GLOBAL JOURNAL OF ENVIRONMENTAL SCIENCES VOL. 2 NO. 1 2003:59 - 65
 ISSN 1596 - 6194 PRINTED IN NIGERIA

ANALYSIS OF THERMAL COMFORT IN LAGOS, NIGERIA

L. K. KOMOLAFE and F. O. A. AKINGBADE

(Received 17 July 2001; Revision accepted 4 June 2002)

ABSTRACT

This paper reports a thermal comfort survey conducted in three locations in Lagos between July 1996 and June 1997 in which 50 fully acclimatized subjects cast over 6,000 individual votes of their subjective assessments of the thermal environments. The survey covered only residential buildings constructed of sandcrete materials. A set of multiple linear regression equations relating comfort votes with the variations of air temperature and relative humidity has been developed. Other regression equations that describe how external climate is altered indoor by the building fabrics have also been derived. Maximum and minimum values of temperature and relative humidity were also obtained for the purpose of air conditioning load estimation. Frequency distribution of air temperatures and comfort votes show a comfortable temperature range of 26°C to 28°C, comfortably cool between 24°C and 26°C, and comfortably warm between 28°C and 30°C.

Keywords: acclimatized subjects, thermal comfort, comfort vote, optimum dry bulb temperature, climatic index.

INTRODUCTION

The built environment is created basically to alter the outdoor climate. Whenever artificial climates are created for human occupation, one of the main aims is that the thermal environment be adapted so that each individual is in thermal comfort. Thermal comfort for a person is defined by Fanger (1970) as "that condition of mind which expresses satisfaction with the thermal environment" – a condition in which the subject would prefer neither warmer nor cooler surroundings. The need for thermal comfort can be justified from the point of view of human performance. Investigations have shown (Fanger, 1970; Kerslake, 1972; and Bedford, 1968) clear tendency for hot or cold discomfort to reduce a person's performance. Man's intellectual, manual and perceptive performance is generally highest when he is in thermal comfort with his environment.

General studies have been carried out in wide variety of climates and countries with the aim of finding the way of describing the thermal environment which correlates well with human response, thus enabling reliable predictions to be made and defining the range of conditions found to be pleasant or tolerable by the population concerned. In the work of Nicol (1974), it was found that individuals accustomed to living and working in Roorkee, India and Baghdad, Iraq (representing hot and dry climate) were most comfortable at globe temperature of 32 °C provided air movement exceeds 0.25 m/s. This finding was contrasted by that of Humphreys and Nicols (1970) on the English office workers, where it was concluded that the English office workers

L. K. KOMOLAFE, Nigerian Building and Road Research Institute, Ota, Ogun State, Nigeria
F. O. A. AKINGBADE, Nigerian Building and Road Research Institute, Ota, Ogun State, Nigeria

were either comfortable or comfortably warm at globe temperature of 20-25 °C. This work also showed an estimated temperature variations that may be permitted for the English workers without causing discomfort. There has been various other thermal comfort studies conducted in Australia (Hindmarsh and Macpherson, 1962; and Wyndham, 1963), USA (Peplar, 1971), Far East (Rao, 1952; Ellis, 1953; and Ambler, 1966), Equatorial region (Moorkerjee, 1952, 1953 and Webb. 1959, 1964) etc.

In spite of the above, there are only two records of thermal comfort studies in Nigeria. The first one was that carried out by the British Ministry of Supply in Port-Harcourt (Ambler, 1954). In this study effective temperature for Southern Nigeria was found to be 21.8 °C. The subjects for this assessment were however "European Laboratory Staff" whose extent of acclimatization was not given. Moreover, it is also well known that Webb (1960) ascertained that in warm humid climates of low latitudes, air temperature (or dry bulb temperature) alone is not adequate as a climatic index of thermal comfort or discomfort. The other study in Nigeria was that conducted by Small and Chandler (1967) in Zaria. In this work, the optimum dry bulb temperature of 25.3 °C was obtained, while the corrective effective temperature was 20.3 °C. Part of this same work by Small (1967) showed that Accra, Ghana has an optimum dry bulb temperature of 26.8 °C and a corrective temperature of 25.0 °C. The optimum corrective effective temperature showed wide discrepancy. This discrepancy confirms that the belief that in warm humid climates of low latitudes, air temperature (or dry-bulb temperature) alone is not enough as an index of thermal comfort or discomfort. No other detailed study on thermal comfort requirements of Nigerians is available anywhere. Studies have always been in bits and scanty (Agarwal and Komolafe, 1983; Ngoka, 1983; Ogunsote, 1989, and Ojo, 1993). Agarwal and Komolafe (1983) gave a broad temperature range between 18 and 28 °C for the four climatic zones the country was divided, while the pilot study conducted by Ojo (1993) gave the limit of 25.6 °C above which thermal comfort is no longer sustained by students used in the study. Hence, there is need for a climatic index applicable to Nigeria, and correlating well with the subjective assessments of the thermal environment made by wholly acclimatized subjects, in order to have a clear understanding of thermal comfort requirement of the Nigerian environment. In this work, a simple formula for thermal index was derived from the subjective thermal assessments of the indoor environment by fully acclimatized individuals and the measurements of the indoor environmental variables.

METHOD OF RESEARCH

Measurements were conducted in three locations in Lagos, namely, Victoria Island / Ikoyi, Somolu / Bariga / Palmgroove, and Ikeja / Oshodi / Mafoluku. A total of fifty houses constructed with sandcrete, clay, mud or wood were studied. The subjects, one from each house, were chosen on the basis of their acclimatization, availability, and ability to give his / her subjective thermal assessments of the indoor environment. Indoor and outdoor temperatures and relative humidity were recorded using Cassela Hygrometers, England. Also recorded simultaneously was the subjective thermal vote of the indoor environment. The ceilings of the spaces to be used for thermal comfort investigations were divided into four square grids in which four hygrometers were hung at their centres of the

Table 1. Subjective Assessment Scale for Thermal Comfort (Bedford, 1936)

COMFORT VOTE	CODE NUMBER
Hot	7
Warm	6
Slightly warm	5
Comfortable	4
Slightly cool	3
Cool	2
Cold	1

Table 2: Maximum, minimum and mean values for indoor and outdoor temperature and relative humidity for the locations

Locations	Indoor						Outdoor					
	Temp. (^{0}C)			Humidity (%)			Temp (^{0}C)			Humidity (%)		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	31.1	18.3	28.8	91.0	36.0	65.2	39.2	18.3	31.0	100.0	33.0	59.9
2	33.9	18.2	27.6	100.0	22.0	68.7	36.1	21.1	28.5	100.0	35.0	64.1
3	33.9	22.2	27.4	100.0	34.0	72.3	35.3	20.1	28.5	100.0	31.0	70.8

grids between 1.90m and 2.0m above the floors. The fifth hygrometer was fixed at the same level with others at the centre of the ceilings. The simple average of the indoor air temperatures and relative humidity were calculated. The outdoor air temperature and relative humidity were obtained with the hygrometer placed outside the building. The hygrometers were excluded from sources of heat radiation. Simultaneously, the subjects were asked to score how they perceived the indoor thermal environment ranging from hot to cold, and these were correspondingly scored on a

7-point scale of thermal preference designed by Bedford (1936). The simple average of the readings were used in the computations. The observations were made twice a day - in the morning and afternoon, from Monday to Saturday, excluding public holidays. Measurements were made from July 1996 to June 1997.

A simple linear relationship combining all the environmental variables of temperature and relative humidity were examined. This was to determine the thermal index as well as other predictive equations. The data obtained were fitted to a multiple linear regression of form

$$CS = a + bt + ch \qquad (1)$$

where CS is the comfort sensation, t is the

Table 3: Comfort votes at observed temperature ranges and the percentage of votes within the selected temperature

	Location 1		Location 2		Location 3	
Comfort zone	Temp Range (°C)	% of Votes Within Range	Temp Range (°C)	% of Votes Within Range	Temp Range (°C)	% of Votes Within Range
Cold	26-29	92.8	22-25	81.9	23-26	88.1
	26-28	78.5	22-24	54.6	23-25	52.4
Cool	27-30	92.5	23-27	92.3	24-27	78.3
	28-30	71.7	23-26	69.2	24-26	52.2
Slightly Cool	28-31	95.6	24-28	88.0	25-28	78.2
	29-31	72.5	25-27	50.7	25-27	55.2
Comfortable	29-32	93.4	26-29	37.0	26-29	85.7
	30-32	50.0	26-28	58.9	27-28	49.7
Slightly Warm	No Vote	-	27-30	80.1	27-30	85.2
			28-30	59.5	28-30	74.6
Warm	No Vote	-	28-32	90.0	28-32	100.0
			29-32	70.0	29-32	75.0
Hot	No Vote	-	No Vote	-	No Vote	-

Table 4. Comfort votes with number of votes in percentage of total votes for the locations

Comfort Vote	Number of Votes			Percentage of total Votes		
	Location 1	Location 2	Location 3	Location 1	Location 2	Location 3
Cold	56	22	82	3.2	1.2	3.2
Cool	1020	78	222	57.4	4.1	8.4
Slightly Cool	546	134	486	30.7	7.1	18.5
Comfortable	152	1208	1550	8.6	63.7	58.8
Slightly Warm	0	414	284	0	21.8	10.8
Warm	2	40	8	0.1	2.1	0.3
Hot	0	0	0	0	0	0

temperature in °C, and h is the relative humidity in %, a, b, and c are constants to be determined. Multiple linear regression analysis was carried out on indoor temperature and humidity, as independent variables and comfort sensation as the dependent variable.

RESULTS AND DISCUSSION

The thermal scale of preference used to assess the subjects perception of their indoor thermal environment is given in Table 1. Maximum, minimum and mean values of the indoor and outdoor air temperature and relative humidity for the three locations is given in Table 2. The thermal indices obtained for each of the locations were as follows:

Location 1 (Victoria Island / Ikoyi)

$$CS = -2.26 + 0.214t_i - 0.022h_i \qquad (2)$$

Location 2 (Somolu / Bariga / Palmgroove)

$$CS = -2.93 + 0.268t_i - 0.006h_i \qquad (3)$$

Location 3 (Ikeja / Oshodi / Mafoluku)

$$CS = -5.60 + 0.367t_i - 0.012h_i \qquad (4)$$

where the symbols have their usual meanings.

The correlation coefficients of Equation (2) to (4) range from 0.54 to 0.75. The coefficients of internal relative humidity in the equations range from 0.1-0.2, indicating that the effect of relative humidity on thermal comfort is less significant when compared to the effect of air temperature. The values of the constants of Equations (2) to (4) show that temperature is more effective in increasing / lowering the indoor comfort level.

For example, in Location 1 (Victoria Island/ Ikoyi) the relative effectiveness of humidity is about one-tenth times as much as temperature. The prediction further reinforces the significance of dry bulb temperature on comfort in this climatic zone where the, humidity is low. Correlations among CS, outdoor temperature, t_0, and outdoor relative humidity, h_0, were poor, with correlation coefficients of about 0.2. Hence, the result is not presented here. There was good correlation between indoor temperature and outdoor temperature, as well as between indoor relative humidity with correlation coefficients ranging from 0.57-0.86. The following regression equations were obtained

Location 1 (Victoria Island / Ikoyi)

$$t_i = 16.21 + 0.408 t_0 \quad (5)$$

$$h_i = 47.08 + 0.302 h_0 \quad (6)$$

Location 2 (Somolu / Bariga / Palmgroove)

$$t_i = 12.16 + 0.543 t_0 \quad (7)$$

$$h_i = 22.98 + 0.713 h_0 \quad (8)$$

Location 3 (Ikeja / Oshodi / Mafoluku)

$$t_i = 18.00 + 0.328 t_0 \quad (9)$$

$$h_i = 31.00 + 0.580 h_0 \quad (10)$$

With these equations, it is possible to predict indoor temperature and relative humidity for sandcrete walling material if the values of outdoor temperature and relative humidity are known. In Victoria Island / Ikoyi, the subjects expressed the feeling of coolness of their thermal environment, while the feelings of warmth or hotness were expressed in the same temperature range of 27 ^{0}C to 32 ^{0}C in Somolu / Bariga / Palmgroove and Ikeja / Oshodi / Isolo locations respectively. At this same temperature range of 27 ^{0}C to 32 ^{0}C, Victoria Island / Ikoyi subjects expressed the feeling of coolness. There was also marked difference in the range of temperature that the subjects in the locations expressed the feeling of coolness. In Victoria Island / Ikoyi, the temperature range was 26 ^{0}C to 29 ^{0}C and in the other two locations, Somolu / Bariga / Palmgroove and Ikeja / Oshodi / Mafoluku, it was between 22°C to 25°C and 23 ^{0}C to 26 ^{0}C respectively. The frequency distribution of air temperature were obtained in other to determine the optimum temperature for a given comfort sensation is given in Table 3. The optimum dry bulb temperature for "comfortable" for the subjects in Victoria Island / Ikoyi was obtained as 29 ^{0}C to 32 ^{0}C, while for Somolu / Bariga / Palmgroove and Ikeja / Oshodi / Mafoluku, it was 26 ^{0}C to 29 ^{0}C.

The same difference in pattern was also noticed if the comfort range was made to include slightly cool and slightly warm; Victoria Island / Ikoyi comfort zone lies between 28 ^{0}C and 32 ^{0}C, Somolu / Bariga / Palmgroove, 24 ^{0}C to 30 ^{0}C and Ikeja / Oshodi / Mafoluku, 25 ^{0}C to 30 ^{0}C. These comfort zones are on the borders of the comfort zone reported by Komolafe et al. (1983) in their study conducted for the warm humid zone. The number of comfort zones in percentage of total votes cast by locations is given in Table 4. The percentage of total votes cast expressing "comfortable" in Somolu / Bariga / Palmgroove and Ikeja / Oshodi / Mafoluku are 63.7% and 58.8% respectively. These percentages were higher when compared with the percentage of total votes expressing "comfortable" at Victoria Island / Ikoyi location, which was 8.6%. Thus, there is a bias towards feeling of coolness in Victoria Island / Ikoyi which was not expressed in other locations. The reason for this feeling of coolness is probably the space commonly found around the building, enhancing the degree of airflow in and around the building, thus contributing to the feeling of well being all the time.

CONCLUSION

The warm and humid Lagos indoor environment have been described in relation to overall thermal sensations of fully acclimatized subjects. Comfortable temperature of 26 °C to 28 °C has been determined. Other ranges of temperatures determined from this study were "comfortably cool", 24 °C to 26 °C and "comfortably warm", 28°C to 30°C. These values are valid over a wide range of relative humidity of 40 % to 85 %. The maximum internal temperature was 33.9 °C, while the minimum value recorded was 18.2 °C. These values are important in sizing cooling plants, that is, a basis for assessing energy conservation options in domestic cooling. The regression equations will enable the prediction of comfort sensation, given values of indoor temperature and relative humidity. The other sets of regression equations will also enable the prediction of other environmental parameters. Thus, it is possible to deduce to extent to which building fabrics (here sandcrete material) alter the outdoor conditions inside the building. The study has also revealed that residents in affluent locations perceived being thermally comfortable most of the time, thus indicating the relevance of strategic location consideration on thermal studies.

REFERENCES

Agarwal, K. N. and Komolafe, L. K., 1983. Nigerian Climatic Zones and Building Design Guidelines. NBRRI Report No. 4, Ranton Offset Centre, Lagos.

Ambler, H. R., 1954. Notes on the Climate of Nigeria with reference to personnel. Journal of Tropical Medicine and Hygiene, 58: pp 99-102.

Ambler, H. R., 1966. Conditions of Thermal comfort in North India. Journal of Tropical Medicine and Hygiene, 69: pp 275-281.

Bedford, T., 1936. The Warmth factor in comfort at work. Industrial Health Resources Board, Report No. 76, Medical Research Council.

Bedford, T., 1968. Environmental warmth and its measurements. Medical Research Council War Memorandum, 17, HMSO, London.

Ellis, F. P., 1953. Thermal comfort in war humid atmosphere-observations on groups and individuals in Singapore. Journal of Hygiene, Cambridge, 51, pp 386-404.

Fanger, P. O., 1970. Thermal Comfort. Danish Technical Press. Copenhagen. Hindmarsh, M. E. and Macpherson, R. K., 1962. Thermal Comfort in Australia. Australia Journal of Science, 24: pp 335-339.

Humphrey, M. A., 1974. Classroom temperature clothing and thermal comfort: A study of secondary school children in summertime. JIHVE, 41: pp 191-2002.

Humphreys, M. A. and Nicol, J. F., 1970. An investigation into thermal comfort of office workers. JIHVE, 38: pp 181-189.

Kerslake, D., 1972. The stress of Hot Environment. Cambridge University Press, London.

Moorkerjee, G. C. and Murgai, M. P., 1952. A preliminary report on the determination of comfort zone of Indian subjects during North Indian summer. Journal of Scientific and Industrial Research, India II: pp 14-16.

Moorkerjee, G. C. and Sharma, R. N., 1953. A report on environmental comfort zone in dry tropics. Journal of Scientific and Industrial Research, India, 2: pp 283-287.

Ngoka, N., 1983. Thermal comfort in an office building in Southern Nigeria. International Journal of Housing, 2 (3): 221-226.

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.

Ogunsote, O. O., 1989. A cultural approach of the comfort conditions in the climatic design zones of Nigeria. Doctoral Thesis presented to the Department of Architecture, ABU, Samaru, Zaria.

Ojo, O., 1993. Urbanisation and physioclimatic responses to thermal conditions in Lagos. In Proceedings of Urban Transition in Africa: Aspects of Urbanisation and Change in Lagos (ed) Kunle Lawal, Purmark Nigeria Ltd., Lagos, pp 140-150.

Peplar, R. D., 1971. The thermal comfort of teachers in climate controlled and non-controlled schools. ASHRAE 77(ii): 43-51.

Rao, M. N., 1952. Comfort range in tropical Calcutta: A preliminary experiment. Indian Journal of Medical Research, 40 (1): pp 45-52.

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

Webb, C. G., 1959. An analysis of some observations of thermal comfort in an equatorial climate. British Journal of Industrial Medicine. 10/16 (1): 87-94.

Webb, C. G., 1964. Thermal discomfort in a tropical environment. Nature, 2002: 1193-1194.