GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 10, NO. 4, SEPTEMBER 2004: 627 - 633
COPYRIGHT(C) BACHUDO SCIENCE CO. LTD. PRINTED IN NIGERIA. ISSN 1118-0579

RESPONSES ON INDOOR THERMAL ENVIRONMENT IN SELECTED DWELLINGS DURING THE HOT SEASON IN IBADAN, NIGERIA

F. O. A. AKINGBADE

(Received 2 November, 2001; Revision Accepted 25 March, 2004)

ABSTRACT

This paper reports the results of a thermal comfort study conducted recently on 12 subjects in the hot season in Ibadan, located in the hot humid climate. A statistical sample was carried out on these subjects casting their thermal comfort votes at half-hourly basis in four major areas of the city between February and April. Simultaneous records of temperature and humidity for indoors and outdoors were obtained. The data were analyzed for each of the subjects as well as the subjects combined. The optimum temperature obtained was 29.5 ^{0}C, thus indicating that the subjects can tolerate higher temperatures during the hot season, when cooling loads have the greatest impact on energy use, and the comfort temperature range was between 28 ^{0}C and 32 ^{0}C. This knowledge of preferred temperature would play a significant role in providing comfort at the least cost of energy through the development of a better design of building using a combination of passive cooling systems.

KEYWORDS: dry-bulb air temperature, relative humidity, hot humid zone, thermal comfort.

INTRODUCTION

In building, thermal comfort condition is a major component of health. It is regarded as being present when an individual is in an environment whose temperature, both air and radiant, humidity and air movement, are within limits found acceptable by most people wearing the amount of clothing which is typically worn in that environment. Ambient temperature, which deviate markedly from the range of body's temperature create stress for the human being and the reaction to this stress can adversely affect health and well-being. Early worker like Fanger (1971) has shown that there is a clear tendency for hot or cold discomfort to reduce a person's performance as well as his / her well-being. Other workers like McIntyre (1985) and Baker and Standeven (1996) have also studied how the human body reacts to environmental temperature changes, air movement, humidity, air changes and purity. These studies have shown that small deviations in temperature within the range 18 ^{0}C and 25 ^{0}C can be experienced without adverse effects, and outside this, there is a range at which discomfort is being experienced and beyond this adverse effect on health may result (Mant and Muir-Gray, 1986). As there are innumerable reasons for occupants to have different levels of perception of the indoor environment, and almost as many reasons for an occupant to have different requirements at different times, a minimum degree of control by body regulatory mechanisms over what the indoor environment provides is much desired. This desire to attain and possibly maintain a thermally comfortable environment has necessitated the studies on buildings, which will require less energy and still provide the required comfort. In Nigeria, only a handful of investigations have been conducted, most of which were not detailed enough to justify their results. There are three well-documented records of thermal comfort studies in Nigeria (Ambler, 1955; Small and Chandler, 1967; and Agarwal and Komolafe, 1984). In particular, Agarwal and Komolafe (1984) gave a broad comfort zone between 21 ^{0}C and 26 ^{0}C Corrected Effective Temperature (CET) recommended from a pilot study for the hot humid, warm humid and the hot dry zones of the country. Full scale studies were later conducted in the warm humid zone (Komolafe and Akingbade, 2003), and in the temperate dry zone (Akingbade, 2003). Thus, there is need to study the hot humid zone using Ibadan as representative. The results of the studies would provide a challenge to the designers of domestic buildings to balance the increasing demand and use of air conditioning with the economics of long-term operational costs, in the era of high cost of providing electricity to power domestic cooling appliances.

This paper reports the result of a thermal comfort study, aimed at finding the optimum conditions for comfort as well as the range of temperatures on either side of the optimum, which can be regarded as comfortable. For consistency with previous thermal comfort research, the findings from the study will be compared with those specified by ASHRAE 55-92R and other existing relevant field studies.

ASSUMPTIONS MADE IN THIS STUDY

The body heat balance is the sum of these variables: radiation, evaporation and heat storage (Butera, 1989). The terms are regarded as independent as an infinite series of combinations of these variables would satisfy the body's heat balance. Thus, the choice of these variables would depend on the purpose and the simplicity of the practical thermal index. In this study, assumptions were made in the collection of data to satisfy the determination of thermal index. Some of the variables affecting thermal comfort like air movement, and mean radiant temperature were assumed constant. The clothing and activity levels have been taken to be lightly clothed in cotton dress (0.5 clo-0.7clo) frequently

---

F. O. A. AKINGBADE, Building Physics Section, Km 10 Idiroko Road, P.M.B. 1055 Ota, GPO, Ota-Ogun State - Nigeria

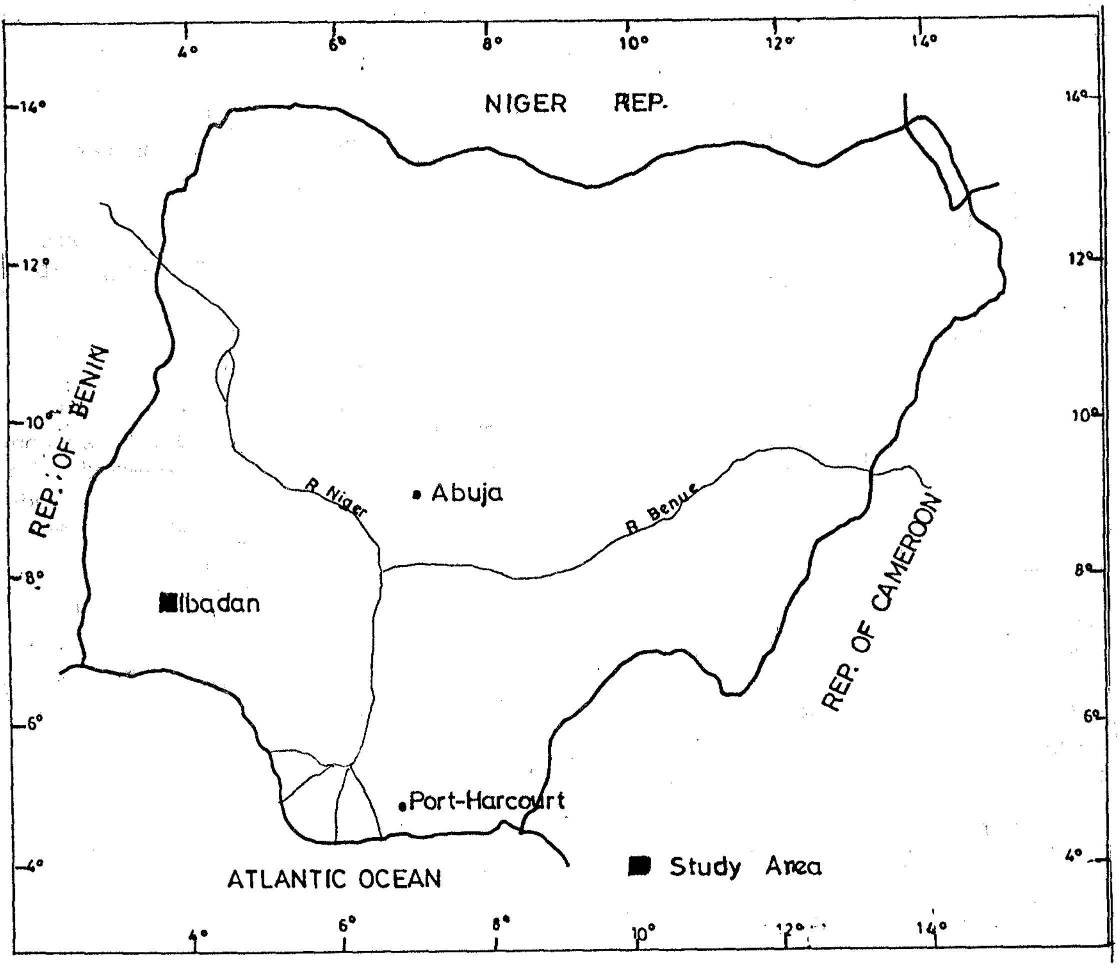

Fig. 1: Map of Nigeria showing the study area.

Table 1. ASHRAE Thermal sensation scale of warmth (ASHRAE, 1997) and author's revised scale of warmth.

	The ASHRAE scale	:		Revised Scale
+3	Hot	:	7	Hot
+2	Warm	:	6	Warm
+1	Slightly warm	:	5	Slightly warm
0	Neutral	:	4	Comfortable
-1	Slightly cool	:	3	Slightly cool
-2	Cool	:	2	Cool
-3	Cold	:	1	Cold

worn in the environment and subjects are sedentary (1 met-1.6 met) (Butera, 1989).

THE CLIMATE AND THE ENVIRONMENTAL CONDITION OF IBADAN CITY.

Figure 1 shows the location of Ibadan. Ibadan, a town in south west of Nigeria, is situated at the boundary between the rain forest and the savannah. The city lies between latitudes 7^0 15′ N and 7^0 30′ N and longitudes 3^0 45′ E and 4^0 00′ E at an altitude generally ranging from 150 m to 210 m with isolated ridges and peaks rising to about 280 m above the sea level. The area is characterized by two distinct seasons, namely, the dry and the wet seasons. The dry season generally begins at October and lasts till March. During this period the harmattan wind, a dry north-easterly air mass blows in

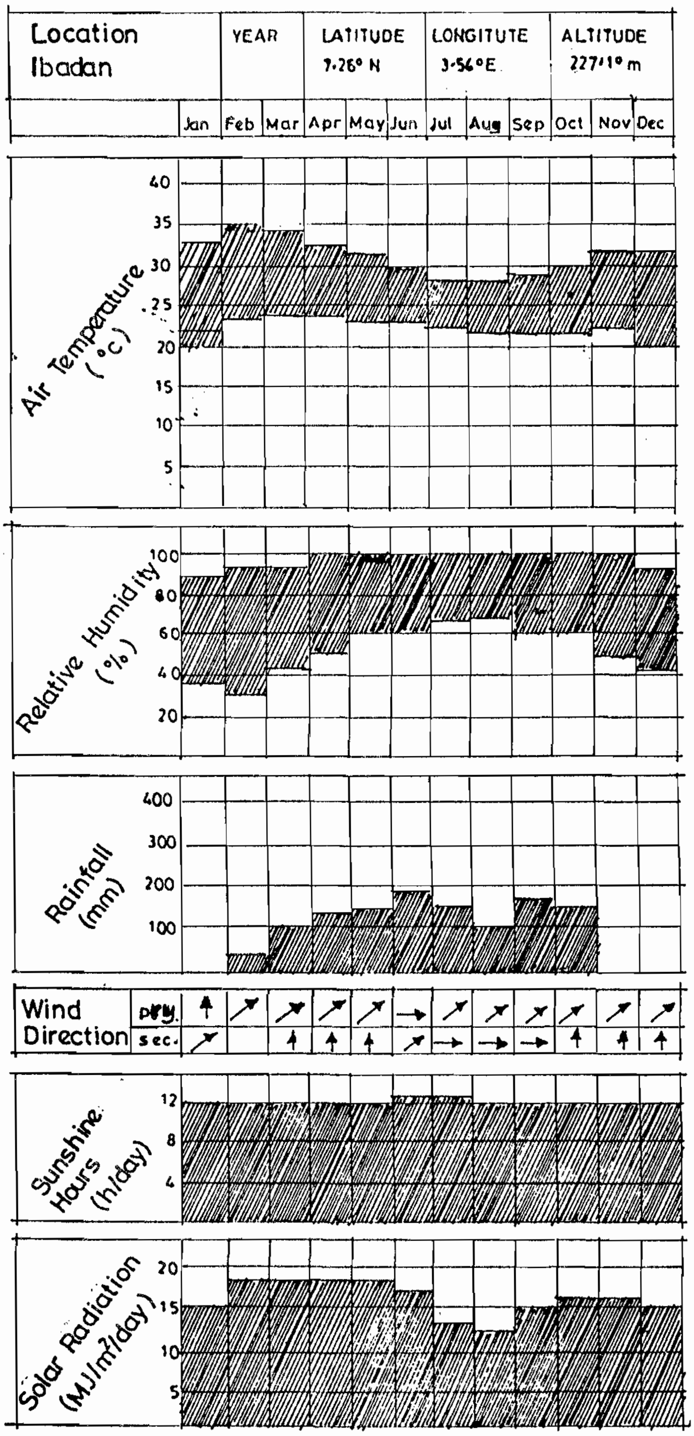

Fig. 2: Climatic graph for Ibadan (1980 - 2000).

from the Sahara desert, causing low temperatures and extreme dryness. Figure 2 shows the climatic graph of this location. The hottest months are February and March with a monthly maximum temperature of over 34 °C, while the wet season covers the rest of the year, April to mid October. These months are relatively cool and recording a monthly mean temperature of 27.8 °C. This season is influenced by another air current blowing in from the south of the Atlantic coast and bringing along rain-bearing cloud, cold and moist winds.

Cool season measurements are planned for the future and it is expected that there would be variation in thermal sensation voting due to seasonal acclimatization and different behaviour patterns.

Table 2: The total number of data collected per individual for each area.

Area	Number of data sets	
	Individual	Total for each Area
1	480 403 464	1347
2	462 123 450	1035
3	393 435 419	1247
4	255 237 399	891

DATA COLLECTION AND ANALYSIS

The 'revised' scale of warmth used in determining thermal sensation of preference of the subjects is similar to that used in ASHRAE scale of warmth (ASHRAE, 1997) and is shown in Table 1. Simultaneous recordings of indoor dry-bulb temperature and indoor relative humidity as well as outdoor dry-bulb and relative humidity were obtained. These measurements were obtained at half-hourly intervals from 0700 hrs to 1700 hrs from Mondays to Saturdays. Temperatures and relative humidity values for both indoors and outdoors were measured using hygrometer (Cassela, -10°–50°C, 10 – 100% range). For the indoor measurements, the sensors were hung at heights between 1.1 m and 1.3 m above the floor level in the center of each of the four grids which the rooms was divided. The reading that was repeated most often was taken as the 'average' value for the room. Another sensor was also placed outside to obtain outdoor readings. Two conditions were made to hold during measurements in order to achieve uniformity in the data collection: the room be used regularly during the period of measurements; and the room be devoid of any direct or strong sources of heat radiation as it will affect the readings on the sensors.

The areas used in the study were Agbowo / University of Ibadan / Orogun (Area 1), Apata / Odo-Ona (Area 2), Bashorun (Area 3) and Mokola / Oremeji (Area 4). The choices of these areas were governed by practical considerations such as availability of respondents and topography of the city. The twelve buildings chosen were regarded as representative of the building types in the city and comprised different walling materials. Twelve fully acclimatized subjects with ages ranging from 19 to 55 years were used in this investigation. The

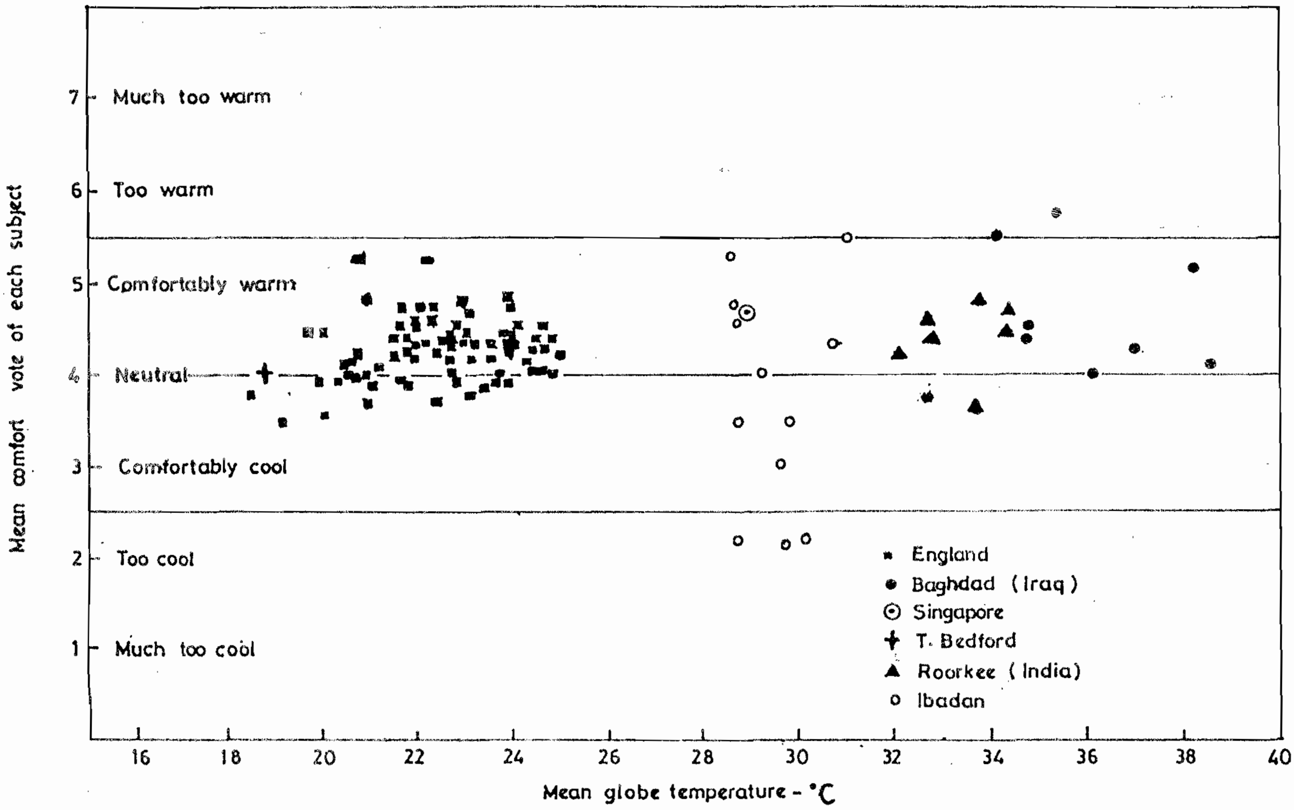

Fig. 3: The mean comfort vate of each individual against the mean air temperature for Ibadan compared with other locations.

Table 3: Summary of statistic variables for the indoor thermal environment.

Variables	N = 4520			
	Min	Max	Mean	Std. Dev
Dry-bulb temp., °C	21.0	44.0	29.8	1.8
Rel. humidity, %	12.0	99.0	51.8	7.4
Comfort vote	1.0	7.0	3.7	2.2

number of responses from the subjects in each area and the total number for each area is given in Table 2.

The average values of thermal comfort votes and corresponding dry bulb temperatures and relative humidity were calculated for each of the respondents. Also noted were the numbers of occasions these variables were recorded. The frequency distributions of the comfort votes and indoor dry bulb temperatures and relative humidity were also obtained for the city.

RESULTS AND DISCUSSION

The total number of data set collected per subject in each area is given in Table 2. Summary statistics for the indoor climate variables measured during visits are given in Table 3. The mean values of comfort experienced by the subjects were plotted against the mean indoor temperature, and compared also with results obtained from range of climates from cold temperate to hot dry (Nicol, 1974) is shown in Fig. 3. The relationship between the mean indoor relative humidity and comfort votes is shown in Fig. 4. The frequency distributions of indoor temperature and comfort vote and indoor relative humidity and comfort votes are given in Tables 3 and 4.

The mean comfort votes of individuals were compared with other comfort sensations earlier reported, the comfort temperature range for the subjects in Ibadan were found to lie within the extremes of temperature and hot-dry climates. The comfort temperature expressed by the subjects in an unconditioned environment is between 28 °C and 32 °C. In order to obtain comfort within this range, 'bio-climatic buildings' which are meant to be responsive to the climatic condition prevailing in the hot humid zone can neither be achieved in the 'foreign' designs of buildings suited to the cold temperate nor the designs from the hot dry climate. Building designs should be able to modify the external

climate to attain, for most of the time, a temperature range between
28 ^{0}C and 32 ^{0}C; the mean relative humidity which corresponds to comfort votes is obtained to be between 40% and 80% (Fig. 4). Frequency distribution of comfort vote against indoor temperature was used to determine the optimum temperature as well as those expressing comfort on either sides of comfortable (CS = 4), including slightly cool (CS = 3) and slightly warm (CS = 5) is given in Table 4. It is assumed that the central three categories (CS=5, CS=4, CS=3) of the thermal sensation scale constitute thermal satisfaction – "that state of mind which expresses satisfaction with the thermal environment" (ASHRAE, 1997). Results from this study showed that more than 90 per cent of the thermal votes cast fall outside these central categories. Using the central three categories of the thermal sensation scale, it was observed that only 3.37% of 4520 readings obtained from the respondents expressed satisfaction. Thus, the thermal sensation rated 'comfortable' does not correlate to the people preferred thermal state. Further extending the categories to include what the has been categorized as 'cool' (CS=2) and 'warm' (CS=6), improved the respondents votes to

Table 4. The distribution of number of assessments, comfort votes and indoor relative humidity (%).

Comfort vote	Midpoint indoor relative humidity (%)																		
	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	Total
Hot (7)	1	3	10	23	39	51	96	110	91	46	36	21	11	7	13	1	2	0	561
Warm (6)	2	7	36	56	47	83	94	96	88	75	73	75	79	91	94	31	13	11	1051
Slightly (5) warm	1	4	4	2	0	6	0	6	4	4	2	2	4	4	5	1	4	0	49
Comfortable(4)	2	4	0	2	4	10	10	14	6	6	2	3	4	10	5	3	3	0	88
Slightly (3) Cool	0	0	0	1	4	6	1	0	0	0	0	0	0	0	1	2	1	0	16
Cool (2)	2	22	71	45	128	195	209	168	167	199	196	201	314	261	307	124	45	14	2668
Cold (1)	0	0	2	7	14	5	1	1	9	3	4	5	7	7	6	7	9	0	87
Total	8	40	123	136	236	356	411	395	365	333	313	307	420	382	431	167	76	25	4520

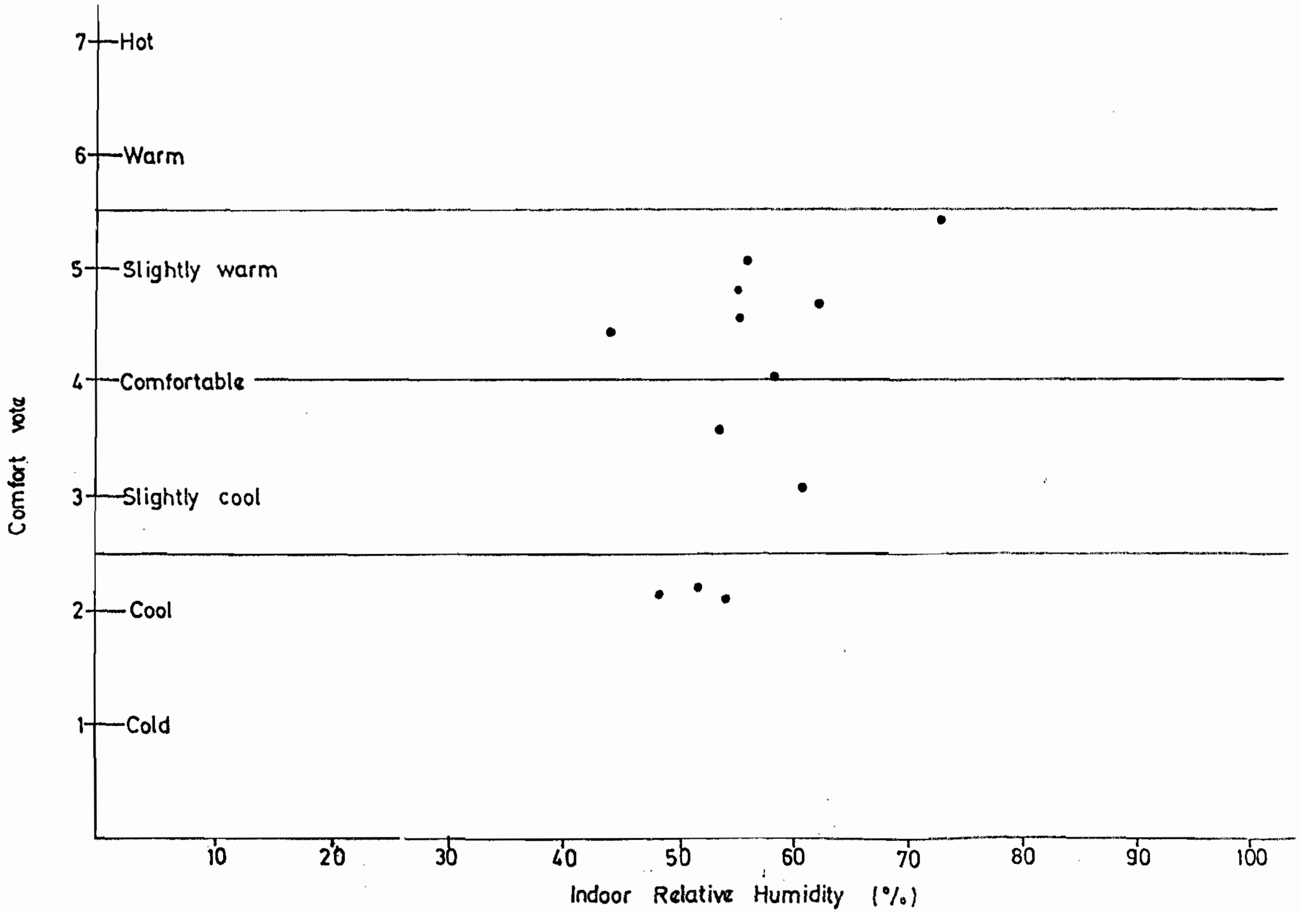

Fig. 4: Scattergrams of mean of comfort votes against
of *mean indoor humidity (%).*

Table 5. The distribution of number of assessments, comfort votes and indoor dry-bulb temperature (°C).

Temperature,°C	MIDPOINT INDOOR DRY-BULB TEMPERATURE																								
Comfort Votes	21.5	22.5	23.5	24.5	25.5	26.5	27.5	28.5	29.5	30.5	31.5	32.5	33.5	34.5	35.5	36.5	37.5	38.5	39.5	40.5	41.5	42.5	43.5	44.5	TOTAL
Hot (7)	1	0	0	0	1	22	9	4	194	7	18	247	7	7	42	1	0	0	0	0	0	0	1	0	561
Warm (6)	2	0	10	1	2	125	60	105	241	47	51	219	56	34	93	5	0	0	0	0	0	0	0	0	1051
Slightly Warm (5)	0	0	2	0	0	8	9	9	2	4	3	8	2	0	0	1	0	0	0	0	0	0	1	0	49
*Comfortable (4)	0	0	3	0	1	14	4	7	5	5	7	22	9	6	5	0	0	0	0	0	0	0	0	0	88
Slightly Cool (3)	0	0	0	0	1	9	2	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	16
Cool (2)	9	3	44	7	41	785	76	109	895	28	56	424	70	4	111	2	4	0	0	0	0	0	0	0	2663
Cold (1)	2	0	19	1	8	42	4	0	4	0	1	5	0	0	0	0	1	0	0	0	0	0	0	0	87
TOTAL	14	3	78	9	54	1005	164	234	1342	91	137	921	144	51	251	9	5	0	0	0	0	0	0	2	4520

85.1% to meet the ASHRAE's 80% thermal acceptability criterion. Similar patterns have been noticed in field studies conducted in tropical schools and office, where respondents reported 'comfortable' had preferred cooler conditions (Wong and Khoo, 2002, Kwok, 1998, de Dear and Fountain, 1994, Busch, 1990). An explanation for this trend is probably the inability of the respondents to match their state of thermal sensation appropriately with comfort voting; especially between the last two categories on either ends of the scale; 'slightly warm' (CS=5) and 'warm' (CS = 6), and between slightly cool (CS = 3) and cool (CS = 2). The optimum temperature, which is the temperature most people (above 80 %) feel comfortable is found to be 29.5 °C. This is 2°C above the value obtained in a similar study conducted in India by Sharma and Ali (1986). The difference in temperature is within the range found tolerable in thermal comfort studies.

CONCLUSION

From the survey of thermal sensations of twelve acclimatized subjects casting their thermal comfort votes in the hot season in the hot humid zone, it was found that:

(i) The optimum temperature for the subjects is 29.5 °C.

(ii) Favourable and tolerable comfort condition can be attained when the air movement is calm, at a temperature range of 28 °C to 32 °C and relative humidity between 40 % and 80 %

(iii) Building designs that are climate responsive for this region can neither be achieved with 'foreign' designs suitable for the cold temperate nor hot dry environments without increased in energy consumption.

(iv) There is need to devise a simpler thermal sensation scale that would be easily understood by the respondents.

ACKNOWLEDGMENT

The study reported here forms part of research activities of the Nigerian Building and Road Research Institute (NBRRI), Ota, Ogun State. The author appreciates the release of meteorological data from International Institute for Tropical Agriculture (IITA), Ibadan, Oyo State.

REFERENCES

Agarwal, K. N. and Komolafe, L. K., 1984. Climatic Zones and Building Design Guidelines. NBRRI Research Report, No. 4, Ranton Press, Lagos.

Akingbade, F. O. A., 2003. Indoor thermal environment and comfort conditions in the temperate dry zone of Nigeria: Case study of Zaria, Nigeria. Global Journal of Environmental Sciences, 2(1): 53-58.

Ambler, H.R., 1955. Notes on the climate of Nigeria with reference to personnel. Journal of Tropical Medicine and Hygiene, 56: 99-112.

ASHRAE.,1997. Handbook of Fundamentals. ASHRAE, Atlanta,USA.

ASHRAE.,1992. ASHRAE/ANSI Standard 55-92R - Thermal Environmental Conditions for Human Occupation. ASHRAE, Atlanta, USA.

Baker, N. and Standeven, M., 1996. Thermal comfort for free-running buildings. Energy and Buildings, 23: 74-82.

Busch, J., 1990. Thermal responses to the Thai office environment. ASHRAE Transactions, 96(1): 859-869.

Butera, P. M., 1989. Principles of thermal comfort. Proceedings of the Workshop on Interaction between Physics and Architecture in Environment Conscious Design. ICTP, Trieste, 25-29 Sept. Serie Simposi, Italy.

De Dear, R.J. and Fountain, M., 1994. Field experiments on occupant comfort and office thermal environments in a hot humid climate. ASHRAE Transactions, 2: 457 – 475.

Fanger, P. O., 1971. Thermal Comfort. Danish Technical Press. Copenhagen.

Komolafe, L.K. and Akingbade, F. O. A.,2003. Analysis of thermal comfort in Lagos, Nigeria. Global Journal of Environmental Sciences, 2(1): 59-65.

Kwok, A.G., 1998. Thermal comfort in tropical schools. ASHRAE Transactions, 104 (pt. 1), pp 1031 - 1047.

Mant, D. C. and MuirGray, J. A., 1986. Building Regulation and Health. BRE Report No. 97. London.

McIntyre, D. A., 1985. Indoor Climate. Applied Science Publishers, London.

Nicol, J. F., 1974. An analysis of some observations of thermal comfort in Roorkee, India and Baghdad, Iraq. Annals of Human Biology, 1(4): 411-426.

Sharma, M. R. and Ali, S., 1986. Tropical Summer Index – a study of thermal comfort of Indian subjects. Building and Environment, 21(1): 11-24.

Small, I. and Chandler, D., 1967. Thermal comfort studies in West Africa. BRRI, Ghana, Academy of Sciences, Kumasi, Research Note 20.

Wong, N.H. and Khoo, S.S., 2002. Thermal comfort in clas in the tropics. Energy and Buildings, 35: 337-351.