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Evaluation of Thermal Comfort in a Warm-Humid Nigerian City Using a Thermal Index

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ABSTRACT

The general applicability of thermal comfort indices is in contention. It is necessary to determine their relevance to indoor thermal comfort at contextual levels. Indoor thermal comfort is evaluated in this paper in relation to the Effective Temperature (ET) index for Ile-Ife, a city in the warm-humid climatic zone in Nigeria. A purposive sampling was used to select seven residential estates within the city to obtain a regulated sample of similar contemporary buildings. 50 respondents each were randomly selected from the 500 residents in each of the 7 residential estates to assess the indoor thermal environment using a seven-point ASHRAE thermal comfort scale for different periods. The Effective Temperature was calculated for the different periods based on the climatic data for the study area. It was found that there was strong correlation between effective temperature and the thermal response. The comfort zone determined for the study area from this study was from 24.5ºC ET to 26.1ºC ET. It was concluded that climatic factors played a very significant role in defining the indoor thermal quality of the built environment in the study area. The thermal index of Effective Temperature was found relevant to indoor comfort assessment.

Keywords*: Climatic Context, Effective Temperature, Indoor Comfort, Residential Building, Thermal Index, Warm-Humid.*

1. INTRODUCTION

Residential buildings in tropical cities particularly need to provide adequate comfort for the occupants. This is because human activities can only be performed best when the environmental conditions are favourable. The climatic conditions in the tropical warm-humid environment pose a challenge to human thermal comfort and buildings can be thermally uncomfortable for considerable periods due to solar heat gains and high relative humidity. Proper consideration should therefore be given to the study of indoor thermal conditions in the warm-humid climate to facilitate improvement in the domestic architecture. According to Costa (1989), buildings in Nigeria have laid too much emphasis on socio-cultural and economic factors to the neglect of environmental factors.

It must be noted that the study of thermal comfort now has a contextual dimension. Recent inferences in literature state that the various comfort limits specified for regional climates need to be revised (Nicol and Humphreys 2002, Ogunsote and Prucnal-Ogunsote 2002, Becker and Pacink 2009, Cheng et al 2011). Some of these findings have disagreed with the general applicability of the established indices of thermal comfort based on climatic and contextual differences. None of the large number of indices appears to be universally satisfactory over the entire range of environmental conditions. This paper reports a thermal comfort study which was based within the context of Ile-Ife, a city in the warm-humid climatic zone in Nigeria with the aim of applying the Effective Temperature (ET) index to assess indoor comfort of residents. This was with a view to determine a relationship between the thermal response of the residents and the outdoor climatic factors indicated by the effective temperature index as well as to determine the range of acceptable environmental conditions. This information will help in the design of buildings for comfort in the study area. It will additionally give insight to the applicability of the Effective Temperature index in the study area.

2. LITERATURE REVIEW

To embark on the study in a conceptual way, some of the cogent issues on the study of indoor thermal comfort are hereby reviewed. Thermal comfort is a necessary feature when considering the functional adequacy of any building space and the sustainability of the built environment. In whatever location, buildings are meant to provide the requisite thermal environment indoors so that human activities may be carried out conveniently. People are affected either positively or negatively inside a buildings because of their innate physiological reactions and psychological responses to the indoor thermal environment. There is therefore a significant role thermal comfort plays in human performance at both mental and physical levels. According to findings in some studies, both thermal comfort and air quality can have important impacts on human productivity (Tsuzuki et al 1999; Wyon 2001; Huizenger et al 2006).

The study of thermal comfort has taken a psychological dimension along with the initial physiological approach. The physiological concept laid the foundation for relating the physical parameters of an environment to the thermal state of the body physiology and health. Building on this, the approach using human subjective psychology gave more insight into the human experience of thermal comfort (Fisk 1982; Frank et al 1999; Szokolay 2008). Fisk (1982) asserted that the psychological approach to the study of thermal comfort is more relevant because of the need to decipher the different levels of comfort within different environmental conditions. To buttress this, Frank et al (1999) and Lin et al (2010) also emphasized the role of subjective thermal comfort. The subject of thermal comfort has become more context specific in terms of the human respondent, the climate of the area and the spatial configuration of buildings. The exposure of the human body to the thermal environment translates into human feelings based on the physiological reactions to the thermal sensation. This introduces the psychological dimension of human thermal comfort. Each individual has a means of reacting to the thermal environment based on human subjective psychology. The level of human comfort can thus be easier examined through the response of the individual than through physiological analysis. The relevance of the psychological approach to thermal comfort is evident in the need to decipher the different degrees of comfort and discomfort responses to different thermal conditions.

Fisk (1982) gave two techniques that have been utilized to produce psychological models of thermal comfort. First is the prompted vote where the human subject is asked to concentrate on his thermal sensation and respond in a controlled manner. Second is the behavioural approach where the condition of comfort is inferred by the subject's reactionary behaviour. All findings concerning the subjective response obtained during thermal comfort surveys are a pointer to the immense contribution of the human expression of feeling in the assessment of thermal comfort (Frank et al ,1999; Tsuzuki et al, 1999; Wyon, 2001; Huizenger et al, 2006; Lin et al, 2010) Each individual is actually free to express himself or herself. The psychological approach has the advantage of defining different levels of comfort and discomfort. The psychological approach was adopted in the study.

Human responses to the thermal environment cannot simply be expressed as functions of a single environmental factor such as temperature, humidity, air velocity or mean radiant temperature. These factors affect the human body simultaneously and the influence of any one depends on the levels of the other factors. Givoni (1976) observed that it is necessary to evaluate the combined effect of environmental factors on the physiological and sensory responses of the body and to express any combination of them in terms of a single parameter. The factors are therefore combined into a single formula known as a thermal index. A thermal index measures the stress imposed by external conditions and predicts the optional environment needed for comfort within dwellings (Ogunsote and Prucnal-Ogunsote 2003). It therefore provides a scientific means of evaluating comfort. Humphreys (1978) in the UK and Auliciems (1981, 1982) in Australia showed quite conclusively that thermal neutrality is a function of the prevailing climate. Nicol and Humphreys (2009) related the indoor comfort conditions to the running mean of the outdoor temperature. It was inferred that the derivation of the equation for thermal comfort in free-running buildings established a relationship between indoor comfort and outdoor climate. The effect of air movement and humidity was also addressed. The result of Haase and Amato's (2009) analysis of thermal comfort in buildings in the warm-humid climate also confirmed climatic condition as the most important factor in the determination of thermal comfort.

The effective temperature index can be defined as the temperature of a still, saturated atmosphere, which would, in the absence of radiation, produce the same effect as the atmosphere in question.(Koenigsberger et al 1973). The ET scale, first developed by Houghton and Yaglou in 1923, with subsequent revisions, integrates the effect of three fundamental environmental variables relevant to thermal comfort in any context. These are air temperature, relative humidity and air movement. The effective temperature has been an internationally accepted thermal comfort scale which has been of wide applicability. However with the recent findings disqualifying the general applicability of thermal indices, it is pertinent to use field survey results to examine the index locally. According to Humphreys (1975), field studies of thermal comfort are with two purposes. First is to find a way of describing the thermal environment which correlates well with human response, thus enabling reliable predictions to be made, and secondly to define the range of conditions found to be pleasant or tolerable by the population concerned. This contextual study in Ile-Ife sought to assess indoor comfort using the mean comfort votes of the thermal responses and to determine the comfort zone for the study area in relation to the effective temperature index.

3. STUDY CONTEXT

Ile-Ife is a small city in South-Western Nigeria located on latitude 7.5ºN and longitude 4.5ºE. The city is fast-growing with the strong impact of urbanization like many other cities in Nigeria, especially due to the location of Obafemi Awolowo University in the township since 1962. The city is worthy of all kinds of study because it has a lot of history behind it as an ancient city. It is the acknowledged cradle of the Yoruba race and serves as a typical Nigerian cultural city. Apart from the socio-magnetic impact of the University, Ile-Ife is also a trade centre with a good number of businesses attracting people from the surrounding rural areas. It is located in the tropical rain forest vegetation belt and has an elevation of about 275m above sea level. Ile-Ife falls within the warm-humid climatic zone. In the warm-humid zone there is very high solar radiation, high temperatures and high humidity but with relatively low wind speed (Hyde 2000). The climatic data for Ile-Ife showed that the climatic context combined high temperature ($mean_{max}$- 31.4ºC), high humidity ($mean_{max}$- 83.3%) and low air velocity ($mean_{max}$– 1.55m/s). The maximum temperatures were above 30ºC for all months with the exception of August and September. The sequence of weather conditions in any place in Nigeria and other West African countries during the course of a given year actually depends on the location of the place in relation to the fluctuating surface position of the Inter-Tropical Discontinuity (ITD). The ITD movements and effects on various locations in West Africa are discussed in Ojo (1977).

The residential estates in the city were selected for the study to obtain a regulated sample of similar contemporary buildings. The seven estates were Moremi, Asherifa, Omole, Ikoyi, Oni/Ajebandele, Sijuade and Road 20-Campus. The house type in the estates was uniform consisting of contemporary design of bungalow and one storey flat buildings with units consisting of living room, two or three bedrooms, kitchen and bathroom (Figure 1). They were generally built of rendered 225mm hollow sandcrete block wall, roofing of corrugated asbestos with asbestos ceiling and windows of glass louvers mounted on wooden frames.

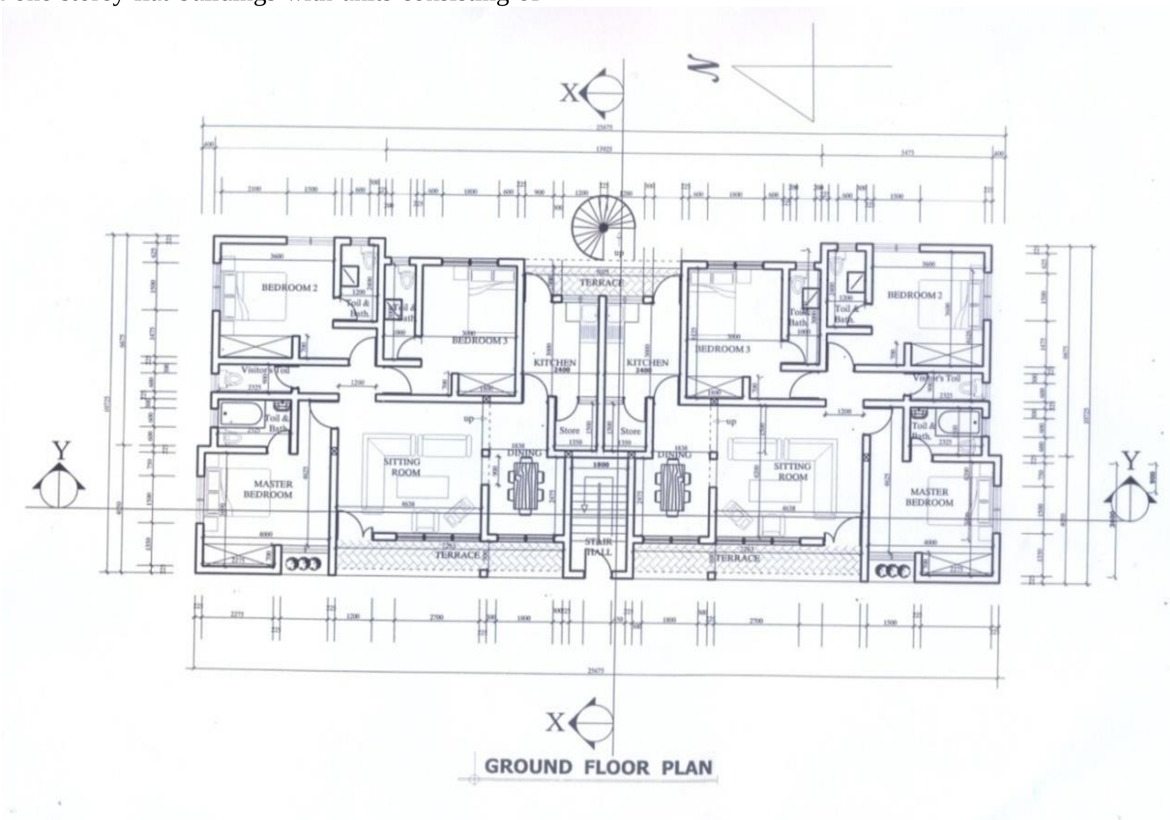

Figure 1: Plan of a typical residential building in the estates

4. METHODOLOGY

A thermal comfort field survey was conducted in the study area in October, 2010. Since the aim of the study was to assess indoor thermal comfort in relation to Effective Temperature, one month characterized with average thermal discomfort in the study area was considered sufficient and appropriate to make all respondents experience the same conditions. The climatic data for Ile-Ife was obtained from a meteorological station at Obafemi Awolowo University, Ile-Ife and bio-climatic analysis was used to determine values of maximum and minimum effective temperatures. The climatic analysis of Effective Temperature showed that the twelve months in the year have hot discomfort with maximum ET greater than 25°C and the afternoon period identified as time of hot discomfort (Table 1). The month of October was selected for the survey and the respective values of ET are shown in Table 2. The hourly temperature calculator was used to determine the hourly values of effective temperature from 8am to 8pm according to the procedure in Koenigsberger et al (1973).

Table 1. Maximum and minimum effective temperature analysis for the study area.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean Max DBT	33.0	33.5	33.0	32.5	31.5	30.5	30.0	29.5	28.5	30.5	32.5	31.5
RH Min	49	49	58	73	80	84	82	82	82	68	71	41
WBT	24.5	24.8	26.0	28.3	28.8	29.3	27.2	28.0	26.0	25.4	28.0	21.8
ET Max	27.3	27.5	28.0	29.0	28.8	28.5	27.5	27.5	26.3	26.9	29.0	25.7
Mean Min DBT	21.5	28.0	23.0	22.5	22.0	22.0	21.0	21.0	20.5	25.5	22.5	18.0
RH max	82	75	86	88	86	90	84	88	86	86	85	69
WBT	19.3	24.5	21.5	21.2	20.5	20.3	19.3	19.8	19.0	23.7	20.8	14.7
ET Min	19.8	25.0	21.5	21.0	20.3	20.0	19.0	19.5	19.0	23.6	21.0	16.8

Legend:
DBT -Dry Bulb Temperature
WBT – Wet Bulb temperature
RH – Relative humidity
ET – Effective temperature

Table 2. Determination of Maximum and Minimum Effective Temperatures for Ile-Ife (October 2010)

Mean Maximum Air Temperature	30.5 ^{o} C
Mean Minimum Relative Humidity	68%
Wet-bulb Temperature (from psychrometric chart)	25.4 ^{o} C
Average Air Velocity	0.5m/s
Maximum Effective Temperature (from ET nomogram)	26.9^{o}C ET
Mean Minimum Air Temperature	25.5 ^{o} C
Mean Maximum Relative Humidity	86%
Wet-bulb Temperature (from psychrometric chart)	23.7^{o}C
Average Air Velocity	0.5m/s
Minimum Effective Temperature (from ET nomogram)	23.6^{o}C ET

Source: Author's Analysis

A purposive sampling was done to select areas within the city having residential estates with similar contemporary buildings. This was done to obtain a regulated sample of similar contemporary buildings for the study. In each area with an estimated population of about 500 residents, ten percent (50 residents) were randomly selected to fill questionnaires concerning the indoor thermal conditions. For this thermal comfort survey, a seven-point thermal comfort scale as developed by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) was used (Table 3). Respondents indicated their subjective thermal response for the different periods of the day from 8 a.m. to 8 p.m for their respective buildings. The mean comfort votes of thermal responses for the buildings in the respective estates were determined for the different periods. The overall mean comfort vote was also determined. Statistical tools of correlation and linear regression were used to analyze the data. With the above study procedure, data was collected and the analysis produced valuable results which addressed the purpose of the study.

Table 3. Thermal scale used in the survey.

Thermal Response	Assessment Rating
Hot	+3
Warm	+2
Slightly warm	+1
Neutral	0
Slightly cool	-1
Cool	-2
Cold	-3

Source: ASHRAE

5. RESEARCH FINDINGS

Reported under this section are the findings in the study. The respective results obtained for the indoor thermal response of the residents in the 7 areas with respect to the mean comfort votes are presented in Table 4.

Table 4. Analysis of values of Mean Comfort Votes of thermal responses

Time	Effective Temperature (ºC ET)	Moremi Mean Vote	Asherifa Mean Vote	Omole Mean Vote	Ikoyi Mean Vote	Oni/Aj Mean Vote	Sijuwade Mean Vote	Rd20 Mean Vote	Overall Mean Vote
8am	23.8	-0.88	-1.22	-1.32	-1.80	-1.40	-1.53	-1.70	-1.41
10am	25.5	0.32	-0.02	0.36	0.00	-0.06	-0.23	-0.96	-0.08
12pm	26.4	1.90	1.06	1.68	1.25	1.00	1.71	0.62	1.32
2pm	26.9	2.68	2.15	2.16	2.79	2.24	2.38	1.94	2.33
4pm	26.6	1.28	1.70	1.38	1.79	1.70	1.71	1.70	1.61
6pm	25.8	0.68	0.61	0.16	0.00	0.76	0.27	0.64	0.45
8pm	25.0	-0.52	-1.04	-1.24	-1.21	-0.04	-0.73	-1.20	-0.91
8am-8pm mean values	25.71	0.780	0.463	0.454	0.403	0.549	0.511	0.149	0.473
12-4pm mean values	26.63	1.953	1.637	1.740	1.943	1.647	1.933	1.420	1.753

Source: Author's Analysis of Fieldwork

It is evident from these results that patterns of the thermal responses were similar across the areas surveyed. The votes tended towards cool for the morning period (8-10am), towards hot for the afternoon period (12- 4pm) and towards slightly cool for the evening period (6-8pm). For all 7 cases considered there is a similar variation of mean comfort votes with the corresponding time of the day from 8am to 8pm. The 8am-8pm overall mean vote was 0.473 (slightly warm) for a corresponding 8am-8pm mean ET of 25.71ºC ET.

From Table 4, it is shown that the afternoon period was a period of discomfort for the respondents in all areas in the city. The afternoon mean vote was 1.753 (warm) for an afternoon mean ET value of 26.63ºC ET. This was in the region of warm discomfort. Buildings in Moremi, Ikoyi and Sijuade had the highest discomfort votes of 1.953, 1.943 and 1.933 respectively while Road 20 had the least discomfort vote of 1.420. At the time (2pm) of maximum ET of 26.9ºC ET, the overall mean vote of the Ile-Ife residents surveyed was 2.33 which fell into the hot discomfort category. Figure 1 shows the graph relating the overall mean comfort vote (OMCV) and the ET. In order to determine the extent of the relationship, Pearson correlation was applied to the two variables (Table 5). The overall mean comfort vote was found to be very strongly correlated with ET.

Table 5. Pearson Correlation analysis indicating correlation of ET and OMCV

		ET	OMCV
ET	Pearson Correlation	1	.967(**)
	Sig. (2-tailed)		.000
OMCV	Pearson Correlation	.967(**)	1
	Sig. (2-tailed)	.000	

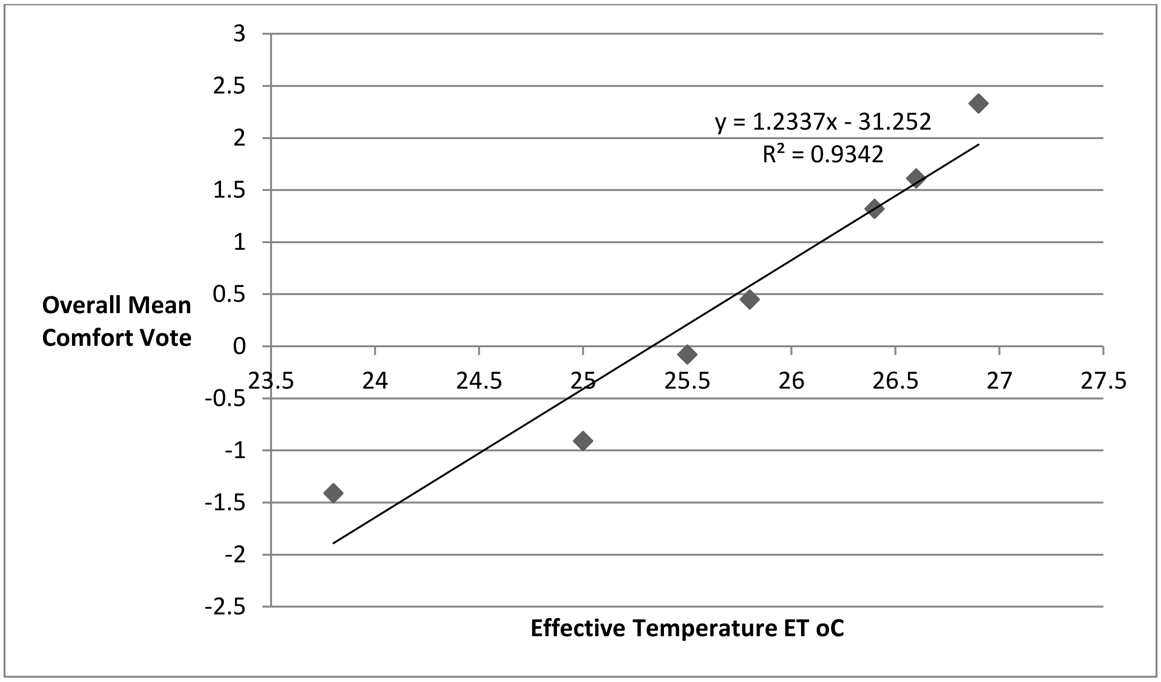

Figure 2. Graph showing relationship between Overall Mean Comfort Vote of respondents' thermal responses and Effective Temperature

The statistical tool of linear regression was applied to determine the equation relating OMCV as the dependent variable and ET as the independent variable. The result of the linear regression also confirmed the strong relationship between thermal response and effective temperature using the values obtained in this study. The ET as the independent variable explained 93.4% of the variance of the OMCV (R^2 = 0.934). The equation obtained from the regression was y = -31.25 + 1.23x, where y = Overall mean comfort vote and x = Effective temperature. Therefore,

OMCV = -31.25 + 1.23ET

The thermal assessment votes for comfort range from -1 (slightly cool) to +1 (slightly warm). Fanger (1970) defines comfort as the conditions under which the subjective thermal comfort votes are between 'slightly cool' and 'slightly warm' on a seven-point thermal comfort scale. Votes outside this range are in the discomfort zone. Using the regression equation obtained, the values of ET corresponding to the comfort zone are 24.5°C ET (for OMCV = -1) and 26.1°C ET (for OMCV = +1). The optimum ET value corresponding to neutral vote (OMCV = 0) is 25.3°C ET.

The findings in the study inferred the relevance of the Effective Temperature index in the determination of thermal comfort in Ile-Ife which is a warm-humid environment. The effective temperature index measures the combined impact of the environmental parameters of thermal comfort- temperature, relative humidity and air velocity. The relative importance of the impact of high temperature, high humidity and low air velocity values typical of such warm-humid zones was emphasized by Hyde (2000). According to Mallick (1996), the perception of comfort in the warm-humid climate is influenced by long-term conditioning of high temperature and humidity. The values of minimum and maximum acceptable ET for tropical regions are 22°C ET and 27°C ET respectively with an optimum value of 25°C ET (Koenigsberger et al 1973). The comfort zone values of 24.1°C ET to 26.1°C ET obtained in this study compare favourably with this standard and give a more restricted range which can be applicable for the study area and places with similar climatic conditions.

The result also further established the dynamic relationship between architecture and climate. According to Pearlmutter (2000), there is presently a dynamic interaction between the built and natural environments that needs to be balanced. The design of buildings should ultimately be climate-responsive to provide building satisfaction. A linear equation relating indoor thermal feeling represented by the overall mean votes of respondents OMCV and effective temperature ET was obtained from the analysis:

OMCV = -31.25 + 1.23ET. The use of ET is applicable for the study area because of the high significance level of this regression equation.

6. CONCLUSION

The study further confirmed the linkage between indoor comfort and climatic factors. It is hereby emphasized that a comprehensive analysis of the local climatic conditions should be the starting point in formulating building design principles aimed at maximizing comfort provision. From the findings, it can be deduced that there is inadequacy of the design and fabric composition of the buildings in the study area with respect to indoor comfort provision. The findings in the study inferred the relevance of the Effective Temperature index in the determination of thermal comfort in Ile-Ife which is a warm-humid environment. This study therefore makes a case for the relevance of the effective temperature index in the climatic context studied. The influence of climatic factors on the indoor thermal response can be established due to the high significance of the correlation between effective temperature and mean comfort vote of the respondents' thermal responses. The regression equation obtained from the analysis inferred thermal response as a function of effective temperature. The relationship is given as OMCV = -31.25 + 1.23ET. It can be concluded that climatic factors played a very significant role in defining the indoor thermal quality of the built environment in the study area. The effective temperature index can therefore be effectively used to assess the indoor comfort in the context of buildings in the study area. The comfort zone defined for the study area from this study is from 24.5ºC ET to 26.1ºC ET. The optimum ET value corresponding to neutral vote (OMCV = 0) is 25.3ºC ET. The results of the survey indicated thermal discomfort of the respondents with the afternoon overall mean vote of 1.75 (warm) and a maximum overall mean vote of 2.33 (hot). It is hereby submitted that thermal indices may be proved to find local applicability and should not be discarded outrightly.

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