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INDOOR THERMAL ENVIRONMENT AND COMFORT CONDITIONS IN THE TEMPERATE DRY ZONE OF NIGERIA: CASE STUDY OF ZARIA, NIGERIA

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ABSTRACT

This paper presents the results of thermal comfort investigation conducted on forty-two acclimatized individuals casting their votes on a scale of preference at half-hourly intervals for a period of seven days. Simultaneously, indoor and outdoor temperature and humidity readings were obtained using simple hygrometers. The mean indoor temperature for the zone is 26.3 ^{o}C and the mean indoor relative humidity 30.5%. The individuals expressed comfort in the temperature range of 24 ^{o}C to 28 ^{o}C. This temperature is compared with an earlier reported study and found to be close to values obtained in the temperate region. The range of temperatures and relative humidity would be useful in the design and development of energy efficient buildings in the temperate dry climate.

KEYWORDS: built environment, thermal comfort, thermal neutrality, temperate dry climate, subjective response.

INTRODUCTION

The built environment is created basically, among other reasons, to provide an enclosure that will keep inhabitants at some preferred level of comfort, for most of the time, while the external environment is either too hot or too cold. Thus, building envelope acts as a barrier as well as a modifier of the external climate. Experiencing a condition of thermal neutrality under which the body need not strain both physically and physiologically to reduce or increase body temperature is regarded as 'thermal comfort' (Fanger, 1970). Thermal comfort can be achieved through proper design of buildings that require less energy by utilizing design measures dictated by the local climatic condition. Several studies have been carried out in a wide variety of climates and countries (Wyndham, 1963; Crowder, 1965; Goromosov, 1968; and Budd, 1974). Most of these studies were carried out in temperate climates. In warm and hot environment, such as is the case in Nigeria, evaporative cooling plays an important part on the thermal adjustments of the body to its environment, and relative humidity thus become an important factor in comfort.

The aim of the studies on thermal comfort is to find a way of describing the thermal environment that correlates well with human response, thus enabling reliable prediction to be made, and defining the range of condition found to be pleasant or tolerable by the population concerned. Humphreys and Nicol (1970) in a study in the temperate zone concluded that the English office workers were

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either comfortable or comfortably warm at globe temperature between 20 °C and 25 °C. In the work of Nicol (1974), it was found that individuals in hot dry climates were most comfortable at globe temperature of 32 °C, provided that the air movement does not exceed 0.25 m/s. These studies showed that there are variations in temperature at which people experience comfort indoors. These studies have shown that the range of temperatures for thermal comfort is dependent on climatic conditions. Since values for the preferred indoor environmental conditions determined in other climates different from that prevailing in the region cannot be applied with confidence, it is therefore essential that current information be collected locally for use in the establishment of comfort zone.

Thermal comfort studies are rarely carried out in Nigeria, because it is very expensive and there are readily available data from other studies conducted elsewhere that can be applied, even though, they may be inappropriate. An important study carried out was by Ambler (1955), which found that people could be comfortable at about 21.8 °C. This study raised some questions: who were the subjects and what was their level of acclimatization. The other study carried out by Small and Chandler (1967) found the optimum dry bulb temperature for Zaria as 25.3 °C, while the corrected effective temperature (CET) was 20.3 °C. At the same time, the work carried out by Small (1967) in a nearby location, Accra, Ghana, has the optimum dry bulb temperature of 26.7 °C and 25.0 °C CET. This wide discrepancy in the optimum value of CET has cast doubt on the validity of the CET as an index of comfort. However, there has been some progress made by Nigerian researchers to determine thermal indices experienced by Nigerian subjects in different climatic

Zones. Ngoka (1983) has carried out an investigation on thermal comfort in an office building in Ile-Ife. Also, Agarwal and Komolafe (1983) gave the comfort zone for each of the four climatic zones in the country. In the report of the study, a comfort zone between 21 °C and 26 °C were given for three climatic zones and between 18 °C and 24 °C for the temperate dry zone, and allowing for ± 3°C on either side of these ranges. In a subsequent field survey conducted by Akingbade and Komolafe (1997) for the hot humid zone of the country, with one hundred respondents for a period of one year, obtained the comfort zone between 24 °C and 28 °C, with optimum dry

Table 1: Maximum, minimum and mean values for comfort vote, indoor and outdoor temperature and relative humidity for the locations

Locations	Temperature (°C)						Relative humidity (%)						Comfort Vote		
	Indoor			Outdoor			Indoor			Outdoor					
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Sabon Gari	32.0	21.5	25.19	38.0	19.8	27.37	60.0	20.2	32.93	60.0	15.0	32.13	7.0	2.0	4.07
Samaru	35.9	21.5	27.11	39.2	20.5	33.57	50.0	20.0	27.70	45.0	18.0	23.41	7.0	1.0	4.35
Tundun-Wada	33.7	21.5	25.65	39.2	20.0	32.18	56.0	29.2	29.20	50.0	20.0	24.55	7.0	1.0	4.26
Wusasa	35.4	17.6	27.17	27.17	18.0	39.90	52.0 31.61		31.61	50.0	18.0	28.23	6.0	2.0	3.95
Zaria City	35.5	16.0	26.02	26.02	19.0	35.28	58.0 33.02		32.02	85.0	14.0	31.62	7.0	2.0	3.86
			26.31			33.40			30.54			27.69			4.01

bulb temperature of 29.5 °C. Ogunsote (1989) has given the comfort zone for subjects in Zaria between 20 °C and 25 °C.

The paper reports the field survey carried out to obtain and assess the indoor thermal environment in the temperate dry zone of Nigeria. This information would be useful in the design and construction of energy efficient buildings to produce indoor thermal conditions as near as possible to those shown by the results of this investigation.

METHOD OF INVESTIGATION AND DATA COLLECTION

Instrumentation.

The indoor spaces were instrumented with five Cassela Hygrometers, England, that can measure the air dry-bulb temperature, in degree Celsius, and relative humidity, in percent, with errors of $\pm 0.2°C$ and $\pm 2\,\%$ for temperature and relative humidity respectively.

Sites

Measurements were obtained from forty-two houses in five locations in the city, namely, Sabon Gari, Samaru, Tundun Wada, Wusasa and Zaria City. In each location, nine buildings were selected, consisting of eight residential and one-office buildings, constructed with sandcrete, mudcrete or bricks as the walling material. These buildings were randomly selected and were chosen from the common designs in the locations.

Data Collection

The ceiling of the space to be used for thermal comfort investigations was divided into four square grids and the hygrometers were hung at the centers of the grids. The hygrometers were hung between 1.9 m and 2.0 m from the floor and the fifth hygrometer was hung at the same level with others in the center of the rooms. The hygrometers were placed in this position because it was assumed that air circulation was generally low and constant, such that the ambient temperature can then be measured accurately with these

sensors as strong sources of radiation was avoided during recordings. The measurements of the outdoor air temperature and relative humidity was obtained with a hygrometer placed outside the building.

The indoor air temperature and relative humidity readings obtained from the five hygrometers placed indoors and the outdoor temperature and relative humidity were recorded on data sheets designed for the survey and given to the research assistants. These readings were obtained on hourly basis from 7.00 am to 5.00 pm for seven days in the month of October 1997. Also obtained every half-hour from the subjects, ages ranging from 19 to 55 years were the indoor thermal votes. The subjects were told to assess the indoor thermal environment between cold and hot and it was rated accordingly on a 7-point scale of preference for thermal comfort devised by Bedford (1936). The respondents' activities were restricted to sitting or standing or doing light work during the period of measurements. A total of 2660 sets of subjective responses and environmental variables were obtained and used for the analysis. Also, recorded are the architectural details such as number and sizes of windows, doors, dimension of the floor, walling materials, colour of the room, roofing material and height of the room.

Thermal Index

In order to obtain a simple thermal index, multiple linear regression analysis was done using indoor air temperature and relative humidity as independent variables and comfort votes as dependent variable. The data was fitted to a linear equation of the form

Table 2 The distribution of number of assessments, comfort votes and indoor relative humidity (%)

	Indoor relative humidity, % (midpoints)														
Comfort Vote	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	Total
Hot		1	7	5	11	9	7	1	1							45
Warm	12	20	41	65	198	105	58	15	11	6						531
Sl. Warm	0	7	21	52	74	65	37	22	6	1						286
Comfortable	23	68	116	154	228	138	89	26	11	2						845
Sl. Cool	0	11	46	92	107	95	58	30	8	1						465
Cool	17	18	42	46	173	90	72	28	4							479
Cold				2	3	4	4									13
Total	54	125	273	416	794	506	325	122	41	10	0	0	0	0	0	2664

$$CS = a + bt_i + ch_i \quad (1)$$

where CS is the comfort vote, t_i is the indoor temperature in ^{0}C, h_i is the relative humidity in %, and a, b, c are constants to be determined.

RESULTS AND DISCUSSION

The readings obtained from the locations for each subject were analysed. These readings included the indoor and outdoor dry-bulb temperature and relative humidity, and the subjective thermal votes from the subjects. The simple average of the readings obtained for the indoor environmental variables were used in these analyses. The maximum, minimum and mean values for comfort votes, indoor and outdoor temperature and relative humidity for the locations are given in Table 1. The range of values of temperature, relative humidity and comfort votes for design purposes can be obtained from the difference between the maximum and minimum values. The mean indoor temperature for the locations is 26.3 ^{0}C. This value is close to the optimum dry bulb temperature of 25.3 ^{0}C obtained by Small and Chandler (1967) in an earlier study. The outdoor temperature is 33.4 ^{0}C. The mean values of comfort sensations of the subjects are plotted against mean dry-bulb temperatures and compared with data from other climates given by Nicol (1974) is shown in Fig. 1. The plots of means of comfort sensations reported by the forty-two subjects in the temperate dry zone of the country are close to comfort sensations reported by English subjects from the cold temperate region. From the theoretical study on comfort zoning of the country, the comfort zone for temperate dry zone was given as 18°C to 24°C (+ / 3°C permissible on either sides of the extremes) (Ojosu et al, 1988). This same range of mean comfort vote was obtained from the thermal comfort study on English workers in England. The mean comfort votes for these workers in the cold temperate regions are shown in Fig.1. A survey on thermal comfort conducted by Ogunsote (1989) gave 20°C to 25°C as the comfort zone for Zaria City, which is located in the temperate dry region. A similar thermal comfort range of 20°C to 25°C was also given for summertime workers in England by Humphrey and Nicol (1970). Generally, the temperate dry climate is warmer and rarely experiences the extremely cold winters as in England, except during the short period of cold harmattan. Hence, the comfort zone of 18°C to 24°C may not be applicable to this temperate dry zone of Nigeria. This study has determined the comfort range to be between 24°C and 28°C. The result of this study is not in agreement with comfort ranges proposed by others for the dry temperate region. The superiority of the determined comfort range from this study over others is yet to be ascertained as the survey was conducted in the cool dry season (NUC, 1978) and for a period less than a year. However, the comfort range will be applicable to cool dry season of the temperate dry region. The variations of mean comfort votes of the subjects with mean relative humidity is shown in Fig. 2. The relative humidity range for comfort in temperate dry zone during this period was between 20% and 35%. The combined effect of indoor temperature and relative humidity on comfort for the locations can be predicted with the equation

$$CS = 0.9947 + 0.0972t_i + 0.0149h_i \qquad (2)$$

The coefficient of determination, r^2, is 0.43. With this value of coefficient of determination, the predictive ability of the equation (2) is fair. From the magnitudes of the coefficients, it is clear th-- temperature is more effective in increasing or lowering the comfort level indoor-. The relative effectiveness of humidity is about one-sixth that of temperature. This predictive equation reinforces the significance of dry-bulb temperature on comfort in this climatic zone with very low humidity. The maximum and minimum values of the indoor temperatures give the extreme values for design of air-conditioning systems in buildings in this zone.

CONCLUSIONS

On the basis of this study, the following conclusions can be drawn:

1. The mean indoor dry bulb temperature for this zone is 26.3 °C and the mean indoor relative humidity is 30.5%.

2. The subjects expressed being thermally comfortable within the relative humidity range of 25% to 35%.

3. A mean outdoor dry bulb temperature of 35 °C is obtained for the town. Thus, for design of an air-conditioned environment to achieve comfort range 24 °C to 28 °C should be targeted. The building fabrics selected should modify the higher outdoors temperature experienced, during other seasons, to maintain the indoor environment in the comfort zone.

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