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Evaluation of the Indoor Thermal Comfort of Selected Residents in Ibadan, Nigeria

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ABSTRACT

This study evaluated the thermal responses of residents of naturally ventilated buildings in Ibadan, Nigeria. 93 buildings were systematically selected in the Olubadan estate, Ibadan and questionnaire was administered to an adult resident in each of the selected buildings. Respondents assessed their respective living rooms at different periods of the day using a seven-point thermal comfort scale. The Mean Votes for the different periods of the day were: morning - cool, afternoon –warm, evening -cool and night-cool. The indoor thermal comfort level of the naturally ventilated buildings was acceptable to the residents. The results of linear regression showed that the thermal response (y) had strong linear relationship with air temperature (x) with these equations:

$y = 9.7 - 0.24x$ for morning (with $R^2 = 0.025$ and $p = 0.132$) and

$y = -7.1 + 0.37x$ for afternoon (with $R^2 = 0.047$ and $p = 0.038$). The study concluded that the acceptable limits of comfort expressed by the residents were between 22.6^0C and 25.6^0C. The value of the neutral temperature was determined to be 24.6^0C.

***Keywords*:** Comfort limits, Naturally ventilated building, Neutral temperature, Thermal response, Warm-humid.

1. INTRODUCTION

Majority of people are living in naturally ventilated buildings in the warm-humid climate of Nigeria. These occupants experience a certain level of indoor thermal comfort which affects their lifestyle on a daily basis. Thermal comfort within these residential buildings should not be taken for granted. Many residents may not really be pleased or comfortable with their houses if there is thermal stress within the spaces. It is of priority therefore to find out if these people are comfortable or not and to determine their degree of comfort as well as the range of acceptable conditions.

There has not been much research findings about the thermal response of people to the indoor environment in Nigeria. Much of what is known in thermal comfort evolved from research work which focused on other countries. This paper is concerned with the determination of acceptable thermal comfort within the living spaces of naturally ventilated residential buildings in the warm-humid climate of Ibadan, a city in Nigeria. The concept of comfort provision through natural means needs to be assessed to determine the viability of residential buildings constructed to be naturally ventilated in the warm humid climate. It is not certain if people living in the warm-humid climate find the endoclimate pleasant or endurable with the general building tradition of free-running buildings. However, the range of conditions for which people are comfortable within the naturally ventilated spaces must be determined so that this can form one of the bases of designing buildings for comfort in Nigeria.

2. ISSUES IN RESIDENTS' THERMAL COMFORT

The warm-humid climate presents environmental challenges of high temperature and high humidity. However, comfortable indoor environment must be created for human activities. Croome (1991) asserted that buildings modify climate, influence behaviour and affect the distribution of resources and the ecological pattern of the earth. His position was that human aspirations could only be met when climate, buildings and people are in balance. The attainment of indoor thermal comfort is highly desirable because unfavourable environmental conditions will reduce the level of human performance.

The study of thermal comfort has taken a psychological dimension along with the initial physiological approach. Whereas the physiological concept laid the foundation for relating the physical parameters of an environment to the thermal state of the body, the human subjective psychology gave insight into the human experience of thermal comfort (Fisk 1982, Szokolay 1985). The psychological approach to the study of thermal comfort has become more relevant because of the need to decipher the different levels of comfort within different environmental conditions. Consequently, the subject of thermal comfort has become more context specific both in terms of the human respondent and the climate of the area as indicated by the bases of many previous works like Sharma and Ali (1986), Ogunsote and Prucnal-Ogunsote (2002), Andreasi and Lamberts (2006), Raue et al (2006), MdZain et al (2007) and Becker and Pacink (2009).

There have not been many findings concerning the thermal response of people to the indoor environment in Nigeria (Ogunsote 1990, Ajibola 2001, Ogunsote and Prucnal-Ogunsote 2002). It must be noted that there is paucity of research findings that are based on African people and their indoor thermal experience. Thermal comfort theory has not been examined thoroughly within the context of the Nigerian people and environment. The derivation of an index for indoor comfort for Ibadan will help us in comprehending the dynamics of thermal comfort in the Nigerian warm-humid climate. It is pertinent to determine the conditions which the majority of residents consider as thermally comfortable. The focus is on indoor thermal comfort using survey of human responses based on the explanation given by Webb (1959) on the appropriateness of field study for thermal comfort evaluation. According to Humphreys (1975), the field studies of thermal comfort have two purposes: (1) to find a way of describing the thermal environment which correlates well with human response, and (2) to define the range of conditions found to be pleasant or tolerable by the population concerned. The results are to be regarded as the phenomena to be explained by theoretical models of thermal comfort.

3. METHODOLOGY

Olubadan estate, a residential estate in Ibadan with contemporary buildings was selected for the study. Selecting such an estate minimized errors of subjectivity since results are from the assessment of people living in similar naturally ventilated buildings. Systematic sampling technique was adopted in the study to select 93 out of the 273 buildings in the estate. The first unit was randomly chosen while subsequent units of investigation were every 3rd building. Questionnaire was administered to the residents to record their responses to the thermal environment within their living rooms. A modified 7-point ASHRAE scale of warmth was used in the thermal assessment (Table 1). The survey design used was the longitudinal design with one respondent in each building providing repeated assessment over a period of 2 weeks.

Table 1 : Thermal scale used in the survey

Thermal Feeling/Response	Assessment Vote Number
Very hot	1
Hot	2
Warm	3
Neutral	4
Cool	5
Cold	6
Very cold	7

Source: Author's Analysis of Fieldwork

Climatic data for Ibadan was obtained from the meteorological station at the International Institute of Tropical Agriculture, Ibadan. The materials specification, the thermal transmittance of the components and their respective areas were used to predict the heat load in the spaces using the procedures in Koenigsberger et al (1973) and Egan (1975). Use was made of the available climatic data and the thermal properties and spatial characteristics of the indoor spaces of the buildings to simulate the indoor values of the air temperature. The results of the survey were subjected to statistical analysis with subjective estimates of warmth obtained and the Mean Vote determined. The acceptable limits of comfort and the neutral temperature were also determined.

4. RESEARCH FINDINGS

Out of the 93 respondents, 68 were male (73.1%) and 25 were female (26.9%). All the respondents had lived in the estate for a minimum of one year. The responses of subjects to the thermal sensation experienced within the living room spaces were obtained from the questionnaires. Figure 1 gives a representation of the results. The respondents' total votes considered by their categories in percentages are presented in a pie chart in Figure 2. Having compiled the assessment of the respondents, the variation of the responses through the periods of the day was examined. The variation of the percentage of people in the comfort zone of warm, neutral and cool is shown in Figure 3. It is remarkable that 72% were in the comfort zone in the afternoon period which was considered the least comfortable period because of the high value of air temperature. The assessment gave morning as the period with most comfort zone votes. The descriptive statistics for the feelings are indicated in Table 2.

The thermal feeling in the morning ranged from hot to very cold with the mean vote of cool. The feeling in the afternoon ranged from hot to cool with the mean vote of warm. The feeling in the evening ranged from hot to very cold with the mean vote of cool. The feeling in the night ranged from warm to very cold with the mean vote of cool. The mean temperatures experienced in the four periods were calculated and rated against the mean feelings during the respective periods (Table 3).The mean feeling was coolest in the night followed by the morning and then the evening. The mean feeling in the afternoon was warm because of the relatively hotter weather condition in the afternoon.

The percentage of people who actually voted neutral for the different periods of the day is shown in Figure 4. The low percentage values indicate that the thermal experience of most people was much more

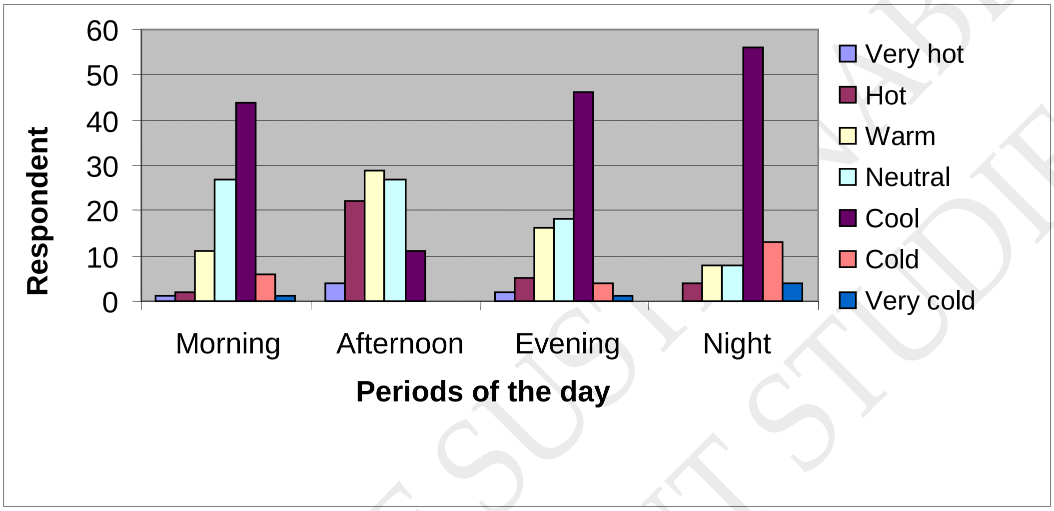

Fig.1: Thermal response of occupants in the living room at different times of the day

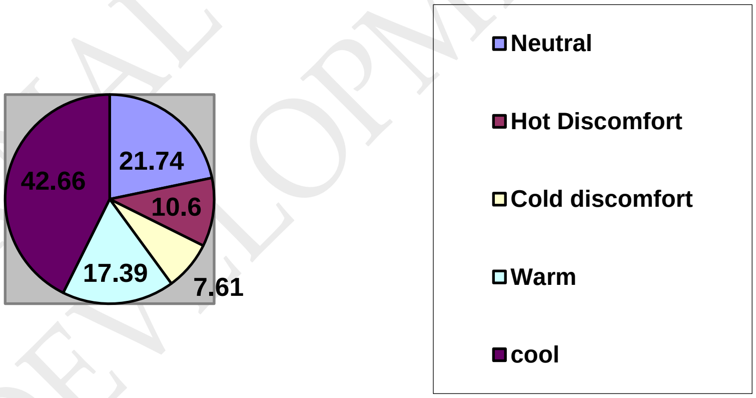

Fig. 2: Percentage of total votes of respondents in the different categories

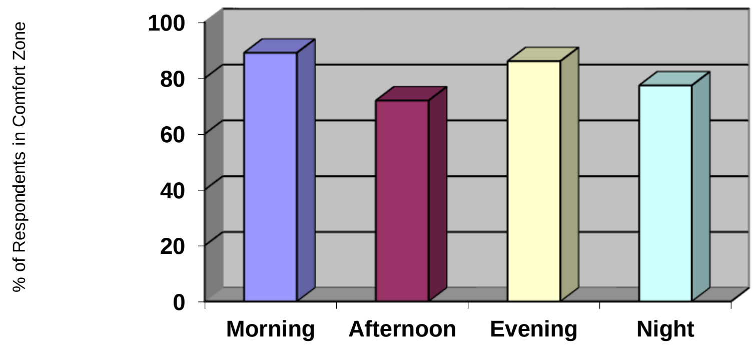

Fig. 3: Percentage of respondents in comfort zone of warm, neutral and cool

Table 2 : Descriptive statistics for thermal responses of subjects

	Minimum	*Maximum*	*Mean*	*Standard Deviation*
Feeling morning	1.00	7.00	4.446	0.9763
Feeling afternoon	1.00	5.00	3.204	1.0689
Feeling evening	1.00	7.00	4.272	1.1397
Feeling night	2.00	7.00	4.839	1.0559

Source: Author's Analysis of Fieldwork

Table 3 : Mean values of indoor air temperature and thermal response.

	Mean Indoor Air Temperature	*Mean Comfort Vote*	*Mean Thermal Response*
Morning	21.25	4.446	Cool
Afternoon	28.25	3.204	Warm
Evening	25.25	4.272	Cool
Night	20.25	4.839	Cool

Source: Author's Analysis of Fieldwork

outside neutral vote than within it. The two other votes in the comfort zone- cool and warm, actually take the greater proportions of the respective percentage comfort votes. Not many occupants actually felt neutral during the course of the study. The neutral votes decreased from morning to the night period. The prevailing feeling in the morning, evening and night was cool as shown in Figure 5 while the prevailing feeling in the afternoon was warm as shown in Figure 6. The percentage of respondents voting "warm" corresponded to the temperature variation for the study area. The daily temperature was highest in the afternoon and lowest at night.

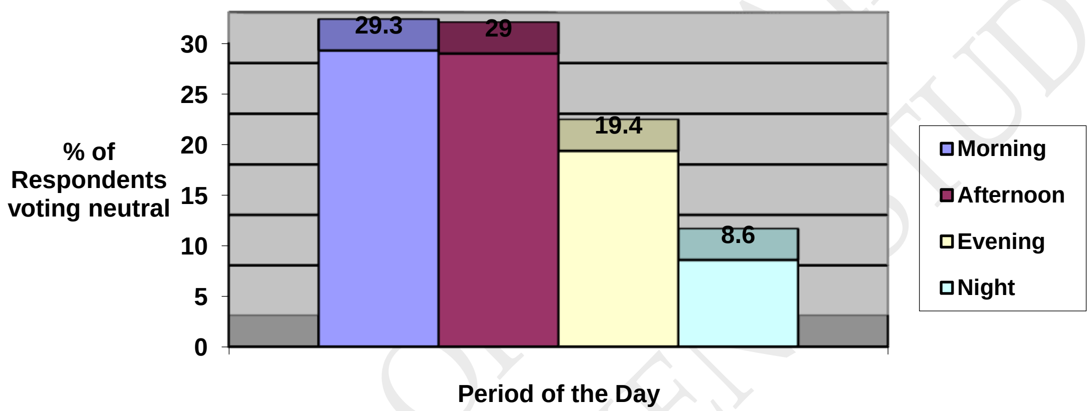

Fig. 4: Percentage of Respondents voting neutral

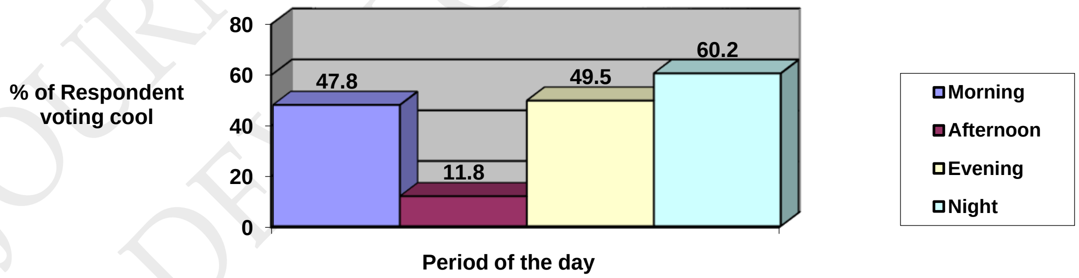

Fig. 5: Percentage of Respondents voting cool

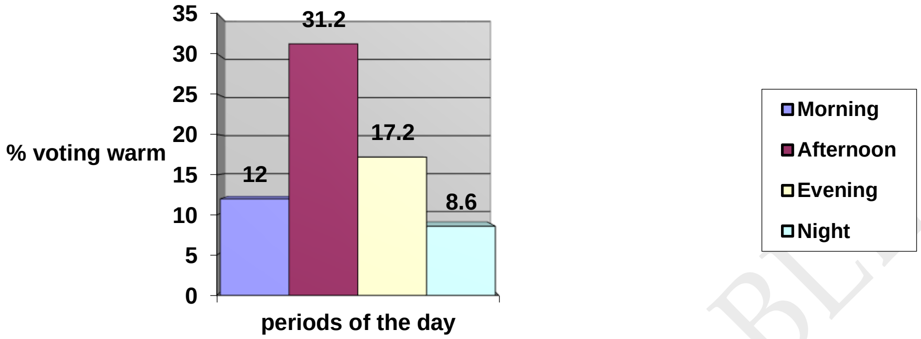

Fig. 6 :Percentage of Respondents voting warm

4.1 Variation of Thermal Responses with Air Temperature

The variation of thermal response with air temperature was of interest in this study. According to Humphreys (1975), in most of the studies of thermal comfort a far greater part of the variation in response can be attributed to change of temperature than to changes of either humidity or air movement. The indoor air temperature relationship with the thermal response of the subjects in this study was therefore analyzed. The mean vote (MV) for each set of response was calculated. It was found that higher values of MV corresponded to lower values of temperatures and the lower values of MV corresponded to higher values of temperatures. It was therefore inferred that thermal feelings increased in the direction of coolness with reduction in temperature and increased in the direction of warmth with increase in temperature (Figure 7).

The mean indoor air temperature experienced in all the living spaces was calculated to be 23.8^{0}C. The mean vote corresponding to this was 4.224 which was taken as cool or comfortably cool because it was within the comfort range of neutral and cool. The thermal experiences of the occupants can therefore be assessed averagely as comfortably cool based on the MV and the mean indoor air temperature. Figure 7 indicates the linear relationship between mean thermal feeling and mean air temperature.

The graph in Figure 8 shows that the proportion in the comfort zone first increased with the temperature and after passing through a maximum then diminished. According to Humphreys (1975), the temperature

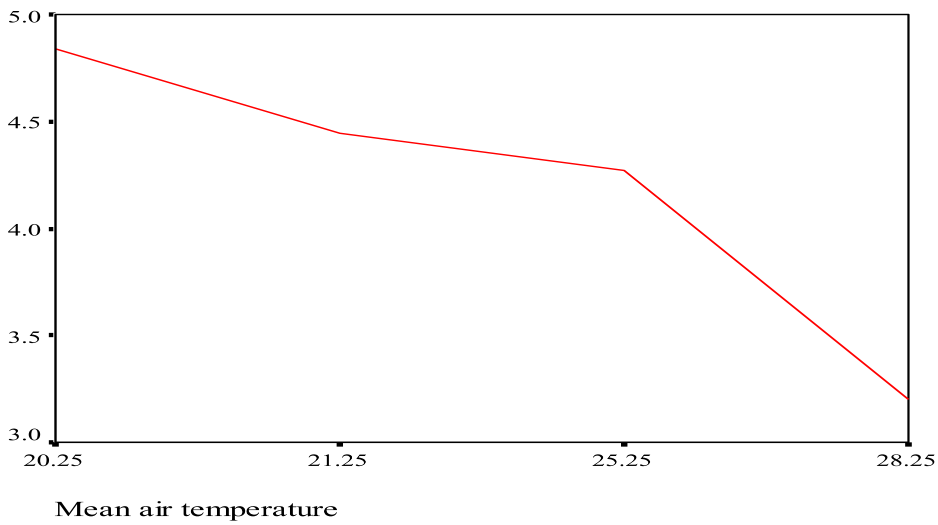

Fig. 7: Graph of mean feeling vs. mean air temperature

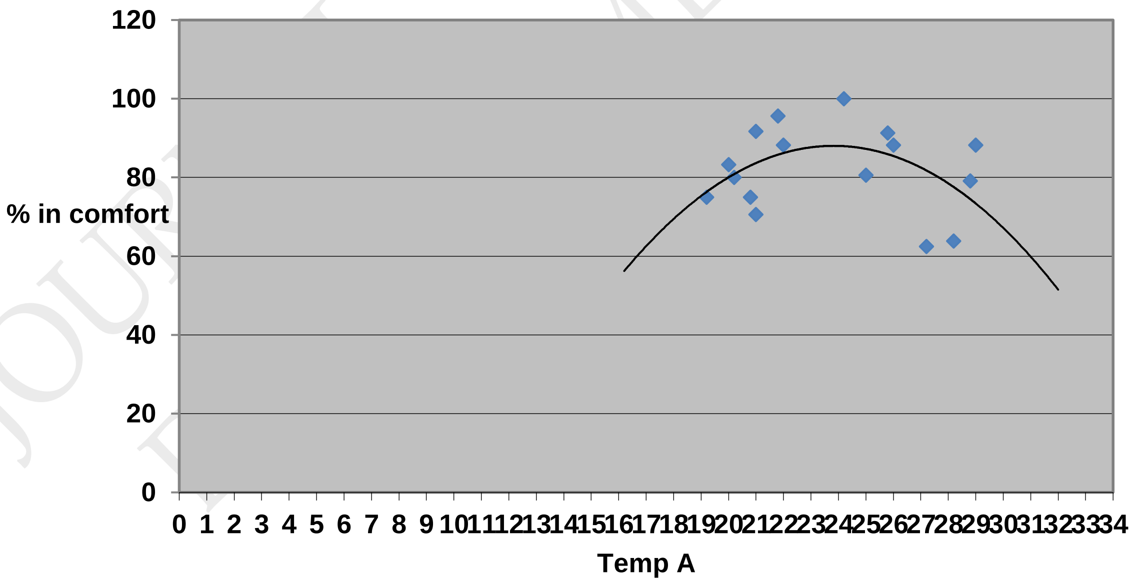

Fig. 8: Percentage of Respondents in Comfort Zone vs. Air Temperature

corresponding to the peak of the curve is called the optimum or neutral temperature. 24.2°C was obtained as the optimum in this case.

Linear regression was applied (Tables 4a, 4b, 5a, 5b) to determine the equations relating thermal feeling of respondent as the dependent variable (y) and room temperature as the predictor variable (x). The regression result for the morning period gave $R^2 = 0.025$ and adjusted R square of 0.014. The predictor variable explained 2.5% of the variance of the dependent variable. The ANOVA test gave the sum of squares for regression to be 2.168, a mean square of 2.168, F value of 2.308 and at 0.132 level of significance. There is a linear relationship between thermal feeling in the morning and air temperature. The equation obtained is: $y = 9.693 - 0.247x$.

The regression result for the afternoon period gave $R^2 = 0.047$ and adjusted R square of 0.036. The predictor variable explained 4.7% of the variance of the dependent variable. The ANOVA test gave the sum of squares for regression to be 4.905, a mean square of 4.905, F value of 4.454 and at 0.038 level of significance. The result is highly significant and indicates the high determinant level of air temperature for thermal feeling in the afternoon. There is linear relationship between thermal feeling in the afternoon and air temperature. The equation obtained is: $y = -7.122 + 0.366x$.

The results for the evening and night regression were however not significant as indicated by the poor level of significance values 0.746 and 0.512 respectively. Equations obtained are $y = 2.693 + 0.062x$ for the evening and $y = 7.17 - 0.115x$ for the night. With these regression results having low R^2 values it can be deduced that additional parameters apart from climatic variables would need to be examined along with the climatic variables in the study of thermal comfort within the context.

4.2 Determination of the Neutral Temperature and the Comfort Limits

The neutral temperature is the temperature at which the respondents were thermally neutral during the study. The aggregate of scores for the neutral option was obtained along with the respective temperatures considered basing the calculation on the Mean Vote. The number of votes that were in the neutral category were taken across the range of temperatures for the study. The summation of the products of temperature values and corresponding number of neutral votes was divided by the total number of votes in the neutral category to obtain the neutral temperature. The neutral temperature obtained for the respondents in this study was 24.6^{0}C.

Table 4a: ANOVA: Table Testing the Significance of Regression Coefficients for Thermal feeling of Respondents.

Model		Sum of Squares	df	Mean Square	F	Sig.	F Table	Sig.
1	Regression	2.168	1	2.168	2.308	.132[a]	3.920	0.05
	Residual	84.560	90	.940				
	Total	86.728	91					

Table4b: Regression Coefficients and the semi partial correlations for the Thermal feeling of Respondents

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	9.693	3.456		2.805	.006
	temp A morning	-.247	.162	-.158	-1.519	.132

Table 5a: ANOVA: Table Testing the Significance of Regression Coefficients for Thermal feeling of Respondents.

Model		Sum of Squares	df	Mean Square	F	Sig.	FTable	Sig.
1	Regression	4.905	1	4.905	4.454	.038[a]	3.920	0.05
	Residual	100.213	91	1.101				
	Total	105.118	92					

Table 5b: Regression Coefficients and the semi partial correlations for the Thermal feeling

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-7.122	4.894		-1.455	.149
	Temp A Afternoon	.366	.173	.216	2.110	.038

The limits of comfort would be exceeded at temperatures beyond the values being voted as warm and cool by the respondents. The neutral temperature is considered to be within this range and temperatures slightly above or below the neutral temperature can be accepted as comfortable up to the calculated values for cool and warm respectively. These will serve as the limits for comfortably cool and comfortably warm respectively. The limits of temperature acceptable for comfort within the considered living spaces based on the MV of the respondents were a maximum indoor air temperature of 25.6^{0}C and a minimum indoor air temperature of 22.6^{0}C.

5. CONCLUSION

The results indicated that the residents found the indoor thermal environment acceptable for the greater part of the day with the mean indoor temperature at 23.8^{0}C. Their thermal responses were found to have strong linear relationship with air temperature. Other additional parameters apart from climatic variables should be examined along in the contextual study of thermal comfort. The neutral temperature was determined to be 24.2^{0}C from the comfort percentage graph and 24.6^{0}C from calculations using the principle of the mean vote. The acceptable limits of comfort expressed by the residents were between 22.6^{0}C and 25.6^{0}C.

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