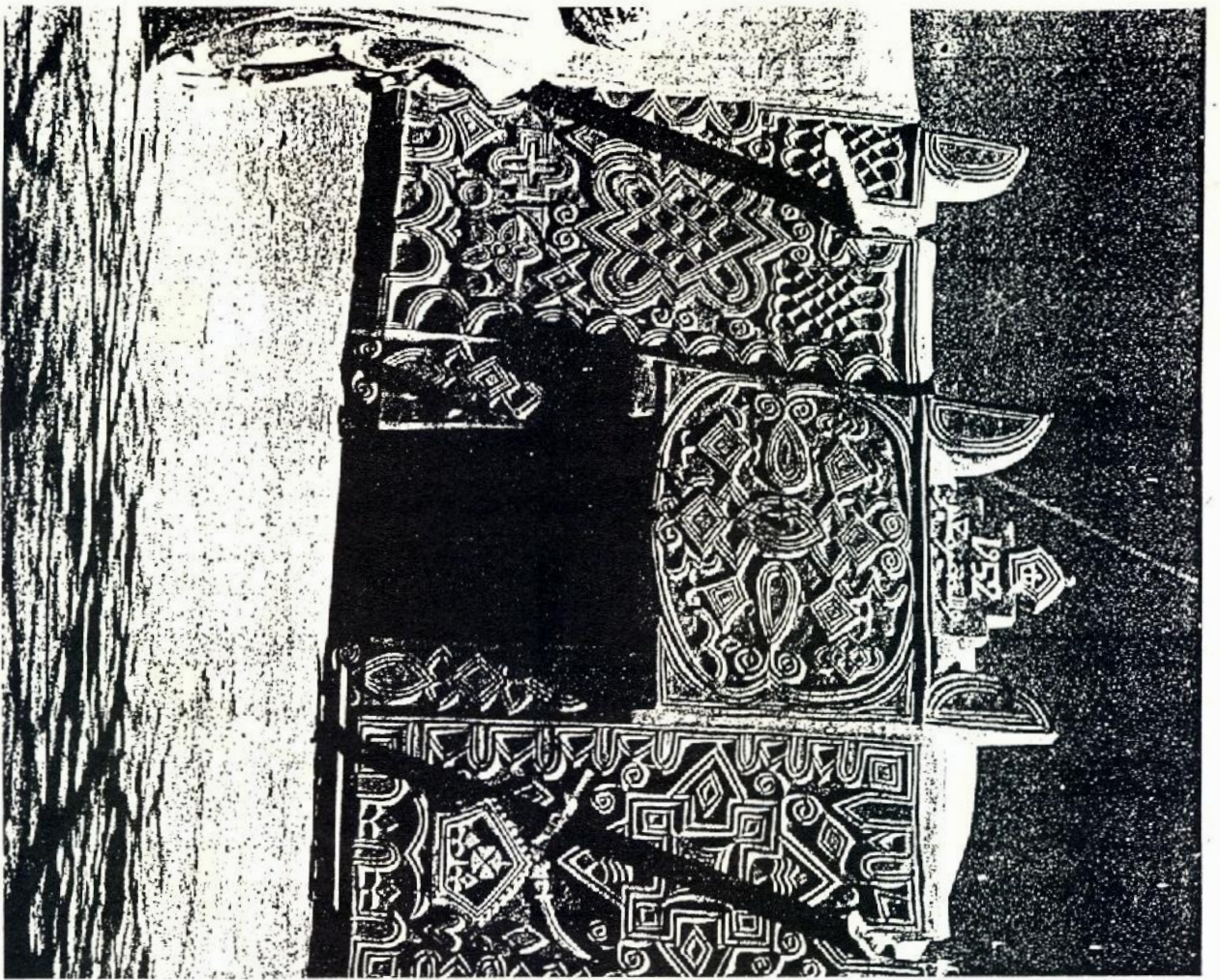


BOOKSHOP HOUSE LAGOS SHADING MASK FOR N/S ELEVATIONS



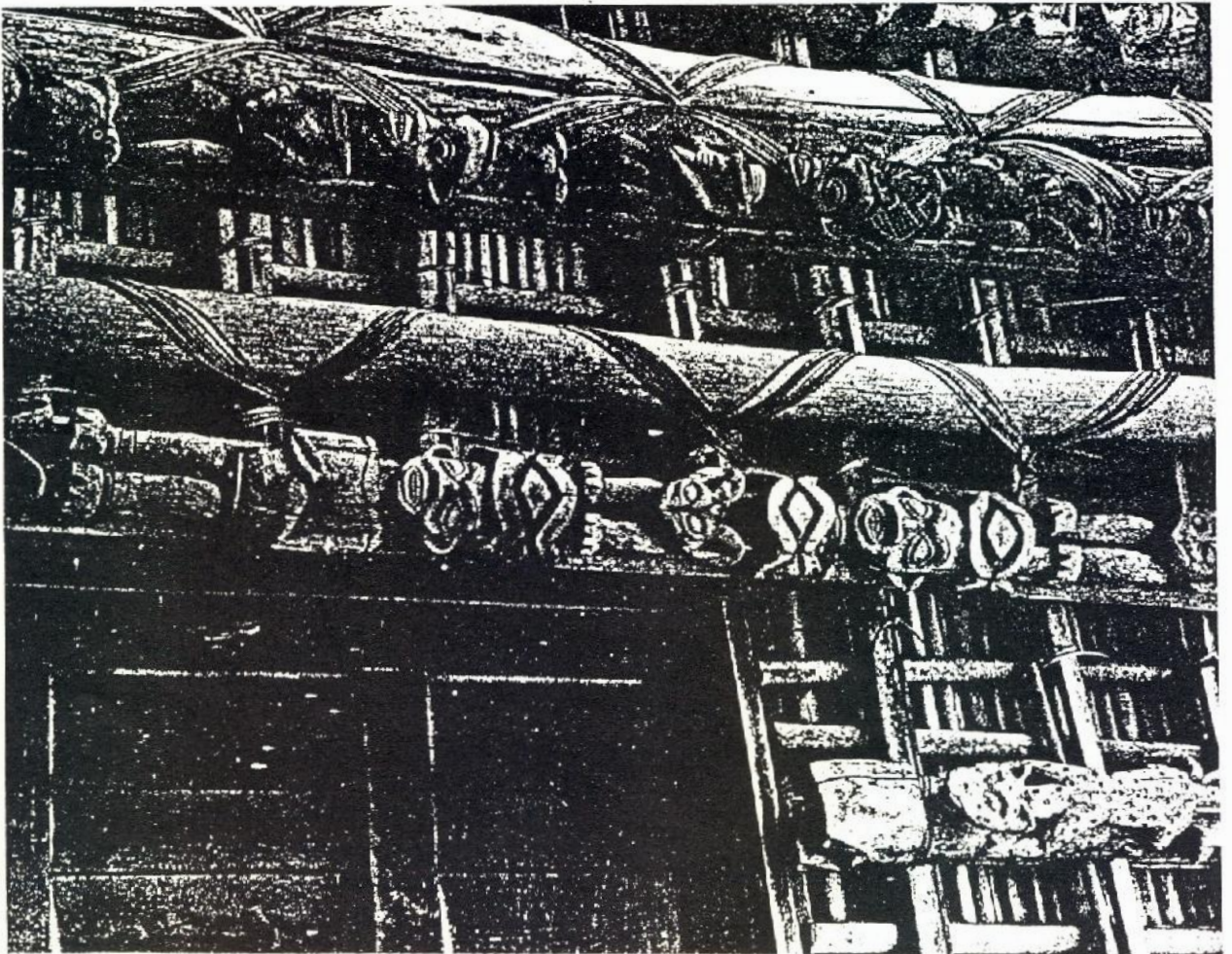
BOOKSHOP HOUSE LAGOS SHADING MASK FOR E/W ELEVATIONS

FIG 7



TRADITIONAL

N. NIGERIA



S. NIGERIA
FIG 9

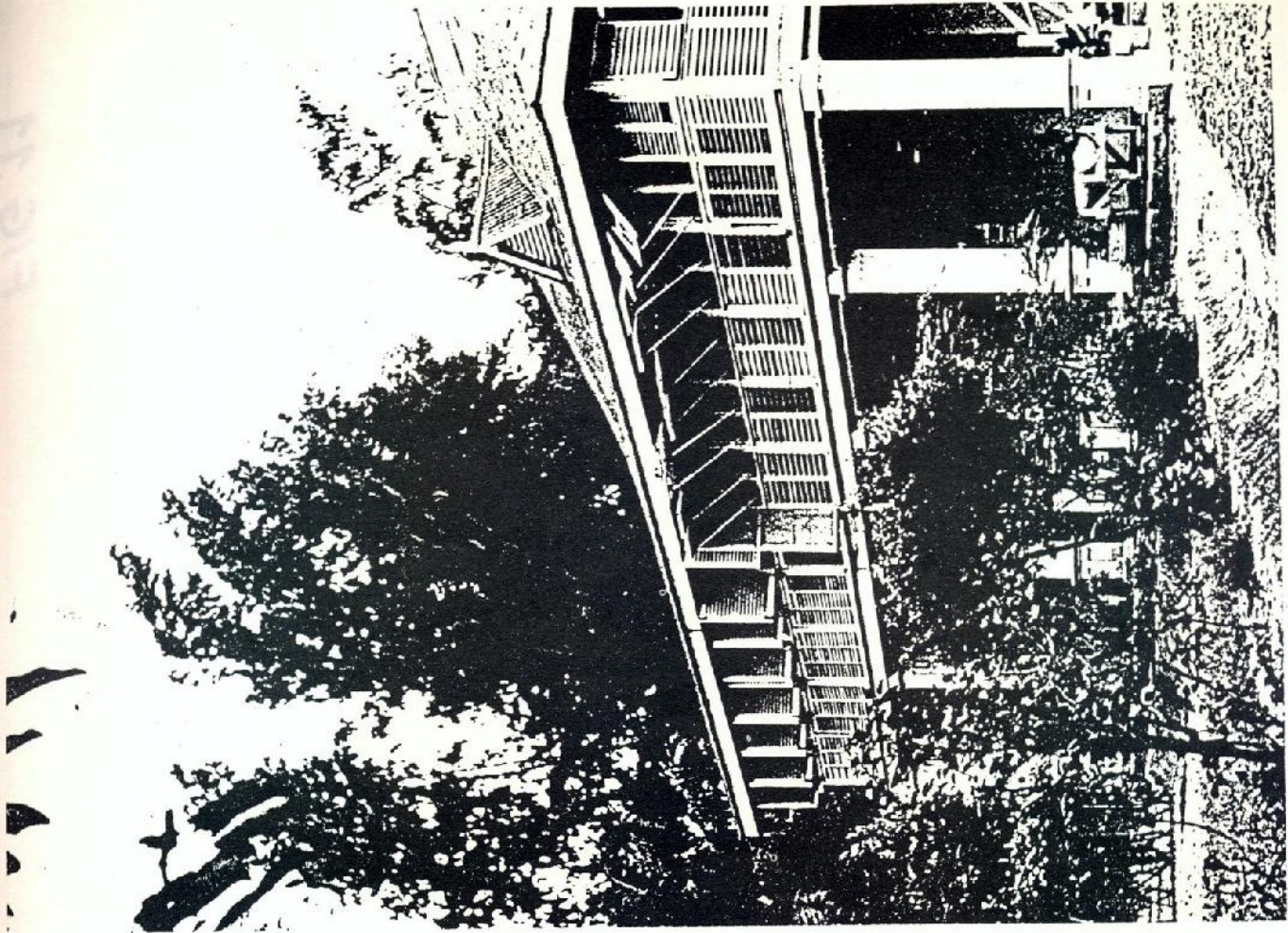
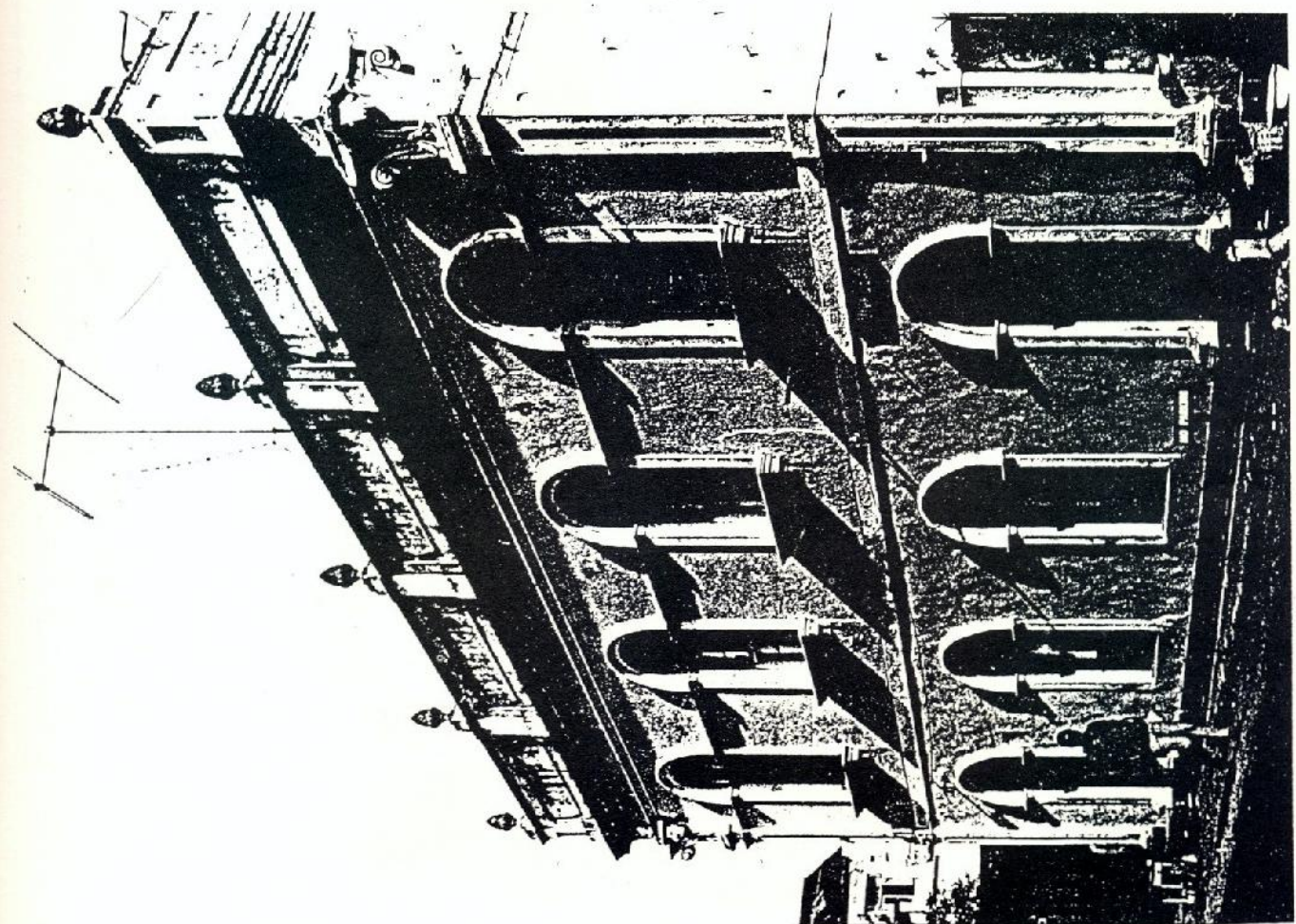
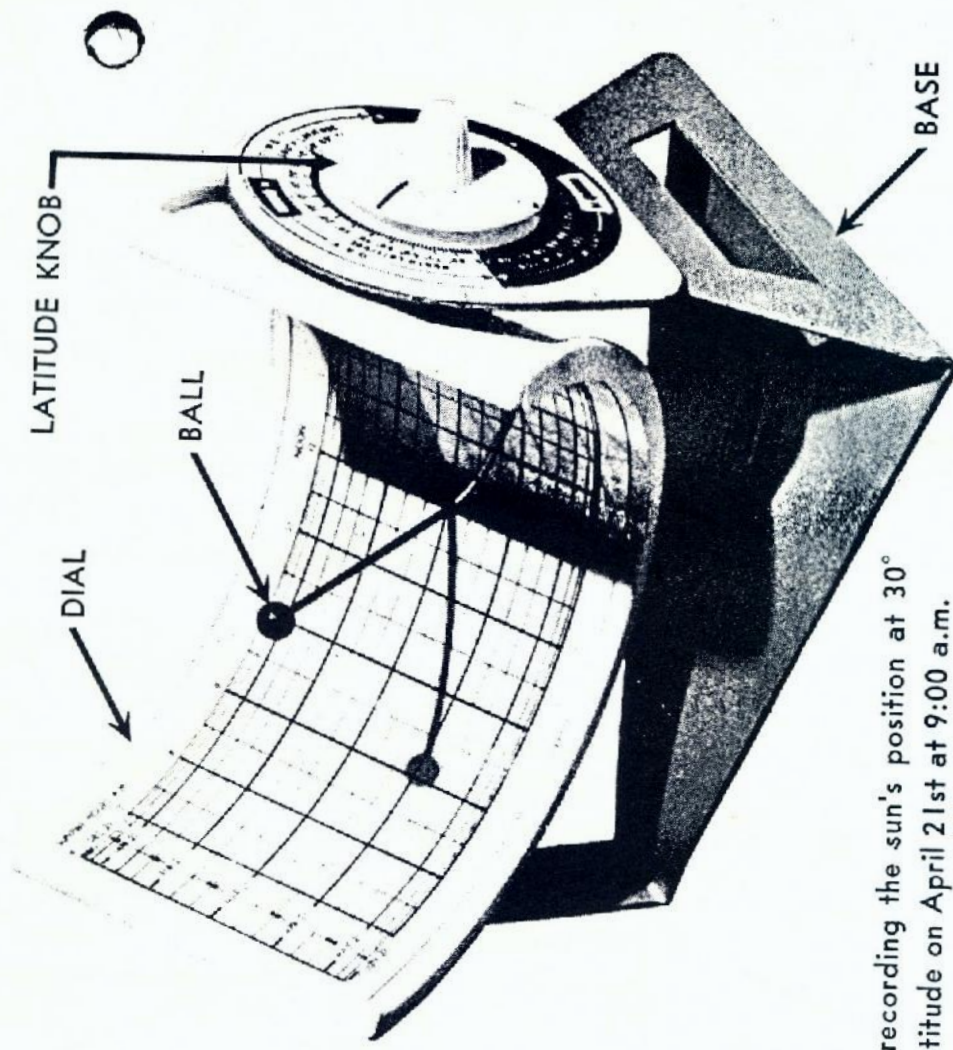


FIG 10

'COLONIAL'



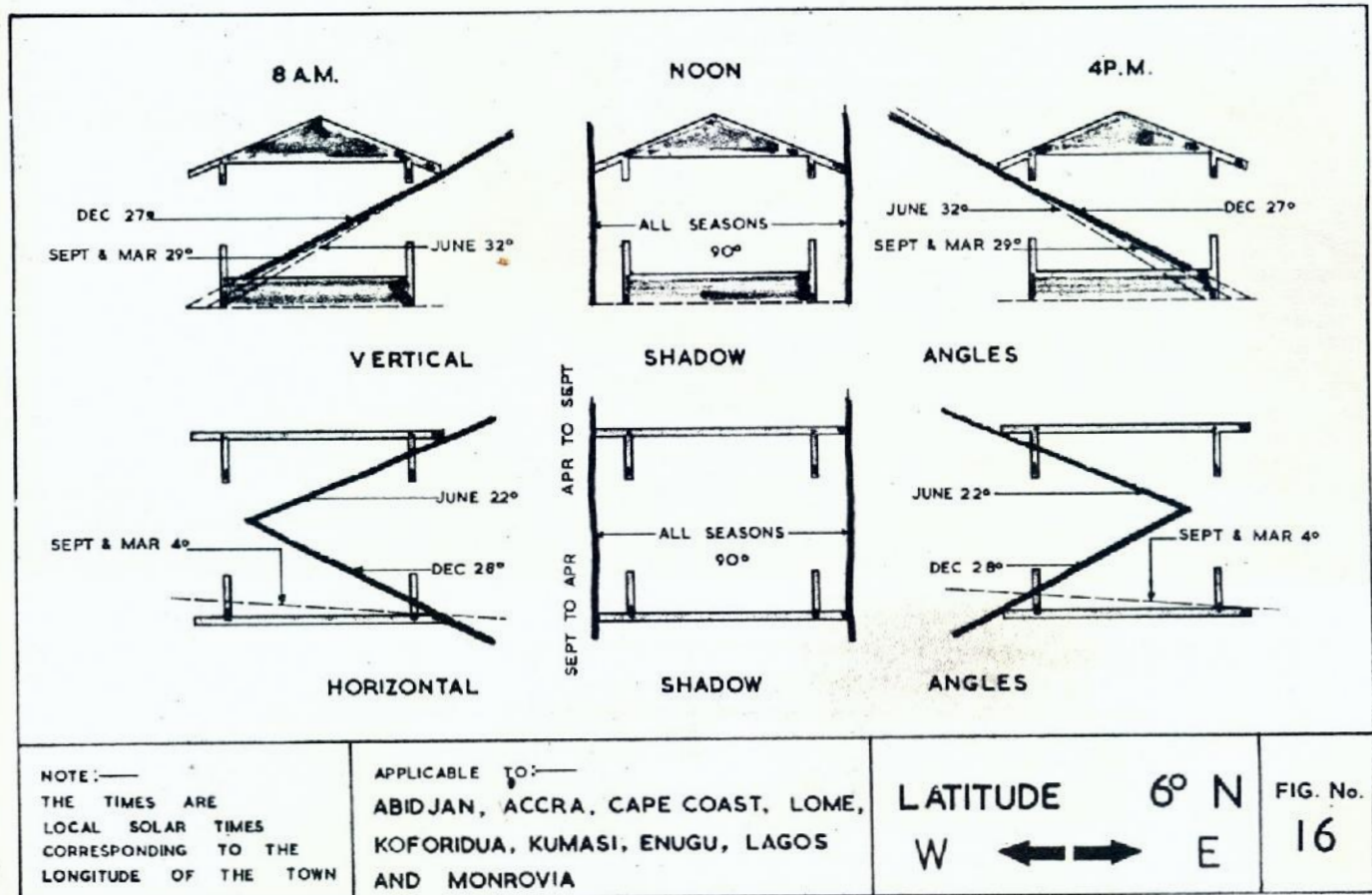
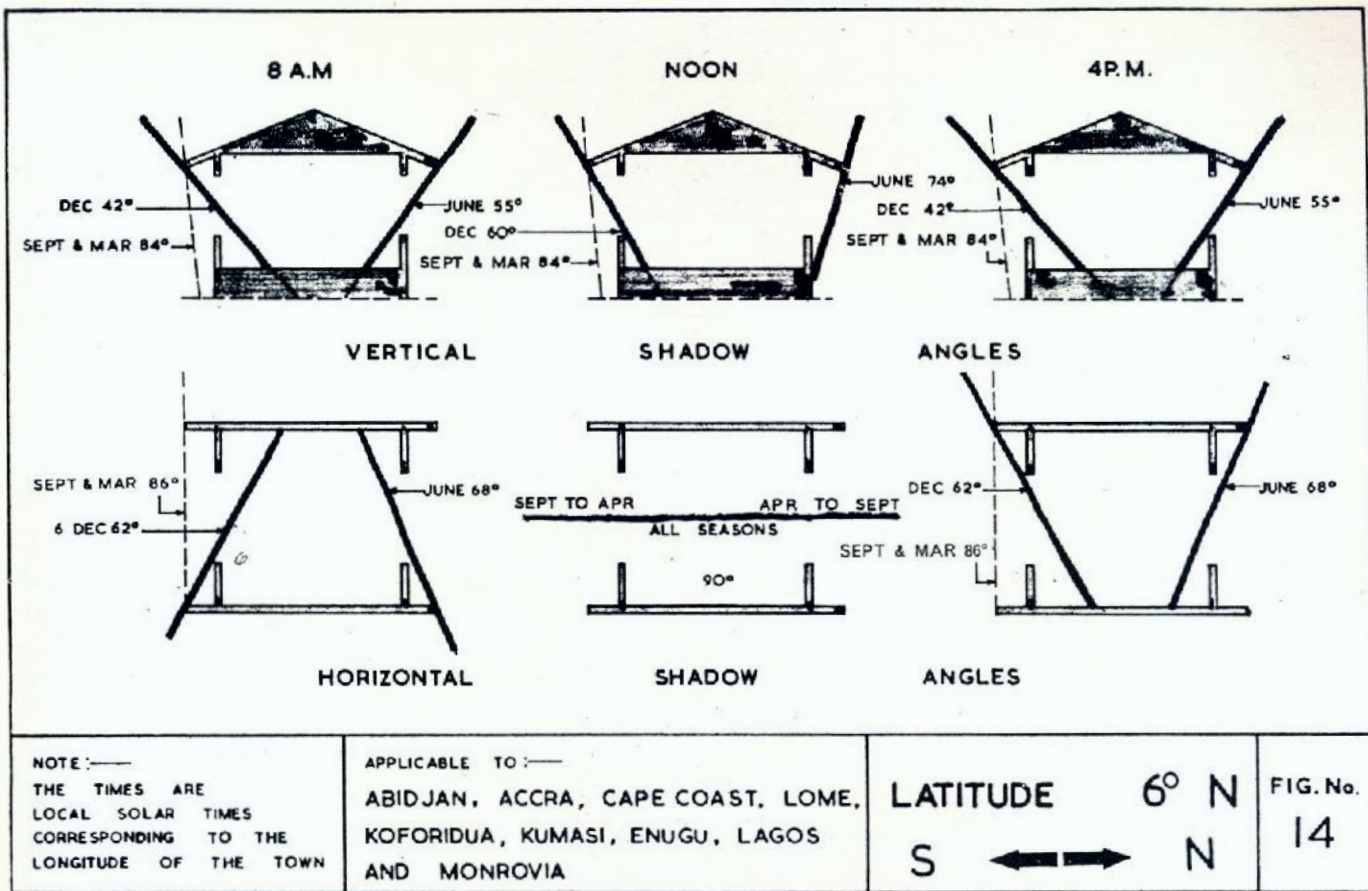
'BRAZILIAN'



Shade-dial recording the sun's position at 30°
 North Latitude on April 21st at 9:00 a.m.

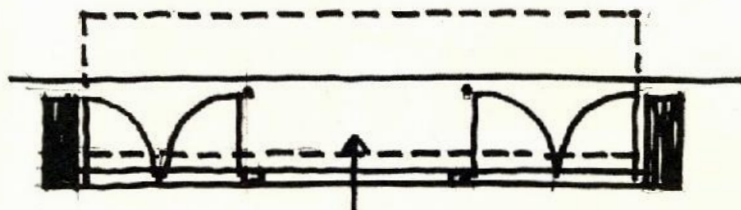
2

SHADE DIAL, OLGAYAY



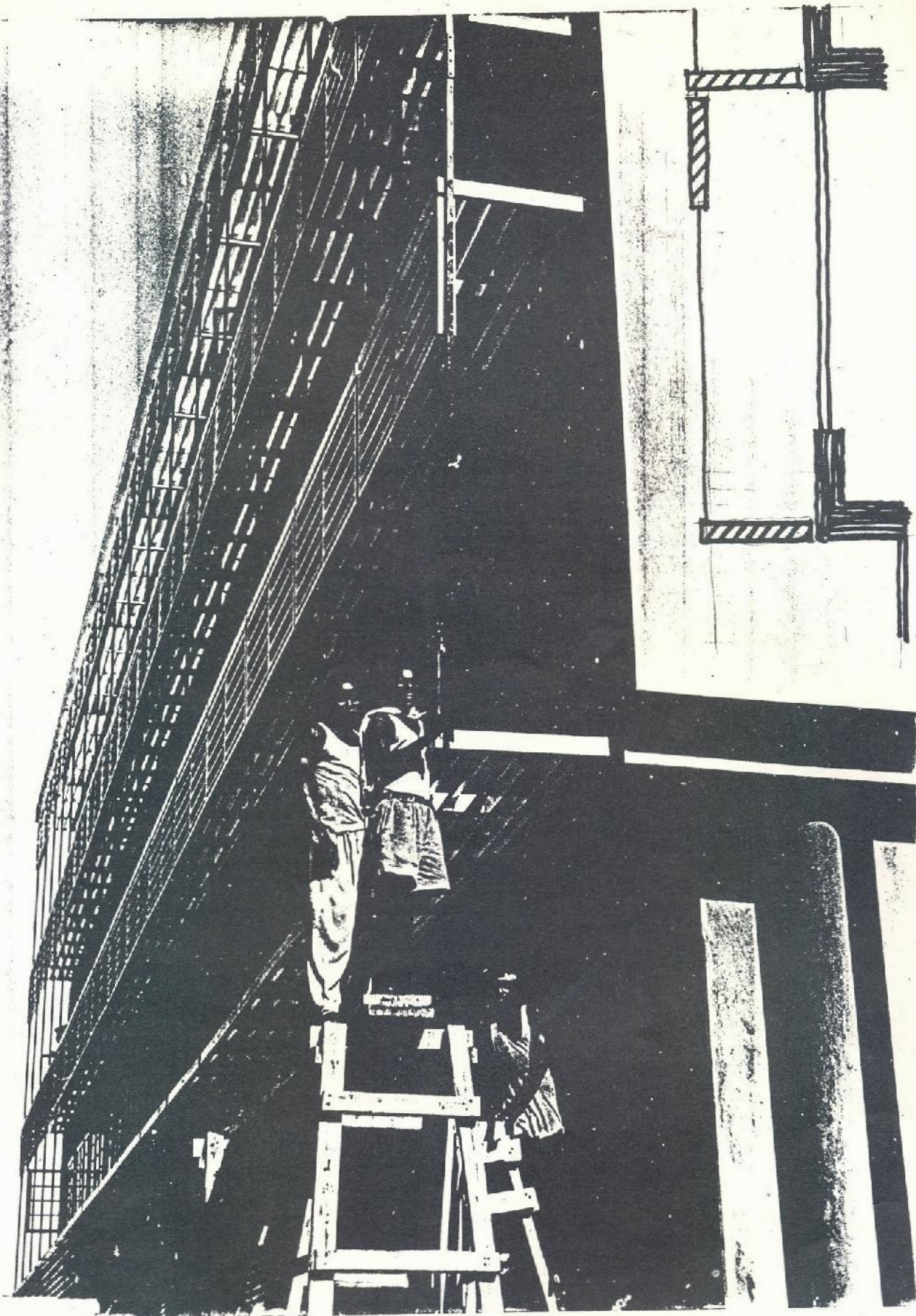
WABRI SHADOW ANGLE DIAGRAMS

FIG 12



SUNBREAKER SYSTEM, IBADAN J GODWIN 1955

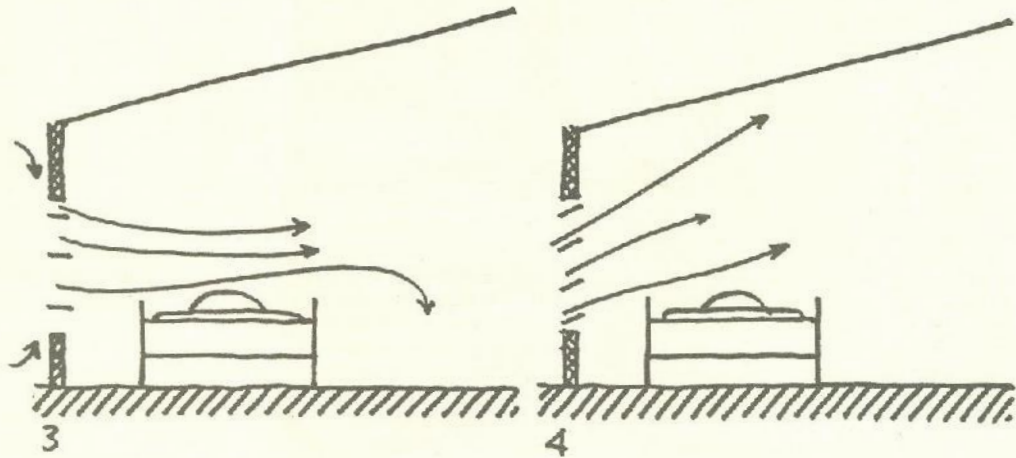
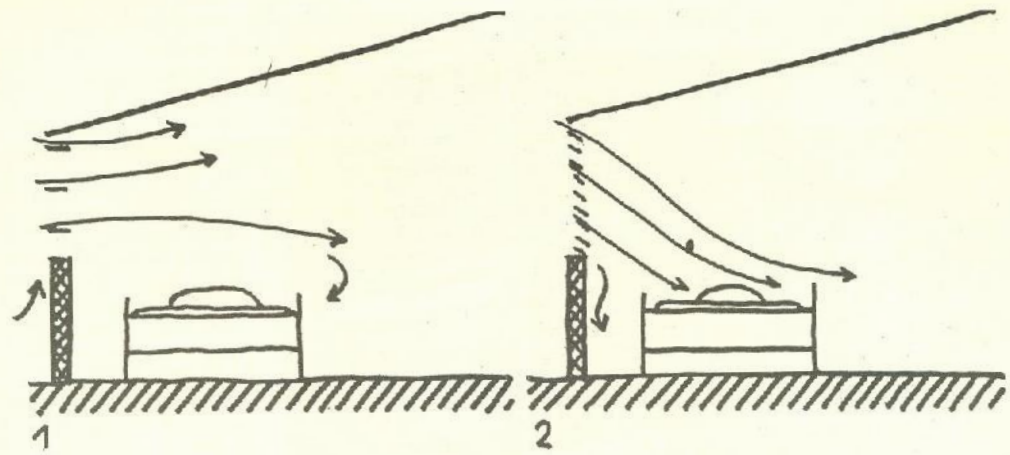
FIG 13



SUNBREAKER SYSTEM, LAGOS

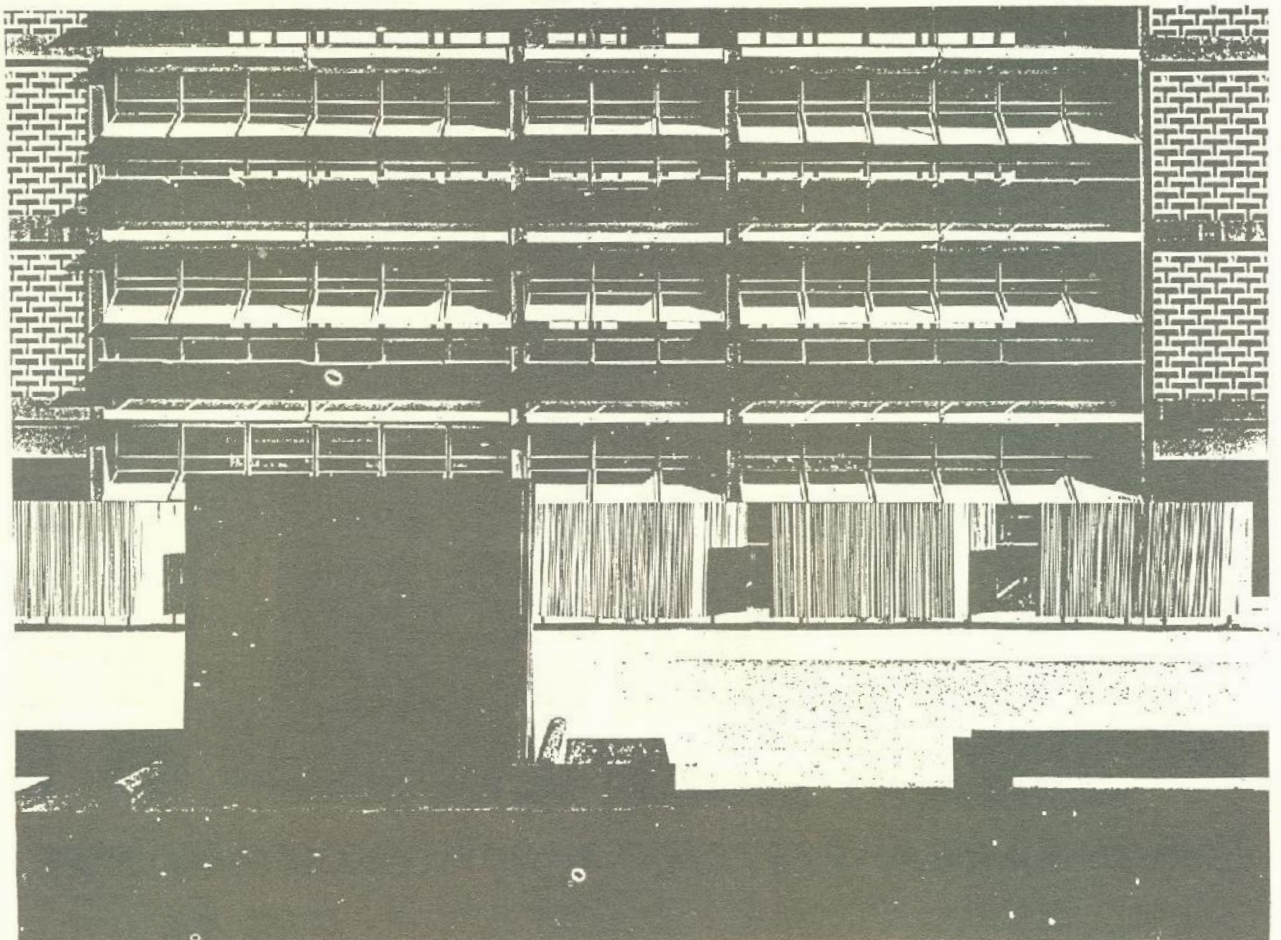
J.GODWIN 1954

FIG 14

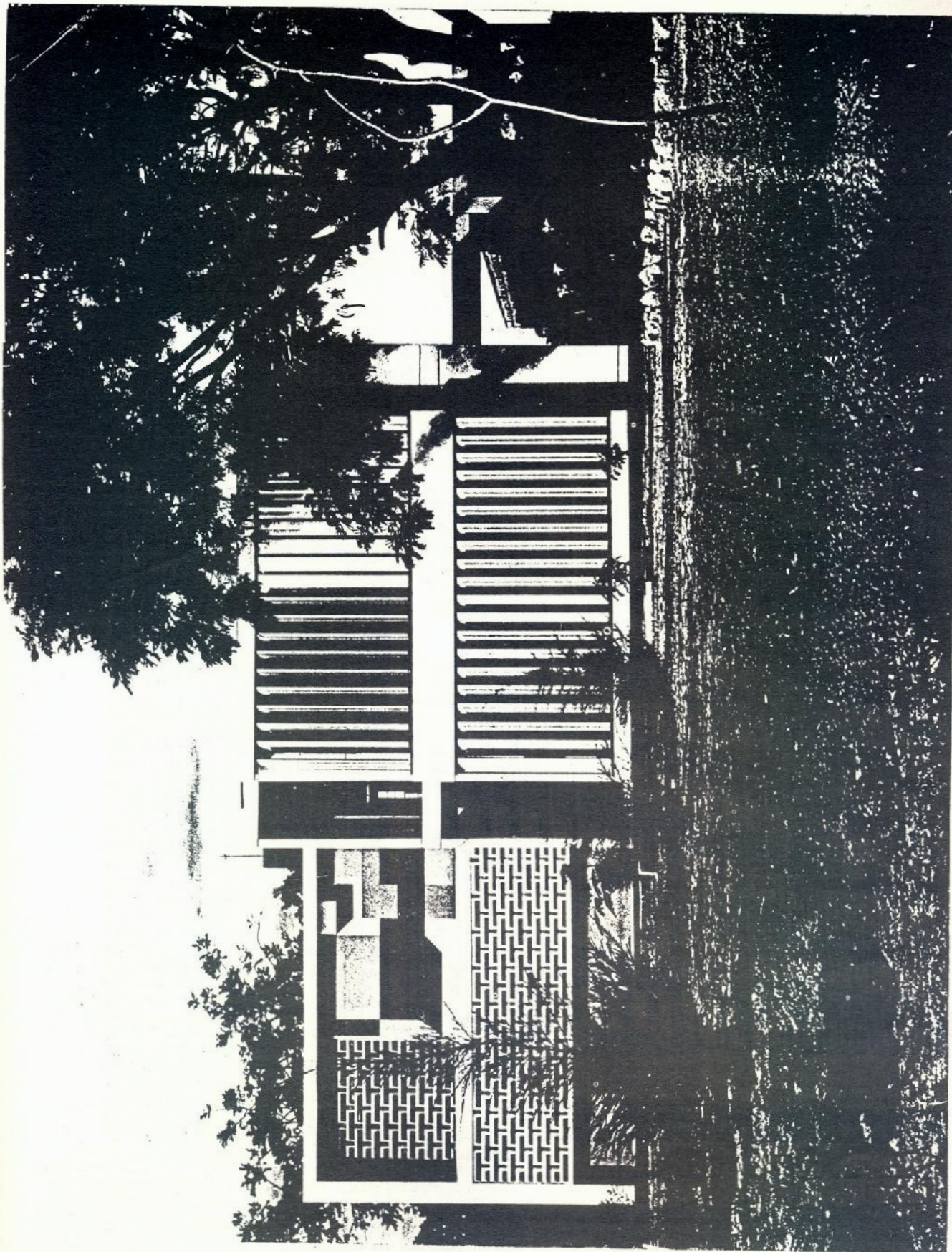


TEXAS ENGINEERING EXP. STATION

FIG 15



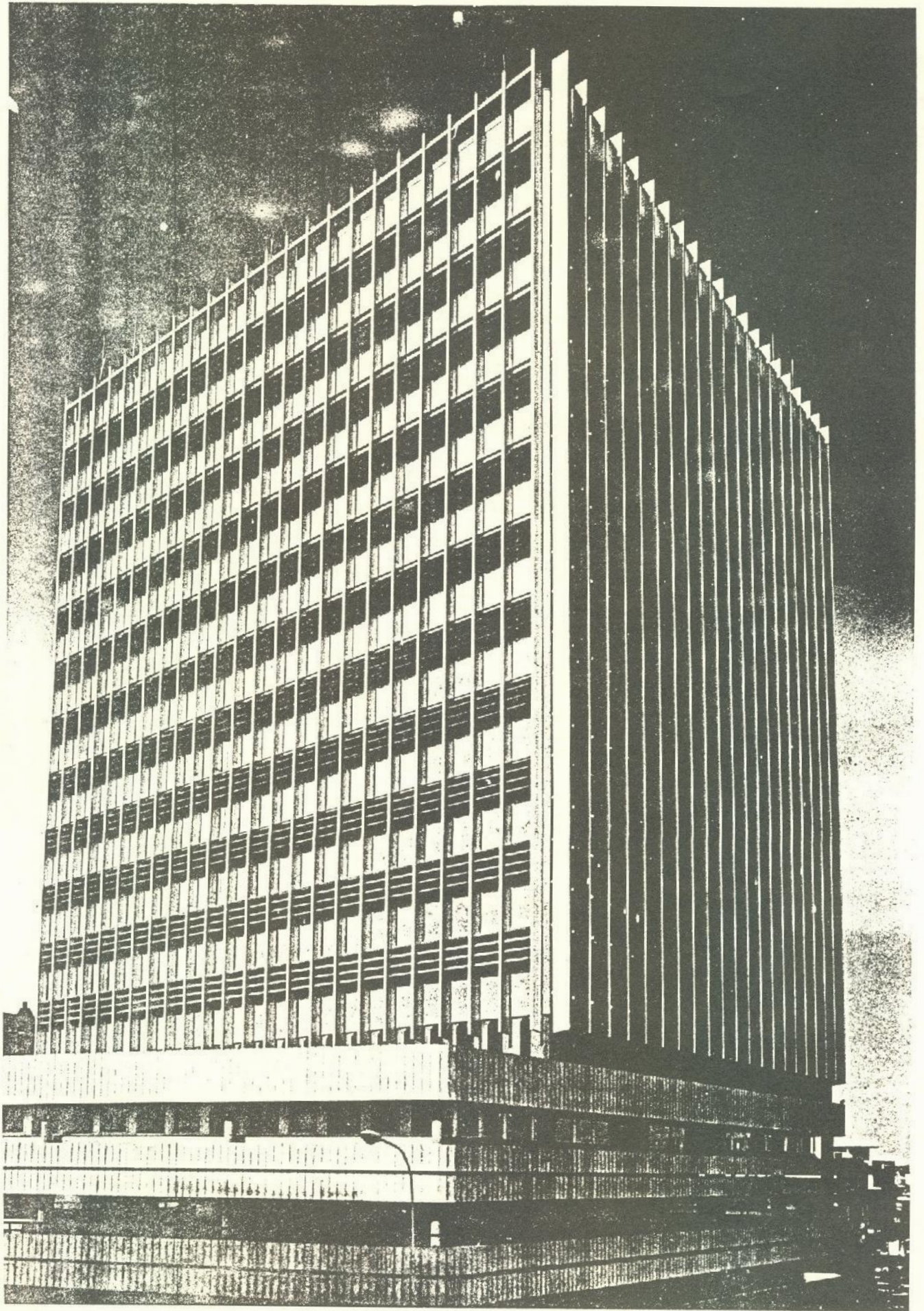
PRIMARY SCHOOL, LAGOS GODWIN + POPWOOD 1958 FIG 16



HOUSE, KANO

GODWIN + HOPWOOD 1960

FIG 17



BOOKSHOP HOUSE, LAGOS

GODWIN + HOPWOOD FIG 18

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- | | | |
|------------------|---|-------------|
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| White B | Aids to the Design of Shading devices for latitude $4^{\circ}\text{N} - 12^{\circ}\text{N}$
West African Building Research Institute
Accra (Note 6) | 1962 |
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(unpublished paper) | 1972 |
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| Godwin & Hopwood | Design for sunbreaker system for Bookshop House, Lagos. | 1977 |

THE PSYCHOLOGICAL IMPLICATIONS OF SOME STRUCTURAL SOLAR DEVICES

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ABSTRACT :

This study examined the aesthetic response of some architects to some conventional sunshading devices; Eggcrate, Vertical, Horizontal and Screenwall. The aim was to determine whether each of the devices exerted a distinguishable and distinct aesthetic effect and the rank order of the 4 devices in terms of their aesthetic appeal. Furthermore, the study sought from the architects the order of priority of the 3 factors; Cost, Aesthetics and Function in their consideration of the design and choice of sunshading devices. The subjects were 24 graduate students in the final year of their Masters degree programme in architecture and the stimulus-conditions were 4 models of the same domestic building each treated with one of the 4 shading devices. The results indicated that the 4 shading devices have significantly distinct aesthetic effects. The architects also considered Aesthetics and function equally in their consideration of the shading devices. The implications of the results for design, Evaluation studies and the current social climate of architecture in Nigeria are discussed.

INTRODUCTION

It is observed that architects are ultimately concerned with form and meaning. The manipulation of meaning in its widest sense through the resolution of form is a primary aim in architecture. While function, including the creation of conducive internal ambience is important, criticism in architecture has always relied on the view that architecture involves sign systems and abstract systems of aesthetic representation. Bonta (1979) has argued convincingly that underlying all architectural movements and criticisms are interpretations of architecture as expressive systems. Thus it is important to examine peoples emotional responses to visually significant structural solutions to practical problems of building designs. In particular it seems worthwhile to examine architects own responses to some conventional structural solutions to building design. In this study one aspect of climatic design, sunshading devices, and their impact on the meaning of the architectural composition was the subject of study. The aim was to relate some physical qualities of the architectural ensemble to its qualitative dimensions. In this case the aesthetic

value of some conventional shading devices were examined in the context of domestic architecture to find out whether they had significantly different aesthetic values for the architects. The underlying rationale was simply that if architects are concerned with aesthetics and are more likely to resolve the "conflict" between utilitarian function and meaning in favour of meaning, then it is useful to examine the experiential values of practical solutions to the problems of building design. Furthermore, if evaluation studies are to become more useful to designers then the approach must be inclusive such that a wider definition of function must include the meaning-value component of the object of study.

The aesthetic dimension has been chosen for some good reasons. It has been suggested that the meaning component in design lumes large in the architect's mind. Studies of meaning in architecture have also revealed that the "aesthetic-pleasantness" component of meaning is the most significant component (Heshberger 1970). It would also appear from existing studies that the aesthetic component of the building is most easily affected by changes in the physical details of the building composition.

The conventional shading devices to which architects responded in aesthetic terms were, the "eggcrate", "vertical", "horizontal" and the screen wall". Even though several permutations of shading devices may be arrived at, these 4 devices particularly the eggcrate, vertical and horizontal, constitute the basic forms of shading devices. (Olgyay & Olgyay 1957, Koenigsberger et al, 1973). The screen wall on the other hand has become particularly attractive because it can serve the dual function of shading and boundary definition.

METHODOLOGY

A simple experiment was conducted to determine the aesthetic ratings and ranking of the four types of sunshading devices, eggcrate, vertical, horizontal, and screenwall. The stimulus-conditions were 4 models of a domestic building each treated with one of the different types of sunshading devices. The models thus were similar and only differed in the types of sunshading devices used on the elevations. (See figures 1,2,3 and 4).

Figure 1
The Eggcrate Shading Device. (EC)

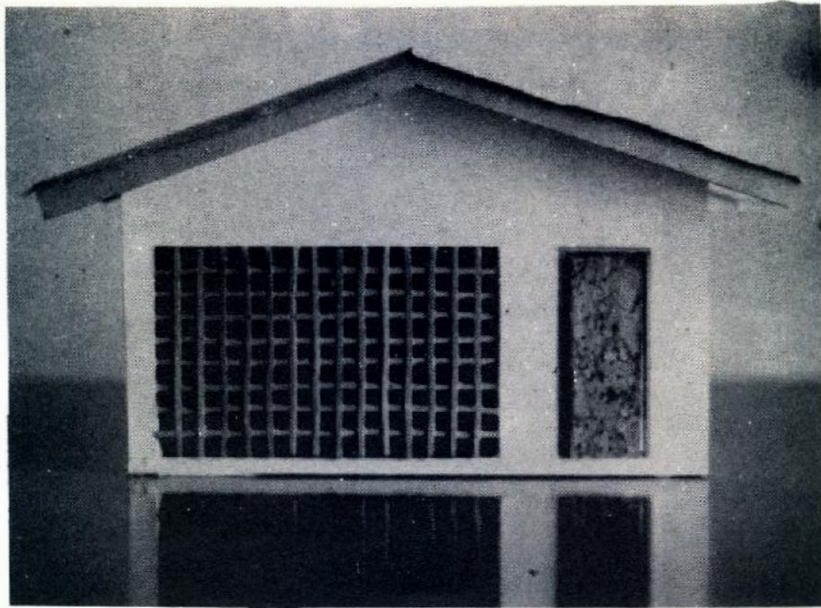


Figure 2
The Vertical Shading Device (VR)

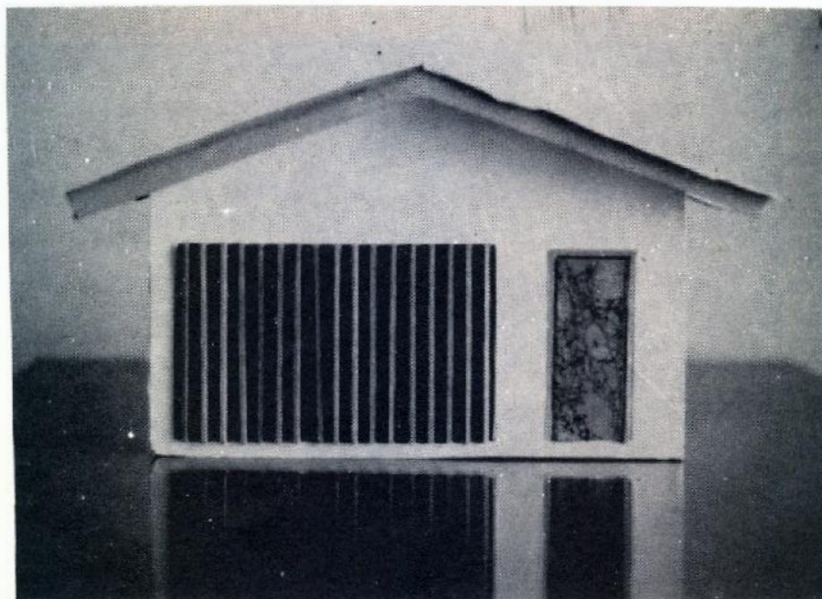


Figure 3
The Horizontal Shading Device (HT)

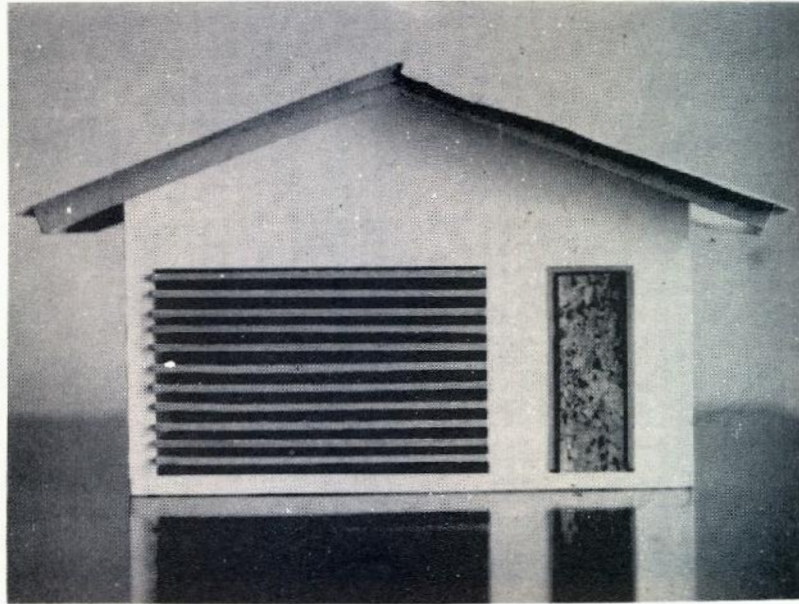
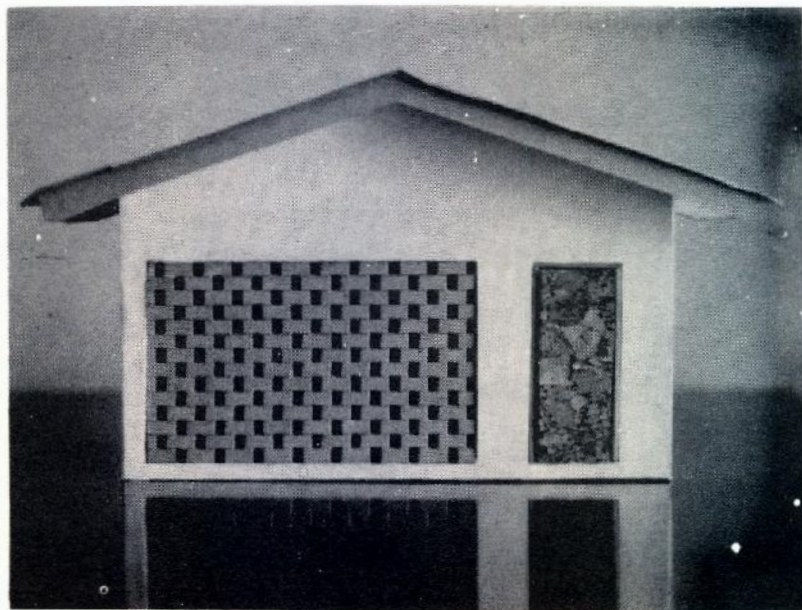


Figure 4
The Screenwall Shading Device (SC)



The use of models to represent the real situation in studies such as this has been shown to give similar results to the real situations. Lau (1970), Wools and Canter (1970).

Subjects:

The subjects were 24 M.Sc. students in the Department of Architecture at the Obafemi Awolowo University. They were final year students who were in the 7th year of their architectural programme and were thought to adequately represent architects. The 24 subjects comprised 4 females and 20 males and their average age was 25.1 years.

Measuring Instrument

The measuring instrument was a 26-item-adjectival scale developed by Alp (1983). Each adjectival scale has weighting from 1 to 7, so that the maximum total score for each elevation is 182 and the minimum 7. The assumption made was that Alp's findings that the instrument has "reliability", "validity" and "comparability" were reliable. However the test was conducted one week later and the results supported the reliability of the measuring instrument.

In addition to the adjectival scale 2 other tasks were contained in the Test Instrument. One asked the subject to rank order the 4 domestic buildings in order of aesthetic preference and the other asked the subject to rank in order of priority how he considered "Aesthetics", "Cost" and "Function" in the choice and design of sunshading devices. The rank order of the 4 buildings was intended to check the consistency of the subject in the use of the rating scales. The rank order if compared with the rank order obtained from the total scores on the rating scale could show this consistency. The second task was intended to obtain the priority of architects in their choice and design of sunshading devices and to confirm or refute the hunch that aesthetics is uppermost in the minds of architects.

Procedure

The 24 subjects who volunteered to participate in an experiment on aesthetics were taken to a seminar room. The subjects were fully briefed on the purpose of the experiment and were allowed to ask questions if anything was not clear to them. The purpose of briefing was to disabuse the subjects minds of any attempts to react to an imaginary aim. They were clearly informed that the experiment was not a test of their ability and that they should be as free as possible in responding to the test.

Initially all the 4 domestic buildings were kept out of view, during the briefing. One building was subsequently presented to the subjects at a time. After all the subjects had finished rating each building it was

taken away and another one was presented until all the 4 buildings had been rated. The order of presentation was "eggcrate" (EC), "vertical" (VR), "Horizontal" (HT) and "Screenwall" (SC). At the end of this procedure all the four buildings were then presented to the subjects and they were asked to rank them in order of aesthetic preference. The task to rank order the factors; Aesthetics, function and cost in the design and choice of sunshading devices was the last item on the test instrument.

RESULTS

The results of the rating scale were computed for each subject for each condition-effect. The sum of the scores on the 26 item scale was computed for each condition-effect and subsequently each subjects ranking of the 4 condition-effects was computed. The ranking based on these scores was then compared with the ranking of the condition-effects originally done by each subject. In fifty percent of the cases, (i.e. for 12 subjects) there was perfect correlation while for the remaining 12 subjects the rankings did not correlate with the scores on the condition-effects.

Table 1 shows the scores of the 4 condition-effects for the 24 subjects. The table also indicates the mean value for each effect. The rank order derived from these scores shows that the "screen" effect (SC) is the most preferred. This is followed by the horizontal effect (HT) and the "Vertical" effect (VT) while the least score is for the "eggcrate" (EC) effect. This ranking was compared with the sum of the ordinary rankings of the condition-effects by all the subjects. This was done by allocating a score of 1 each time an effect was ranked first, a score of 2 when it was ranked second and a score of 3 when ranked last. The effect with the least score was then ranked first and so on for the subjects taken as a group. There was perfect correlation between the two rankings for the whole group taken together, in the order SC, HR, VR and EC.

A profile (figure 5) of the scores of each of SC, HR, VR and EC was prepared by using the mean score for the 24 subjects in each of the 26 items in the adjectival scale. Figure 5 confirms the rank order obtained from the total scores and indicates the consistency with which each shading device was judged by the group.

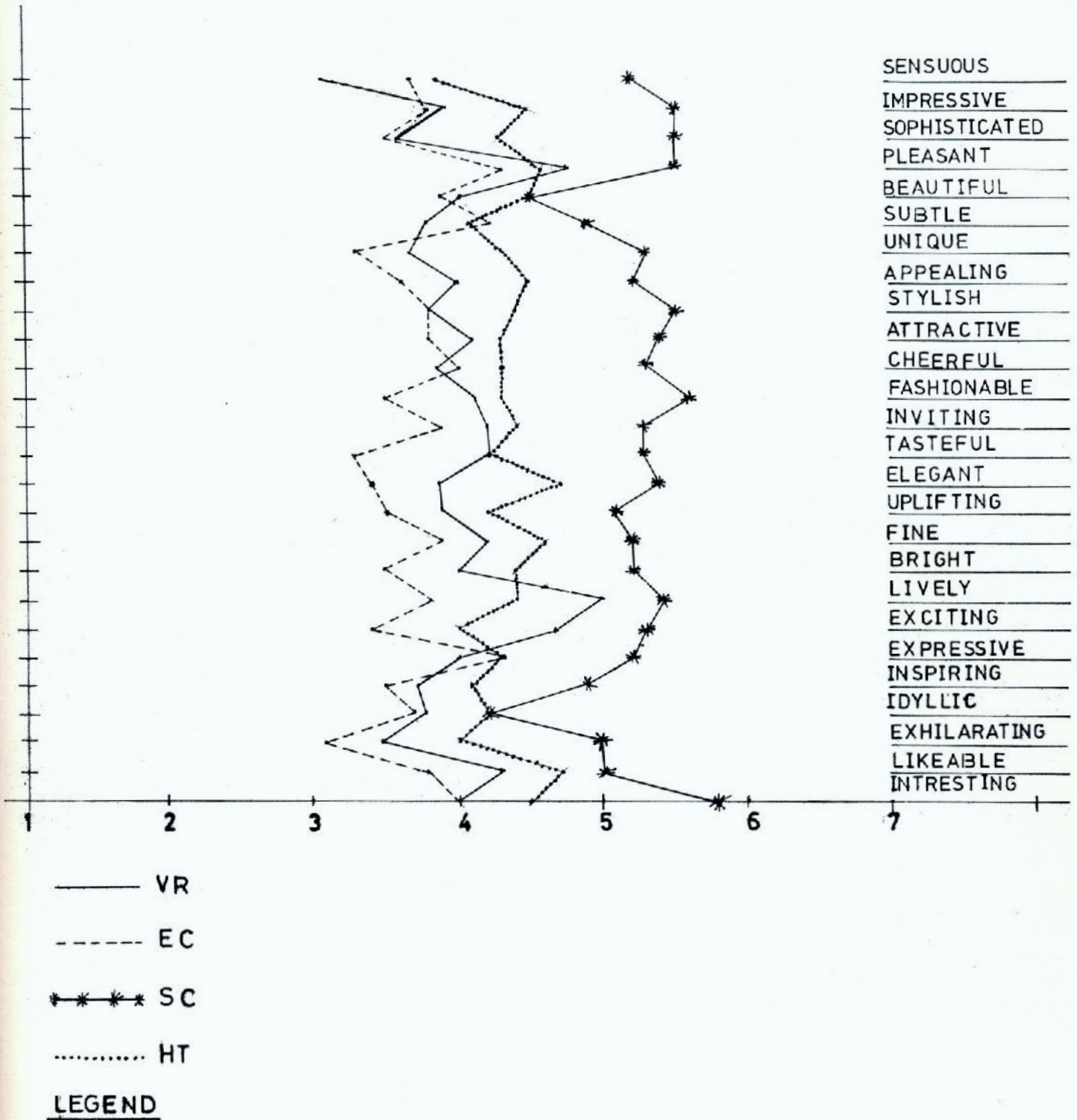
The architects finally ranked in order of priority, the factors, Aesthetics, Function and Cost, in relation to the design and choice of shading devices. The data was again treated the same way as was the rank order of the condition-effects discussed previously. The results indicate that as a group the architects equally ranked Aesthetics and Function and cost was placed last in the order of priority.

TABLE 1
Total Score for Each Condition-Effect for individual subjects

Subject	<u>CONDITION—EFFECT</u>			
	EC	UR	HT	SC
1	94	91	126	145
2	102	108	117	149
3.	97	101	122	126
4.	104	102	91	143
5.	101	117	86	139
6.	92	81	120	139
7.	83	78	83	95
8.	100	85	140	103
9.	102	125	145	162
10	103	100	91	148
11	95	117	90	124
12	86	106	136	113
13	63	68	120	132
14	125	119	120	139
15	88	98	117	150
16	98	96	99	160
17	80	101	96	128
18	91	144	153	164
19	128	134	88	155
20	103	85	122	158
21	110	99	80	153
22	90	122	119	115
23	111	94	89	136
24	80	106	47	122
MEAN	96.92	103.21	112.38	137.42

Figure V

Profile drawn from the mean Scores on the 26 item adjectival scale



The "t" - test was performed on the means of the different condition-effects taken in pairs. The intention was to determine whether the differences between the means of each pair were significant. Table II clearly shows that in all the six cases the differences were highly significant.

TABLE 2

Significance of the Differences Between Means of the Condition - Effects

Condition-Effect	Differences of means	"t"
UR - EC	6.29	< 0.01 (significant)
HT - EC	15.46	< 0.01 (significant)
SC - EC	40.50	< 0.01 (significant)
HT - VR	9.17	< 0.01 (significant)
SC - VR	34.21	< 0.01 (significant)
SC - HT	25.04	< 0.01 (significant)

DISCUSSION

The results show some inconsistency in the architect's judgements, with half of the subjects' rankings not perfectly correlated with the rankings based on the scores. This result is similar to Alp (1983), in which he compared Architects' and Chemists' judgements and found that the architects were less consistent. It would appear that Alp's suggestion that architects are inconsistent in their aesthetic judgements because they are informed by highly contradictory values is valid. However, there was perfect correlation between the ordinary rankings and the rankings based on the scores of the sunshading devices when the architects were taken as a group. As a group therefore there was consistency.

The rankings indicated that the shading devices were preferred in aesthetic terms in the order, SC, HR, VT and EC. The most preferred is the screenwall followed by the horizontal device and the vertical device while the least preferred was the eggcrate device. In aesthetic terms therefore the architects eminently think that the screenwall is the best in the particular context in which it was used. Since the differences between the mean scores were also found significant, it shows very clearly that in the domestic context examined, these sunshading devices had significantly different aesthetic appeals. This means that for the architects their choice of shading device, if aesthetics is of priority, will be highly controlled by its aesthetic appeal. This position was confirmed by the result which indicated that aesthetics and function are judged equal in priority in the choice of sunshading devices. Cost for these architects was of very little importance in comparison with aesthetics and function.

SUMMARY AND CONCLUSION

This study has examined one aspect of meaning, aesthetics, in the context of sunshading devices used in a particular domestic architectural design. It has examined architects aesthetic responses to the conventional shading devices in the particular domestic architectural context. 24 subjects, architects, responded to 4 similar domestic buildings treated each with one of the four conventional shading devices, "Screwwall", "horizontal", "vertical" and eggcrate; The measuring instrument was a 26 - item adjectival scale weighted from 1 to 7. The study also examined the priorities of architects in the design and choice of sunshading devices. The study was conducted through a simple experiment.

The results indicated that, for architects, these sunshading devices have significantly different aesthetic impacts on the domestic building design used. The implication is simply that in designing shading devices the aesthetic or more generally the meaning - value component must be a part of the consideration. On the other hand in studies of building performance or indeed in assessing the thermal performance of buildings, for example shading devices, if they have such strong aesthetic implication must be seen to perform much more than their utilitarian role and must be judged in an all inclusive manner.

Finally it is pertinent to mention a value of studies such as this, particularly within the current social climate of architecture in Nigeria. The protagonists of modern architecture have relied almost exclusively on the scientific approach of climatic design in their attempts to evolve an appropriate architecture for Nigeria. (see for example Fry, 1958). While such an approach may be valid, it remains only a small or indeed marginal aspect of architectural design. The way forward is perhaps to examine the wider meaning-value implication of these practical solutions in order to manipulate form in a manner central to the architectural tradition. This study represents part of such an attempt.

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DESIGN DATA FOR NATURAL LIGHTING OF BUILDINGS IN THE WARM HUMID ZONE OF NIGERIA

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ABSTRACT

Sky luminance, diffuse and total illuminance measurements on horizontal and vertical surfaces were taken with sensors at different solar altitudes and at hourly intervals. The data base from which results were derived exceeds 30,000 measurements taken from 0700 – 1700 hrs.

A design illuminance of 10 klx (A value exceeded in over 80 percent of the time of daylight hours) is recommended. This corresponds to solar altitude of 20°. The average design sky Luminance of 10,000 FL is recommended. More reliable daylight availability data will be obtained from collection and evaluation of daylight measurements over a period of about five years.

INTRODUCTION:

In the warm humid zone, adoption of the C.I.E. Standard Overcast Sky for daylighting design is grossly misleading, so also, is the C.I.E. Clear Sky. Design techniques based on data collected from daylight measurements in the temperate climates are used in Nigeria. A considerable amount of daylight is available outdoors for most of the daylight hours. This can be used to provide satisfactory illumination in buildings. In view of the rising cost and increase in demand for electricity, artificial lighting during daylight should be minimal as far as possible – especially in those buildings which are meant for work during the hours of daylight.

Since daylight is an economic means of lighting a building, there is a need for optimal use of this natural lighting. Presently, the size and position of windows, seem to have been determined more by the skill and experience of the designer. More consideration is given to the outward appearance of the building than to the effects of the design options on the internal environment. The amount of daylight available for use is continually variable. The daily and seasonal motions of the sun with respect to a particular building surface, produce a regular and predictable pattern of gradual variation in the amount and direction of daylight available. Super-imposed, however, is another variable pattern caused by the changes of the weather like the degree of cloudiness.

For effective design of buildings using natural lighting, daylight availability data is essential. These data, not

only provide the basis for specifying illuminance on a given surface at a specific time, day and location, they also describe:

- (1) Maximum and minimum conditions on vertical and horizontal surfaces;
- (2) Clear, partly clear and overcast illuminance values;
- (3) Average illuminance conditions (hourly data for months or season);
- (4) Probability of a given illuminance values and the cumulative probability data that a given value will be exceeded;
- (5) Correlation of illuminance to solar radiation Ref. (1). However, each type of data provides specific useful information to help solve a particular design problem. In many cases, approximate data will suffice if it is derived from a broad data base. Results of daylight availability studies in some parts of the world have been reported (2–5). Data for Nigeria are not available.

For effective design of buildings for natural lighting, daylight availability data are necessary. From these data, criteria and guidelines for design are obtained. Building designers can, therefore, integrate natural lighting with artificial lighting for effective performance of the tasks for which a building is built. Apart from the satisfactory level of general illuminance which is obtained from such an integrated lighting design, the reduced energy consumption for lighting is significant. However, a lack of proper integration of daylighting with artificial lighting could create problems, such as glare. Hence, it is necessary to have such an integration on a scientific and rational basis. Nigerian Building and Road Research Institute has undertaken to provide these data for designers. Preliminary measurements have been made in Victoria Island for 1 year. These measurements include:

- (a) Sky Luminance distribution at various times;
- (b) Illuminance on horizontal and vertical elevations.

From these, recommendations are made with respect to design conditions for the Nigerian Climate. Design criteria are better made from measurements taken over a period of 3–5 years for greater reliability. However, our preliminary results are good basis for further work in future.

INSTRUMENTATION AND DATA COLLECTION:

Victoria Island is situated on Lat. 6 27 N and Long. 3° 25 E. Measurements were made on top of a 15 – storey building having an unobstructed view of the sky. The station is located near the sea. Simultaneously with the measurements of the sky luminance distribution, measurements of total and diffuse illuminances on horizontal plane and vertical surfaces in the four major cardinal orientations were obtained using colour and cosine corrected photometer – Hagner S2 and Luxmeter DA Megatron. Hagner S2 photometer was mounted on a specially designed tripod which can be rotated for altitudinal, azimuthal and zenithal readings. The Luxmeter, DA Megatron, was mounted on a square box, coated matt black, which can be rotated to face the major cardinal orientations. Diffuse and total illuminances were measured – using a shading disc for diffuse measurements. The vertical illuminance sensor measured total values.

DATA EVALUATION AND RESULTS:

A total of about 30,000 readings of luminance and illuminance measurements were obtained. The Hagner S2 meter has a maximum range of 99,000 Lux (99 klx) which is exceeded sometimes between 1200 hrs and 1400 hrs. The percentage of readings off the scale to the measurable at this period in March is about 22.5 per cent. This is quite high in comparison with the total number of illuminance measurements. These values are not relevant in the formulation of daylight design criteria, hence, they were not taken into consideration in our analysis. The hourly values of total and diffuse illuminances are shown below in figures and tables,

1. PARTLY CLEAR SKY ILLUMINANCES:

Much of the analysis concentrated on partly clear sky conditions as this sky condition is prevalent in this region (6). Fig. 1 shows the variation of total and diffuse illuminances with solar altitude for March/April. The maximum average total illuminance on an unobstructed horizontal surface for the period of measurement is 73.4 klx. The maximum average diffuse illuminance is 37.8 klx. Instantaneous values are higher and sometimes lower than these. The method of making the distinction in cloud cover was

visual (with a definition of clear sky as no cloud present, and cloudy for the case where no blue portion of the sky is visible.) Figures 2–5 show the variation of total and diffuse illuminances with solar altitude for months of May, July, August and November respectively. Average illuminance values are higher in the months of March/April and May than other months – especially the total and diffuse illuminances for July and August are comparably lower. These show that illuminance values are higher in the dry season.

OVERCAST SKY CONDITION:

Attempts were made to plot average overcast sky illuminance as a function of solar altitude in the months of July and August when overcast sky was available. Figures 6 and 7 show both total and diffuse illuminance values for the months of July and August. These values are higher in August. However, for these months, measurements for long periods of the day could not be taken as there was usually rain within two hours of full overcast.

DATA ANALYSIS FOR ALL SKY CONDITIONS:

Analysis of all the data collected was done for illuminances on horizontal and vertical surfaces for months of April, July, August and November. The percentage of time incident total illuminance exceeded a specific value is given in Tables 1–4 respectively.

2. LUMINANCE:

Average sky luminance for the months of March/April, May, July, August, and November are given in Tables 5–9 respectively. Variations of luminance values (for partly clear sky condition) with azimuth for some solar altitudes at certain observation altitudes are given for a typical day in July (23rd) in figures 8–9. Important azimuthal angles are 0°, 90°, 180° and 270° which are North, East, South and West respectively. There is little or no change in average sky luminance from the azimuth angle of 150° to 330°. But in the vicinity of the sun, average luminance values vary with degree and distribution of cloud cover, and can be very high at 90° azimuth angle.

CONCLUSION:

1. Design illuminance value of 10 KLX on a horizontal plane with a corresponding solar altitude of 20° is recommended.
 2. The high variability of average luminance of partly clear sky shows that neither the C.I.E. standard Overcast nor C.I.E. Clear Sky is appropriate in this zone.
 3. Areas (60° – 120°) within azimuth of sun's track have higher luminance values than the average. At other azimuthal positions the luminance values are fairly constant
- *Azimuth 0° (degree) was taken from North.
4. There is apparent dependence of sky brightness on position of sun in the sky than on the observation altitude. In general, the brightness increases with the solar altitude.
 5. The average design luminance value of 10,000FL at observation angle of 60° is recommended.

TABLE 1:
DAYLIGHT AVAILABILITY IN VICTORIA ISLAND, LAGOS FOR HOURS
OF 0700 HRS TO 1700 HRS INCLUSIVE MONTH: APRIL, 1987.

AVERAGE INCIDENT EXTERIOR ILLUMINANCE (KLX)	PERCENTAGE OF TOTAL TIME INCIDENT ILLUM. EXCEEDED THE VALUE IN THE LEFT COLUMN.				
	NORTH VERTICAL SURFACE	EAST VERTICAL SURFACE	SOUTH VERTICAL SURFACE	WEST VERTICAL SURFACE	HORIZONTAL SURFACE
5	100	100	100	100	93
10	99	100	99	99	88
20	96	97	99	96	82
30	92	96	88	95	78
40	89	88	85	88	76
50	88	87	84	86	74
100	85	84	77	83	35
150	81	82	76	—	—
200	78	80	—	—	—
250	77	79	—	—	—
300	76	77	—	—	—

TABLE 2
DAYLIGHT AVAILABILITY IN VICTORIA ISLAND, LAGOS FOR HOURS
OF 0700 TO 1700 HOURS INCLUSIVE FOR AN AVERAGE OF 15 DAYS
MONTH: JULY, 1987

AVERAGE INCIDENT EXTERIOR ILLUMINATION (KLX)	PERCENTAGE OF TOTAL TIME INCIDENT ILLUMINATION EXCEEDED THE VALUE IN THE LEFT COLUMN				
	NORTH VERTICAL SURFACE	EAST VERTICAL SURFACE	SOUTH VERTICAL SURFACE	WEST VERTICAL SURFACE	HORIZONTAL SURFACE
5	100	100	100	100	92
10	98	96	95	96	77
15	91	82	89	79	75
20	86	70	72	65	66
30	65	31	40	54	58
40	57	29	10	23	38
50	46	23	00	17	34
100	32	19	—	12	00
150	13	16	—	08	—
200	08	14	—	01	—
250	03	02	—	00	—
300	00	00	—	—	—
350	—	—	—	—	—

TABLE 3
DAYLIGHT AVAILABILITY IN VICTORIA ISLAND, LAGOS FOR HOURS OF
0700 TO 1700 HOURS INCLUSIVE FOR AN AVERAGE OF 15 DAYS
MONTH: AUGUST, 1987

AVERAGE INCIDENT EXTERIOR ILLUMINATION (KLX)	PERCENTAGE OF TOTAL TIME INCIDENT ILLUMINATION EXCEEDED THE VALUE IN THE LEFT COLUMN				
	NORTH VERTICAL SURFACE	EAST VERTICAL SURFACE	SOURTH VERTICAL SURFACE	WEST VERTICAL SURFACE	HORIZONTAL SURFACE
5	100	100	100	100	92
10	91	94	94	89	85
15	81	94	87	83	70
20	72	87	72	72	59
30	57	60	34	42	43
40	34	47	02	17	34
50	19	34	00	09	23
100	09	28	—	06	00
150	04	21	—	06	—
200	02	19	—	06	—
250	00	11	—	04	—
300	—	04	—	00	—
350	—	—	—	—	—

TABLE 4.

DAYLIGHT AVAILABILITY VICTORIA ISLAND, LAGOS FOR HOURS OF
0700 TO 1700 HOURS INCLUSIVE FOR AN AVERAGE OF 15 DAYS
MONTH: NOVEMBER 1987.

INCIDENT EXTERIOR ILLUMINATION (KLX)	PERCENTAGE OF TOTAL TIME INCIDENT ILLUMINATION EXCEEDED THE VALUE IN THE LEFT COLUMN.				
	NORTH VERTICAL SURFACE	EAST VERTICAL SURFACE	SOUTH VERTICAL SURFACE	WEST VERTICAL SURFACE	HORIZONTAL SURFACE
5	94	97	97	100	96
10	87	85	92	89	90
15	64	65	75	86	85
20	47	50	72	64	73
30	10	36	49	49	62
40	02	23	35	32	55
50	00	10	22	29	42
100	—	04	08	22	00
150	—	01	03	05	—
200	—	00	00	04	—
250	—)	—	00	—
300	—	—	—	—	—
350	—	—	—	—	—

TABLE 5.

AVERAGE SKY LUMINANCE (X10KCD/M²)

MONTH: MARCH/APRIL 1987

SKY CONDITION: PARTLY CLEAR

SUN POSITION (SOLAR ALT.)	POINT ON SKY (OBSERVATION ALT)	AZIMUTH OF THE POINT OBSERVED											
		0	30	60	90	120	150	180	210	240	270	300	330
10	10												
	15												
	30	.22	.31	.45	.68	.45	.35	.28	.21	.18	.19	.20	.20
	45	.22	.40	.43	.53	.54	.33	.23	.21	.20	.18	.18	.20
	60	.25	.41	.41	.44	.39	.28	.23	.22	.26	.30	.21	.22
15	10												
	15		.12	.57	.94	.60	.39	.29	.39	.26	.28	.29	
	30	.30	.45	.77	1.87	.80	.48	.36	.33	.28	.26	.25	.24
	45	.28	.40	.58	.70	.62	.39	.32	.29	.23	.22	.20	.24
	60	.28	.38	.40	.43	.55	.35	.30	.26	.30	.21	.21	.21
30	10			.70	.95	.60	.42	.38	.29	.31	.33	.30	
	15			.90	1.80	.80	.55	.40	.40	.30	.35	.35	
	30	.45	.45	.95	2.55	1.00	.52	.49	.41	.40	.38	.38	.45
	45	.46	.69	1.00	1.50	.75	.45	.40	.40	.40	.40	.40	.45
	60	.40	.50	.85	.95	.85	.60	.50	.30	.30	.30	.40	.40
45	10			.90	1.15	1.00	.80	.55	.55	.50	.55		
	15			1.00	1.50	1.20	.80	.80	.50	.60	.60	.60	
	30	.70	1.20	1.55	.22	1.70	1.50	.95	.50	.50	.50	.55	.70
	45	.75	.90	1.15	1.80	3.00	2.35	1.20	1.20	.65	.65	.50	.70
	60	.65	1.40	1.30	4.10	1.90	1.20	1.10	.80	.60	.45	.45	.60
60	10			1.03	1.13	.93	.80	.68	.65	.88	.75	.70	.55
	15			1.05	1.20	1.05	1.00	.75	.73	.85	.65	.65	.30
	30	.63	.88	1.33	1.48	1.25	1.10	.85	.75	.73	.96	.68	.65
	45	.88	1.25	2.10	2.78	1.60	1.30	.95	.80	1.05	.68	.78	.85
	60	.88	1.55	3.03	6.50	3.58	1.57	1.15	.90	1.05	.88	.90	1.08

TABLE 6.

AVERAGE SKY LUMINANCE (X10KCD/M²)

MONTH: MAY 1987

SKY CONDITION: PARTLY CLEAR

SUN POSITION (SOLAR ALT.)	POINT ON SKY (OBSERVATION ALT.)	AZIMUTH OF THE POINT OBSERVED											
		0	30	60	90	120	150	180	210	240	270	300	330
10	10	.40	.50	.80	—	.90	.55	.40	.40	.50	.50	.30	.30
	15	.45	.50	.85	—	.90	.50	.40	.40	.50	.50	.40	.40
	30	.30	.50	.57	1.0	.70	.53	.37	.37	.40	.40	.37	.37
	45	.43	.57	.53	.63	.50	.43	.40	.40	.40	.40	.40	.40
	60	.40	.43	.53	.57	.43	.50	.50	.43	.40	.33	.33	.47
15	10	.45	.50	.70	3.3	.75	.60	.45	.50	.50	.55	.50	.45
	15	.50	.55	.70	—	.90	.60	.50	.50	.50	.50	.50	.50
	30	.60	.75	.75	.95	.85	.55	.50	.50	.45	.50	.45	.45
	45	.40	.53	.57	.70	.77	.40	.40	.40	.40	.40	.37	.37
	60	.47	.40	.47	.47	.43	.40	.37	.33	.33	.33	.33	.33
30	10	.54	.61	.83	—	1.04	.67	.56	.53	.51	.53	.50	.53
	15	.61	.66	.87	—	1.23	.74	.60	.57	.57	.60	.54	.56
	30	.69	.80	1.04	—	1.15	.80	.64	.61	.61	.61	.63	.65
	45	.73	.83	1.25	—	1.17	.85	.66	.63	.60	.61	.61	.66
	60	.69	.77	—	1.01	.98	.79	.67	.65	.60	.61	.63	.64
45	10	.70	.72	.88	1.055	.90	.85	.80	.65	.65	.63	.62	.53
	15	.73	.75	1.05	1.23	1.08	.97	.78	.72	.70	.67	.70	.61
	30	.92	1.10	1.24	2.0	1.30	1.00	.83	.73	.65	.73	.67	.69
	45	1.92	1.04	1.46	—	1.21	1.08	.96	.74	.67	.64	.74	.77
	60	1.01	1.31	—	—	1.41	1.12	1.03	.74	.69	.67	.77	.77
60	10	.78	.83	.95	1.02	.90	.82	.73	.70	.75	.70	.75	.77
	15	.88	.97	1.02	1.07	.98	0.87	.77	.73	.73	.73	.80	.82
	30	.92	1.00	1.30	1.15	1.25	0.97	.84	.77	.73	.83	.90	.82
	45	.97	1.13	1.58	1.88	1.50	1.00	.90	.88	.75	.73	.77	.85
	60	1.08	1.53	2.65	—	1.83	1.13	.87	.78	.75	.75	.82	.97

TABLE 7.

AVERAGE SKY LUMINANCE (X10KCD/M²)

MONTH: JULY 1987

SKY CONDITION: PARTLY CLEAR

SUN POSITION (SOLAR ALT.)	POINT ON SKY (OBSERVATION ALT.)	AZIMUTH OF THE POINT OBSERVED											
		0	30	60	90	120	150	180	210	240	270	300	330
10	10	.40	.50	.60	2.40	.50	.50	.40	.40	.40	.40	.30	.30
	15	.30	.40	.60	.50	.70	.50	.40	.40	.40	.40	.30	.30
	30	.40	.50	.60	.90	.60	.50	.40	.40	.40	.40	.40	.40
	45	.50	.50	.60	.70	.60	.50	.40	.40	.40	.40	.40	.50
	60	.40	.50	.60	.50	.40	.30	.40	.30	.30	.40	.30	.40
15	10	.30	.40	.60	.90	.80	.50	.40	.40	.40	.40	.40	.40
	15	.40	.40	.70	1.00	1.10	.50	.40	.40	.50	.40	.60	.40
	30	.50	.60	.70	1.70	.80	.40	.40	.40	.40	.40	.40	.50
	45	.40	.50	.60	.80	.60	.40	.40	.40	.40	.40	.40	.50
	60	.40	.40	.60	.60	.50	.40	.40	.40	.40	.40	.40	.40
30	10	.60	.65	.65	1.25	.90	.55	.50	.50	.50	.50	.50	.40
	15	.50	.65	.65	1.00	.90	.60	.50	.50	.55	.55	.50	.55
	30	.65	.70	1.0		.90	.60	.55	.55	.55	.55	.45	.55
	45	.60	.85	1.0	1.00	1.00	1.00	.85	.65	.55	.55	.50	.70
	60	.65	.65	.85	.85	1.00	.70	.60	.50	.50	.50	.50	.65
45	10	.60	.75	.90	1.10	.95	.75	.80	.65	.65	.65	.65	.55
	15	.55	.55	.60	1.00	.85	.80	.70	.65	.60	.60	.55	.70
	30	.65	.60	.60	1.60	.90	.90	.70	.60	.60	.65	.55	.55
	45	.80	.60	.75	—	.95	.60	.55	.65	.50	.50	.50	.65
	60	.70	.85	.75	.80	.85	.80	.70	.70	.60	.50	.52	.38
60	10	.70	.90	1.00	.90	.90	.90	.80	.80	.70	.70	.85	.85
	15	.85	1.00	1.00	1.00	1.00	1.00	.90	.90	.80	.85	.85	.90
	30	1.00	1.20	.60	.90	1.00	1.00	1.00	.90	.80	.95	.85	.80
	45	1.25	1.30	1.40	1.30	1.10	1.30	1.30	1.10	1.10	.90	.95	.80
	60	1.00	1.30	2.80	2.70	1.70	1.40	1.20	1.00	1.10	1.10	.90	.90

TABLE 8..
AVERAGE SKY LUMINANCE (X10KCD/M²)

MONTH: AUGUST 1987

SKY CONDITION: PARTLY CLEAR

SUN POSITION (SOLAR ALT.)	POINT ON SKY (OBSERVATION ALT)	AZIMUTH OF THE POINT OBSERVED											
		0	30	60	90	120	150	180	210	240	270	300	330
10	10	.30	.30	.50	—	.30	.20	.20	.20	.20	.20	.20	.20
	15	.20	.30	.70	—	.50	.30	.30	.20	.20	.20	.20	.20
	30	.30	.30	.70	.80	.50	.30	.30	.20	.20	.20	.20	.20
	45	.30	.50	.50	.40	.30	.40	.30	.30	.30	.30	.30	.30
	60	.30	.30	.30	.30	.20	.20	.20	.20	.20	.20	.20	.20
15	10	.40	.40	.70	3.10	.70	.40	.30	.40	.40	.30	.30	.30
	15	.30	.40	1.10	—	.90	.50	.40	.40	.40	.40	.40	.30
	30	.50	.50	.70	1.60	.70	.30	.30	.30	.30	.30	.30	.30
	45	.40	.30	.50	.70	.50	.40	.30	.30	.30	.30	.30	.30
	60	.40	.40	.40	.40	.20	.20	.20	.20	.20	.20	.30	.20
30	10	.65	.75	.95	1.55	1.20	.70	.60	.60	.60	.75	.65	.65
	15	.65	.75	.90	2.25	1.10	.85	.65	.55	.55	.95	.65	.55
	30	.55	.70	—	—	1.20	.65	.55	.55	.55	.65	.55	.55
	45	.55	.70	1.10	1.75	.75	.65	.55	.65	.65	.55	.45	.45
	60	.45	.80	.80	.65	.55	.65	.70	.55	.45	.55	.45	.45
45	10	.60	.60	.82	1.00	1.14	.84	.64	.64	.65	1.05	.60	.55
	15	1.15	.75	1.55	1.00	1.02	.75	.60	.55	.55	1.15	1.00	.60
	30	.64	1.20	.94	1.92	1.10	.65	.65	.55	.55	.50	.60	.80
	45	.45	.52	.62	1.30	—	1.00	.94	.40	.44	.45	.45	.45
	60	.45	.64	.80	1.00	.95	.55	.55	.45	.34	.34	.40	.40
60	10	.70	.90	.90	1.00	.70	.80	.70	.70	.70	.70	.70	.70
	15	.70	1.20	.80	1.00	.90	.60	.70	.70	1.00	1.20	.80	.70
	30	.90	1.40	.90	1.60	1.40	.80	.80	1.10	.90	.70	.90	.90
	45	.60	.70	2.00	3.50	1.90	1.80	1.00	.80	.70	.70	1.00	1.0
	60	.70	.70	1.10	—	3.20	1.90	1.50	1.30	.00	1.00	1.00	1.3

TABLE 9.

AVERAGE SKY LUMINANCE (X10KCD/M²)

MONTH: NOVEMBER 1987

SKY CONDITION: PARTLY CLEAR

SUN POSITION (SOLAR ALT.)	POINT ON SKY (OBSERVATION ALT.)	AZIMUTH OF THE POINT OBSERVED											
		0	30	60	90	120	150	180	210	240	270	300	330
10	10	—	0.69	0.44	0.31	0.57	0.50	0.36	0.33	0.34	0.39	0.37	0.38
	15	2.06	0.70	0.45	0.36	2.15	0.54	0.41	0.33	0.34	0.40	0.35	0.35
	30	0.74	0.61	0.43	0.35	0.93	0.38	0.34	0.34	0.35	0.39	0.34	0.33
	45	0.44	0.43	0.39	0.31	0.55	0.31	0.30	0.30	0.30	0.35	0.31	0.31
	60	0.36	0.35	0.34	0.30	0.36	0.29	0.29	0.29	0.30	0.34	0.30	0.29
15	10	1.86	0.99	0.53	0.43	0.96	0.66	0.51	0.42	0.39	0.41	0.41	0.41
	15	—	0.92	0.56	0.44	0.95	0.72	0.48	0.43	0.40	0.40	0.41	0.41
	30	1.69	0.82	0.51	0.43	1.37	0.73	0.46	0.39	0.40	0.37	0.34	0.37
	45	1.04	0.64	0.47	0.38	0.73	0.59	0.46	0.39	0.39	0.36	0.33	0.34
	60	0.52	0.47	0.39	0.38	0.56	0.46	0.46	0.37	0.38	0.33	0.36	0.32
30	10	1.35	0.93	0.58	0.56	0.90	0.81	0.64	0.57	0.48	0.54	0.48	0.48
	15	1.60	1.19	0.73	0.58	1.00	0.86	0.62	0.54	0.52	0.57	0.50	0.50
	30	—	1.09	0.70	0.61	0.96	0.96	0.60	0.59	0.51	0.57	0.50	0.51
	45	1.39	0.98	0.70	0.56	0.97	0.78	0.58	0.56	0.51	0.54	0.51	0.51
	60	0.80	0.77	0.62	0.56	0.79	0.72	0.57	0.51	0.52	0.54	0.58	0.61
45.	10	1.04	0.90	0.63	0.63	0.99	0.77	0.59	0.58	0.62	0.56	0.56	0.59
	15	1.20	0.93	0.83	0.66	1.10	0.87	0.64	0.63	0.69	0.59	0.60	0.61
	30	1.77	1.06	0.80	0.73	1.09	0.86	0.64	0.66	0.60	0.69	0.69	0.74
	45	—	1.31	0.90	0.77	1.64	1.01	0.71	0.73	0.63	0.63	0.64	0.79
	60	2.28	1.30	0.87	0.69	1.40	1.00	0.84	0.76	0.80	0.81	0.83	0.90
60	10	1.00	0.90	0.80	0.65	1.03	0.93	0.78	0.83	0.68	0.73	0.65	0.70
	15	1.08	0.95	0.95	0.75	1.13	0.85	0.78	0.73	0.68	0.68	0.75	0.83
	30	1.20	1.00	0.90	0.93	1.15	1.03	0.95	0.98	0.90	0.75	0.85	0.95
	45	2.10	1.23	1.08	0.88	1.53	0.94	0.93	0.68	0.90	0.93	0.83	0.98
	60	—	1.37	1.10	0.88	2.25	1.43	1.05	0.93	1.03	1.10	0.95	1.03

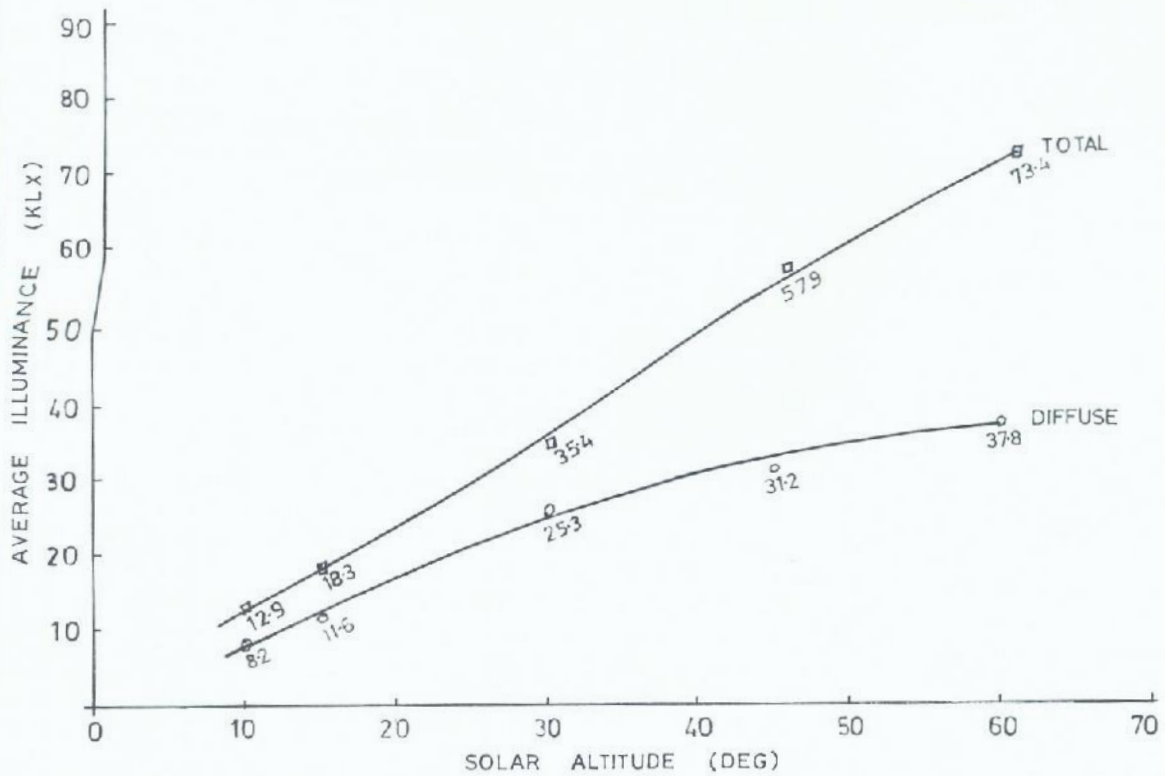


FIG. 1: VARIATION OF TOTAL AND DIFFUSE ILLUMINANCE (KLX) WITH SOLAR ALTITUDE (DEG) FOR PARTLY CLEAR SKY - MARCH/APRIL

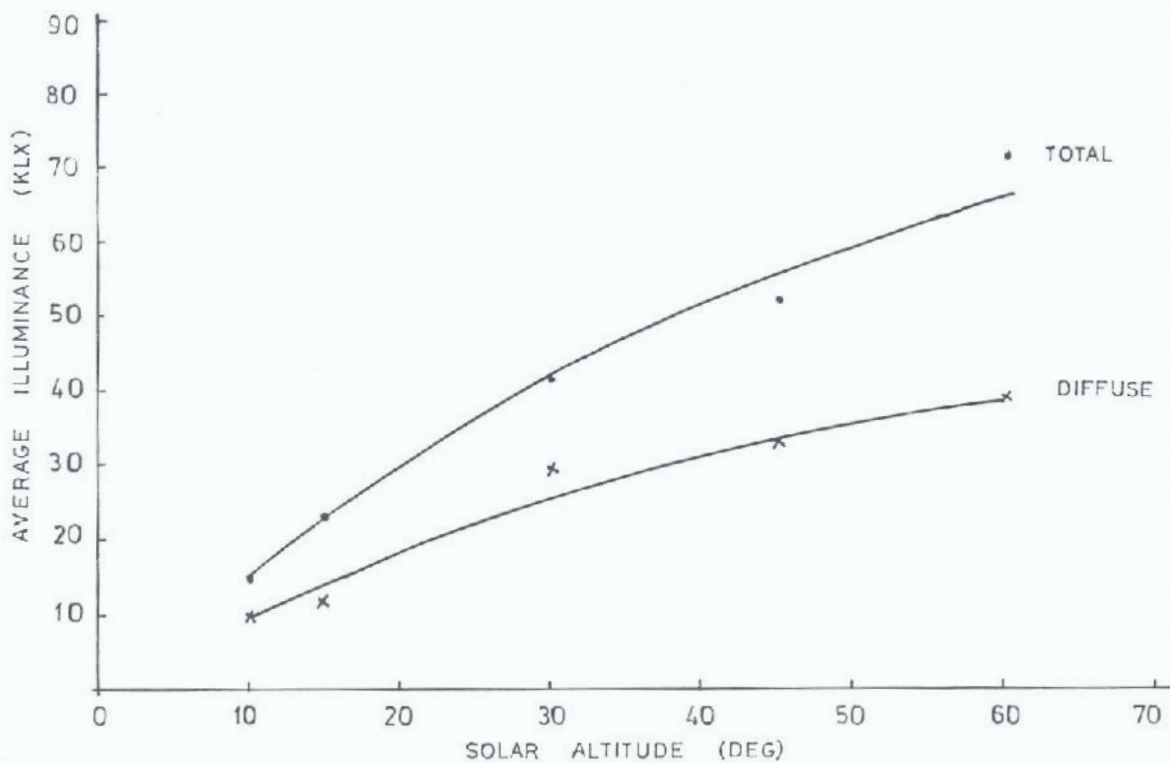


FIG. 2: VARIATION OF TOTAL AND DIFFUSE ILLUMINANCE (KLX) WITH SOLAR ALTITUDE (DEG) FOR PARTLY CLEAR SKY CONDITION - MAY

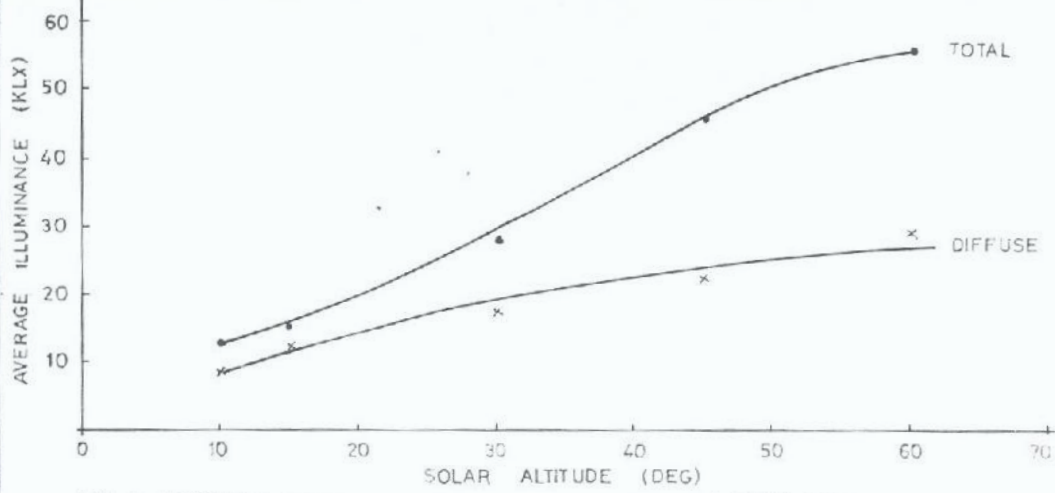


FIG. 3: VARIATION OF TOTAL AND DIFFUSE ILLUMINANCE (KLX) WITH SOLAR ALTITUDE (DEG) FOR PARTLY CLEAR SKY CONDITION - JULY

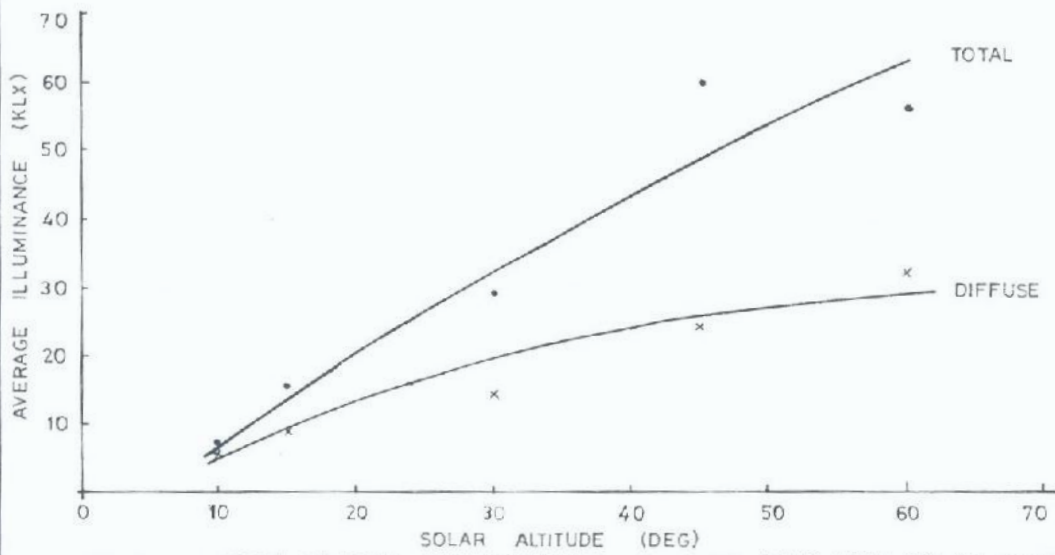


FIG. 4: VARIATION OF TOTAL AND DIFFUSE ILLUMINANCE (KLX) WITH SOLAR ALTITUDE (DEG) FOR PARTLY CLEAR SKY CONDITION - AUGUST

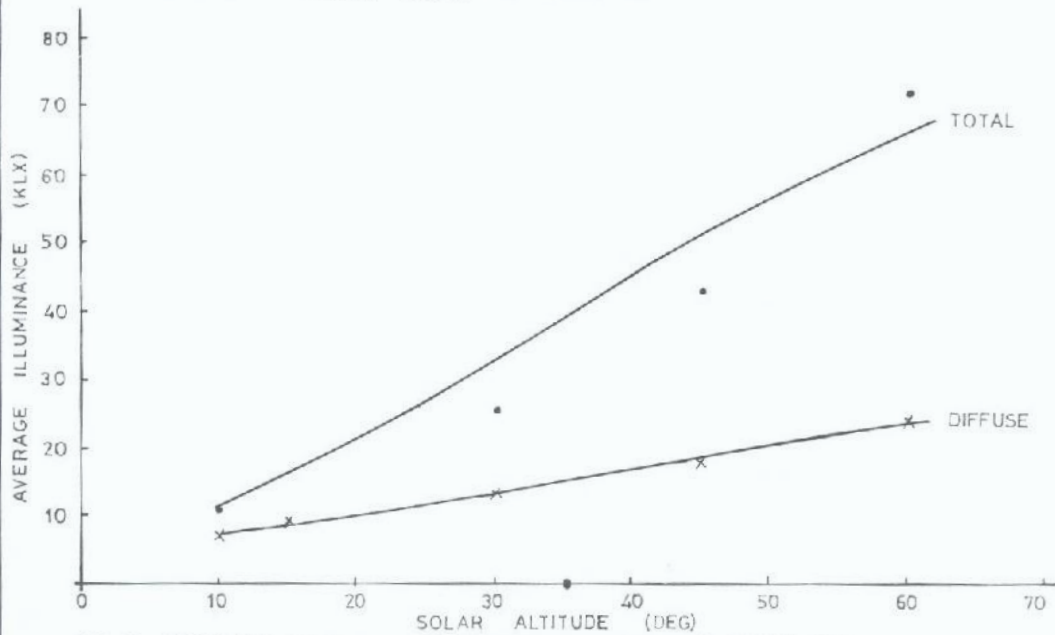
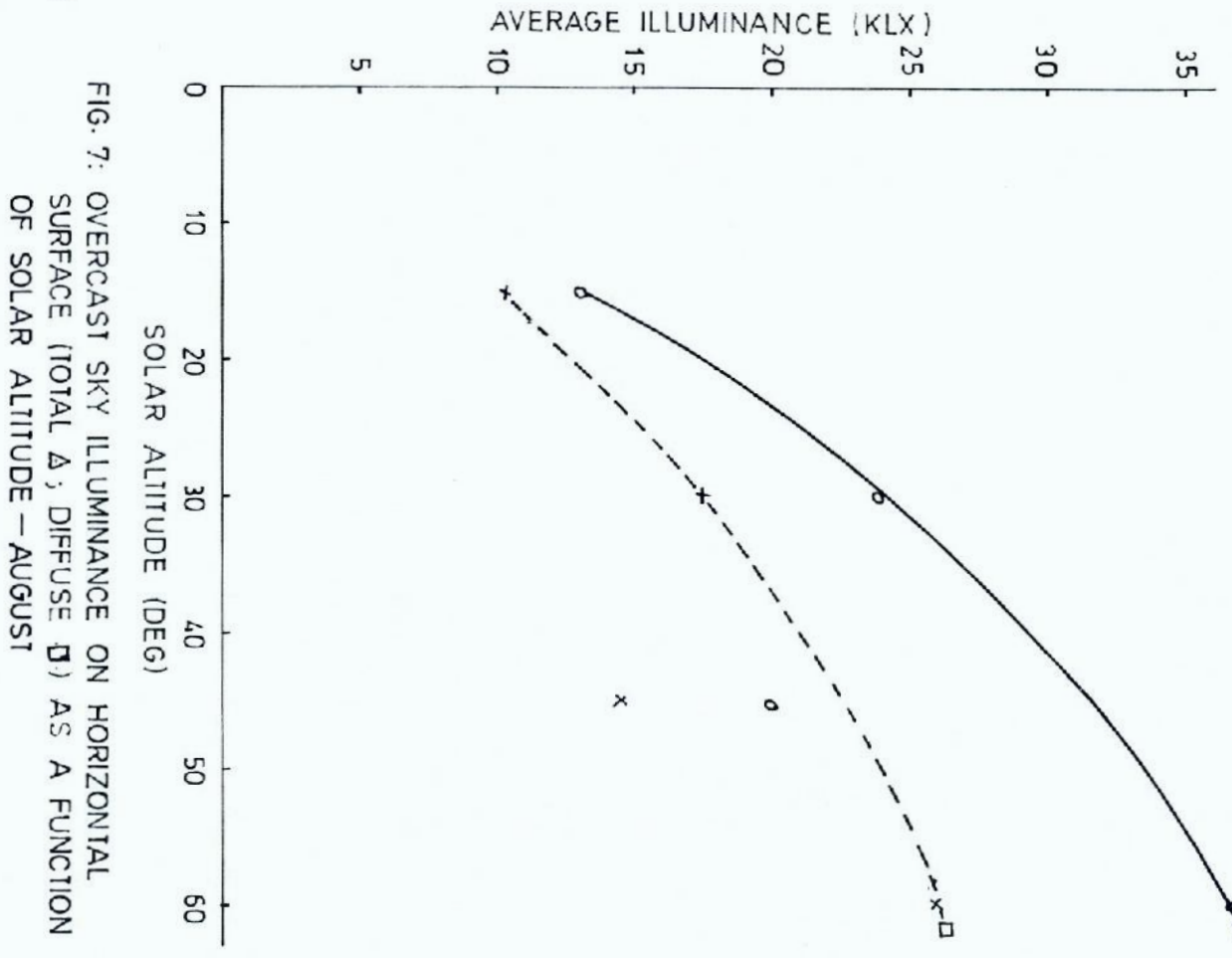
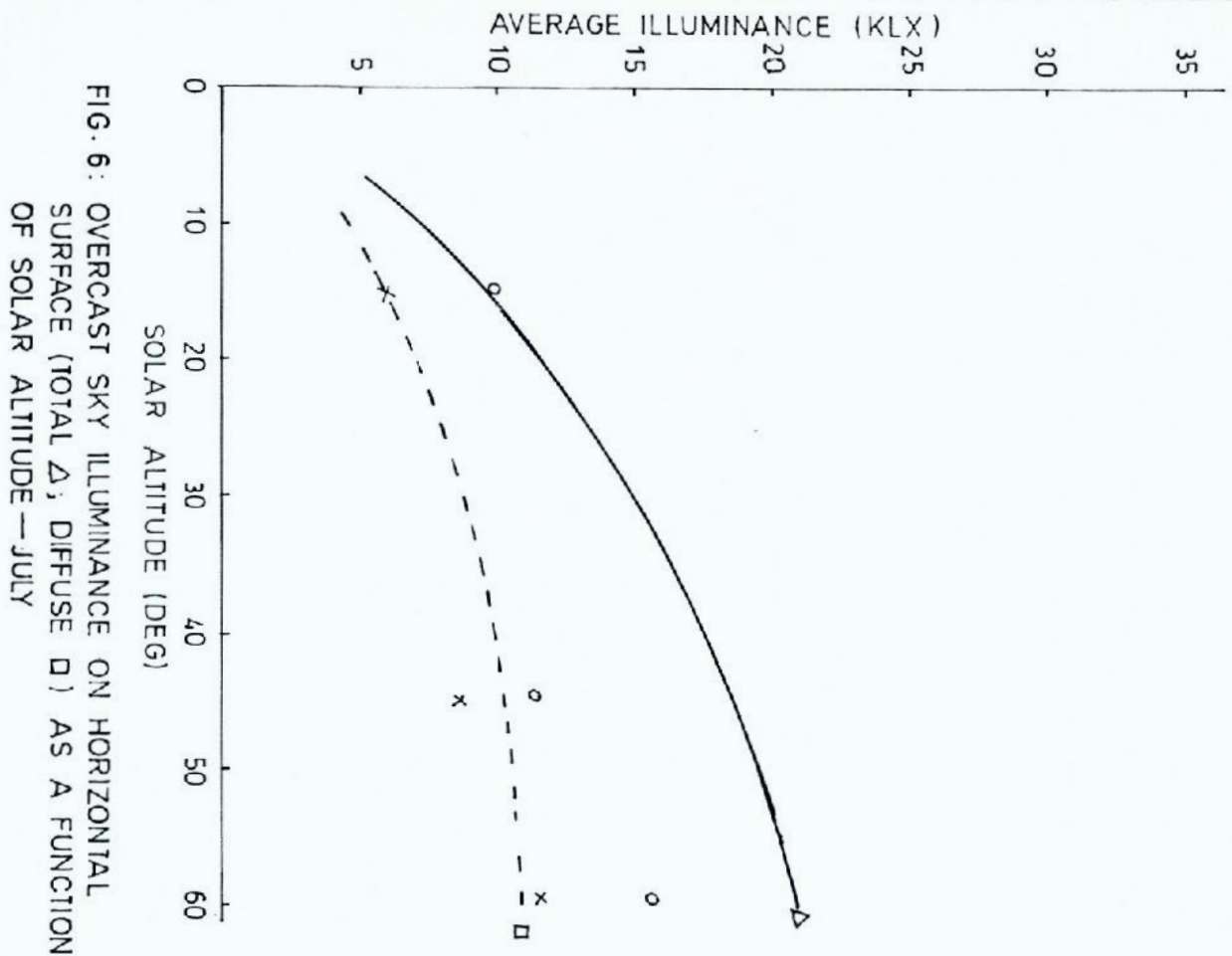


FIG. 5: VARIATION OF TOTAL AND DIFFUSE ILLUMINANCE (KLX) WITH SOLAR ALTITUDE (DEG) FOR PARTLY CLEAR SKY CONDITION - NOVEMBER



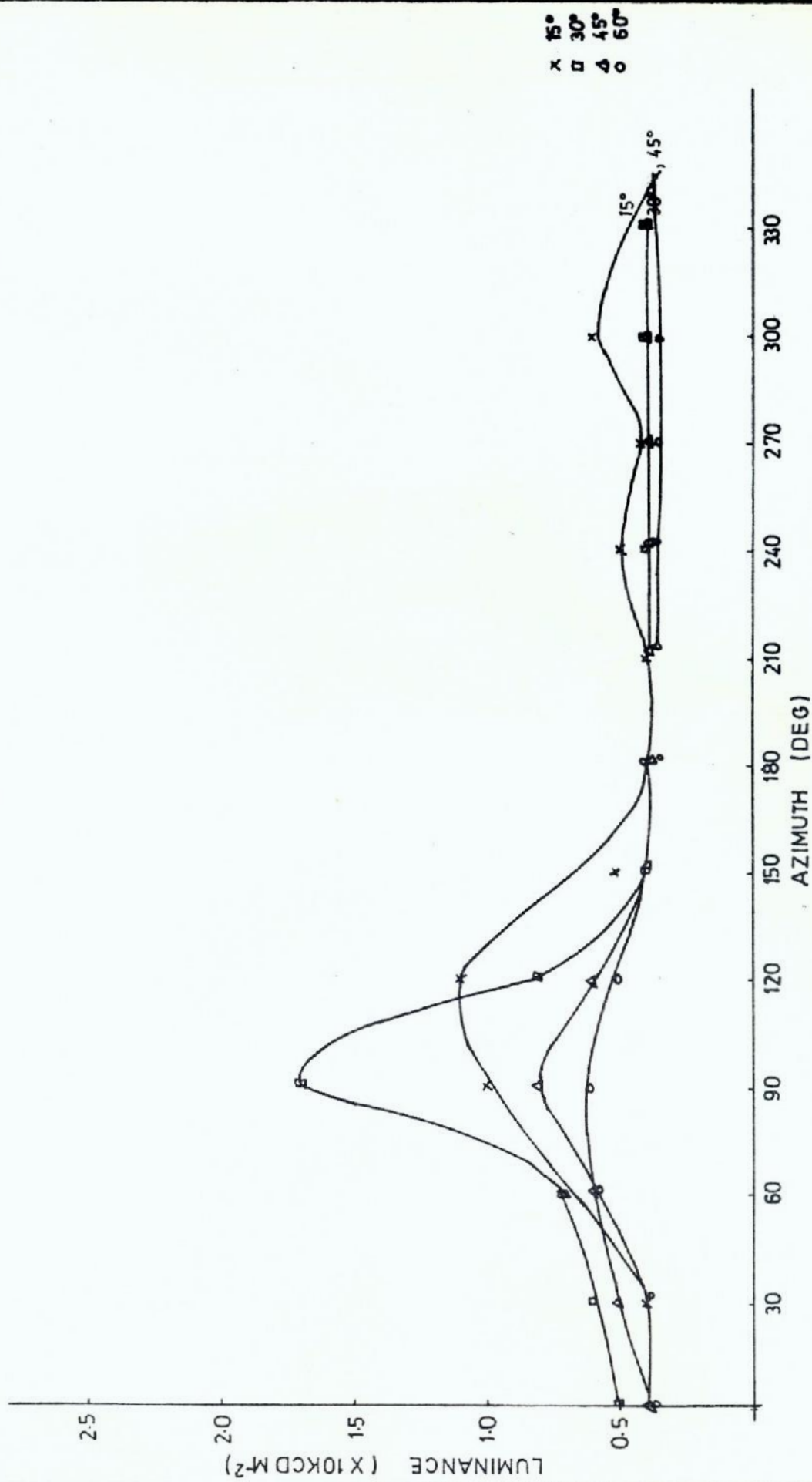


FIG. 8: LUMINANCE DISTRIBUTION FOR A TYPICAL PARTLY CLEAR SKY CONDITION ON JULY 23RD AT SOLAR ALTITUDE 15° AND VARIOUS OBSERVATION ALTITUDES.

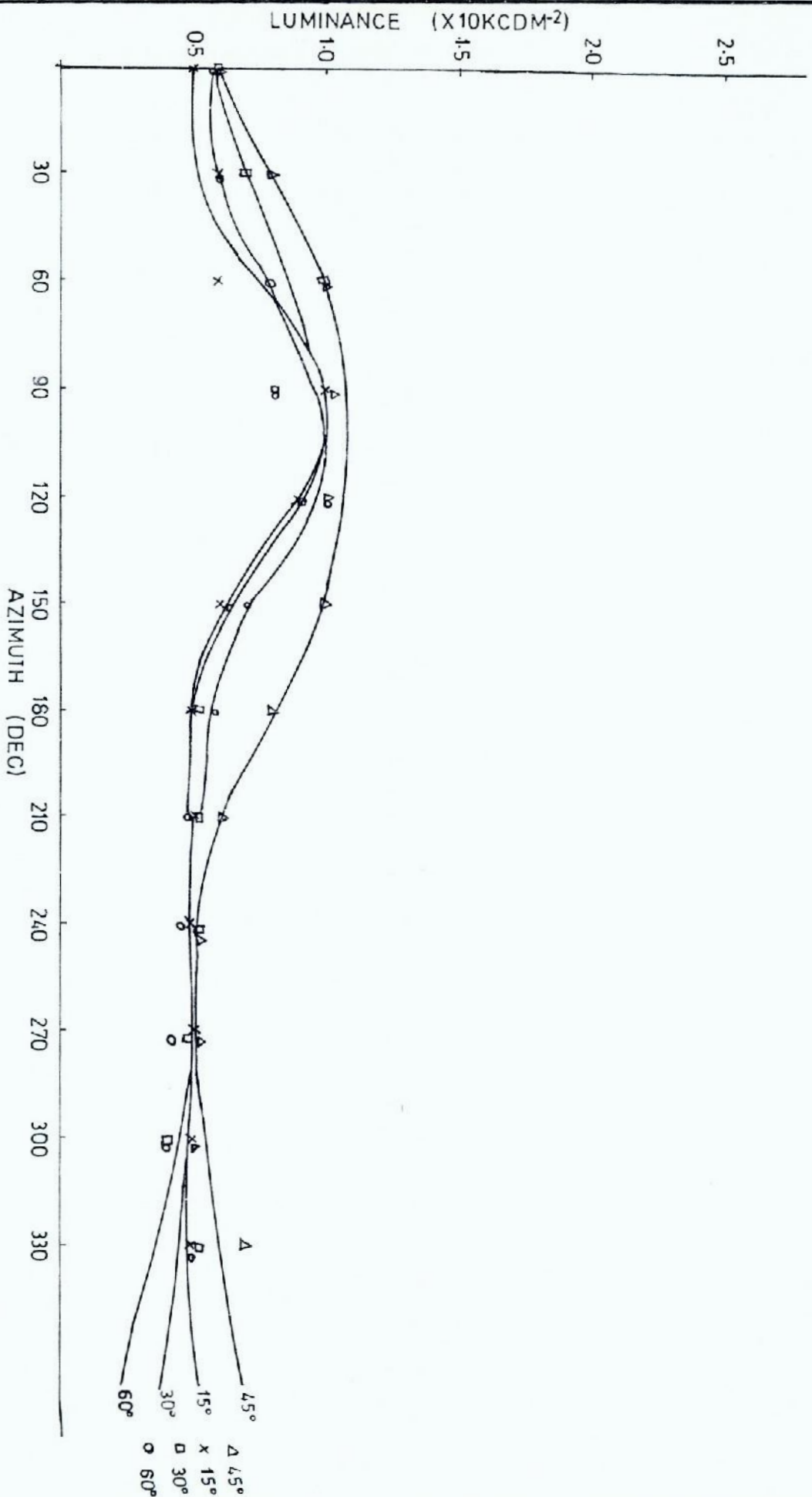


FIG. 9: LUMINANCE DISTRIBUTION FOR A TYPICAL PARTLY CLEAR SKY CONDITION ON JULY 23RD AT SOLAR ALTITUDE 30° AND VARIOUS OBSERVATION ALTITUDES.

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ALTERNATIVE SOUND ABSORBING LOCAL BUILDING MATERIALS WITH APPLICATIONS TO ACOUSTIC DESIGN OF BUILDINGS AND ENVIRONMENTAL NOISE CONTROL

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ABSTRACT:

A good acoustic performance is a basic requirement in building design especially in the design of special buildings like auditoria, conference halls and cinema halls. The physical dimensions affect the internal acoustics only to a limited extent, optimal conditions can be better achieved by the use of effective sound absorbing materials at the appropriate positions. Thus data on the acoustical properties of different building materials will be invaluable to the architects and engineers. Locally produced materials from wastes are needed as substitutes for imported building materials. The acoustic properties of some fibre boards developed at the Nigerian Building and Road Research Institute (NBRRI) Building Materials Laboratory — palm fibre, coconut fibre and rice husk are tested along with some locally manufactured boards from expanded polystyrene, polyurethane — rigid and flexible foam, fibre cement and mineral fibres.

The results presented here are obtained using the Standing Wave method. The patterns of behaviour of the results are discussed. The NBRRI acoustic boards give very good results compared with locally manufactured boards. Some applications in noise control and sound insulation of dwellings are given.

1. INTRODUCTION

The initial task of a designer is to plan a layout such that minimum external noise flows into the building. Acoustical treatment of the building enclosure is also determined by the type of building.

Lack of proper sound treatment in functional enclosures leads to excessive noise level and reverberation, creating the difficulty of speech communication. The adverse effects of noise — the unwanted sound or signal — on man's ability for concentration can be reduced using acoustic or sound insulating materials. Acoustic design methods and materials are developed for schools, auditoria, concert halls, churches, mosques, cinemas and other places where acoustical considerations play important roles. Such enclosures, interior walls and ceilings designed using functional architectural geometry, if treated with suitable sound absorbent materials, help to avoid reverberant behaviour with a resultant considerable reduction in

the noise level. The sound absorption characteristics of a material depend on its thickness, density, flow resistance and porosity.

It also depends on the frequency and angle of incidence of the sound, air absorption, the effects of pattern, area, edge and diffraction; and the mounting conditions of the material [1-4].

External noise in urban areas is another serious problem for roadside buildings. The rooms which face the roads on the lower floors of multistorey buildings in busy commercial areas are exposed to high noise level from the traffic (at times greater than 80dB). The noise level can be reduced by offsetting the building by about 20-30m from the road and by providing barriers, hedges, shrubs and plants between the road and the building. In this paper, the acoustic properties of some local building materials developed at the Building material section of the Nigerian Building and Road Research Institute and some other locally manufactured boards from extruded and expanded polystyrene, polyurethane rigid and flexible foam, fibre cement and mineral fibres were determined. The standing wave method [1-3] is used for determining the sound absorption coefficient and the acoustic impedance of the materials while a locally fabricated flow resistance apparatus is used to find the acoustic impedance of the materials. The acoustic properties and the pattern of behaviour are shown. Applications in sound insulation of dwellings and noise control in the building environment are given.

2. ACOUSTIC PROPERTIES OF SOME SOUND ABSORBING LOCAL BUILDING MATERIALS

2.1 Sound Absorption and Absorption Coefficients;

All the incident waves on rigid wall of a complete enclosure are reflected, setting up a standing wave pattern with non-uniform distribution of acoustic energy density. If the walls are porous and soft, a substantial part of the incident wave is absorbed and the distribution of mean-square pressure is reduced and uniform. The properties [1,5] which make a material suitable for sound absorption are:

- i. Surfaces that are relatively transparent to sound waves.
- ii. A means for the vibratory energy of the waves to be completely transformed into heat energy by friction.
- iii. The total depth of air volume between the face of the material and the rigid backing surface behind it (this includes air in the pores of the material).

The value of the friction which damped out the amplitude of vibration of the incident sound wave energy depends on the resistance of the material to direct air flow. It is called the dc acoustic resistance or flow resistance (F) and defined as the ratio of the pressure drop across a sample of material to the volume velocity of air (flow rate) passing through it. It is expressed in MKS rayls.

The value of the flow resistance is a function of the thickness and density of the material, fibre diameter, percentage binder and the average orientation of fibre with respect to the direction of air flow. The optimum value varies with frequency, thickness and method of mounting. Acoustical materials display a peaked absorption frequency curve, the shape at low frequency being largely determined by the depth of air volume, in the peaked region by the flow resistance and at the high frequencies by the amount of surface opening.

Three variations of the absorption coefficients parameter can be distinguished.

- (a) Sabine absorption coefficient, α_{sab} ,
- (b) Statistical (energy) sound absorption coefficient, α ,
- (c) Sound absorption coefficient for a given angle of incidence α_{θ} .

The audience in a room provide 0.46 units (sq. metres) of sound absorption per person, each of the unoccupied seats (fully upholstered) causes nearly 0.4 units (sq. meters) of absorption. On the other hand, concrete and masonry act as reflectors and have absorption coefficient less than 0.05.

The Standing Wave method employed here measures α_{se} the ratio of the sound energy absorbed by a surface to the sound energy incident upon it at a given angle, for $\theta = 90^\circ$ and this result is normally referred to as the normal incidence absorption coefficient, α_n [1,12]

2.2 THE STANDING WAVE THEORY:

The Standing Wave method is used in determining the absorption coefficient and acoustic impedance of the building material samples [1-3,5-9]. For an acoustic plane wave incident normally on a sample in the standing wave tube of Figs. 1 and 2 at a point or distance, x, the total sound pressure is

$$P_x(x,t) = (P_i(x,t) + P_r(x,t)) \dots\dots(2)$$

where $P_i(x,t) = A \cos 2\pi ft$ is the incident sound

pressure and $P_r(x,t) = B \cos 2\pi ft (t-2x/c)$ is the reflected sound pressure.

The RMS maximum and minimum pressures measured are $P_{max} = (A+B) \cos 2\pi ft$ occurring at $x = \pi/4$ and $P_{min} = (A-B) \cos 2\pi ft$ occurring at $x = 3\pi/4$

The sound absorption coefficient (α) defined as the ratio between the energy absorbed by the sample and the total energy incident on the sample is given by

$$\alpha = 1 - (P_{min}/P_{max})^2 \dots\dots\dots(3)$$

$$\text{where } n = P_{max}/P_{min} = \frac{A+B}{A-B}$$

is the standing wave ratio measured using the standing wave apparatus and $r = \frac{n-1}{n+1} = \frac{A-B}{A+B}$ is the reflection coefficient. Simplifying, the absorption coefficient is given by

$$\alpha = \frac{4n}{n^2 + 2n + 1} \dots\dots\dots(4)$$

The normal acoustic impedance [5,6] defined as the ratio of the sound pressure acting to the associated particle velocity normal to the surface is given by

$$Z = P/u = \rho c (P_{max}/P_{min})$$

$$Z_n = \rho c n \dots\dots\dots(5)$$

where ρ and c are density and speed of sound respectively. From equations (4) and (5), the absorption coefficient in terms of z is

$$\alpha_n = 1 - I(z-\rho c)/(z+\rho c) I^2 \dots\dots\dots(6)$$

and the acoustic impedance in terms of n is

$$Z_n = \rho c \frac{(1 + (1-n)^{1/2})}{1 - (1-n)^{1/2}} \dots\dots\dots(7)$$

where $\rho c = 408.0$ rayls for air at 1 atmosphere and 300k or $\rho c = 415.03$ for air at S.T.P.

The value of z in equation (7) can be complex, real (resistive) or purely imaginary (reactive).

3. EXPERIMENTAL MEASUREMENTS

The samples were obtained from:

1. The Building Material Section, NBRRI – palm and coconut fibre boards, rice husk with binders.
2. ENKAY plastics, Sango Otta, Nigeria - expanded polystyrene products.
3. Nigerite Limited, Ikeja – Fibre cement product (Ceiling board).
4. Vitafoam (Nig.) Ltd., Ikeja – Polyurethane rigid and flexible foam, polyurethane rigid foam with hard paper backing, extruded polystyrene insulation board.
5. Gottchocks Nigeria, Limited, Ikorodu Road – mineral fibre ceiling tiles (classic, fissured, cortega) and joints filler board.

A flow resistance apparatus designed and fabricated at the Architectural Acoustic laboratory of NBRRI

is used in measuring the dc acoustic impedance. Steady air flow is maintained through sample. Air flow is proportional to the rate of water drop. The pressure through the sample is measured by means of a manometer. The result is presented in Table 1.

The Bruel & Kjaer standing wave apparatus Type 4002 was used with schematic layout as shown in Fig. 2. The sample to be tested is mounted at the end of the tube using the sample holder. The diameter of the sample must not be greater than $\frac{1}{2}$ wave length ($\frac{1}{2}\lambda$) of the sound to ensure the required plane sound waves in the tube and exclude the possibility of a transverse wave (6). To cover a sufficiently wide frequency range, the standing wave apparatus uses two measuring tubes — the larger tube with a diameter of 10cm covers the frequency range 90Hz to 1800Hz and the small tube with a diameter of 3cm covers the frequency range 800Hz to 6500Hz. Pure tones at selected frequencies — 125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz — from the sine generator 1023, energise the loudspeaker mounted at the opposite end of the tube and sets up a sound field in the tube terminated by the sample to be investigated. Reflections from the samples produced standing wave pattern in the tube. The travelling microphone picks up the pressures at the nodes (maxima) and antinodes (minima). The maximum and minimum pressure readings in volts or dB are taken using the Measuring Amplifier 2610 or the Frequency Analyser 2120 and the normal incidence sound absorption coefficient is determined using equations (3) and (6). The distances between the surface of the sample and the minima and maxima pressures are also recorded from which the acoustic impedance is determined using equation (5). Alternatively, the Frequency Analyser may be fitted with a special scale from which the absorption coefficient may be read directly, and the acoustic impedance calculated from equation (7).

The results obtained from the above measurements are presented in Tables 2 and 3 and Figs. 3–7.

4. RESULTS AND DISCUSSIONS:

Some physical properties of the materials tested such as the thickness, the flow resistance and the bulk density are as shown in Tables 1 and 2.

The acoustic impedance is shown in Table 2, the sound absorption coefficients, and the Noise Reduction coefficients (NRC) — the average of the absorption coefficients at 250, 500, 1000 and 2000Hz are shown in Table 3. At high and middle frequencies, the magnitude of the acoustic impedance in Fig. 3 is low which results in high absorption coefficients as in Figs. 4 – 7. At low frequencies, the acoustic impedance is high in magnitude thereby restricting the volume of air flow through the material, resulting in lower absorption coefficient. Porous materials like the coconut and palm fibre boards of Fig. 4 have higher absorption coefficients at middle frequencies, and the absorption coefficients decrease at high frequencies.

The absorption peak in fibre cement ceiling board Fig. 6 is broadened, making it behave like a thin ply-

wood panel on a hard backing. The expanded polystyrene and the extruded polystyrene of Fig. 5 behave like a curtain of thin plastic sheet in front of a soft porous material such as a sponge rubber rather than a cavity resonator at high frequency.

The almost flat curve shows the true behaviour of a dissipative absorber. It represents the ultimate in sound absorption and can be used for the treatment of free-field sound rooms in which the reflection from the boundary surfaces are negligible.

The polyurethane boards of Fig. 7 are recommended for use at high frequencies.

Tables 8 and 9 show some typical values of sound absorption and noise reduction coefficients of some common commercial building materials [1,3,5,10,11].

5. APPLICATIONS: Accoustical treatment of Buildings:

5.1 Environmental noise control:

It has been determined that intense noise is harmful to the person exposed to it and can also cause adverse psychological disturbance (12–16). Outdoor noise — from road traffic and community noise, Table 4 — flows almost unabated through open windows and doors close to and facing the street. The noise may be structure-borne or airborne. The maximum permissible octave band levels of background noise is given in table 5. The noise criteria curve 25(NC–25) and NC–35 are acceptable for noise levels for sleeping areas in apartment buildings. The best approach to limit the effect of noise is to locate the buildings as far as possible from the noise source. Off-setting buildings (by 20 – 30m) from the road is an effective way of cutting down inflow of noise. The noise level drops 6dB each time the distance is doubled. Screens and shutters on windows facing the road can also provide some relief. A better method is to layout the building such that the critical areas requiring privacy, quiet conditions or clear speech communication such as bedrooms and living spaces are located on the quieter side and shielded away from the road by the non-critical areas such as corridors, kitchens, bathrooms, elevators and service spaces (Fig. 8a). External noise can also be effectively reduced at the site by having natural terrain, hedges, shrubs or plant growth (trees) between the road and the building. A noise barrier can also be made by building compound wall around the building. The taller the wall, the better the shadowing effect. Such walls should be built very near the noise source (the road) (see Fig. 8b).

Walls built from bricks more than 2.5cm thick and weighing more than 3.83kN/m² can give an average transmission loss of 50dB and more. A 12cm brick wall with 1.4cm plaster weighing 1.724kN/m² (361bs/sq.ft) can give a transmission loss between 45dB and 49dB. Table 6 shows commonly used windows for sound insulation against airborne noise.

5.2 Sound Insulation of Dwellings and Room Design

Correct room shape should be adopted. Rectangular

shapes are acoustically good. Curved surfaces, concave on the inside should be avoided for uniform distribution of sound energy from the source to the entire listening area. Reflecting convex surfaces can be employed for uniform distribution of sound if they are carefully designed. Fig. 9 shows some bad and good shapes for halls and auditoria.

For the design of auditoria and cinema halls, a floor area of 0.46 to 0.65 sq m per seat is taken. The size of hall determines the number of seats on the floor and hence the sound absorption that can be provided by individuals and upholstered seats. The length of a hall must not be more than twice the width. A rectangular hall with dimensions (length, width and height) in the ratio 2:1:1 is found to have good acoustical behaviour. A typical dimension is 50m by 25m by 25m. The fan or horse-shoe shape has the added advantage of drawing the audience nearer to the stage, and thereby reducing the length of the hall. Seats in the room should be raked so that the head of the person in the front row does not intercept direct sound to persons in the row behind. A clearance of 10cm should exist between consecutive rows of seats. [4,15,16].

A wide hall may cause delayed reflection. It is customary to treat the rear wall (areas remote from and facing the speaker) of auditoria, cinema halls and large theatres to avoid delayed reflections. Absorbing materials of high absorption coefficient are used in treating the rear part of ceiling and walls. The overall maximum acceptable noise levels for different activities and functional enclosures are shown in Table 7. The noise reduction coefficients (NRC) of some sound absorbing materials that can be used for treating these enclosures are given in Table 8. Absorption coefficients of some common building materials are

given in Tables 2. and 9. Fig. 10 shows examples of useful reflections from the walls, the correct ceiling layout and absorbents applied in rear areas. The total absorption required or needed is determined by measuring the reverberation time (4,16). Column loudspeakers are used in some cases in sound insulated halls to reinforce the sound for the benefits of the rear listeners.

Partial partitioning can be made from the materials tested, these are used as acoustic screens in large open-plan offices. The screen can be about 1.8m by 3.0m. They can be used to screen personnel against intruding noise.

The effect of impact noise in multistorey buildings may be reduced by using resilient floors. Here a 2.5cm layer of fibrous materials is laid on the structural floor and overlaid with cement tiles or concrete cement finish. Tables 8 and 9 show some typical values of sound absorption and noise reduction coefficients of some common commercial building materials [1,3,5,10,11].

6. CONCLUSION:

The normal incidence absorption coefficients are comparable with the value for standard acoustic materials as shown. They can be used as ceiling board, surfacing board, partitioning of offices, sound insulation of theatres and functional spaces. Waste papers, saw dust, maize stalks, wood shaving, wood pulps and other waste materials are also recommended for trial.

Examples of how the materials can be used in sound insulation of dwellings and environmental noise control are provided.

7.

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No.	Sample	Thickness (mm)	Mass (gm)	Bulk Volume cm ³	Bulk Density kg/m ³	Flow Resistance (Rayls)
1.	Classic Mineral fibre ceiling tiles	10.350	14.215	38.395	365.616	749.531
2.	Fissured mineral fibre ceiling tiles	14.575	16.435	53.690	305.34	905.021
3.	Cortega mineral fibre ceiling	14.825	20.90	55.480	376.878	646.705
4.	Fibre-pak (Expansion joint filler board)	4.80	16.27	18.287	890.087	
5.	Fibre-pak	17.613	27.91	68.223	407.241	829.811
6.	Kork-pak (non-absorbent joint filler board)	25.25	19.65	99.417	197.729	5.13.219

Table 1: Flow resistance and mean bulk density of the material tested.

TABLE 2: MEAN BULK DENSITY AND ACOUSTIC IMPEDANCE OF THE Materials (in Rayls)

NO. Sample	Mean Bulk Density kg/m ³	Thickness (mm)	125	FREQUENCY (HZ)						Mean Z (Rayls)
				250	500	1000	2000	4000		
1. Coconut fibre board	549.742	30.90	992.4310	6580632	8613.288	2491.144	741.336	23.14.176	5,111.648	
2. Coconut fibre board	520.669	14.95	5245.656	5924.568	8046.576	5649.168	2092.224	1161.984	4,686.696	
3. Palm fibre board	466.581	39.80	5245.656	6054.312	8939.28	2550.0	790897	2371.296	4,325.240	
4. Expanded Polystyrene board	25.036	17.90	32903.23	36992.136	23032.416	15795.312	5676.504	14023.00	20903.766	
5. Expanded Polystyrene board	31.192	19.27	32380.92	48392.88	57936.0	15445.696	14450.00	26744.4	32558.316	
6. Expanded Polystyrene board	20.542	20.33	19498.32	47833.92	48392.88	6630.0	4456.584	9822.192	22773.150	
7. Expanded Polystyrene board	20.662	25.39	20400.00	41102.328	21565.656	6243.40	3826.432	2088.96	15871.00	
8. Expanded Polystyrene board	17.389	41.12	2042.184	25593.84	9296.28	4080.0	8743.44	4692.00	12074.624	
9. Expanded Polystyrene board	19.050	50.10	19287.384	21436.32	6676.512	7478.64	13345.68	13496.64	13620.196	
10. Fibre cement ceiling board	1386.953	5.00	18392.64	47258.64	45900.00	13464.00	18600.00	15120.48	26455.96	
11. Extruded Polystyrene Insulation Board		18.55	13315.41	58592.69	80412.06	7546.08	8174.85	6161.12	29033.70	
12. Standing wave tube cover	33.03	—	19343.28	47940.00	95198.65	48218.256	43790.64	50184.00	50779.136	
13. Polyurethane Flexible foam	22.88	25.55	17119.99	17940.09	11990.22	4034.64	2193.85	1556.36	7140.82	
14. Polyurethane Rigid foam	35.05	56.80	7168.81	10564.59	13023.23	4652.49	2948.91	2057.10	5541.09	
15. Polyurethane Rigid foam with hard paper backing	37.15	47.15	15092.15	44499.52	29371.26	6264.46	6032.46	2754.14	14820.31	

TABLE 3: ABSORPTION COEFFICIENTS (α) AND THE NOISE REDUCTION COEFFICIENT (NRC) ARE CALCULATED AT THESE FREQUENCIES 250,500,1000 AND 2000HZ

NO. Sample	Thick- ness (mm)	FREQUENCY (HZ)						Mean	N.R.C.
		125	250	500	1000	2000	4000		
1. Coconut fibre board	30.90	0.152	0.220	0.173	0.483	0.916	0.509	0.409	0.448
2. Coconut fibre board	14.95	0.268	0.241	0.184	0.251	0.546	0.769	0.377	0.306
3. Palm fibre board	39.80	0.268	0.237	0.167	0.476	0.898	0.501	0.425	0.445
4. Expanded polystyrene board	17.90	0.048	0.043	0.068	0.098	0.250	0.110	0.103	0.115
5. Expanded polystyrene board	19.27	0.049	0.033	0.028	0.100	0.107	0.059	0.063	0.082
6. Expanded polystyrene board	20.33	0.051	0.034	0.032	0.218	0.307	0.0153	0.133	0.148
7. Expanded polystyrene board	25.39	0.077	0.039	0.0729	0.230	0.348	0.547	0.219	0.173
8. Expanded polystyrene board	41.12	0.078	0.062	0.161	0.311	0.170	0.294	0.159	0.181
9. Expanded polystyrene	50.10	0.081	0.73	0.217	0.196	0.115	0.114	0.133	0.150
10. Fibre cement ceiling board	5.00	0.085	0.034	0.036	0.114	0.084	0.102	0.076	0.067
11. Extruded Polystyrene insulation board	18.55	0.117	0.028	0.021	0.198	0.184	0.237	0.131	0.108
12. Standing wave Tube	—	0.081	0.022	0.017	0.033	0.037	0.032	0.037	0.027
13. Polyurethane flexible foam	25.55	0.013	0.089	0.129	0.302	0.535	0.462	0.264	0.264
14. Polyurethane Rigid foam	56.80	0.207	0.146	0.120	0.301	0.433	0.559	0.294	0.250
15. Polyurethane Rigid foam with hard paper backing	47.15	0.104	0.037	0.055	0.114	0.241	0.455	0.168	0.118

TABLE 4:-

LOUDNESS OF SOME COMMON SOUNDS

Noise	dba
Large jet airline	140
Train on a steel bridge	110
Heavy road traffic at kerbside	85
Make speech at 1-m distance	75
Light road traffic at kerbside	55

TABLE 5:
Maximum Permissible Octave Band Level (dB)
of Background Noise for Different Activities

	37.5-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-9600
NC - Curve								
NC - 25	57	47	39	32	28	25	22	21
NC - 35	63	55	47	41	37	35	33	32
NC - 45	69	62	56	50	47	45	43	42
NC - 55	76	69	64	59	57	55	53	52

TABLE 6:

AIRBORNE SOUND INSULATION OF WINDOWS

S/NO	Situations where used	Type of Window	Transmission Loss dB.
1.	Bedrooms facing arterial roads, major roads with heavy traffic.	Double window of 26 or 32oz glass, spacing 8", tightly sealed with absorbent in reveals	40
2.	Living rooms, classrooms facing through fare	Same as (1) plate but spacing 4"	35
3.	Bedrooms, Classrooms facing residential roads with local traffic or living rooms facing heavy traffic.	Single 1/4" plate glass window, all edges sealed	30
4.	Bedrooms facing quiet areas living rooms facing residential minor traffic.	Single 26 or 32oz glass window, all edges sealed.	25
5.	General office facing heavy traffic or living rooms facing minor traffic.	Same as (4) in wood or metal frames openable.	20

TABLE 7: OVERALL MAXIMUM ACCEPTABLE NOISE LEVELS FOR DIFFERENT ACTIVITIES

S/No.	Activities	Maximum acceptable noise level dB.
1.	Office	50 – 60
2.	Dwellings (House and flats)	45 – 55
3.	Schools, Conference rooms	45 – 50
4.	Hospitals	40 – 50
5.	Broadcast Studios, Houses (sleeping areas)	30 – 40

TABLE 8: Sound Absorbing Materials and Their Noise Reduction Coefficients (NRC)

NO.	DESCRIPTION OF MATERIAL	Thickness (mm)	Density kg/m ³	NRC
1.	Coconut fibre board	30.90	549.74	0.45
2.	Palm fibre board	39.80	466.58	0.45
3.	Fibre cement ceiling board	5.00	1286.95	0.07
4.	Expanded polystyrene	17.90	23.04	0.12
5.	Expanded polystyrene	41.12	17.39	0.18
6.	Extruded polystyrene	18.55	33.03	0.11
7.	Wood panels, plywood with perforated holes	12.00	—	0.75
8.	Fibreglass resin-bonded board screwed to wall.	25.00	—	0.60
9.	Polyurethane flexible foam stock on concrete floors	50.00	—	0.80
10.	Polyurethane rigid foam	56.80	35.05	0.25

TABLE 9: ABSORPTION COEFFICIENT OF SOME COMMON BUILDING MATERIALS

NO.	Common Building Materials	Thick- ness mm	F R E Q U E N C Y H Z				
			125	250	500	1000	2000
1.	Curtain (medium fabrics hung straight and close to wall)		0.05	—	0.25	—	0.30
2.	Curtain (medium fabrics hung infolds or spaced away from wall)		0.10	—	0.40	—	0.50
3.	Fibre board (normal soft) mounted on solid backing unpainted	(½ inch) 12.00	0.05	0.10	0.15	0.25	0.30
4.	Ditto — painted	12.00	0.05	0.10	0.10	0.10	0.15
5.	Fibre board (normal soft) mounted over 25mm air space on solid backing or studs — unpainted	12.00	0.30	—	0.30	—	0.30
6.	Ditto — painted	12.00	0.30	—	0.15	—	0.15
7.	Glass windows glazed with up to 32oz glass	4.00	0.30	—	0.10	—	0.05
8.	Glass wool or mineral wool mounted over airspace on solid backing	25.00	0.40	—	0.80	—	0.90
9.	Glass wool or mineral wool on solid backing	15.00	0.20	—	0.70	—	0.90
10.	Plywood mounted solidly		0.05	—	0.05	—	0.05
11.	Plywood panel mounted over airspace on solid backing, or mounted on studs, without porous material in airspace		0.30	—	0.15	—	0.10
12.	Ditto - with porous materials in airspace		0.40	—	0.15	—	0.10
13.	Walls — plasters		0.02	—	0.02	—	0.04
14.	Walls-plywood panel with absorbed backing	—	0.03	—	0.15	—	0.10
15.	Floor — tiles hard	—	0.03	—	0.03	—	0.05
16.	Floor — wood block	—	0.02	—	0.05	—	0.10
17.	Floor — carpet	—	0.10	—	0.30	—	0.50
18.	Ceiling — plaster or concrete	—	0.03	—	0.02	—	0.04
19.	Ceiling-suspended plaster board	—	0.02	—	0.02	—	0.04
20.	Brickwood	—	0.02	—	0.02	—	0.04
21.	Woodblock, cork, line rubber floor	—	0.02	—	0.05	—	0.10

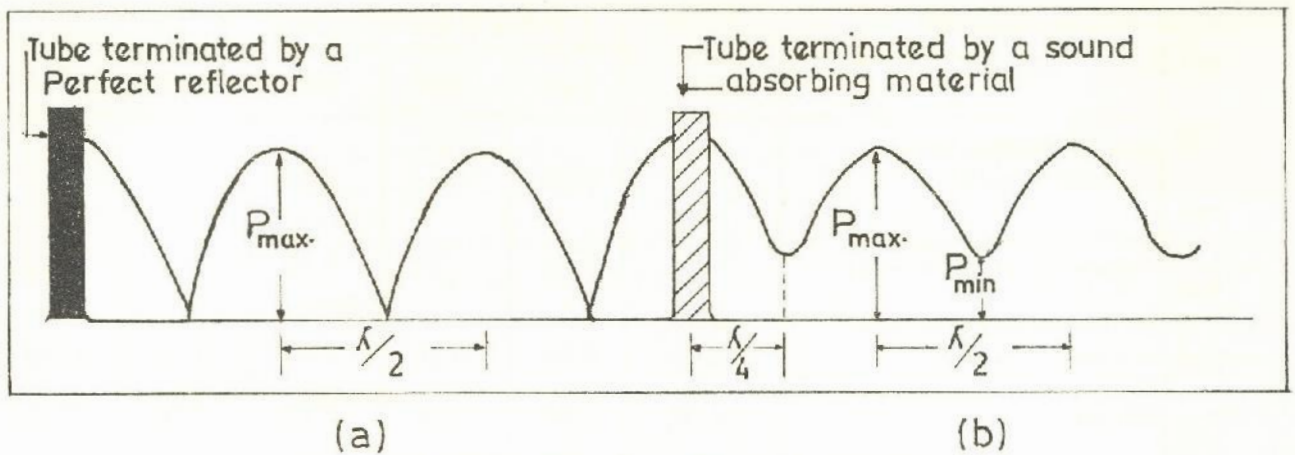


FIG. 1: STANDING WAVE PRESSURE PATTERNS SHOWING THE EFFECT OF TERMINATING THE WAVE TUBE WITH SOUND ABSORBING MATERIAL

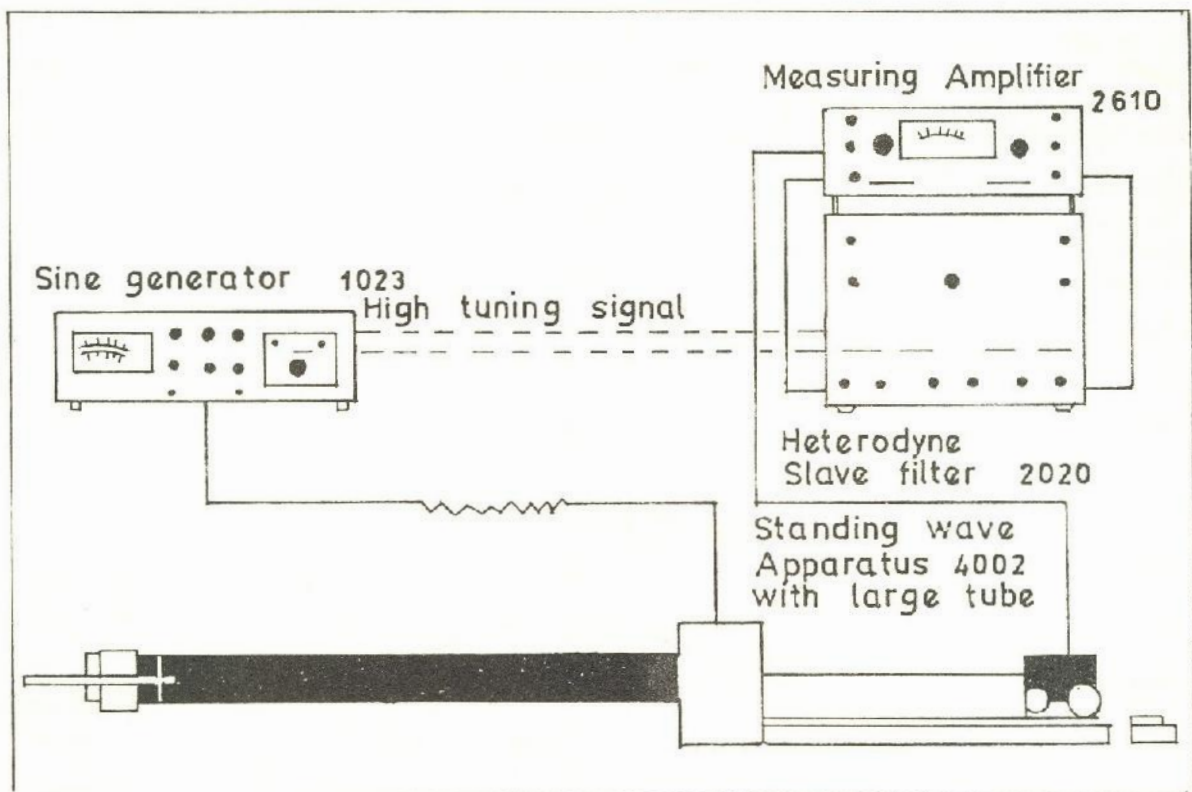


FIG. 2: MEASUREMENT OF ABSORPTION COEFFICIENT EMPLOYING THE STANDING WAVE APPARATUS TYPE 4002

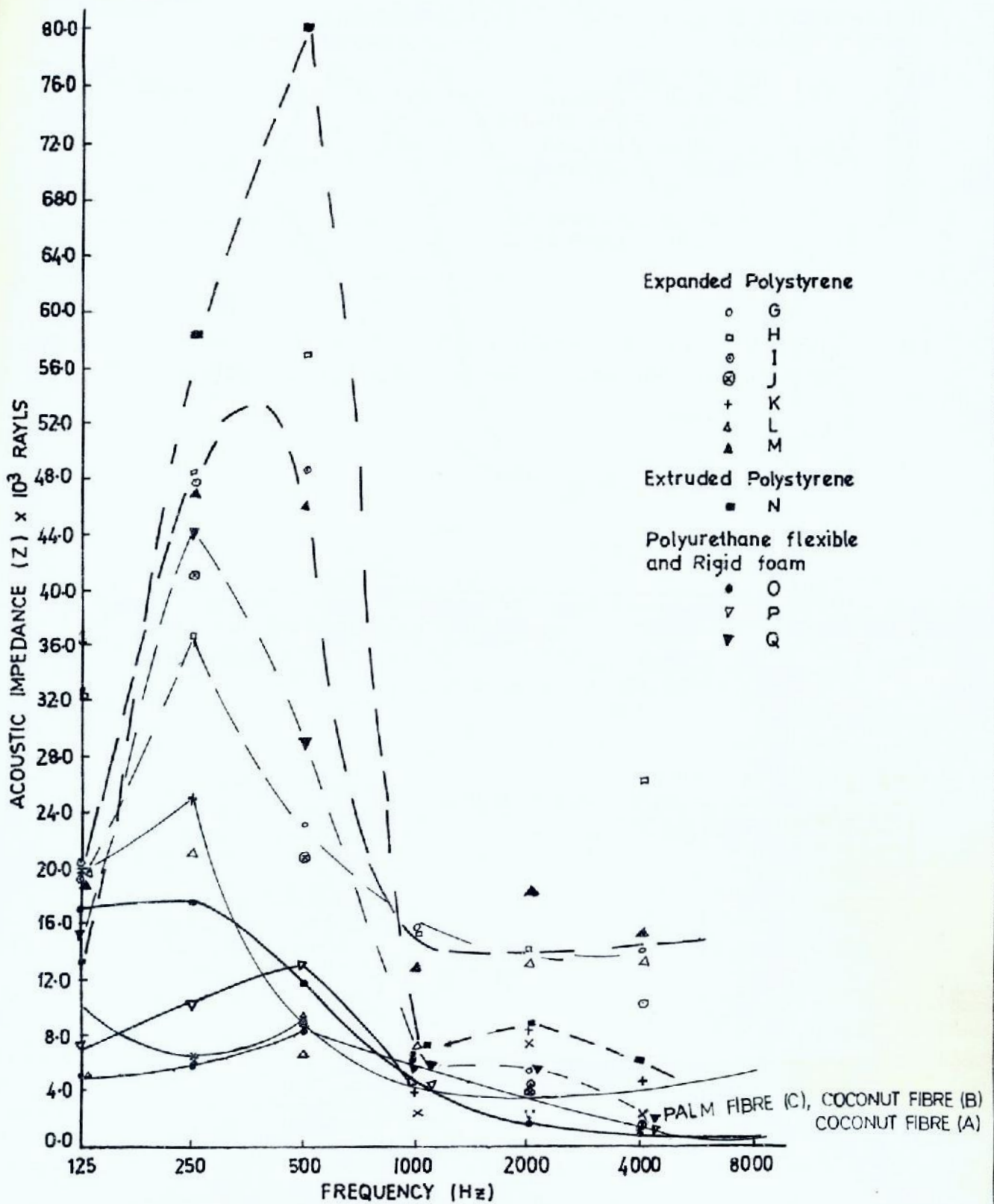


Fig. 3: VARIATION OF ACOUSTIC IMPEDANCE WITH FREQUENCY

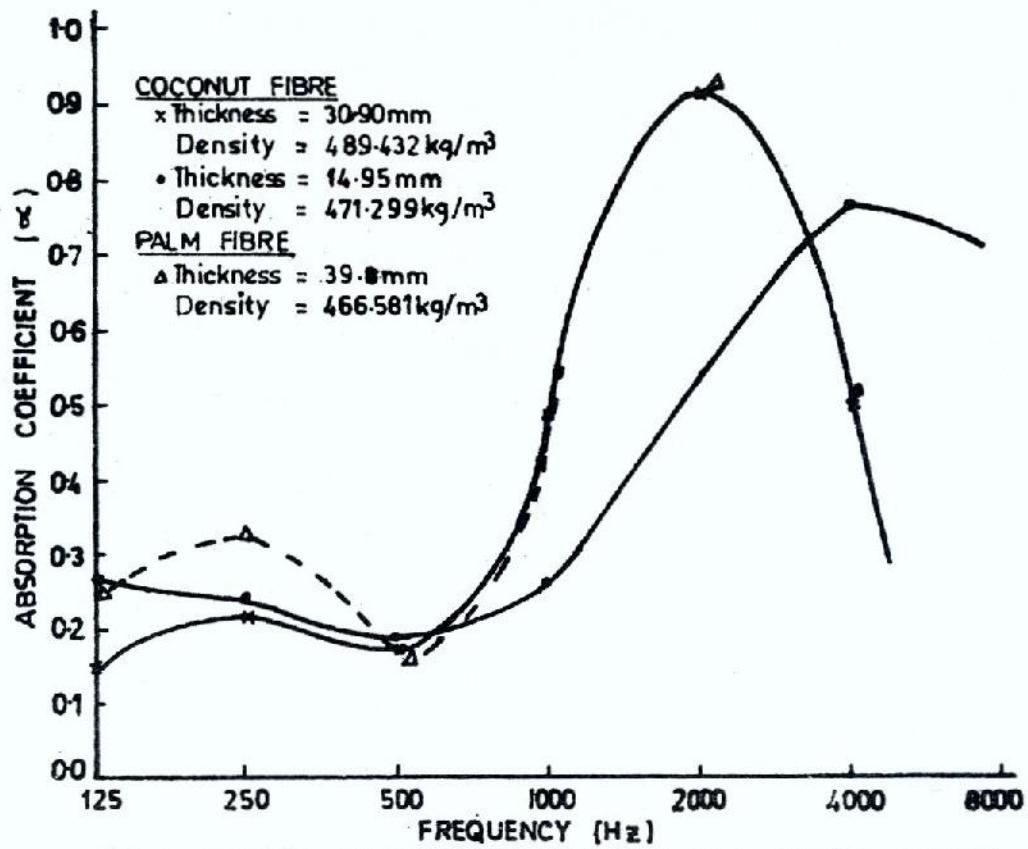


FIG. 4: SOUND ABSORPTION OF COCONUT FIBRE BOARD AND PALM FIBRE BOARD.

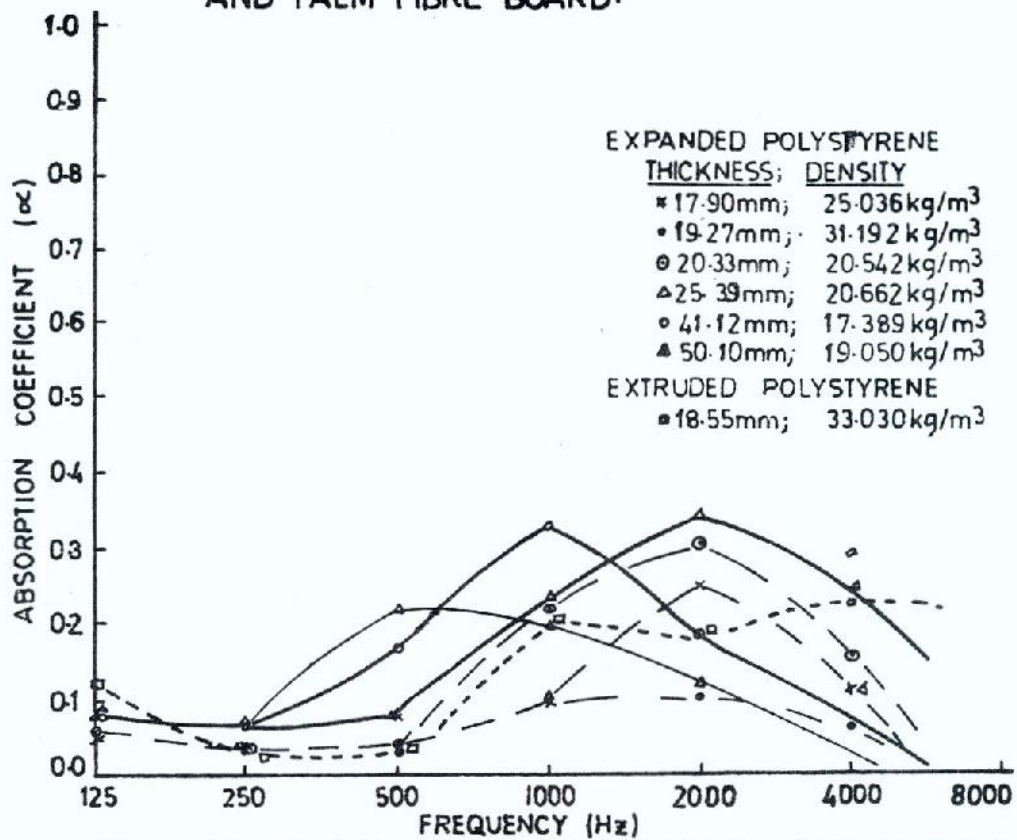


FIG. 5: SOUND ABSORPTION OF EXPANDED AND EXTRUDED POLYSTYRENE INSULATION BOARD.

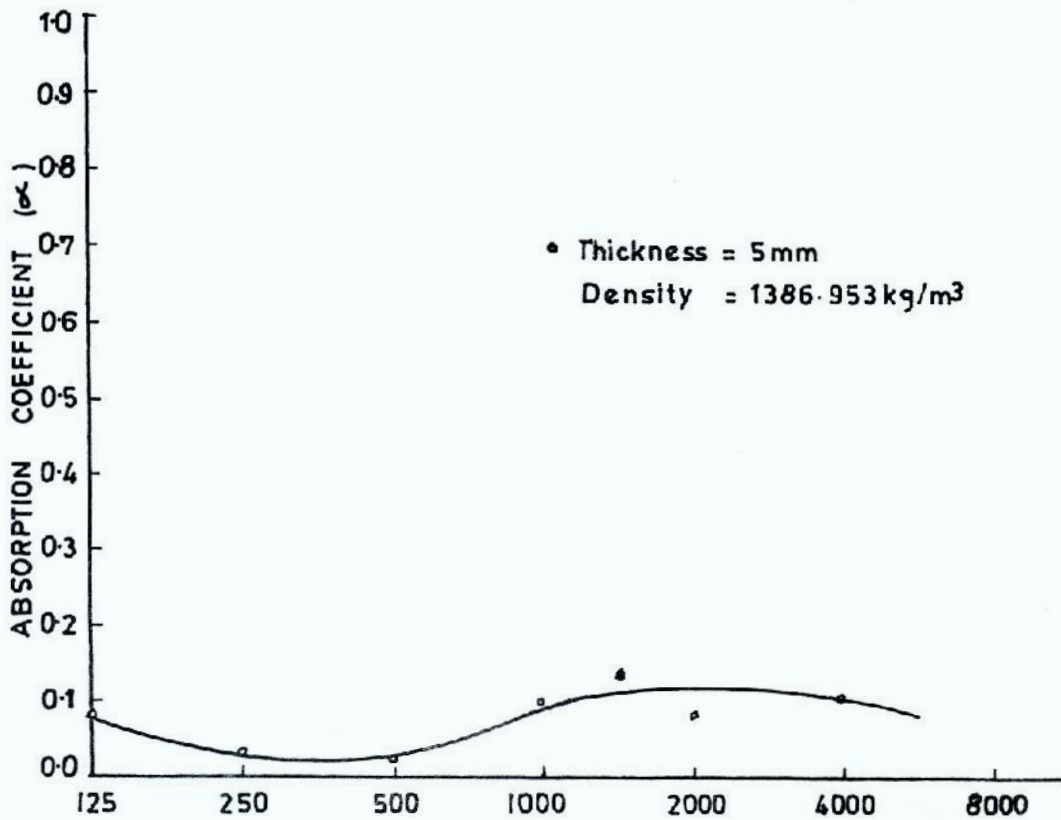


FIG. 6 SOUND ABSORPTION OF FIBRE CEMENT CEILING BOARD.

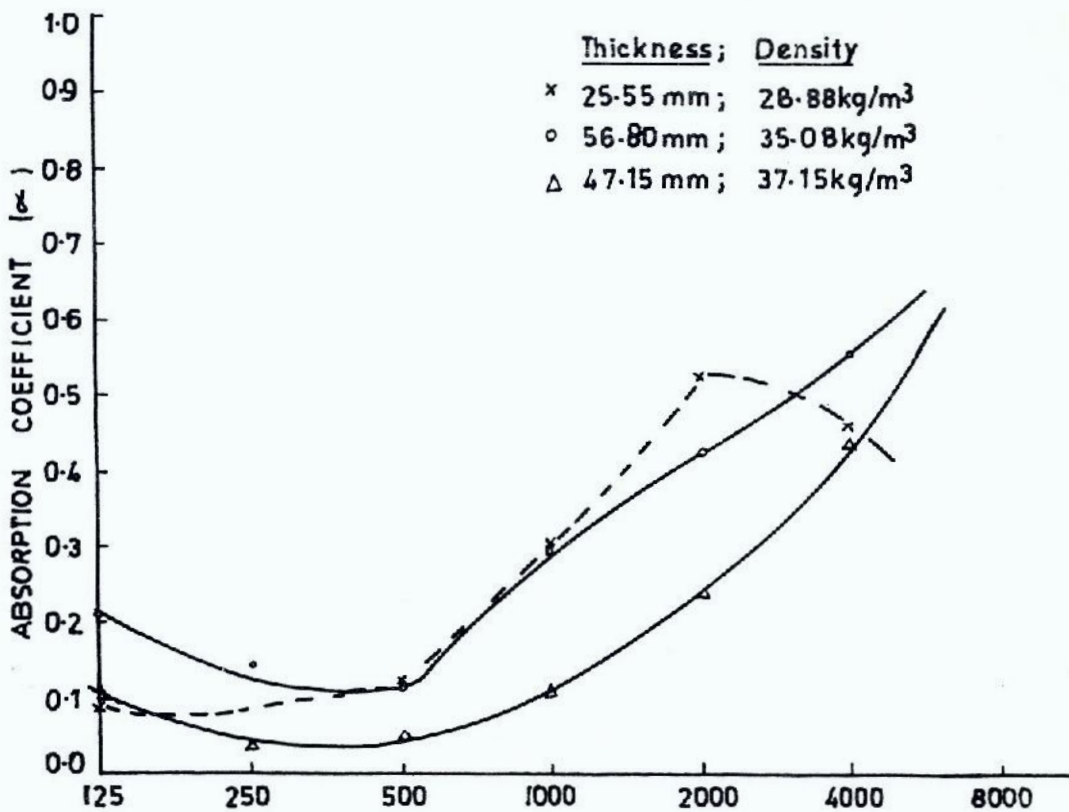


FIG. 7 SOUND ABSORPTION OF POLYURETHANE RIGID AND FLEXIBLE FOAM BOARD.

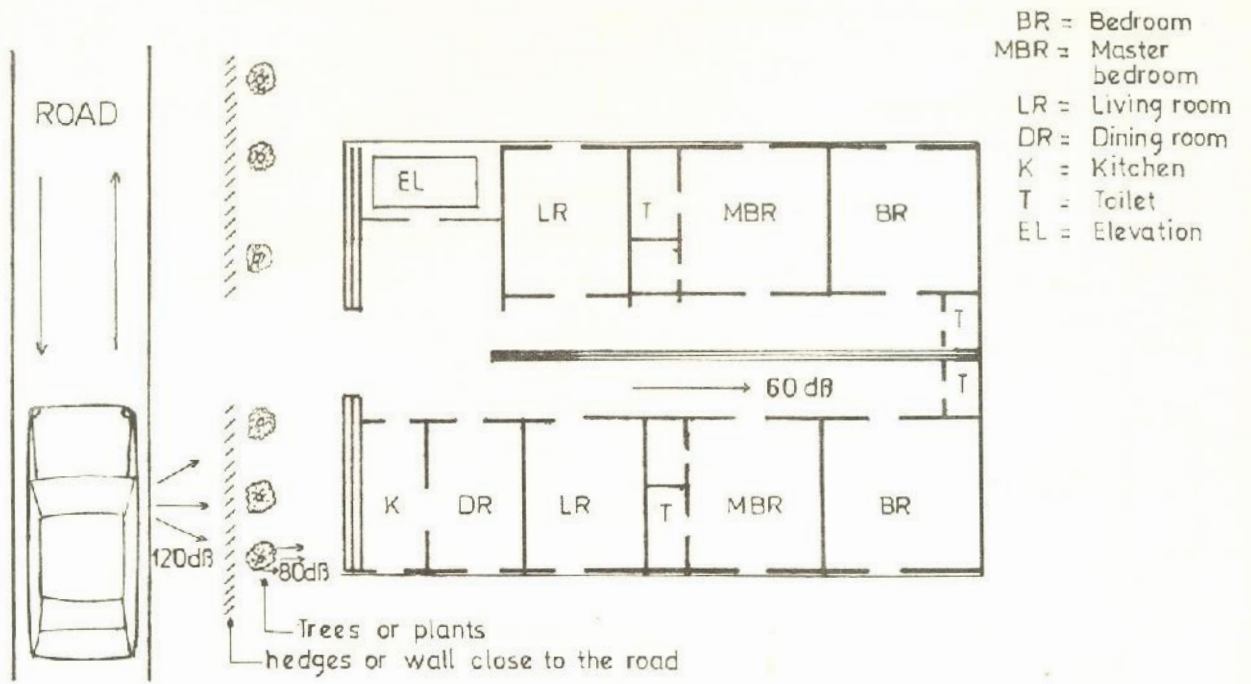


Fig. 8(a): Example of a well planned building in which the quiet area is separated from the noise area

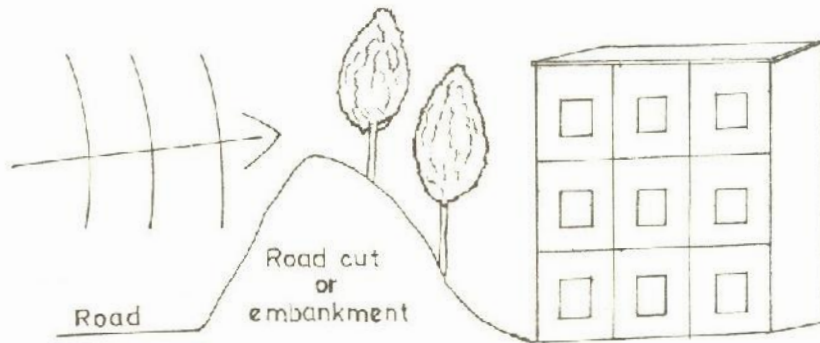
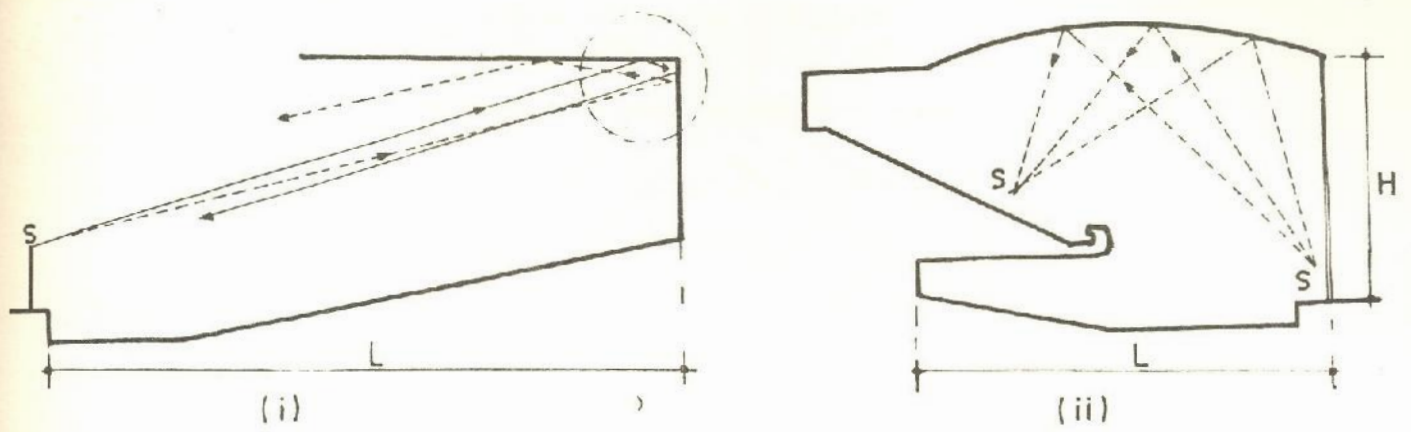
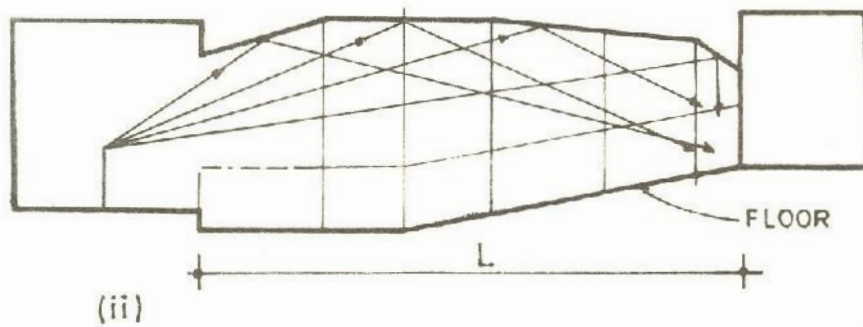
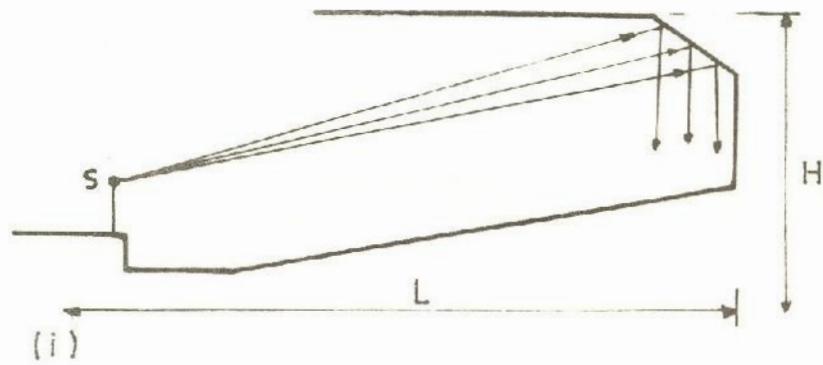


Fig. 8(b): Noise barriers using a combination of natural barriers



9(a) bad shapes



9(b) good shapes

Fig. 9: Some bad and good shapes of halls and auditoria

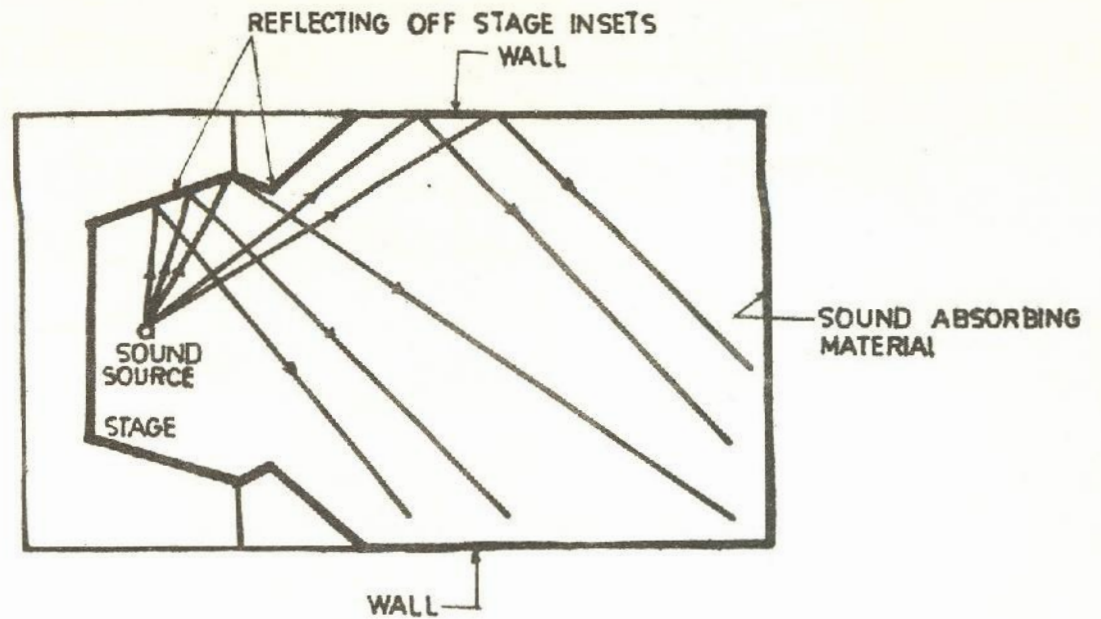


FIG. 10(a) : PLAN OF RECTANGULAR HALL SHOWING USEFUL REFLECTIONS FROM THE WALLS PLUG AND STAGE INSETS

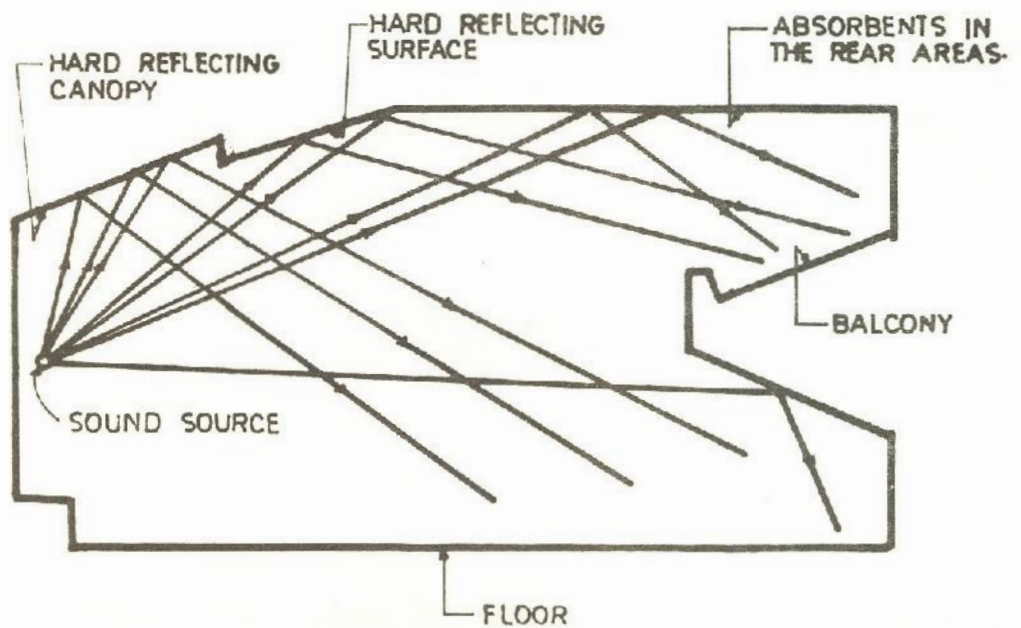


FIG. 10(b): LONGITUDINAL SECTION THROUGH A HALL SHOWING A CORRECT CEILING LAYOUT FOR USEFUL SOUND REFLECTIONS TO THE REAR SEATS. PATH DIFFERENCE BETWEEN THE DIRECT AND THE REFLECTED SOUND AT NON-LISTENING POINT EXCEEDS 12M.

CLIMATIC DATA AND SOLAR ENERGY RESOURCES AS DESIGN TOOLS FOR MODELLING LOW ENERGY AND CLIMATE -RESPONSIVE ARCHITECTURE IN NIGERIA

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ABSTRACT:

Meteorological information is critical to the assessment of the energy performance of many different types of systems, for example, buildings. The knowledge of the climate of an area also enables us to obtain sound criteria for the simulation of architectural solutions, shapes and materials necessary for controlling adverse climatic conditions, especially Nigeria's seasonal climatic variations.

Available data on wind speed and direction; solar radiation on horizontal surfaces, sunshine duration, ambient temperature and relative humidity in Nigeria have been compiled, evaluated and presented for a number of years. Statistical analyses are used in determining the wind power from the mean wind speeds and in estimating the solar radiation for those stations where there are no measurements. The monthly daily mean global radiation ranges from 3.0 to 8.1 kwhm^{-2} per day while the wind speed varies from 2.3 to 5.12 m/s at 10m above the ground. Guidelines for the design of low energy and passive solar buildings are given. Comfort indices and zones, climatic zones and prevailing wind directions are derived for applications in designing climate-responsive architectural systems for Nigeria.

INTRODUCTION:

Climate is an area's characteristic weather over a long time. It depends on the latitude, moving air masses, relative distribution of land, water and other landforms. Weather commonly refers to temperature, pressure, wind direction and speed, cloud cover, solar radiation, humidity and precipitation that occurs in a given area at a given time.

Every site has its own unique climate which is the result of modification by local features thus creating a microclimate. The knowledge of the climate of an area is a fundamental parameter in the choice of sites for settlements [1]. The factors affecting microclimate are topology (hills, mountains etc), surface characteristics (vegetation) and local obstructions (buildings and urban landscape). The microclimate can be altered mainly by the influence of vegetation

in the passive design of buildings. The most important microclimate factors for the tropical climate are the reduction of solar radiation and the enhancement of wind incident on the buildings [2].

We need to know climatic parameters such as solar radiation (global, direct, diffuse), sunshine hour, cloud cover, air temperature, humidity, wind speed and directions. This will enable us to obtain for an area, computer simulations of a number of architectural solutions, shapes and materials in a given or simulated climate. The solar and wind formation is also essential in the design and study of solar energy conversion systems [3-5]. The data presented here can serve as a good indicator for researchers and policy makers in planning towards the utilization of climatic, solar and wind energy in Nigeria.

1.1 The House and Climate:

The original functions of the house is to protect its inhabitant from the external environment. The architectural solution has always been dictated by the climate in the past. The extreme climate results in the Igloos for the Eskimos, the Kraals for the Bushmen/Hotentos of the Kalahari desert, the round huts in the northern part of Nigeria and the rectangular forms in the South-West part of Nigeria. Another factor that determines housing topologies is the materials which are available in the area. Some of the traditional house forms are determined by the shortage or complete lack of wood.

Nowadays, the house has more complex functions. A predominant function is the creation of an internal microclimate which guarantees the conditions of comfort. The development and discovery of new materials have helped in the purpose of creating a satisfying internal microclimate. The high cost of energy necessitates the development of low energy and passive building design, which will take into consideration the factors of climate. Enclosures operating in interaction with the exterior environment has associated thermal capacity which is very important in determining the internal dynamic thermal responses to the varying external environmental factors [1,2,6].

Therefore, the meteorological information presented here, is critical to the assessment of the energy performance of many different types of systems. For example, in buildings where indoor environmental control is important and consumes half the national energy consumption in cooling, heating, cooking and other domestic energy use. A comfortable free running state in which the natural energy supply system and natural energy demand achieves environmentally acceptable balance can be reached by establishing suitable system design [6].

2. COLLECTION AND ANALYSIS OF DATA:

Nigeria occupies a geographical zone, lying in the tropics and stretching from the Atlantic Ocean in the South, latitude 4°N , to latitude 14°N . It also stretches from Longitude 3°E to Longitude 15°E . A map of Nigeria is shown in Fig. 1.

2.1 Sunshine Hours:

This parameter is one of the most important climatic factors in the estimation of solar radiation. The Campbell-Stokes sunshine recorder is used by the Institute in Lagos and the Nigerian meteorological office for measuring sunshine hours. The monthly average of the daily sunshine hours for 35 towns in Nigeria over a period of about 35 years (1951–1985) are shown in Table 1. The daily annual average of sunshine hours are shown in Fig. 2. The sunrise and sunset times, the possible duration of sunshine on roof and different wall surfaces and the change-over times; when the sun shifts from one wall on to opposite walls, are required in calculating the solar loads on buildings and in the design of shading devices. These data are published elsewhere [7,8]

2.2 Solar Radiation Data and Assessment of Solar Radiation on Buildings:

The amount of solar radiation that falls on different building facades determines a substantial part of total heat flow through the buildings fabrics. The choice of building orientation, positioning of opening in external walls, the placing of structural projections (e.g. balconies, etc.), provision of glass areas and the type of glass greatly depend on the assessed quality of solar radiation incident on the building surfaces. The practical assessment of solar radiation on various surfaces of buildings is made by theoretical computations. In tropical countries, especially Nigeria, the problem is mainly that of overheating of buildings. Observational data on incident solar loads in Nigeria are very meagre. The Institute started such observation recently. Design values of solar radiation which take into consideration the hottest and worst conditions from the thermal comfort point of view are then obtained. [7,9]. The solar recording equipment, MR-5A Pyranometer were installed in 30 stations all over Nigeria (see Fig. 1). Table 2 shows the summary of the monthly average hourly solar radiation for Lokoja. Similar tables were obtained for all the

stations [10, 11] showing the daily totals (in Whm⁻² per day). The monthly mean daily global radiation on a horizontal surface for all the stations are shown in Table 3. The reference booklet: Climatological and Solar Data for Nigeria [7], gives detail information on the azimuth, altitude, solar chart and comfort chart for the stations.

For stations where solar radiation data are not available, estimation of the global solar radiation are done using the Angstrom – Page type regression equations and meteorological data available [12, 13]. A composition of measured, estimated or predicted values are shown in Fig. 3 for Lagos and Ibadan. Fig. 4 shows the iso-radiation map for annual averages of global solar radiation in Nigeria in Kwh/m² day. Fig. 5 compares the mean monthly global solar radiation for some stations in Nigeria.

2.3 Ambient Air Temperature and Relative Humidity:

The Meteorological Station, Oshodi, records the mean maximum and mean minimum dry bulb temperatures. However, in studying the performance of solar collectors, heat balance at ground level, space heating and cooling design and the thermal behaviour of solar systems, most researchers working in the solar energy field require the mean monthly temperature. Therefore, the monthly mean ambient temperatures presented in Table 4 were based on the mean maximum and mean minimum temperatures of those reported by the meteorological stations [12].

The data on relative humidity, air temperatures and Rainfall are processed and printed in Tables showing the monthly and annual means, the lowest and highest mean for the month, the minimum and maximum ever recorded and the heaviest rainfall within twenty-four hours for each station [7].

2.4 Wind Data:

The effect of wind in building is twofold: it increases the convective exchanges at the external envelope of the building and increases the air infiltrations at windows, doors and every other opening. Hence, it is a very important parameter in 'energy conscious' planning because of its influence on the thermal balance of a building. The results of wind energy analysis are used by designers to determine wind force on buildings and structures, and for proper orientation of buildings for optimum ventilation [6, 14, – 16].

The wind speed recording instruments installed in each of these stations give the 3-hourly records for the period 1951–1975. Analyses were carried out which give the prevailing wind directions. The orientation of buildings for optimum air infiltrations at windows and determination of window sizes for ther-

TABLE 1: MONTHLY MEAN DAILY SUNSHINE HOUR (1951 – 1985) IN NIGERIA

S.NO.	STATION	m JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	AVE
1	Abeokuta	5.00	5.35	5.35	5.55	5.90	4.30	3.03	2.15	3.05	4.15	5.73	6.00	4.65
2	Akure	6.52	5.86	6.30	6.37	5.30	4.24	2.74	2.65	3.50	4.83	6.37	6.40	5.09
3	Badeggi	7.88	8.18	7.66	7.13	7.63	7.02	5.05	3.78	5.62	8.12	8.96	8.84	7.16
4	Bauchi	9.10	9.0	8.24	7.23	7.73	6.98	6.90	6.12	7.10	8.74	9.46	9.32	7.99
5	Benin City	5.90	6.07	5.57	5.55	6.03	4.70	2.91	2.56	3.0	4.61	6.06	6.60	4.96
6	Bida	7.35	6.77	6.2	7.10	6.62	5.40	4.50	4.10	5.30	6.80	7.20	7.40	6.23
7	Calabar	5.40	5.20	4.54	5.10	4.92	4.24	2.74	1.90	2.27	3.62	4.96	5.76	4.22
8	Enugu	6.90	6.70	5.25	5.83	5.94	5.37	4.15	3.72	3.71	5.36	7.23	7.20	5.61
9	Ibadan	6.32	7.05	6.09	5.60	6.37	5.11	3.44	2.70	3.10	5.63	6.80	6.84	5.42
10	Ibi	7.51	7.60	7.82	7.80	7.10	5.70	4.30	5.20	5.60	7.00	7.90	8.20	6.81
11	Ikom	5.40	5.73	5.24	6.27	5.20	4.25	2.55	1.90	2.80	4.50	5.20	7.10	4.68
12	Ilorin	7.41	7.61	7.28	6.71	7.19	6.70	4.91	3.59	4.22	6.56	7.80	7.68	6.47
13	Ikeja	6.13	6.92	6.05	5.91	5.80	3.46	2.43	3.06	3.36	5.28	6.27	6.38	5.09
14	Jos	9.40	9.34	8.30	6.97	6.47	6.73	5.01	4.48	5.73	8.09	9.82	9.86	7.52
15	Kaduna	9.20	9.10	8.10	7.83	8.0	7.66	5.91	5.09	6.35	8.18	9.33	9.26	7.83
16	Kano	8.52	8.47	8.02	8.29	8.89	8.78	7.69	6.75	7.87	8.47	8.82	8.51	8.26
17	Katsina	9.45	9.10	8.50	8.10	8.70	7.98	9.96	7.30	8.61	9.50	9.56	9.83	8.72
18	Lagos	5.70	6.33	6.65	6.65	5.63	4.42	3.64	3.84	4.54	6.02	6.84	6.74	5.58
19	Lokoja	7.06	7.01	6.90	6.42	6.52	5.40	4.18	5.55	5.15	6.57	7.80	9.47	6.50
20	Maiduguri	9.34	9.44	8.91	8.47	8.37	8.60	7.20	6.53	7.48	9.12	9.43	10.0	9.34
21	Makurdi	7.70	8.01	7.30	6.83	6.96	6.40	4.90	4.46	4.85	6.79	8.15	8.40	6.73
22	Minna	8.60	8.50	8.05	7.33	7.84	6.12	5.16	4.35	6.25	8.23	9.15	9.20	7.40
23	Nguru	8.95	7.85	7.70	8.10	9.10	8.00	7.45	8.68	8.05	9.10	9.00	9.3	8.44
24	Ogoja	7.10	6.37	5.97	7.13	6.27	5.20	3.50	2.70	4.10	5.94	6.60	7.17	5.67
25	Ondo	7.24	6.62	5.76	5.60	5.56	4.85	3.05	2.58	2.95	5.01	6.54	6.78	5.21
26	Oshogbo	6.81	6.90	7.14	6.27	6.70	5.73	3.64	2.55	3.44	5.83	7.34	7.54	5.82
27	Owerri	5.45	5.54	5.20	5.00	5.10	2.95	2.75	2.15	3.00	4.10	5.40	5.85	4.37
28	Onitsha	4.74	5.30	5.45	6.54	5.60	4.66	3.37	2.77	3.30	4.50	5.94	6.20	4.87
29	Port Harcourt	4.79	5.0	4.15	4.58	4.50	3.13	2.09	2.59	2.20	3.14	4.70	5.30	3.85
30	Potiskum	8.50	9.15	7.10	8.25	7.75	7.20	6.40	6.20	7.40	8.52	8.20	9.35	7.84
31	Sokoto	9.15	9.10	8.83	8.62	8.67	9.00	8.10	7.42	8.28	9.28	9.60	9.43	8.79
32	Warri	5.62	5.58	4.98	4.85	5.11	3.53	1.93	2.80	2.41	4.27	5.64	5.89	4.38
33	Yola	9.06	8.81	8.38	8.17	8.03	8.06	6.72	6.09	6.73	8.72	8.74	9.42	7.46
34	Yelwa	8.42	7.81	7.34	7.91	7.53	7.15	6.82	5.54	7.35	8.23	6.94	8.52	7.46
35	Zaria	9.15	8.10	7.5	7.9	8.5	7.6	6.15	6.4	7.20	8.20	8.55	9.10	7.86

mal comfort depend on the prevailing wind directions given in Table 5 and the annual mean shown in Fig. 6. Expressions were derived for determining the wind speed at 10m height [14]. Fig. 7 shows the isovents at 10m height of the annual average wind speeds while Table 6 shows the mean monthly wind speeds in meter per second and offers an overall survey of the wind regimes in Nigeria.

The windiest parts of Nigeria are the boarder areas towards the northern semi-arid regions with mean wind speed reaching 5.1 m/s for Sokoto in June. The highland areas (Jos and Enugu) have high wind speeds. The southern part of the country is characterised by low wind speeds. The maximum peak for the country occurs between April and August for most sites and wind speeds greater than 8m/s (No. 4 on the Beaufort scale) occur for half of the days in the year for nearly all stations. See Table 7.

The frequency distribution of wind speeds is essential in estimating the wind power potential at a given site. The available wind power in the wind is the flux of kinetic energy crossing the wind energy conversion system and its cross sectional area, A. The theoretical instantaneous wind power, P, extractable by any wind energy system is given by the equation [14-16].

$$P = C_p \cdot \frac{1}{2} \rho A V^3 \dots\dots\dots (1)$$

where C_p is the power coefficient ($C_p = 0.593$), ρ is the air density at the given site, air density at sea level is taken to be 1.225kg/m^3 and V is the wind velocity.

The estimated wind power for the stations are given in table 7.

TABLE 2a: MONTHLY AVERAGE HOURLY SOLAR RADIATION FOR AZARE (LAT 11°55'N,

LONG. 10°10'E) (in Watt-Hours/m²)

TIME	6	7	8	9	10	11	12	13	14	15	16	17	18	19	TOTAL
JAN	13	67	245	401	602	732	771	744	694	560	350	191	43	6	5202
FEB	17	87	271	468	656	738	809	780	672	542	358	187	51	9	5756
MAR	27	104	286	523	687	781	832	803	735	642	462	260	92	18	5491
APR	23	84	290	460	602	746	736	733	673	575	433	249	89	18	5491
MAY	—	109	318	480	603	706	725	717	641	552	423	245	110	22	5638
JUN	28	120	289	482	589	717	760	735	671	576	419	252	100	24	5771
JUL	27	104	237	452	596	677	725	699	627	521	431	300	124	27	5370
AUG	20	125	591	593	641	668	746	696	601	527	383	249	90	15	5592
SEP	16	103	334	481	606	716	752	781	693	593	440	282	106	13	5880
OCT	15	92	295	445	606	711	766	799	701	561	426	255	96	15	5828
NOV	9	66	254	399	631	722	755	780	677	523	254	202	72	4	5301
DEC	—	44	193	355	551	681	733	594	664	473	360	170	32	—	4842
MEAN															5571

TABLE 2b: MONTHLY AVERAGE HOUR SOLAR RADIATION FOR LOKOJA

(LAT. 7.784°N, LONG.) (in Watt-Hours/m²)

TIME	G HOURS ENDING AT (L.A.T.)														TOTAL
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
JAN	17	89	229	401	557	659	666	658	572	452	307	158	60	13	4815
FEB	18	93	230	407	550	650	654	667	550	454	303	154	55	18	4749
MAR	46	139	269	426	522	580	616	610	552	484	386	243	125	50	5039
APR	45	180	347	497	588	631	698	723	662	557	452	310	151	40	5890
MAY	45	187	320	473	559	611	624	633	585	482	403	287	153	33	5388
JUN	28	136	290	366	487	497	503	508	507	460	371	260	122	23	4622
JUL	46	152	307	436	503	656	594	567	537	390	420	230	85	15	4891
AUG	40	150	300	430	500	645	590	565	540	410	400	225	110	25	4930
SEP	38	136	285	343	464	529	637	610	495	450	357	250	113	21	4737
OCT	34	147	304	414	520	612	663	667	611	537	412	260	109	24	5309
NOV	21	110	277	413	525	622	647	665	636	534	393	207	72	13	5085
DEC	29	111	253	412	548	622	651	613	559	471	333	192	83	19	4845
MEAN															4634

TABLE 3: MONTHLY MEAN DAILY GLOBAL RADIATION ON A HORIZONTAL SURFACE
(in Watt/m²/day)

MONTHS STATIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN
1. Abuja	5149	—	—	—	—	—	—	—	—	—	4825	4582	4852
2. Akure	—	—	—	—	—	—	—	—	3685	3690	3938	3673	4152
3. Azare	5202	5756	6176	5491	5638	5771	5370	5592	5880	5828	5301	4842	5571
4. Bauchi	4994	4747	5414	4475	5142	5222	5509	4776	4854	5345	5097	5073	4246
5. Calabar	3935	4527	4575	4591	4450	—	—	2581	—	—	—	—	4042
6. Enugu	4211	4311	4033	4172	5360	4172	3894	3690	4022	3604	3178	3150	4283
7. Ibadan	4647	5600	5617	5570	5006	4631	3967	3922	4406	4878	5000	4675	5328
8. Ilorin	4667	5405	5912	5647	5675	4972	4268	3444	4448	4715	4982	4777	4923
9. Jos	5436	5425	5489	5749	5556	5528	4778	4968	5111	5450	5415	5071	5326
10. Kaduna	5972	6319	6222	6403	6581	6028	4945	5011	5956	6000	6139	5278	5905
11. Kano	5711	6500	6833	7128	6975	6456	5695	5950	6475	6261	5875	5592	6288
12. Katsina	3554	3691	4910	5834	5870	5839	5342	4014	4150	4750	5482	3757	4766
13. Lagos	4781	5861	5342	5292	4500	3450	3231	3261	3520	4500	4261	3350	4323
14. Lokoja	4815	4797	5099	5890	5388	4622	4891	4931	4737	5309	5154	4845	5035
15. Makurdi	3380	—	—	—	—	4891	3585	3242	3463	3932	—	—	3749
16. New Bussa	4647	5103	5557	5509	5292	4786	4268	4032	4975	5083	5135	5040	4952
17. Nguru	6297	5036	6850	7960	8048	7288	7761	7793	7825	6719	6538	6356	6966
18. Obudu	3574	4438	5505	4797	4520	3879	3176	3750	4160	4425	4275	3850	4224
19. Onitsha	3756	3198	3717	3752	—	—	—	—	—	—	3752	4009	3698
20. Owerri	4364	4894	4832	4569	4342	—	—	—	—	3735	3943	3839	4368
21. P. Harcourt	—	4468	4375	—	—	—	—	—	—	—	—	—	4422
22. Serti	3936	4522	4678	4758	4281	4476	4670	4009	4611	4696	4416	4786	4488
23. Sokoto	4756	5178	5569	5600	5281	6139	4458	4459	4945	5428	5123	4973	5159
24. Warri	3060	3486	3822	4429	3919	3420	3585	3386	3764	4045	3865	3462	3748
25. Yola	5212	5737	5858	5567	5577	5587	5522	5258	6178	5680	5474	5253	5575

TABLE 4: MONTHLY MEAN AMBIENT TEMPERATURE (e°C) IN NIGERIA — (1951 — 1985)

S/No STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. Akure	26.58	29.08	28.38	27.85	26.72	26.05	24.43	24.52	25.45	26.08	26.25	26.68
2. Bauchi	22.05	24.75	28.35	29.85	28.65	26.55	24.80	24.3	24.65	25.6	23.7	22.15
3. Benin City	26.9	28.05	28.15	27.80	27.30	26.10	25.05	24.8	25.35	26.25	27.25	26.90
4. Bida	27.65	30.0	31.20	30.45	27.40	27.10	26.20	25.95	26.15	27.05	24.9	31.20
5. Calabar	26.95	28.0	27.65	27.30	27.00	26.10	25.10	24.90	25.30	25.90	26.65	26.80
6. Enugu	26.70	28.45	29.00	28.05	27.40	26.35	25.80	25.75	25.90	26.40	26.85	26.30
7. Ibadan	26.70	28.30	28.30	27.40	26.70	25.70	24.70	24.30	24.85	25.60	26.65	26.45
8. Ibi	26.78	29.33	31.53	31.67	28.28	26.87	26.10	26.37	26.15	27.17	26.50	25.90
9. Ilorin	26.20	28.40	29.35	28.50	27.40	26.20	25.30	24.90	25.35	25.50	26.70	26.10
10. Jos	20.70	22.55	24.50	24.45	23.30	21.95	20.60	20.25	21.20	22.30	21.85	20.70
11. Kaduna	22.10	25.25	27.90	28.30	26.65	24.85	23.80	23.45	24.20	25.00	24.15	22.80
12. Kano	21.20	24.05	28.15	30.85	30.70	28.55	26.20	25.35	26.30	26.80	24.50	21.95 ⁰
13. Katsina	19.23	24.25	29.45	31.60	32.42	30.80	27.77	26.75	27.95	28.13	24.03	22.45
14. Lagos	27.10	28.15	28.60	28.35	26.80	26.40	25.55	25.50	25.60	26.55	27.75	27.45
15. Lokoja	27.00	29.4	30.30	29.50	29.30	27.10	26.50	26.25	26.25	27.05	27.20	26.50
16. Maiduguri	22.13	25.46	28.62	32.36	32.51	31.34	28.20	27.00	27.73	27.57	25.07	22.90
17. Makurdi	26.60	29.23	31.08	30.38	27.65	27.00	26.05	26.35	26.25	27.05	26.57	26.57
18. Minna	27.52	29.93	30.42	29.75	27.68	26.00	25.07	25.08	25.38	26.25	26.45	26.75
19. Nguru	20.05	24.77	27.65	32.00	32.58	30.63	27.57	26.53	28.00	28.47	24.10	22.50
20. Ondo	26.00	27.8	27.45	26.85	26.30	25.05	24.70	24.30	25.00	25.30	26.20	26.15
21. Owerri	27.92	29.10	28.53	28.17	27.40	27.07	25.98	25.69	26.13	26.63	27.22	27.70
22. Port Harcourt	26.45	27.75	27.70	27.45	27.10	26.05	25.30	25.30	25.50	25.95	26.60	26.10
23. Potiskum	20.17	24.70	27.77	31.53	32.18	30.15	27.31	26.55	27.50	28.17	23.97	22.27
24. Sokoto	23.50	27.19	30.37	32.86	32.55	30.44	27.88	26.50	27.69	28.81	26.54	24.63
25. Warri	27.00	28.20	28.30	28.15	27.65	26.45	25.45	25.40	25.80	26.85	27.85	26.90
26. Yola	25.40	29.04	32.10	32.55	30.70	29.00	26.90	26.20	26.40	27.75	26.70	25.30
27. Yelwa	25.05	28.20	31.55	32.35	30.40	28.30	26.90	26.10	26.25	25.55	24.20	22.85
28. Zaria	20.72	24.33	26.72	29.23	27.73	26.03	24.57	24.63	25.20	25.85	23.40	22.40

3. DISCUSSION OF RESULTS AND APPLICATIONS:

Designing buildings for comfort in the tropics requires the establishment of sound criteria for the development of reliable specifications and standards. The data presented in the above analysis can be used in determining the effective temperatures for comfort. The Effective Temperature which depends on temperature, humidity and wind speed is an accepted index of physiological comfort. The data are used in dividing the country into climatic zones and comfort zones.

3.1 Climatic Zones and Thermal Comfort Zones:

Nigeria is divided into four climatic zones for building design. The area under each zone is a fair representation of the climatic zones in that area for building design guidelines [7, 17, 18].

Thermal comfort indices refer to a set of conditions under which thermal comfort is experienced. It is a scale of measure which takes into consideration the effect of air temperature, relative humidity, air move-

TABLE 5: PREVAILING WIND DIRECTION

PLACE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEARLY
Benin City	W-SW-NW	W-SW	W-SW	W-SW	W-SW	W-SW	W-SW	W-SW	W-SW	W-SW	W-SW	W-NW-SW	W-SW
Calabar	N-W-SW-NE-NW	S-SW-W	S-SW-NE	S-SW	S-SW-NE	SW-S-W	SW-S-W	SW-W-S	SW-W-S	SW-S	SW-S	SW-S-W-N-NW	S-SW
Enugu	W-SW-S	W-SW-S	SW-S-W	SW-S-W	SW-S-W	SW-S-W	SW-W-S	SW-W-S	W-SW-S	S-W-SW	W-S-SE	W-NE-E	W-SW-S
Ibadan	S-SW	SW-S	SW-S	SW-S	SW-S	W-SW	SW-W	SW-W	SW-W	SW-S	SW-S-W	SW-S-W	W-SW
Ilorin	SW-W-NW	SW-W	SW-W	SW-W	SW-W	SW-W	W-SW	W-SW	W-SW	SW-W	W-SW	W-SW-NW	SW-W
Jos	NE	NE	NE-SW	SW-W	SW-W	SW-W	SW-W	SW-W	SW	E-NE	NE-E	NE-E	SW-NE
Kaduna	NE-E	NE-E	NE-SW	SW	SW	SW	SW	SW	SW	SW-NE	NE-E	NE-E	SE-NE
Kano	NE-E	NE-E	NE-E-N	SW-NE	SW	SW-W	SW-W	SW-W	SW-W	SW-W	E-NE	E-NE-SW	SW-NE-E-W
Lagos	SW-S-W	SW-S-W	SW-S-W	SW-S-W	S-SW-W	SW-W-S	SW-W	SW-W	SW-W	SW-W	SW-S-W	S-SW-W	SW-W-S
Maiduguri	N-NE	N-NE	N-NE	NE-N-SW	SW-S	SW-S	SW-S-W	SW-S-W	S-SW	SW-S	NE-N	N-NE	NE-SW-S
Makurdi	E-S-NE	S-SW	SW-S-W	SW-S-W	SW-W-S	SW-W-S	SW-W-S	SW-W-S	SW-W-S	SW-S-W	SW-S-W	S-E-NE	SW-W-S
Minna	N-NE-E	N-NE-E	S	S	S	S	S	S	S	S	N-NE-E	N-NE	S-N-NE
Oshogbo	SW-W-S	SW-W-SE	SW-W-S	SW-W-S	SW-W	SW-W	SW-W	SW-W	SW-W	SW-W	SW-W	SW-W-S	SW-W-S
Port Harcourt	W-SW-N-NW	SW-W-S	S-SW	S-SW	S-SW-W	SW-S-W	SW-W-S	SW-W-S	SW-W-S	SW-S-W	S-SE-W	N-W-NW	SW-S-W
Sokoto	E-NE	E-NE	E-NE	SW-E	SW-W	SW-W	SW-W	SW-W	SW-W	E-SW	E	E	E-SW
Yola	N-S-NE	N-S-NE	NW-W-S	NW-W	NW-W	NW-W	NW-W	NW-W	NW-W	NW-W	NW-W	S-SW	NW-W

TABLE 6: MEAN MONTHLY WIND SPEEDS IN MS⁻¹ (AT 10M HEIGHT) — DERIVED FROM 1951—1975
METEOROLOGICAL DATA

S/NO. STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	S.D.
1. Benin-City	1.39	1.95	2.20	2.0	1.84	1.89	2.09	2.36	2.14	2.78	2.36	1.47	1.873	0.310
2. Calabar	1.45	1.25	1.70	1.53	1.39	1.39	1.53	1.59	1.64	1.50	1.45	1.50	1.493	0.116
3. Enugu	2.81	3.03	3.34	3.37	3.06	2.98	3.12	3.28	2.75	2.50	2.39	2.87	2.958	0.298
4. Ibadan	1.61	2.50	2.95	2.61	2.50	2.39	2.92	3.17	2.45	1.75	1.34	1.39	2.298	0.596
5. Ilorin	1.12	2.16	2.76	2.49	1.99	1.82	2.42	1.82	1.48	1.52	1.18	1.12	1.823	0.536
6. Jos	3.53	3.53	3.95	4.34	4.03	4.34	4.03	4.0	3.48	3.28	3.89	4.25	3.886	0.340
7. Kaduna	4.00	3.04	2.84	3.17	3.27	3.24	3.04	2.81	2.19	2.12	3.17	5.05	3.162	0.740
8. Kano	2.55	2.03	2.70	3.25	3.99	3.89	3.83	2.76	2.63	2.40	3.70	3.28	3.084	0.632
9. Lagos (Ikeja)	2.23	2.40	2.59	2.45	2.35	2.35	2.62	2.86	2.35	1.97	1.88	2.07	2.343	0.268
10. Lokoja	1.35	1.95	2.88	2.59	2.02	1.93	1.77	1.71	1.81	1.73	1.88	1.90	1.980	0.388
11. Maiduguri	3.29	3.37	3.52	3.24	3.24	3.34	3.18	2.48	2.22	2.67	3.14	3.01	3.058	0.379
12. Makurdi	2.38	1.82	2.88	2.88	2.51	2.45	2.19	2.55	2.12	2.55	2.25	1.73	2.359	0.345
13. Minna	1.55	1.37	1.48	1.48	1.37	1.35	1.25	1.19	1.35	1.01	1.53	1.79	1.394	0.189
14. Nguru	4.07	3.78*	4.08	3.46	3.6	3.98	3.87	3.44	3.53	3.15	3.95	4.12	3.736	0.313
15. Oshogbo	1.11	1.64	1.78	1.64	1.39	1.39	1.67	1.67	1.50	1.17	0.97	1.17	1.425	0.255
16. Port Harcourt	2.09	2.36	2.36	3.36	2.25	2.25	2.25	2.42	2.36	2.25	1.84	2.00	2.316	0.354
17. Potiskum	2.84	2.73	3.13	3.65	3.94	4.84	4.00	2.91	2.34	2.16	2.28	3.45	3.189	0.777
18. Sokoto	4.51	4.64	3.08	3.43	4.78	5.12	4.64	3.38	3.02	2.58	3.73	4.20	3.926	0.792
19. Warri	1.69	1.53	1.78	1.85	1.77	1.80	1.94	2.06	2.08	1.97	1.44	1.43	1.778	0.213
20. Yelwa	2.57	2.29	3.38	4.30	4.41	4.06	3.26	2.85	2.37	2.26	1.92	1.69	2.947	0.891
21. Yola	1.21	1.43	2.00	2.51	2.29	2.19	1.60	1.43	1.27	1.03	1.03	1.21	1.600	0.494
22. Zaria	3.19	2.09	2.04	2.56	2.63	3.58	2.19	2.39	2.14	2.11	2.50	3.01	2.536	0.472

TABLE 7: MEAN ANNUAL POWER FLUX DENSITIES $0.593PV^3/2$ IN W/M^2 , THE MEAN WIND POWER (W) FROM CIRCULAR AREAS AND THE AVERAGE NUMBER OF DAYS WITH WIND FORCE GREATER THAN 8M/S IN A YEAR. (NO. 4 ON THE BEAUFORT SCALE 5.5 – 7.9m/s)

S.NO. STATION	Mean Annual Wind Speed (m/s) at 10m Level	Expected Power or Mean Power Flux Density W/m^2		Mean Power in Watts(W) from Circular Areas (Using Pe2)		Average No. of Days with Wind Force Greater Than 8m/s (1973 – 1985)
		Pe1	Pe2	Dia-2m	Dia-4m	
1. Benin City	1.873	2.32	2.51	7.89	31.54	229 days
2. Calabar	1.493	1.18	1.20	3.77	15.08	240 days
3. Enugu	2.958	9.06	9.34	29.34	117.37	184 days
4. Ibadan	2.298	4.21	5.06	15.90	63.59	243 days
5. Ilorin	1.823	2.08	2.62	8.23	32.92	202 days
6. Jos	3.886	18.02	18.43	57.90	231.60	319 days
7. Kaduna	3.162	10.43	12.15	38.17	152.68	220 days
8. Kano	3.084	9.89	11.13	34.97	139.86	279 days
9. Lagos (Ikeja)	2.343	4.57	4.76	14.95	59.82	226 days
10. Lokoja	1.960	2.43	2.98	9.36	37.45	144 days
11. Maiduguri	3.058	9.78	10.23	32.14	128.55	196 days
12. Makurdi	2.359	4.61	4.90	15.39	61.58	167 days
13. Minna	1.394	0.94	0.99	3.11	12.44	179 days
14. Nguru	3.736	17.83	18.21	57.21	228.83	231 days
15. Oshogbo	1.425	0.99	1.09	3.42	13.70	104 days
16. Port Harcourt	2.316	4.32	4.63	14.55	58.18	201 days
17. Potiskum	3.189	10.99	12.95	40.68	162.74	258 days
18. Sokoto	3.926	20.70	23.22	72.95	291.79	288 days
19. Warri	1.778	2.0	2.09	6.57	26.26	60 days
20. Yelwa	2.947	8.86	11.29	35.47	141.87	132 days
21. Yola	1.600	1.43	1.83	5.75	23.00	212 days
22. Zaria	2.536	5.38	5.94	18.66	74.64	264 days

ment and mean radiant temperature. It is universally agreed that thermal comfort is subjective.

A study on a limited basis undertaken at the Nigerian Building and Road Research Institute yields a classification of comfort zones for each of the four climatic zones. Table 8 shows the climatic and comfort zones. These information can serve as guidelines for the design of low-energy and passive solar buildings.

It is important to exclude excessive solar heat and take advantage of the prevalent winds during cool periods in the design for comfort. The data have been transferred on to the solar chart for each latitude ranging from 5°N to 14°N. Comfort charts for different cities are given in the publication of Reference 7. The comfort index range for some cities and latitudes are also given in Table 8. The comfort charts will help

architects and designers to determine the time and months during which discomfort occurs. The clear part of the chart represents comfort zone and the shaded portion – discomfort zone. This will help in determining the month of the year in which shading is needed [8]. The comfort chart for Ibadan is shown in Fig. 8.

TABLE 8: CLIMATIC ZONES, COMFORT ZONES AND COMFORT INDEX RANGE FOR NIGERIA

S.NO.	CLIMATIC ZONES	MEAN MAX. DRY BULB TEMPERATURE °C	RELATIVE HUMIDITY PER CENT	MEAN YEARLY RAINFALL (mm)	DIURNAL RANGE OF TEMPERATURE	HEIGHT ABOVE M.S.L.	COMFORT ZONES	NAME OF STATES	REPRESENTATIVE CITIES	LATITUDE
1.	HOT DRY (H.D.)	35 - 40	up to 40%	528-960	15-20°C	300m	21°C-29°C	Borno, Sokoto, part of Kaduna, Bauchi, Kano, Gongola and Katsina	Maiduguri, Yelwa, Katsina, Bauchi, Kano, Yola, Sokoto, Gusau and Maiduguri	12°N
2.	TEMPERATE (T.D.)	30 - 36	upto 40%	1077-1390	10°C	300m	18°C-24°C	Part of Kaduna Plateau, Abuja and Benue	Zaria, Kaduna, Jos, Abuja, and Makurdi.	10°N
3.	HOT HUMID (H.H.)	30 - 35	40 - 70%	1183-1787	less than 10°C	300m 100m	21°C-26°C	Niger, Kwara, Oyo, Ondo, Imo and Anambra	Bida, Ilorin, Ibadan, Minna, Akure, Ondo, Enugu, Oshogbo, Owerri and Onitsha.	10°N 8°N
4.	WARM HUMID (W.H.)	25 - 32	70 - 100%	1185-2788	less than 8°C	100m	21°C-26°C	Lagos, Bendel, Rivers, Ogun, Cross River, and Akwa-Ibom	Lagos, Ikeja, Benin City, Uyo, Calabar, and Port Harcourt	6°N

4. CONCLUSION:

The prevailing climatic condition is a major factor that should be considered in designing a building, since it is essentially a form of protection against the external climate. Meteorological parameters are presented in this paper for the design of buildings for thermal comfort and for designing more efficient solar devices. It will also help the architects in designing energy-efficient buildings.

5. ACKNOWLEDGEMENT:

The work reported here forms part of the research activities of the Nigerian Building and Road Research Institute, Lagos.

The data presented can be considered as the nucleus information for research and development of solar and wind energy projects, designing solar control for improved thermal environment and as the basis for establishing specifications and standards in the design of buildings for comfort in the tropics.

The windspeeds and prevailing wind directions, the global solar radiation, the ambient temperature, the comfort indices and the guidelines for the design of buildings for comfort are given.

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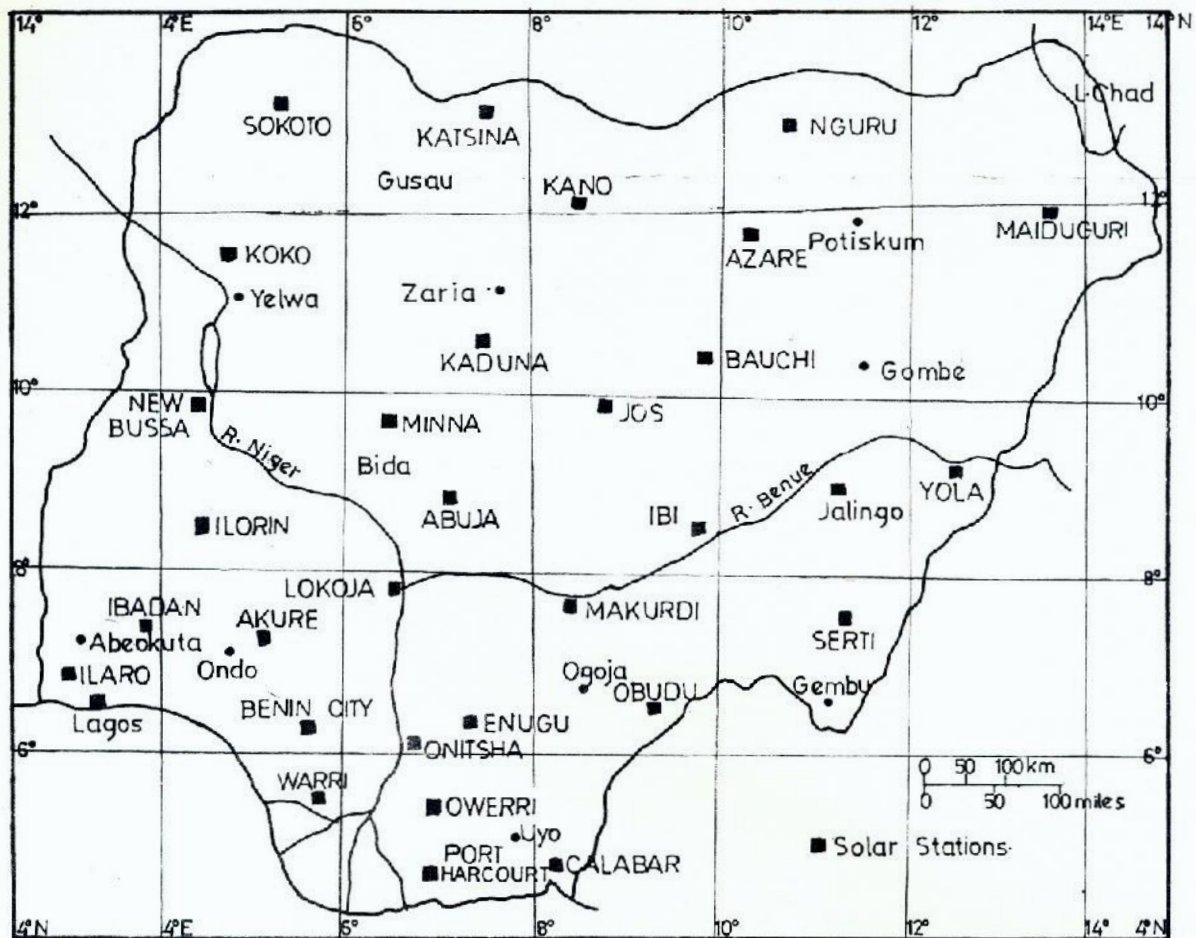


Fig. 1: Locations of NBRRI Solar Stations in Nigeria.

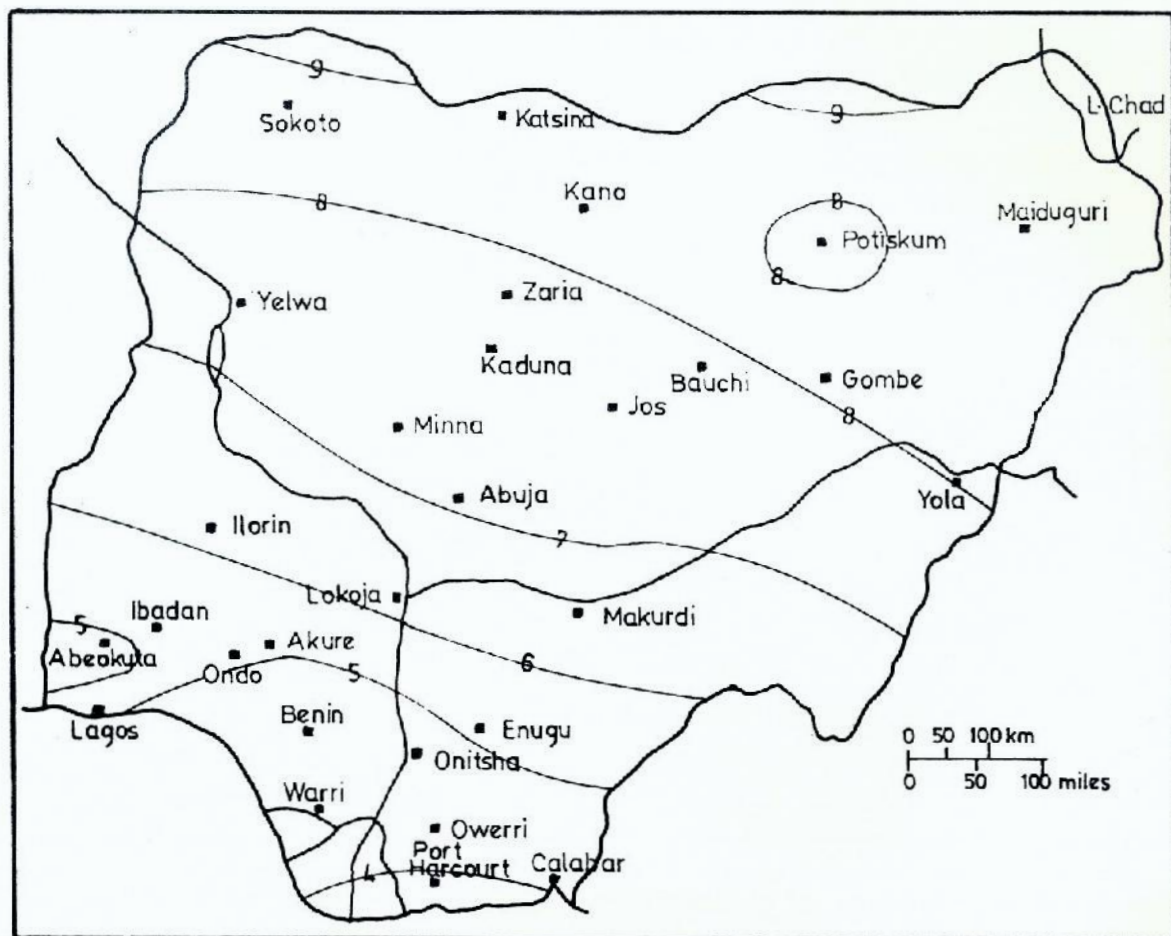
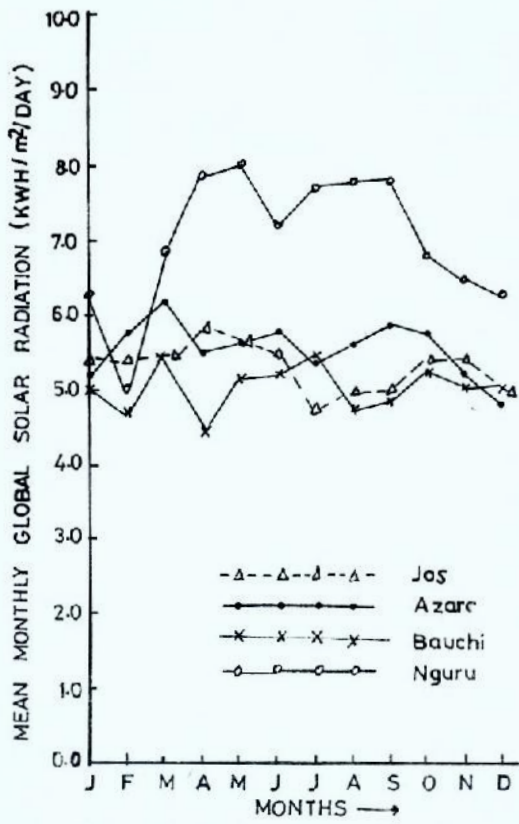
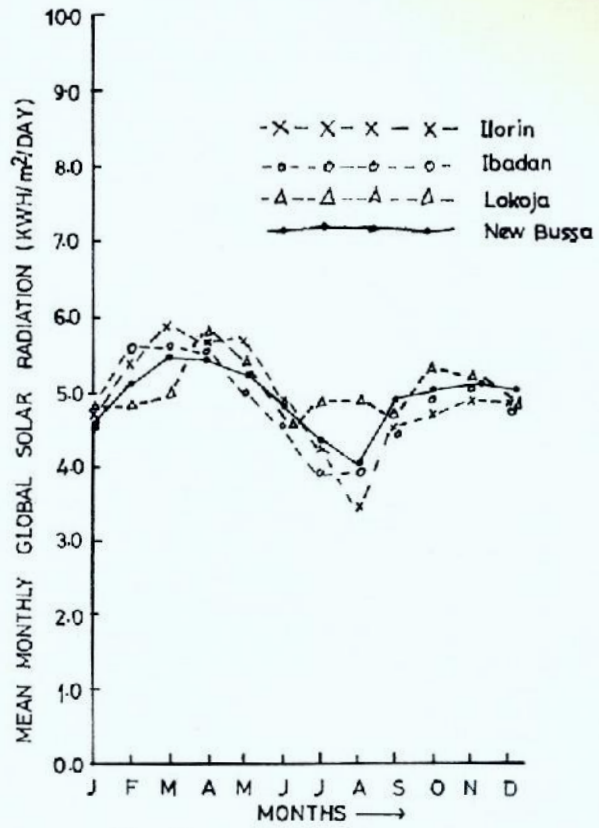


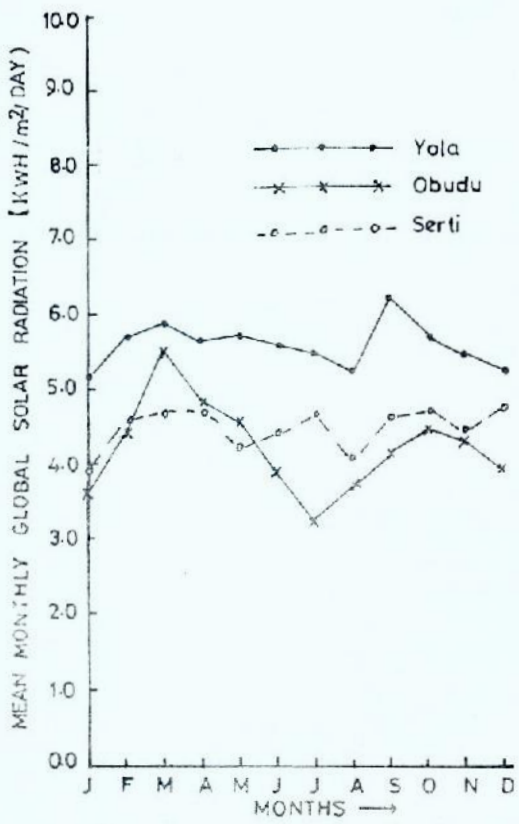
Fig. 2: Annual average of daily sunshine hours in Nigeria (1951-1985).



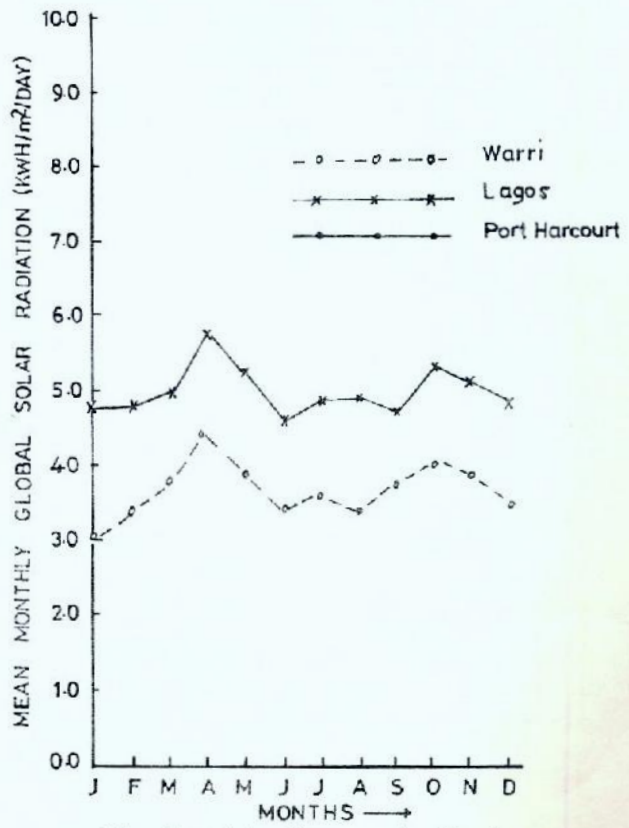
5a. North Eastern Nigeria



5b. West Central Nigeria



5c. East Central Nigeria



5d. Coastal Areas of Nigeria

Fig. 5: Variations of the mean monthly global solar radiation for Nigeria.

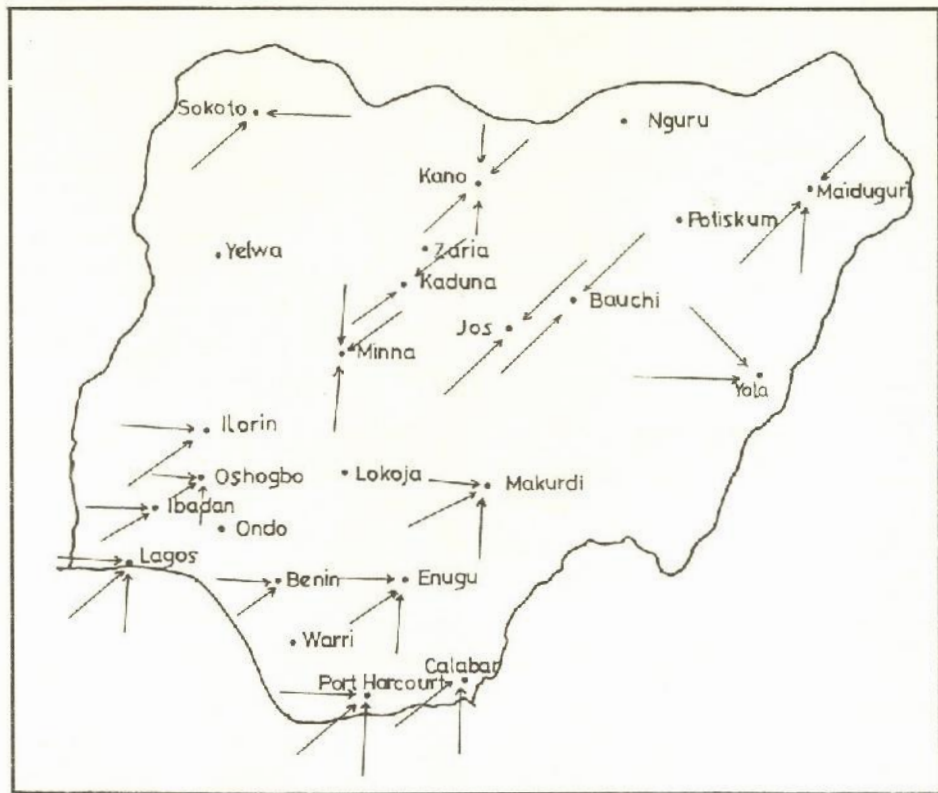


Fig. 6: Prevailing Wind Directions.

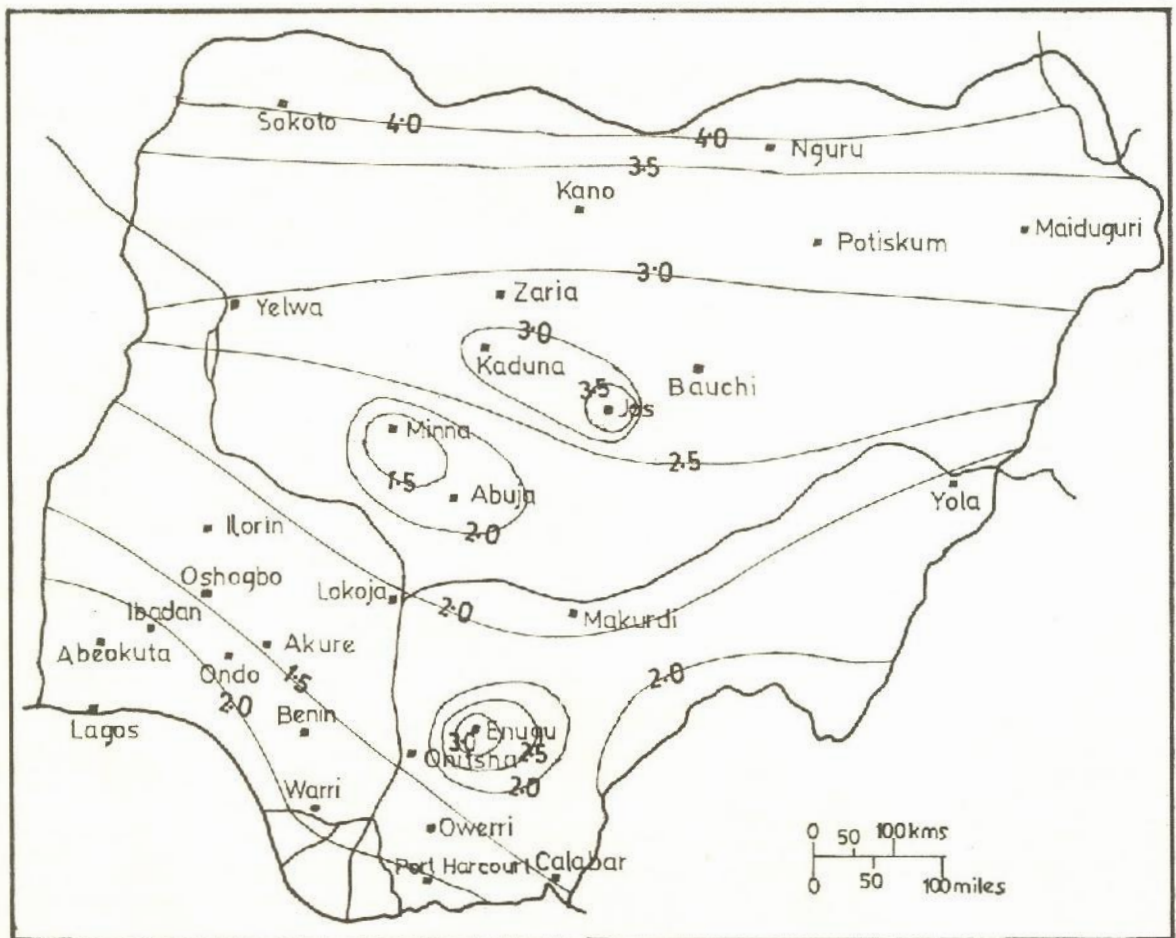
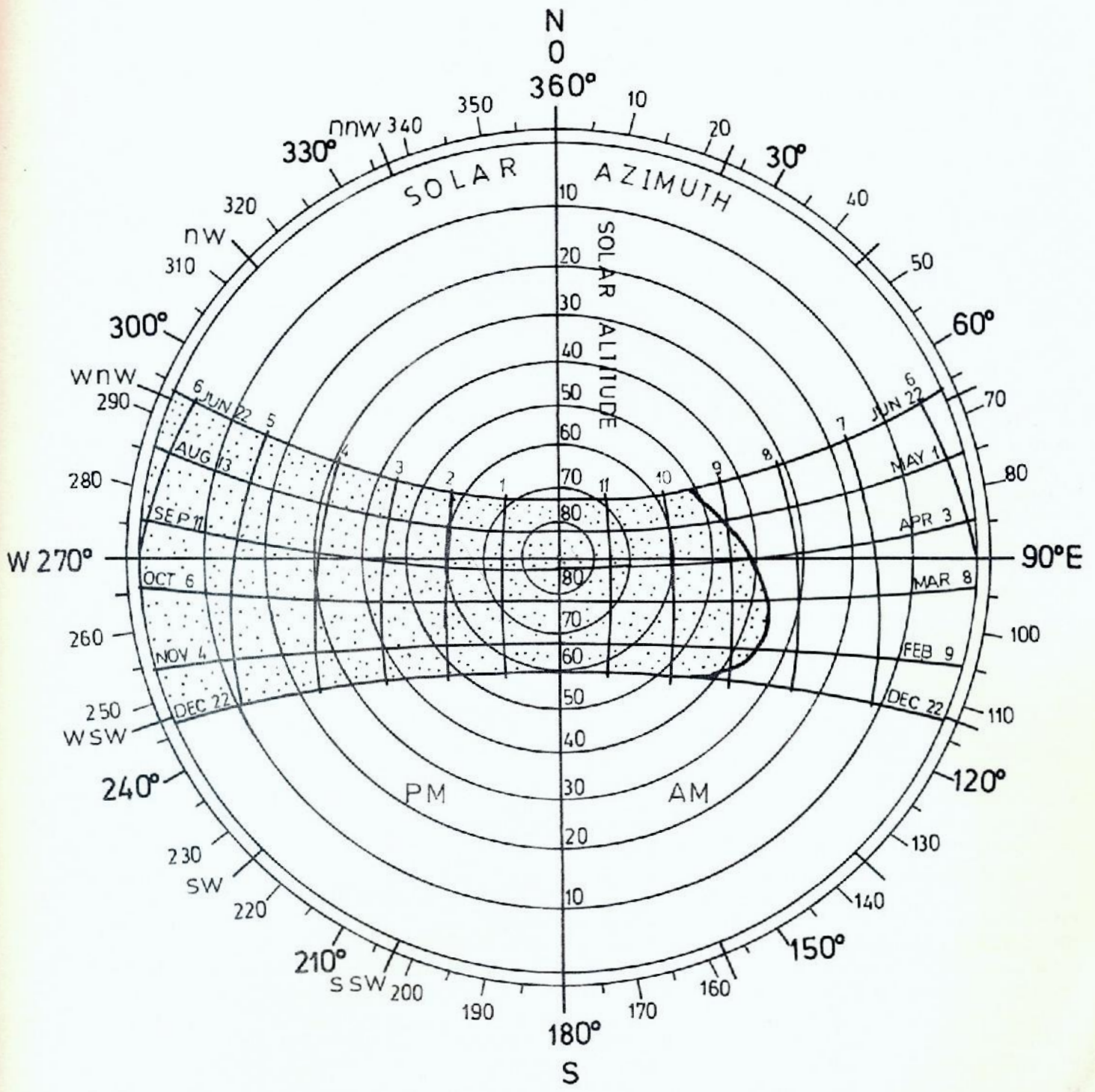


Fig. 7: Annual Average Wind Speeds (ms^{-1}); Isovents at 10m height.



IBADAN (H01-HUMID)

Fig. 8: COMFORT CHART.

ANALYTICAL INVESTIGATION OF THERMAL PERFORMANCE OF CONVENTIONAL ROOF SYSTEMS IN NIGERIA

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ABSTRACT

Warm ceilings usually contribute to thermal discomfort of occupants of a building during the daytime. A theoretical investigation of thermal performances of most commonly used roof constructions in Nigeria was carried out.

The results show that, if roof insulation is not provided, the underside of almost all the roof constructions is extremely hot. When insulation is introduced, there is a significant drop in the temperature of the ceiling underside. This is an indication of the need to insulate roofs in a warm, humid climate in order to curtail overheating of building interiors. The results also identify those roof constructions that are considered satisfactory in their heat flow control.

INTRODUCTION

In a well ventilated interior with adequately shaded openings (doors and windows), the indoor air temperature is rarely much higher or lower than the prevailing shade temperature outside. Also internal surface temperatures of walls and floors gradually attain the value of indoor air temperature.

In the tropics, it is essential to adopt design measures that are aimed at controlling excessive rise of temperature of internal surfaces above the indoor air temperature. Such surface that is prone to overheating is the underside of the roof. The position of the roof in a building leaves it exposed and unprotected against the direct radiation from the sun or diffused radiation from the sky. If the roof system is badly designed, with respect to its thermal performance, external heat is conducted to the underside of roofing sheets or ceiling sheets, where used, and from there heat is radiated on to the occupants of the rooms.

From the point of view of heat exchange between man and an internal environment, it is essential that the temperature of the ceiling or roof underside should not be excessively higher than the indoor air temperature. The heat flow from or to the surface of the clothed body, due to radiation and convection is

given by the following equation (M.A. Humphreys, 1974))

$$q = (hr + hc) (T_c - T_h)$$

q is the heat flow from / on to the surface of the clothed body (W/m^2)

hr is the coefficient of heat transfer by radiation at the surface of the clothed body ($W/m^2 \text{ } ^\circ C$)

hc is the coefficient of heat transfer by convection at the surface of the clothed body ($W/m^2 \text{ } ^\circ C$)

T_c is the mean surface temperature of the clothed body ($^\circ C$).

T_h is seen as the 'index temperature' of the thermal environment that is exchanging heat with the clothed body ($^\circ C$) T_h is a weighted average of the room air temperature (T_a) and the mean radiant temperature of the room interior (T_s)

$$T_h = \frac{hc T_a + hr T_s}{hc + hr}$$

If the ceiling temperature is excessively high, the mean radiant temperature of the room (T_s) will be much higher than the room air temperature, T_a . The contribution of T_s to the value of T_h is more pronounced, resulting in a high value of T_h . If this value is higher than the mean surface temperature of the clothed body, the net flow of heat is towards the body from the thermal environment.

In order to effect a reduction in the high ceiling temperature resulting from the radiant heat gain by the roof, the roof system must be designed to absorb as little solar radiation as possible and/or otherwise be designed to offer a high resistance to heat flow from outside to the underside of the ceiling. The roof system is not expected to offer a complete resistance to heat flow, rather the objective is to be able to have a roof that can limit the rise in ceiling temperature above that of room air temperature to an acceptable value.

Limit of Increase in Ceiling Temperature

The range of skin temperature is 30°C to 35°C. The normal skin temperature for people engaged in sedentary task is 34°C.

Meteorological records show that the outdoor air temperature in the Southern part of Nigeria is not higher than 34°C at any time of the year while in the Northern part it is higher than 34°C only in the months of March, April and May. As mentioned earlier, if buildings are well ventilated, the indoor air temperature is usually slightly lower than the outside shade air temperature. Hence, the indoor air temperature is seldom higher than the normal skin temperature of 34°C. Whereas due to the direct exposure of the roof to solar radiation, the temperature of the underside of roof ceiling can attain values much higher than the skin temperature of 34°C. In Khartoum (Sudan) the ceiling temperature of an unprotected roof was found to rise up to 49°C (A.M. Ahmad, 1975). The ceiling of badly designed roof, thus, becomes a warm surface and in effect a heat source, radiating heat to other internal surface and to the occupants of the interior. The effect of the warm ceiling on the thermal comfort of people is significant when it is realised that radiant heat transfer accounts for about 55% of the total heat gain by the body from the surrounding. The presence of any warm surface, much warmer than the skin temperature is unfavourable for thermal comfort. In order to eliminate or minimize the effect of a radiating ceiling on thermal comfort, ceiling temperature should not be excessively higher than the indoor air temperature or the skin temperature. Otto Koenigsberger and Rober Lynn recommended a permissible increase in the ceiling temperature of not more than 4.5°C above the indoor air temperature. The analysis that follows is based on this recommended thermal performance standard.

Evaluation of ceiling temperature

The roof systems considered are of light weight materials having low heat capacities. Heat flow calculations are for the steady state condition. A typical sloping roof of 15° pitch is assumed. The roof construction investigated is the horizontal ceiling type. In Nigeria, this is the conventional roof construction in which the ceiling panels are laid horizontal under the joists.

The instantaneous quantity of heat conducted into the ceiling underside through the roof system is $Q(W/m^2)$ and it is given by

$$Q = \frac{1}{R} (\theta_{sa} - \theta_{cu}) = (U_r(\theta_{sa} - \theta_{cu}))$$

where,

θ_{sa} is the so-air temperature outside the roof surface in °C

θ_{cu} is the temperature of the ceiling underside (°C)

R is the total thermal resistance of the roof construction

U_r is the thermal transmittance of the roof construction in $W/m^2 \text{ } ^\circ C$.

The same quantity of heat Q , is transferred from the underside of ceiling into the room. This heat is

$$\frac{1}{R_{si}} (\theta_{cu} - \theta_i)$$

where,

θ_i is the indoor air temperature in °C

R_{si} is the internal surface resistance at the underside of the ceiling.

Thus,

$$\frac{1}{R} (\theta_{sa} - \theta_{cu}) = \frac{1}{R_{si}} (\theta_{cu} - \theta_i)$$

$$\therefore \theta_{cu} = \frac{R_{si}}{R_{aa}} \theta_{sa} + \frac{R}{R_{aa}} \theta_i \quad \text{where } R_{aa} = R + R_{si}$$

$$\theta_{cu} = \frac{R_{si}}{R_{aa}} \theta_{sa} + \frac{(R_{aa} - R_{si})}{R_{aa}} \theta_i$$

$$\theta_{cu} = \frac{R_{si}}{R_{aa}} (\theta_{sa} - \theta_i) + \theta_i$$

$$(\theta_{cu} - \theta_i) = \frac{R_{si}}{R_{aa}} (\theta_{sa} - \theta_i)$$

OR

$$\theta_{cu} - \theta_i = \frac{U}{F_{si}} (\theta_{sa} - \theta_i)$$

where $U = \frac{1}{R_{aa}}$ and $\frac{1}{F_{si}} = R_{si}$

U is the air to air thermal transmittance or U -value of the roof construction.

F_{si} is the internal surface conductance at the underside of the ceiling.

$\theta_{cu} - \theta_i$ is the ceiling temperature excess above the indoor air temperature.

Roofing Materials

Four commonly used roofing materials that were considered in the analysis are:

- i) Corrugated asbestos cement sheet
- ii) Corrugated fibre cement sheet
- iii) Corrugated galvanised iron sheet
- iv) Corrugated aluminium sheet

Ceiling materials

The ceiling materials used in the analysis are:

- i) 13mm. fibre board
- ii) 13mm. timber board
- iii) 5mm asbestos cement sheet
- iv) 13mm. fibre cement sheet.

Insulation Materials

The insulation materials used in the analysis are:

- i) fibre glass
- ii) Polyurethane foam slab
- iii) Rockwool.

Sol-air temperature, Θ_{sa}

The effective temperature at the outside surface of the roof is the sol-air temperature given by

$$\Theta_{sa} = \Theta_o + \frac{I\alpha'}{F_{so}}$$

where Θ_o is the dry bulb temperature of the outside air in $^{\circ}\text{C}$

I is the incident solar radiation on the roof in (W/m^2) .

α' is the absorptivity of the roofing materials

F_{so} is the outside surface transfer co-efficient in $\text{W}/\text{m}^2\text{ }^{\circ}\text{C}$.

Table of ceiling temperature excess

Calculations are carried out for building roofs assumed to be located on latitude 9°N . The new Federal capital-Abuja, is on this latitude.

The climatic conditions used in the heat flow calculations are those at 12 noon on April 30. April is one of the four months that are characterised by high heat stress (M.B. Olufowobi 1986) other months are February, March and May.

The solar radiation, I on a 15° pitched roof is $950\text{W}/\text{m}^2$

The outside air temperature Θ_o is taken to be 30°C

The temperatures of the indoor air, walls and floors are assumed to be 30°C .

Heat flow calculations were carried out for four types of roofing materials in combination with four types of ceiling materials and three insulating materials.

The results of the investigations are recorded in tables of ceiling temperature excess.

Conclusions

The results of the analysis show that:-

- i) Most of the conventional roofing sheets, when used over the common ceiling sheets and without any insulating materials in between, do not provide adequate resistance to the heat flow that results from the roof's radiation (see items 1,2,3,7,8,11,12,13,14 in table.
- ii) Corrugated aluminium sheets, especially when new or re-painted, provide adequate protection against solar radiation. (see items 21,22,23,24 in table).
- iii) All the conventional roofing and ceiling materials, when used in combination with insulating materials, meet the recommended thermal performance standard. Obviously insulation of roofs is necessary to control overheating of buildings.
- iv) In a roof construction where ceiling sheets are left out, the underside of the roof can be very hot. In fact, the temperature of the roof underside may rise above 60°C (see item 34 in the table). Where this type of roof construction is to be used, for example on community halls, church, mosque or a warehouse, aluminium sheets give a better thermal performance than any other roofing materials.

Table of Ceiling Temperature Excess

	Material of Roof Deck	Horizontal Ceiling Material	Condition of Roofing Material	'Temp. of Ceiling Underside deg. C	Ceiling temp. excess above indoor air temp. deg.C
1.	Corrugated Asbestos cement sheets (5mm)	13mm. Fibre board	New or painted Old	36.3 37.8	6.3 7.8
2.	As above	13mm. timber board	New Old	38.9 41.1	8.9 11.1
3.	As above	5mm. Asbestos cement sheets	New Old	39.8 42.3	9.8 12.3
4.	As above	25mm fibre glass on 13mm fibre board	New Old	33.1 33.8	3.1 3.8
5.	As above	25mm. Fibre glass on 13mm. timber board	New Old	33.6 34.5	3.6 4.5
6.	As above	25mm. fibre glass on 5mm. asbestos cement sheets	New Old	33.7 34.7	3.7 4.7
7.	Corrugated fibre cement sheets – type 'Amiantus' (9mm)	13mm. fibre board	New Old	36.2 37.7	6.2 7.7
8.	As above	13mm. fibre cement sheet-type super flat sheet	New Old	39.1 41.4	9.1 11.4
9.	As above	25mm. fibre glass on 13mm. fibre cement sheet.	New Old	33.6 34.5	3.6 4.5
10.	As above	25mm. fibre glass on 13mm. fibre board	New Old	33.0 33.8	3.0 3.8
11.	Corrugated galvanised iron sheets (0.8)	13mm. fibre board	New Old	35.8 37.5	5.8 7.5
12.	As above	13mm. timber board	New Old	38.4 40.7	8.4 10.7
13.	As above	5mm. Asbestos cement sheets	New Old	39.3 41.9	9.3 11.9
14.	As above	13mm fibre cement sheets	New Old	38.8 41.2	8.8 11.2
15.	As above	25mm. fibre glass on 13mm. fibre board	New Old	32.8 33.6	2.8 3.6
16.	As above	25mm. fibre glass on 5mm Asbestos cement sheets	New Old	33.5 34.4	3.5 4.4
17.	As above	25mm fibre glass on 13mm fibre cement sheets.	New Old	33.4 34.3	3.4 4.3

Table of Ceiling Temperature Excess

	Material of Roof Deck	Horizontal Ceiling Material	Condition of Roofing Material	Temp. of Ceiling Underside deg. C	Ceiling temp. excess above indoor air temp. deg.C
18.	As above	25mm polyurethane foam slab on 13mm. fibre board	New	32.0	2.0
			Old	32.6	2.6
19.	Corrugated galvanised iron sheets (0.8mm)	25mm polyurethane foam slab on 5mm. Asbestos cement sheets	New	32.3	2.3
			Old	33.0	3.0
20.	As above	25mm. polyurethane foam slab on 13mm fibre cement sheets	New	32.3	2.3
			Old	32.9	2.9
21.	Corrugated Aluminium sheets (0.8mm)	13mm fibre board	New	32.1	2.1
			Old	33.7	3.7
22.	As above	13mm timber board	New	33.1	3.1
			Old	35.3	5.3
23.	As above	5mm Asbestos cement sheets	New	33.4	3.4
			Old	35.9	5.9
24.	As above	13mm fibre cement sheets	New	33.2	3.2
			Old	35.6	5.6
25.	As above	25mm rockwool on 13mm. fibre board	New	30.9	0.9
			Old	31.5	1.5
26.	As above	25mm. rock wool on 13mm. timber board	New	31.0	1.0
			Old	31.7	1.7
27.	As above	25mm. rockwool on 5mm. asbestos sheets	New	31.0	1.0
			Old	31.8	1.8
28.	As above	25mm. rockwool on 13mm. fibre cement sheets	New	31.0	1.0
			Old	31.8	1.8
29.	As above	25mm. polyurethane foam slab on 13mm. fibre board.	New	30.7	0.7
			Old	31.3	1.3
30.	As above	25mm. polyurethane foam slab on 13mm. timber board	New	30.8	0.8
			Old	31.4	1.4
31.	As above	25mm. polyurethane foam slab on 5mm asbestos cement sheets.	New	30.9	0.9
			Old	31.5	1.5
32.	As above	25mm. polyurethane foam slab on 13mm fibre cement sheets	New	30.8	0.8
			Old	31.5	1.5
33.	Corrugated Asbestos cement sheet (5mm)	None	New or painted	47.7	17.7
			Old	52.1	22.1

Table of Ceiling Temperature Excess

	Material of Roof Deck	Horizontal Ceiling Material	Condition of Roofing Material	Temp. of Ceiling Underside deg. C	Ceiling temp. excess above indoor air temp. deg.C
34.	Corrugated fibre cement sheets – type 'Amiantus' (9mm)	None	New Painted Old	55.1 61.4	25.1 31.4
35.	Corrugated galvanised iron sheets (0.8mm).	None	New Old	47.7 52.6	17.7 22.6
36.	Corrugated Aluminium sheets (0.8mm.)	None	New Old	36.4 41.2	6.4 11.2

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BUILDING DEVELOPMENT PROBLEMS AND REQUIREMENT FOR SOLUTION

APPENDIX (A)

Town Planning Stage

Building Problems	Meteorological Data Required for Solution
1. Radiation Climate	1.1 Solar radiation data Solar irradiance: (a) Global on Horizontal (b) Diffuse on horizontal.
	1.2 Sunshine duration.
	1.3 Sun-paths.
2. Wind (cold stress)	2.1 Air temperature.
	2.2 Wind speed.
	2.3 Wind direction.
3. Exposure to Rain	3.1 Wind speed.
	3.2 Wind direction.
	3.3 Rainfall values (a) Intensity (b) Duration (c) Frequency.
4. Soil Moisture	4.1 Solar radiation data
	4.2 Air temperature.
	4.3 Air humidity.
	4.4 Wind speed.
	4.5 Rainfall values.
5. Drainage Rise of Floods.	5.1 Rainfall values.
6. Availability of illumination in buildings	6.1 Illuminance values (a) Global on horizontal. (b) Diffuse on horizontal.
7. Height Control	7.1 Air temperature.
	7.2 Wind speed.
	7.3 Wind direction.
	7.4 Wind vertical variation.

APPENDIX (D)

Maintenance and Running Costs

Building Problems	Meteorological Data Required for Solution
1. Thermal Movements	1.1 Solar radiation data 1.2 Air temperature 1.3 Wind speed
2. Moisture Movements	2.1 Air temperature 2.1 Air humidity 2.3 Wind speed 2.4 Rainfall values (amount)
3. Corrosion of Metals	3.1 Air humidity 3.2 Pollution content
4. Condensation and Growth	4.1 Air temperature 4.2 Air humidity 4.3 Wind speed
5. Cooling cost	5.1 Solar radiation data 5.2 Equivalent sky temperature 5.3 Air temperature 5.4 Air humidity 5.5 Wind speed
6. Lighting Cost	6.1 Illuminance: global on horizontal 6.2 Illuminance: diffuse on horizontal
7. Dirtying of Exteriors	7.1 Pollution content 7.2 Wind speed 7.3 Wind direction 7.4 Wind vertical variation 7.5 Rain intensity 7.6 Evaporation rate

