TOWARDS THE SPECIFICATION OF WINDOWS SIZES FOR NATURAL VENTILATION IN CLASSROOMS IN A WARN CLIMATE, NIGERIA

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Abstract

The paper presents a fundamental approach to the establishment of window sizes, essentially to facilitate (achieve) the promotion air movement in classrooms. A procedure that entailed the analysis of prevailing climatic conditions in relation to the thermal comfort requirement of classroom users has been used to establish some design parameters for windows. The parameters, which are areas of openings and orientation of windows, are basic to the design of classrooms for which adequate air movement is an essential requirement for achieving thermal comfort of pupils. The procedure and results can find relevance as aids or input in the design of classrooms and for policy makers charged with the responsibility of providing space facilities for basic education in the country. On another application, the procedure and results can also be sued to estimate the likely average air speeds in existing classrooms, or classroom on the drawing board, when the relevant parameters of outdoor wind speed, wind direction, areas of window openings window orientation are known.

Keywords: Warm Climate, Thermal Comfort, Ventilation and Humidity.

Introduction

A building is required to perform many functions; provision of thermal comfort is one of them. Energy consumed in buildings to provide thermal comfort is related to the climate in which the buildings are located as well as the thermal properties of the fabrics. In the course of providing thermal comfort for building occupants, it is essential to consider the influence of prevailing climatic conditions on the thermal performance of such buildings. This is particularly important in the design of low-energy consuming buildings. Funds for the construction and operation of public buildings are generally not sufficient as to stretch it to provide air-conditioning facility in these buildings. Such public or non-prestigious buildings include schools, hospitals, and government offices in rural areas. Despite the paucity of funds, it goes without saying, that the thermal comfort of the users of these buildings is essential to their health and performance at work. Particularly for school buildings, thermal comfort and mental ability are important and are related to each other.

It is known that ventilation has the following three major functions:

i. Replacement of stale air with fresh air from outside to promote good health
ii. Cooling of indoor air and cooling of building structures
iii. Body cooling for comfort.

Functions (ii) and (iii) are related to the use of natural ventilation to provide relief from thermal discomfort. The supply of fresh air for good health is required in all buildings throughout the world. Whereas health ventilation is all that may be required in buildings located in temperate and cold climates, this is not so in low-energy buildings in warm climates, where the need goes beyond fresh air supply; there is additional requirement for natural ventilation to offer relief from warm discomfort by way of physiological cooling. The focus of this study is to apply the principles of natural ventilation as a passive cooling strategy to promote high indoor air speeds in order to facilitate heat transfer from pupils' bodies, by means of evaporation.

Natural ventilation is created by pressure differences between the outside and the inside of the building; this pressure difference may be wind-driven, or due to air temperature differences (buoyancy effect). In general, wind-driven natural ventilation is easier to achieve in a warm-humid climate, as that of Nigeria; it merely requires a low outdoor wind speed to create adequate indoor air speeds. The air temperature differences are usually not high enough to generate any effective air movement. In a study by Shodeinde (1990) on thermal conditions in some naturally ventilated residential buildings in Lagos, the temperature differences between the outside air and inside air were not more than 1.5degC. In another study of natural ventilation for houses in Thailand, Tantasavasdi, et al (2001) found that buoyancy effect can create indoor air speeds only as high as 0.1m/sec. On the other hand the study found that wind-driven effect could easily create higher indoor air speeds up to 0.4m/sec.

Ventilation Rates

Standards of ventilation rates in codes of practice are based on the requirement for the supply of fresh air in buildings, or on the basis of attaining acceptable indoor air quality. The typical units used for these standards are cubic feet of air per minute (CFM) or Litres per second (L/sec). The ventilation rate can also be expressed on the basic of per person or per unit floor area, such as litres per second per person (L/sec)/p and litres per second per m^2 (L/sec)/m^2. It can also be expressed as air changes per hour, (air changer/hr). Extract from ASHRAE (2002), standards 62-89, state that appropriate guidelines are (9.2 L/sec) per person in an office building and (7.1 L/sec) per person for schools. The Nigerian Building Code (2006) does not offer guidelines as to the ventilation rates and units for any building type section 6 of the code's requirement with regards to natural ventilation merely states that 'the minimum open able area to the outdoors shall be 4 per cent of the floor area being ventilated'.

Effective natural ventilation for body cooling entails good breeze penetration through windows, resulting in adequate air movement across a room. In this regard, the appropriate standard rate of ventilation is the speed of indoor air movement in m/sec. The level of ventilation achieved, for body cooling, will depend on the indoor air speed, size and placement of openings in a building. These parameters are serve used as design guidelines for the purpose of using natural ventilation for body cooling. These guidelines may be processed to form the basis for specifying standards for end use by building designers. The knowledge of these standards will afford the prediction to be made at the design stage, whether a classroom is likely to provide the air movement required for thermal comfort of occupants.

Climatic Zone

Komolafe (1988) and Godwin (1988) proposed four climatic zones for building design in Nigeria. The zones proposed by Godwin are adopted for the purpose of this study. Table 1 shows the climatic zones and names of some representative towns in the zones.

Comfort Index

Six principal parameters (consisting of four environmental and two personal parameters respectively) influence the establishment of a thermal balance between an individual and his surrounding environment. The environmental parameters or conditions are air temperature; mean radiant temperature; relative humidity, and air speed. The personal conditions are the activity rate and the type of clothing. A device for combining these parameters in the assessment of thermal comfort is the thermal index. Various studies have thrown up several thermal indices. Some of these devices exist as tables and charts. The thermal index adopted for this study is the effective temperature (ET) monogram. It is a chart that is used for assessing the thermal comfort of persons wearing lightweight clothing, similar to the uniform worn by school pupils in Nigeria. Olufowobi (1989), using the ET as an index of thermal comfort proposed a comfort range of 24^{o}C to 27^{o}C effective temperature, for all the climatic zones in Nigeria.

Procedure

Detailed step-by-step procedure is described in the following sections.

Step 1 – Determination of Period of Neat Stress

It is known that the higher the value of air speed blown across human body, the higher the rate of evaporation of sweat from the skin and clothing, which results in an improved thermal comfort or relief from heat stress. Therefore, the initial step in the procedure is the determination of the months and time of day when relief is required from heat stress. The shaded area on the Effective Temperature (ET) nomogram, Fig. 1, represents the comfort area for Nigeria. This area is bounded by the upper and lower effective temperature lines for comfort of 27^{o}C and 24^{o}C respectively. It is expected that an occupant of a room will feel comfortable when exposed to aggregate climatic conditions that lie within this area. Schooling is normally done between the period of 0700hr are determined. These ET values were determined for Lagos, Ilorin, Jos and Yola; each town represents a climatic zone. The scattered points, indicating the variation in the three-hourly values of ET are marked as points on the nomogram. The variations in the 3 hourly ET values on a typical day in each of the twelve months of the year were plotted for Lagos, Ilorin, Jos and Yola. Fig. 1 shows a typical 3-hourly ET positions on a day in March for Lagos. Point 7, indicates the position of ET value at 0700hr. Any point that lies outside the comfort area, beyond the 27^{o}C ET boundary, implies the likelihood of warmth discomfort, or heat stress occurring at that time. Any point below the 24^{o}C ET line implies cold discomfort. For air temperature and wet-bulb temperature (or relative Humidity) combinations outside the recognized comfort area, the nomogram shows the changes to the air speed that need to be implemented in order to re-establish thermal comfort.

Step 2:- Establishment of desired indoor air speeds

The 3-hourly ET values determined under step 1 and plotted in Fig. 1 are based on the indoor air speed of 0.1m/sec. With an increase in the indoor air speed some ET values outside the comfort area may be re-established within the area. This step describes the procedure for the determination of the average air speeds that will reposition any out-of-zone ET values to within the comfort zone.

ET nomogram has be used to establish the minimum air speed that would reposition any outside effective temperature to a value that falls within the comfort zone. In Fig. 2, a typical ET of 27.4^{o}C occurs at point A due to the combined effect of 30^{o}C dry-bulb temperature, 25.8^{o}C wet-bulb temperature and 0.1m/sec air speed. Point A is outside the comfort area. An increase in air speed to 0.5m/sec would reduce the ET to 26.8^{o}C, at point B, inside the comfort area.

By this procedure, the minimum air speeds that will promote some level of thermal comfort were established for each month in all the representing towns of the four climatic zones. These are known as the derived minimum, average indoor air speeds, needed to promote thermal comfort; they form part of Table 2.

Step 3:- Determination of Design Outdoor Air Speeds

Ojosu (1988) compiled the mean monthly wind speeds for several towns in Nigeria. These are free wind speeds; they need to be modified to provide appropriate wind speeds at the building interface with the external air. The free air speeds for Lagos, Ilorin, Jos and Yola extracted from Ojosu's compilation are reproduced in the appropriate columns of Table 2.

The magnitude of wind pressure impacting directly on a building depends on the speed of wind contiguous with the external surface. This surface wind pressure differs from the free wind pressure. The INVE guide states that the pressure on the windward face of a building varies from 0.5 to 0.8 times the pressure of the free wind.

The free wind speed is denoted by V_f(m/sec_ and the surface wind speed by Vs(m/sec). the free wind pressure is Pf. The surface wind pressure is Ps.

It is known that pressure is proportional to the square of velocity or speed. According to the Building Research Establishment, BRE (1974)

$$P_f = 0.612V_f^2 \qquad (1)$$

Also, $$P_s = 0.612\,V_s^2 \qquad (2)$$

According the IHVE Guide, as previously stated,

$$P_s = 0.8P_f \qquad (3)$$

Using eqns 1 and 2 in eqn. 3,

$$0.612\,V_s^2 = 0.8 \times 0.612V_f^2 \qquad (4)$$

Thus $$V_s = 0.89V_f \qquad (5)$$

It follows that the surface wind speed is 0.89 times the speed of free wind. The surface wind speed is the speed on the windward side of a building. It motivates the movement of air across a room, in cross ventilation. It is regarded as the design outdoor wind speed. In effect,

Design outdoor speed = 0.89 x Free wind speed

Design outdoor air speeds derived from the corresponding free wind speeds are contained in Table 2.

Step 4:- Determination of inlet window size

Givoni (1969) provides a formula that relates the average indoor air speed to the window area. The formula is

$$\frac{\overline{V_i}}{V_0} = 0.45\,\left[1 - \exp(-3.84w)\right] \qquad (6)$$

where,

$\overline{V_i}$ = average indoor air speed (m/sec)

V_0 = outdoor wind speed (m/sec)

ω = ratio of window area to wall area

The ratio $\frac{\overline{V_i}}{V_0}$ when plotted against ω , in eqn. 6, produced the curve in Fig. 3.

Eqn. 6 or fig. 3 provides an exponential relationship between the average air speed indoor and the window area (as percentage of wall area), based on the prevailing outdoor surface wind speed. One relevance of this relationship is that it can be used to pre-determine the area of inlet windows adequate to provide indoor air movement at a desired average speed. Another relevance of this relationship is that it can be used to check whether an existing window, of a known area, is large enough to admit sufficient air from outside that promotes an acceptable air speed in a classroom.

Table 3 contains window areas (as percentages of wall areas) and their associated average indoor air speeds, determined for each month of the year. These are the minimum areas of window openings, on the windward face of buildings deemed adequate to promote air movement across classrooms at the indicated minimum average speeds. This ratio of window area to wall area is known as wall porosity. The porosity values differ from month to month and also for the different zones.

Results And Discussion

Periods of Heat Stress

In planning for ventilation, the design wind speeds and direction, on which any analysis is based, should be those prevailing in the months of heat stress. The months and time of day when heat stress is likely to occur in classrooms, during school hours, have been established earlier in step 1, under PROCEDURE. Table 4 shows the month and period of heat stress five months of heat stress are established for Lagos and Yola zones, four for Ilorin zone, and none for Jos.

Olufowobi (1989) established similar months of heat stress for Ibadan/same zone with Lagos), Ilorin and Yola.

Average Indoor Air Speed for Comfort

The procedure for determining the average indoor air speed expected to provide some relief from heat stress has been previously described under step 2. The various of indoor air speed that are of relevance at this stage, are those for the months of heat stress; and they are reproduced in Table 4 alongside the corresponding months of heat stress. It is observed that it may be difficult or impossible to achieve thermal comfort by means of natural cross ventilation in Yola during the five months of heat stress. The heat is so intense that the naturally occurring breeze outdoors, is not of sufficient speed to effect relief through evaporation of sweat from the skin. For example, the desired average indoor air speeds for comfort in the months of March, April and May are 2m/sec, 4m/sec, and 2.5m/sec respectively, but the design outdoor air speeds of 1.79m/sec, 2.24m/sec, and 2.05m/sec for the same months respectively are less than the desired indoor speeds.

Attainable Average Indoors Air Speeds

The results of a simulation study, of air motion inside buildings, by Kindangen et al (1997) are drawn upon to predict attainable average indoor air speeds in classrooms located in each climatic zone. The authors studied the effects of roof shapes on wind-induced air motion inside buildings. The results adopted here, are those associated with roofs having a pitch of 20^o; this is typical of classroom roofs in Nigeria. The ratio of window area to wall area (described as wall porosity by Kindangen) is 30 percent. The average velocity coefficient, C_v, is a ratio relating the mean indoor air speed to the outdoor reference air speed. C_v corresponds to the ratio $\frac{\overline{V_i}}{V_0}$ in equation 6. Therefore

$$C_v = \frac{\overline{Vi}}{V_0} \qquad (6)$$

where $\overline{V_i}$ is average indoor air speed (m/sec)

V_0 is outdoor design air speed (m/sec)

Consequently, from the knowledge of C_v, and the direction of the outdoor wind, relative to window orientation, the attainable average indoor air speed can be predetermined at the design stage of classrooms using the appropriate graph in Kindangen's study, values of C_v were determined for five angles of incidence of outdoor air. The angles are 0^o, 30^o, 45^o, 60^o and 90^o. This was followed by the determination (using equation 6) of the attainable average air speeds inside classrooms in Lagos, Ilorin, Jos and Yola, based on 30 per cent wall porosity. These average indoor air speeds were determined for each month of the year. For the purpose of comparison, the values of attainable indoor air speeds and the desired indoor air speeds for thermal comfort are provided in Table 5. The tables clearly indicate whether the desired indoor air speed for comfort is achievable or not, and if achievable the wind directions that make this possible. Looking at Table 5a, and the month of February, in Lagos, the desired indoor air speed f 1.0m/sec is achievable only when the outdoor wind blows normal to the window opening, that is, at 0^o angle of incidence of course, apart from the months of heat stress (February, March, April and May) for the remaining months the other angles of incidence, 30^o, 45^o. and 60^o seem to be able to promote desired indoor air speeds. In Ilorin (Table 5b) the desired indoor air speeds seem unachievable in the months and period of heat stress, regardless of outside wind direction.

In Yola (Table 5d) desired indoor air speeds in the months of heat stress are not achievable, except in the month of June when there is some slight possibility of achieving the desired indoor air speed provided that windows are appropriately orientated to admit outside air at normal angle of incidence.

In Jos air movement for body cooling is not a paramount requirement as there is no single month of heat stress. A minimum indoor air speed of 0.1m/sec is merely desired to meet the demand for fresh air supply in classrooms. However, the attainable indoor air speed in Jos, at all times is higher than this minimum value. Indeed, due to the high outdoor wind speed in Jos, it is suggested that windows are orientated to receive the outdoor wind at 45^o or 60^o incidence, this is to ensure that the indoor air speed does not become unnecessarily high as to cause unpleasant draught. At 45^o angle of incidence and 30 percent wall porosity, the highest attainable average indoor air speed is 1.28m/sec occurring in April and June. Air speed values in other months are about 1m/sec, an air speed that is described to be generally pleasant but causing constant awareness of air movement.

Recommended Window Sizes

Areas of inlet windows, deemed to be sufficiently large to promote the desired indoor air speed have been estimated in step 4. The window areas are expressed as percentages of wall areas, and they are given in Table 3. For each town, the estimated window are varies in accordance with the desired indoor air speed in a particular month. It will be awkward to alter window sizes every month just to conform with the air movement requirement imposed by the changing climatic conditions. For design purposes, the recommended size or range of sizes should be sufficiently large to provide optimum indoor air speed for body cooling throughout the year or during a longer period of the year. The requirement of air movement for body cooling is crucial in the months of heat stress. Consequently, recommendation of window sizes will in the first instance be dictated by the intention to achieving the desired indoor air speeds during the period of heat stress. Of course this may not be possible in all situations. It may be totally impossible to promote body cooling through natural cross ventilation during some period of excessive heat and high humidity. In such cases the compromise is to base the window area on the desired and achievable air speed not necessarily associated with the months of heat stress.

In table 3, for Lagos the maximum wall porosity is 47% for conditions in February which is a month of heat stress. Therefore a maximum design window area specified as 50% wall porosity is recommended for classrooms in Lagos and towns within the same climatic zone.

In Ilorin, the desired wall porosity values in the months of heat stress are 100%, 94%, 81%, 67% and 56% (Table 3). Using 100% and 94% wall porosity suggests that windows will take up the whole area of external façade. Even with such high porosity values, the desired indoor air speeds are not attainable (see table 5b) an observation of fig. 3 shows that an increase in wall porosity of 10% above 60% merely provides an increase in the air speed of about 1.5%; this elevation decreases rapidly with further increase in wall porosity. Thus there is a diminishing return in air speed, when the wall porosity goes beyond 60%. This is another important point against the adoption of all window external façade. A recommendation of 60% wall porosity as the maximum design window area seems acceptable for Ilorin and the associated climatic zone.

For Yola, wall porosity values for the months of heat stress are in descending 179%, 122%, 112%, 109% and 51%. These window sizes are impracticable and unachievable, except 51% value. The combination of the results in Table 3 and Table 5d seems to support a 50% wall porosity as the maximum design window size for Yola and other towns within the same climatic zone.

Influence of Orientation

Table 5 shows the indoor air speeds resulting from different angles of incidence of outside air. Some angles of incidence seem to promote adequate indoor air movement for longer period of the year than others. For example, in Lagos, inlet air at normal incidence (0^o angle of incidence) is highly expected to promote adequate air movement inside classrooms all year round, whereas, in Ilorin, at the same normal incidence, adequate air movement is expected to be attainable during seven months of the year. In essence, orientation of buildings, in relation to the outside wind direction, is a factor in the design of classroom windows towards the achievement of satisfactory natural air movement. Table 6 shows the number of months during which adequate air movement is attainable at different angles of air incidence. Areas and orientation of openings expected to promote air movement across classrooms, at optimum average speed are contained in Table 7.

Conclusions

In the climatic analysis carried out in this paper, the internal air temperature used in the estimation of the effective temperature is of the same value as the outside air temperature. This means that, during school hours, the two temperatures are deemed to be about equal in values. This is possible to achieve with detailed thermal design of a classroom resulting in the control of overheating of internal space.

The analysis carried out in this study has resulted in the establishment of guidelines for the design of windows in classrooms for the purpose of achieving thermal comfort. In concluding this study, these guidelines have been used as inputs in the design of window openings for classrooms located in the four climatic zones. Figs. 4, 5, and 6 show typical arrangements of windows on elevations for two different modules of 6000mm and 900mm. Of course, other arrangements and modules are possible. What is essential, is for the areas and orientation of windows to be in conformity with the recommended parameters.

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Appendix

Table 1: Nigerian Climatic Zones for Building Design.

S/N	Climatic Zones	Some Representative Towns
1	Warm Humid	Lagos, Benin, Enugu, Port Harcourt
2	Hot Humid	Ilorin, Markurdi, Lokoja
3	Temperature Dry	Jos, Mambila
4	Hot Dry	Kaduna, Yola, Kano, Zaria, Kastina, Sokoto

Table 2: Monthly average indoor air speed for comfort; free outside air speeds, design outside air speed.

	LAGOS			ILORIN			JOS			YOLA		
Months	Av. indoor air speed for comfort	Free outside air speed m/sec	Design outside air speed m/sec	Average indoor air speed for comfort m/sec	Free outside air speed m/sec	Design outside air speed m/sec	Average indoor air speed for comfort m/sec	Free outside air speed m/sec	Design outside air speed m/sec	Average indoor air speed for comfort m/sec	Free outside air speed m/sec	Design outside air speed m/sec
Jan	0.1	2.23	1.99	0.1	1.12	1.00	0.1	3.53	3.16	0.1	1.21	1.08
Feb	1.0	2.49	2.15	1.0	2.16	1.93	0.1	3.53	3.16	0.1	1.43	1.28
Mar	1.0	2.59	2.32	2.0	2.76	2.47	0.1	3.95	3.53	2.0	2.00	1.79
Apr	1.0	2.45	2.19	1.5	2.49	2.23	0.1	4.34	3.88	4.0	2.51	2.24
May	0.5	2.35	2.10	1.0	1.99	1.78	0.1	4.03	3.60	2.5	2.29	2.05
June	0.1	2.35	2.10	0.5	1.82	1.63	0.1	4.34	3.88	1.0	2.19	1.96
July	0.1	2.62	2.34	0.1	2.42	2.16	0.1	4.03	3.60	0.5	1.60	1.43
Aug	0.1	2.86	2.56	0.1	1.82	1.63	0.1	4.00	3.58	0.1	1.43	1.28
Sept	0.1	2.35	2.10	0.1	1.48	1.32	0.1	3.48	3.11	0.5	1.27	1.14
Oct	0.1	1.97	1.76	0.1	1.52	1.36	0.1	3.28	2.93	1.0	1.03	0.92
Nov	0.5	1.88	1.68	1.0	1.18	1.06	0.1	3.89	3.48	0.1	1.03	0.92
Dec	0.5	2.07	1.85	1.0	1.12	1.00	0.1	4.25	3.80	0.1	1.21	1.08

Table 3: Estimated Window Area as Percentage of Wall Area (Wall Porosity)

Month	Lagos		Ilorin		Jos		Yola	
Month	Desired min. av. Indoor air speed m/sec	Wall porosity %	Desired Min. av. Indoor air speed m/sec	Wall Porosity %	Desired Min. av Indoor air speed m/sec	Wall Porosity %	Desired min. av Indoor air speed m/sec	Wall Porosity %
Jan	0.5	5	0.1	10	0.1	4	0.1	10
Feb	1.0	47	1.1	52	0.1	4	0.1	8
Mar	1.0	43	2.0	81	0.1	3	2.0	112
Apr	1.0	20	1.5	67	0.1	3	4.0	179
May	0.5	24	1.0	56	0.1	3	2.5	122
June	0.1	5	0.5	31	0.1	3	1.0	51
July	0.1	4	0.1	5	0.1	3	0.5	35
Aug	0.1	4	0.1	6	0.1	3	0.1	8
Sep	0.1	5	0.1	8	0.1	4	0.5	44
Oct	0.1	6	0.1	8	0.1	4	1.0	109
Nov	0.5	30	1.0	94	0.1	3	0.1	11
Dec	0.5	27	1.0	100	0.1	3	0.1	10

Table 4: Required average indoor air speeds in the months and periods of heat stress

Town	Months of Heat Stress	Period of Heat street	Required av. Indoor air speed m/sec	Design outside air speed m/sec
Lagos	February	12.00hr – 16.00hr	1.0	2.15
	March	10.00hr – 16.00hr	1.0	2.32
	April	12.00hr – 16.00hr	1.0	2.19
	May	12.00hr – 16.00hr	0.5	2.10
	November	12.00hr – 16.00hr	0.5	1.68
Ilorin	March	12.00hr – 16.00hr	2.0	2.47
	April	12.00hr – 16.00hr	1.5	2.23
	May	12.00hr – 16.00hr	1.0	1.78
	November	12.00hr – 16.00hr	1.0	1.06
	December	12.00hr – 16.00hr	1.0	1.00
Yola	March	10.00hr – 16.00hr	2.0	1.79
	April	10.00hr – 16.00hr	4.0	2.24
	May	10.00hr – 16.00hr	2.5	2.05
	June	12.00hr – 16.00hr	1.0	1.96
	October	12.00hr – 16.00hr	1.0	0.92

Table 5: Expected Average Air Speeds inside Classrooms for various angles (α) of outdoor air incidence and 30% Wall Porosity

Table 5a: Lagos

Month	Desired min. air speed indoors V_im/sec	Design outside air speed V_0m/sec	Expected Average Air Speeds Indoors				
			When $\alpha = 0^0 C_v = 0.5$	$\alpha = 30^0$ $C_v = 0.4$	$\alpha = 45^0$ $C_v = 0.33$	$\alpha = 60^0$ $C_v = 0.25$	$\alpha = 90^0$ $C_v = 0.05$
Jan	0.1	1.99	1.00	0.80	0.66	0.50	0.10
Feb	1.0	2.15	1.08	0.86	0.71	0.54	0.11
Mar	1.0	2.32	1.16	0.93	0.77	0.58	0.12
Apr	0.5	2.19	1.10	0.88	0.72	0.55	0.11
May	0.1	2.10	1.05	0.84	0.69	0.53	0.11
Jun	0.1	2.10	1.05	0.84	0.69	0.53	0.11

July	0.1	2.34	1.17	0.94	0.77	0.59	0.12
Aug	0.1	2.56	1.28	1.13	0.85	0.64	0.13
Sept	0.1	2.10	1.05	0.84	0.69	0.53	0.11
Oct	0.1	1.76	0.88	0.77	0.58	0.44	0.09
Nov	0.5	1.68	0.84	0.67	0.55	0.42	0.08
Dec	0.5	1.85	0.93	0.74	0.61	0.46	0.09

Table 5b: Ilorin

Month	Desired min. air speed indoors V_im/sec	Design outside air speed V_0m/sec	Expected Average Air Speeds Indoors				
			When $\alpha = 0^0 C_v = 0.5$	$\alpha = 30^0$ $C_v = 0.4$	$\alpha = 45^0$ $C_v = 0.33$	$\alpha = 60^0$ $C_v = 0.25$	$\alpha = 90^0$ $C_v = 0.05$
Jan	0.1	1.00	0.50	0.40	0.33	0.25	0.05
Feb	1.0	1.93	0.97	0.77	0.64	0.48	0.10
Mar	2.0	2.47	1.24	0.99	0.82	0.62	0.12
Apr	1.5	2.23	1.12	0.89	0.74	0.56	0.11
May	1.0	1.78	0.89	0.71	0.59	0.45	0.09
Jun	0.5	1.63	0.82	0.65	0.54	0.41	0.08
July	0.1	2.16	1.08	0.86	0.71	0.54	0.11
Aug	0.1	1.63	0.82	0.65	0.54	0.41	0.08
Sept	0.1	1.32	0.66	0.53	0.44	0.33	0.07
Oct	0.1	1.36	0.68	0.54	0.45	0.34	0.07
Nov	1.0	1.06	0.53	0.42	0.35	0.27	0.05
Dec	1.0	1.00	0.50	0.40	0.33	0.25	0.05

Table 5c: Jos

Month	Desired min. air speed indoors V_im/sec	Design outside air speed V_0m/sec	Expected Average Air Speeds Indoors				
			When $\alpha = 0^0 C_v = 0.5$	$\alpha = 30^0$ $C_v = 0.4$	$\alpha = 45^0$ $C_v = 0.33$	$\alpha = 60^0$ $C_v = 0.25$	$\alpha = 90^0$ $C_v = 0.05$
Jan	0.1	3.16	1.58	1.26	1.04	0.79	0.16
Feb	0.1	3.16	1.58	1.26	1.04	0.79	0.16
Mar	0.1	3.53	1.77	1.41	1.17	0.88	0.18
Apr	0.1	3.88	1.94	1.55	1.28	0.97	0.19
May	0.1	3.60	1.80	1.44	1.19	0.90	0.18
Jun	0.1	3.88	1.94	1.55	1.28	0.97	0.19
July	0.1	3.60	1.80	1.44	1.19	0.90	0.18
Aug	0.1	3.58	1.79	1.43	1.18	0.90	0.18
Sept	0.1	3.11	1.56	1.24	1.03	0.78	0.16
Oct	0.1	2.93	1.47	1.17	0.97	0.73	0.15
Nov	0.1	3.48	1.74	1.39	1.15	0.87	0.17
Dec	0.1	3.80	1.90	1.52	1.25	0.95	0.19

Table 5d: Yola

Month	Desired min. air speed indoors V_im/sec	Design outside air speed V_0m/sec	Expected Average Air Speeds Indoors				
			When $\alpha = 0^0 C_v = 0.5$	$\alpha = 30^0$ $C_v = 0.4$	$\alpha = 45^0$ $C_v = 0.33$	$\alpha = 60^0$ $C_v = 0.25$	$\alpha = 90^0$ $C_v = 0.05$
Jan	0.1	1.08	0.54	0.43	0.36	0.27	0.05
Feb	0.1	1.28	0.64	0.51	0.42	0.32	0.06
Mar	2.0	1.79	0.90	0.72	0.59	0.45	0.09
Apr	4.0	2.24	1.12	0.90	0.74	0.56	0.11
May	2.5	2.05	1.03	0.82	0.68	0.51	0.10
Jun	1.0	1.96	0.98	0.78	0.65	0.49	0.10
July	0.5	1.43	0.72	0.57	0.47	0.36	0.07

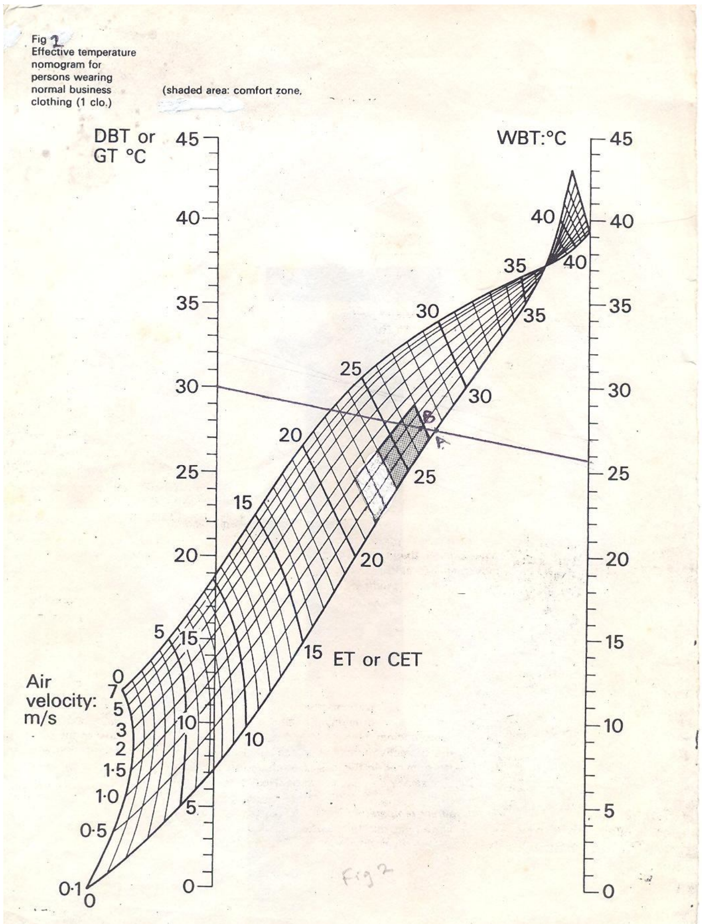
Aug	0.1	1.28	0.64	0.51	0.42	0.32	0.06
Sept	0.5	1.14	0.57	0.46	0.38	0.29	0.06
Oct	1.0	0.92	0.46	0.37	0.30	0.23	0.05
Nov	0.1	0.92	0.46	0.37	0.30	0.23	0.05
Dec	0.1	1.08	0.54	0.43	0.36	0.27	0.05

Table 6: Influence of angle of incidence on number of months in which classroom air speed may be adequate

Towns/Zones	Angles of Incidence				
	0^o	30^o	45^o	60^o	90^o
	No of months	Not of months	No of months	No of months	No of months
Lagos (warm Humid)	12	9	9	7	5
Ilorin (Hot, Humid)	7	6	6	5	1
Yola (Hot, Dry)	8	7	7	6	0

Table 7: Recommended wall porosity and window orientation for classrooms in the different climatic zones

Towns/Zones	Wall Porosity	Preferred orientation of openings
Lagos (warm Humid)	50%	W; S; Sw; S15^0W; 5150W; S75^oW
Ilorin (Hot, Humid)	60%	SW
Jos (Temperature, Dry)	30%	S
Yola (Hot, Dry)	50%	SW; S15^0W; S75^0W; W; S



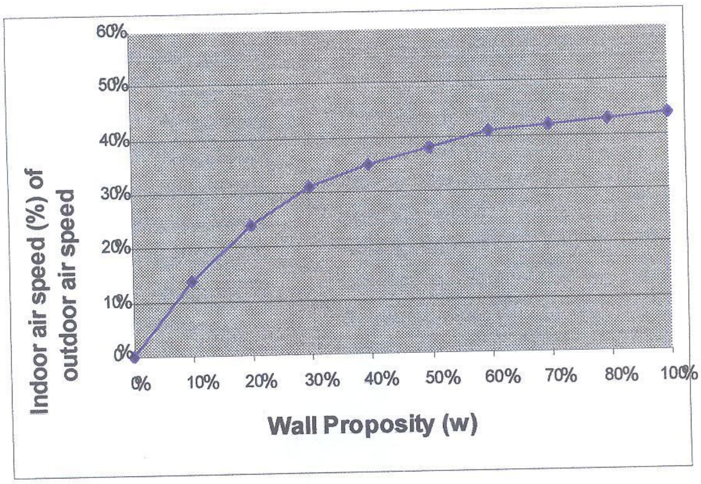


Figure 3: **Relationship between Wall Porosity and Average Indoor Air Speed**

LAGOS / YOLA ZONE

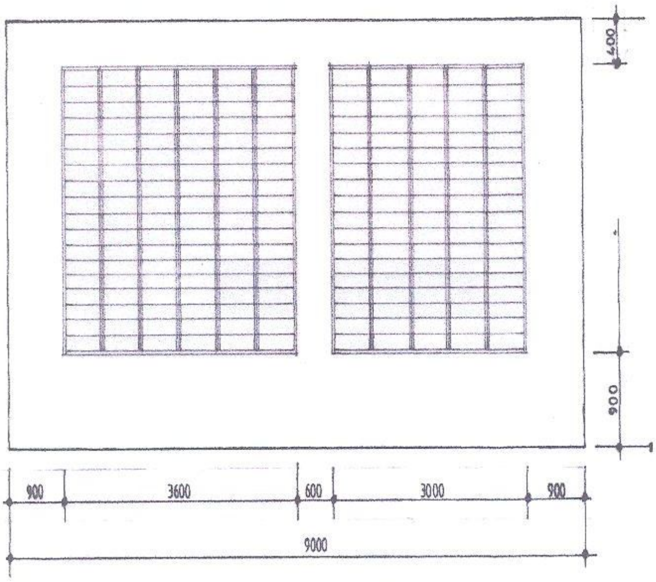
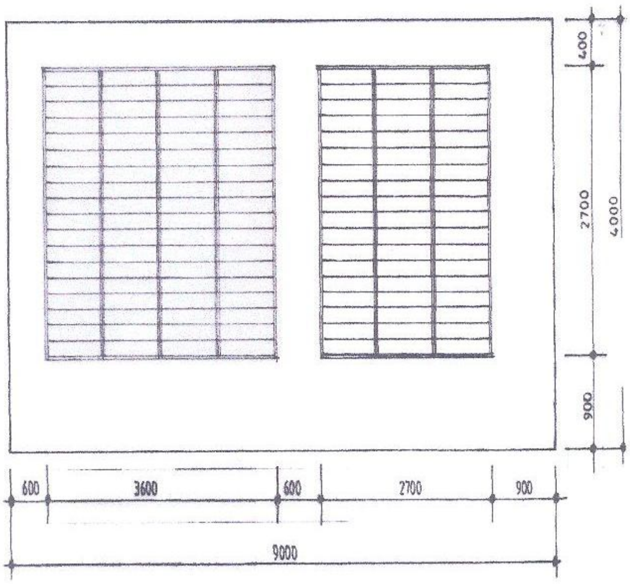


Fig. 4a WINDOW ELEVATION AT 600mm MODULE



4b WINDOW ELEVATION AT 900mm MODULE

ILORIN ZONE

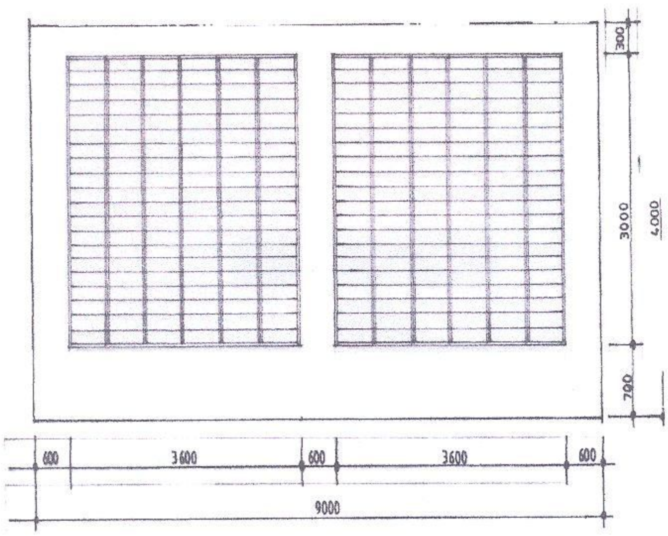


Fig. 5a WINDOW ELEVATION AT 600mm MODULE

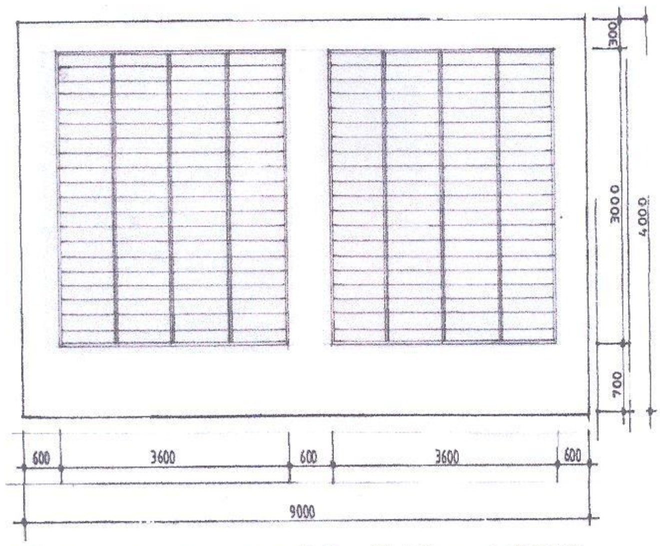
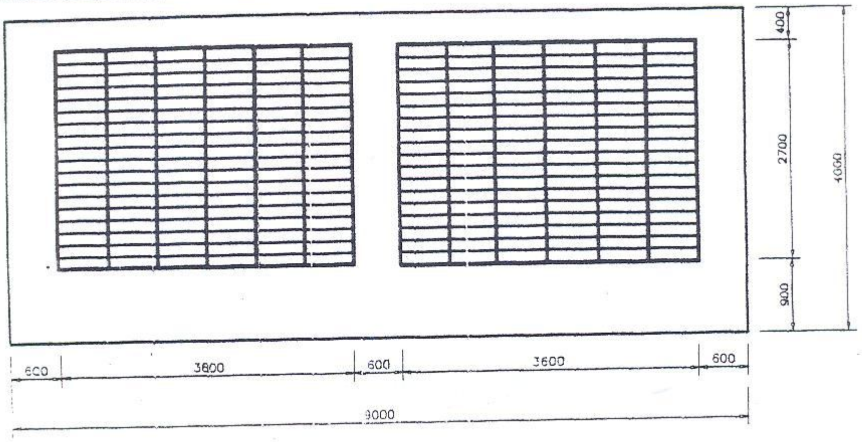
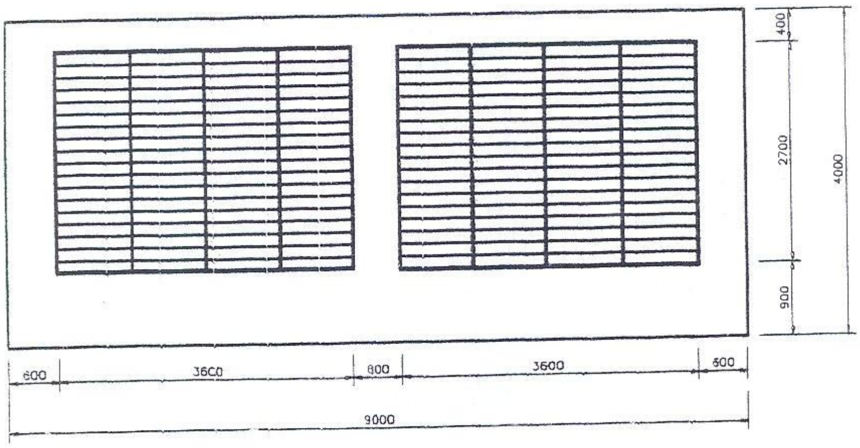


Fig. 5b WINDOW ELEVATION AT 900mm MODULE

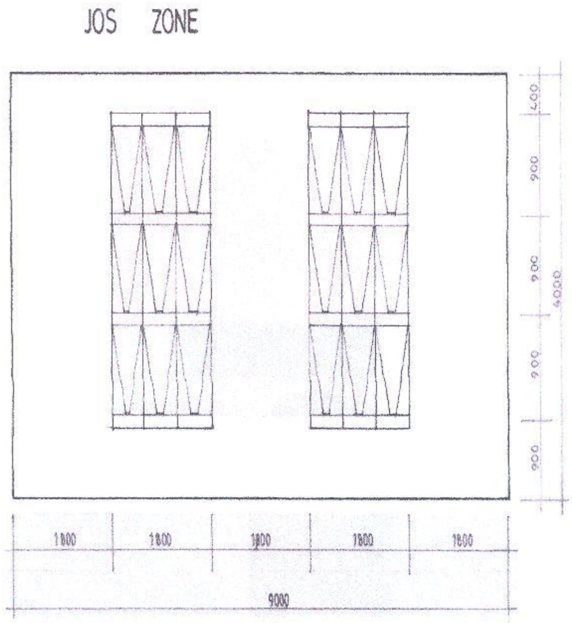
ILORIN ZONE



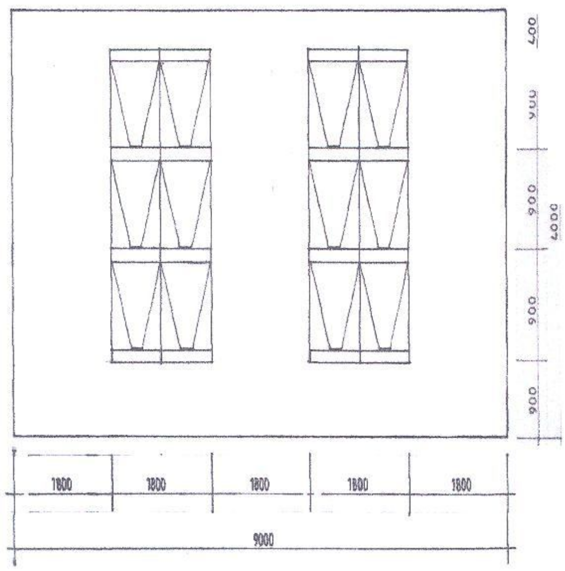
5a WINDOW ELEVATION AT 600mm MODULE



5b WINDOW ELEVATION AT 900mm MODULE



6a WINDOW ELEVATION AT 600mm MODULE



6b WINDOW ELEVATION AT 900mm MODULE