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Thermal Comfort and Occupant Behaviour in a Naturally Ventilated Hostel in Warm-Humid Climate of Ile-Ife, Nigeria: Field Study Report During Hot Season

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Abstract- Naturally ventilated buildings have been observed to be ineffective in warm-humid tropical especially during hot season. To ascertaining this observation, this study presents the results of a short-term thermal comfort survey performed in a naturally ventilated hostel building in Obafemi Awolowo University, Ile-Ife, Nigeria during hot season. Using the data obtained from questionnaire survey and physical measurement of (air temperature, relative humidity and air velocity) using Kestrel model 4500, thermal environmental conditions, occupant comfort and adaptation methods were investigated considering class II protocol. Ninety six respondents participated in the study. Statistical analysis of students` responses and measured thermal environmental variables was performed to determine existing indoor environmental conditions and priority of using adaptive controls. All the measured environmental variables fell below the comfort range recommended by ASHRAE standard 55 and ISO 7730 standard. On the contrary, respondents were comfortable, preferring cooler, no change environments and more air movement. First preference of the respondents adaptive control was window opening (77.4%), closely followed by wearing light clothes (77.3%) and lastly, the use of electric fans. This study concludes that in warm-humid climate of Ile-Ife, during the hot season the desire for sustainable thermal comfort may not be achieved without mechanical ventilation system.

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Absract- Naturally ventilated buildings have been observed to be ineffective in warm-humid tropical especially during hot season. To ascertaining this observation, this study presents the results of a short-term thermal comfort survey performed in a naturally ventilated hostel building in Obafemi Awolowo University, Ile-Ife, Nigeria during hot season. Using the data obtained from questionnaire survey and physical measurement of (air temperature, relative humidity and air velocity) using Kestrel model 4500, thermal environmental conditions, occupant comfort and adaptation methods were investigated considering class II protocol. Ninety six respondents participated in the study. Statistical analysis of students` responses and measured thermal environmental variables was performed to determine existing indoor environmental conditions and priority of using adaptive controls. All the measured environmental variables fell below the comfort range recommended by ASHRAE standard 55 and ISO 7730 standard. On the contrary, respondents were comfortable, preferring cooler, no change environments and more air movement. First preference of the respondents adaptive control was window opening (77.4%), closely followed by wearing light clothes (77.3%) and lastly, the use of electric fans. This study concludes that in warm-humid climate of Ile-Ife, during the hot season the desire for sustainable thermal comfort may not be achieved without mechanical ventilation system.

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I. Introduction

The chief goal of hostels is to provide quality living and sleeping environment for the occupants. Sekhar and Goh [1] noted that a quality night sleep allows adequate daytime functioning: concentration, attention and comprehension as well as learning level. Similarly, [2-3] also believed that thermal discomfort can affect the quality of sleeping environment and subsequently the performances of daytime functions. Sleep is also an important factor that affect a person`s health and well-being. Health symptoms like fatigue, headache, stress and tiredness, undesired physiological stress on the body and aggressiveness are common scenario faced by occupants due to lack of quality sleep and bad thermal comfort conditions [4-5]. Regarding the relationship between thermal comfort and academic performance, [6-8] highlighted some reduction in the learning performance of the students. Dhaka et al. [9] and Dahlan et al. [10] from their undergraduate hostel buildings studies in Malaysia noted that the intellectual capabilities as well as academic performance of occupants of hostel buildings was closely related to the quality of indoor environment Several research projects [11-12] revealed that man`s physical strength and mental activities are their best within a given range of climatic conditions, and outside this range efficiency lessens, while stresses and the possibility of disease increases. Based on the foregoings, the importance of thermal comfort topic in Hostel Architecture can be appreciated. It is therefore important to study thermal comfort in learning environments.

In Nigeria, the issues of thermal comfort and occupant adaptive behaviour in the case of naturally ventilated family residential and office buildings have been studied by several researchers and are well documented in the scientific literature [13-16]. However, the indoor spaces in naturally ventilated hostel, especially season by season types using subjective and objective approach have not been much studied as other forms of buildings. Only the study recently carried out by Adebamowo and Olusanya [17] involved student hostel buildings in Southwest Nigeria uses both approaches. Correspondingly, thermal comfort study in student hostels has not been fully explored using occupants comfort needs. This gap in literature motivated the researcher to conduct a field survey on indoor environmental conditions, occupants` thermal comfort and adaptation in a naturally ventilated hostel building during the dry season. The results can be helpful to recommend the sustainable thermal standards for future hostel buildings in Nigeria. Besides, this study is expected to provide relevant and recent data to provide a better understanding of how student living in warm-humid have adapted to their naturally ventilated (NV) hostel.

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II. Methodology

Two major approaches used to assess thermal comfort were field experiments and laboratory climate chamber experiments. Field experiment was adopted in this study because a recent study revealed that the results from the field measurements were widely accepted to predict the comfort temperature of naturally ventilated buildings [18]. Field studies have immediate relevance to living condition

a) Climate and description of object building

The field study focused on one undergraduate female hostel at the Obafemi Awolowo University in Ile-Ife, Nigeria as a pilot study. Ile-Ife is situated in the tropical area of Southwest Nigeria. Its geographical coordinates are 4°35´ north latitude and 7°30´ east longitude. It has a warm-humid climate characterised by two seasons (rain and dry). It experiences constant high temperatures and relative humidity and low air movement throughout the year. It has a diurnal temperature range of minimum 23–27◦C and maximum 30– 34◦C, with a mean annual RH value of 84%. Abundant rainfall occurs from April to November, and the dry season occasion and with cold-dry harmattan wind blowing from November to March.

The hostel building is a two-storey building including ground floor, first and second floors under a concrete flat roof. The roof overhanged over a balcony at the front elevation. The walls are made of 225 mm aerated hollow sandcrete block with inserted columns rendered with brown and white paints while the internal wall is painted with cream colour. The size of a typical room is 6.3 m (l) x 4.0 m (w) x 3.0 m (h) with windows on north and south for cross ventilation and admission of natural light. Both its north and south facing windows are 1.5 m wide by 1.8 m high and consisted of wooden/aluminium frame and single (4mm thick) common plain glass. The windows accounted for 40% of the floor area. The Window to Wall Ration (WWR = 0.35). There are two doors in each room of size 0.9 x 2.1m made of wood. Electric lighting is provided through a 40W fluorescent lamp. The hostel building is in the midst of other hostel buildings of similar height. The hostel block was built according to the country`s climatic features, suitable orientation with appropriate shading devices. The main features of the hostel is summarised in Table 1. Purposive sampling was used for the selection of the building due to insufficient measuring equipment and was specifically chosen because it is one of the mainstream typology of the country`s student housing, for its similar size with other buildings and location. Figure 1 illustrates the general view of the selected hostel block.

Table 1 : Main features of the analysed hostel

No. of occupant	Volume (m^3)	Floor area (m^2)	Height (m)	Wall/Floor ratio	Exposure	Ventilation system	No. of floor
150	10200	3400	10	0.43	N-S	NV	3

Figure 1: General view of the case study building (a) roof overhang (b) screen wall

b) Data Collection

Objective and subjective assessments approaches were used for data collection. Using a combination of research methods is common in thermal comfort field studies and helps to balance the strengths and weaknesses inherent in individual data collection strategies.

i. *Objective measurement of indoor climate*

Kestrel 4500 multi-purpose pocket and handheld indoor climate tracker was utilized to measure the indoor climate conditions. The multi-purpose Kestrel 4500 is ideal because it measures air velocity, temperature and relative humidity with sensory accuracy of ±0.3m/s, ±0.3oC and ±1.6% respectively. The system collected concurrent physical data: air temperature, relative humidity and air velocity. The instruments were placed at 1.1 m from the floor closed to the subjects to record the thermal comfort variables simultaneously, as the subjects filled in the subjective thermal comfort questionnaire. The data logger was set to acquire data at 60-min intervals manually from 9.00 am till 7:00 pm. The readings were recorded in separate data sheets. All the completed questionnaires and data sheet entries were given serial numbers for easy identification and synchronization. The readings were transferred onto the corresponding questionnaires at the end of every survey day. Mean radiant temperature was calculated based on the equation provided by the ASHRAE standard 55. While the instruments recorded the surrounding environmental conditions, the researcher observed and kept track of the respondents` clothing levels as well as the utilization of environmental controls. Figure 2 shows the equipment employed. The outdoor environmental data was procured from the local meteorological station for all the dates of surveys. During the measurement periods, the building was in free-running conditions.

Figure 2 : Thermal Comfort equipment

ii. *Subjective assessment*

The subjective assessment consisted of a questionnaire administered to a group of respondents and was used to address occupant thermal, relative humidity and air movement sensations, preferences and acceptability. The questionnaire survey was designed as transverse data collection and consisted of four parts. Contained in the questionnaire are the respondents` demographic information, most preferred method of adaptation when they sensed thermal discomfort and votes for thermal sensation, preference and acceptability, with regards to the current conditions. Questions on relative humidity and air movement as well as overall thermal comfort were also included. Subjective assessments of the indoor thermal conditions were also conducted between the three sessions of the day: morning, afternoon and evening sessions. The questionnaire was distributed personally to the respondents. The subjects were asked to fill in the questionnaire while the instruments continuously recorded the surrounding environmental conditions. The thermal sensation vote was based on the ASHRAE 7-point sensation scale. Thermal preference vote employed McIntyre`s 3-point scale of preference namely; I wish for a warmer or cooler thermal condition or no change, Acceptability was aimed to understand if the interviewee considers the current environment condition as acceptable and was assessed using binary scale (acceptable/unacceptable). The relative humidity, air movement and overall thermal comfort were recorded on 5-point Nicol`s scale. To facilitate the observational study on the common behavioural adaptation, a set of questions were also given. The answers provided for those questions were in the form of five-scale frequency of actions (5-very important, 4-important, 3-sometime important, 2-not important and 1-not at all important). Stratify random sampling method was employed in the selection of the rooms for this study. All students in each of the selected room were given an opportunity to complete the questionnaire. Most of the subjects were surveyed for eight consecutive days in a month. They were interviewed three times a day: morning, afternoon and evening between 9am and 7pm. A fresh questionnaire was filled by the subjects in all the interviews. The field study was conducted from January to March, 2013. The months of January to March were chosen because most places in southwest of the country had higher than average temperature in these months.

iii. *Unit of analysis*

The data from the questionnaire survey and measured indoor environmental were imported to the SPSS (Statistical Package for the Social Sciences (SPSS) version 16.0) for analysis in different format. Data analyses were mainly descriptive statistics. It included the calculation of mean values, standard deviation, minimum, maximum and frequency distribution. Line graphs and bar charts related to different measured indoor environmental conditions were generated. Additionally, correlations between the measured data were carried out.

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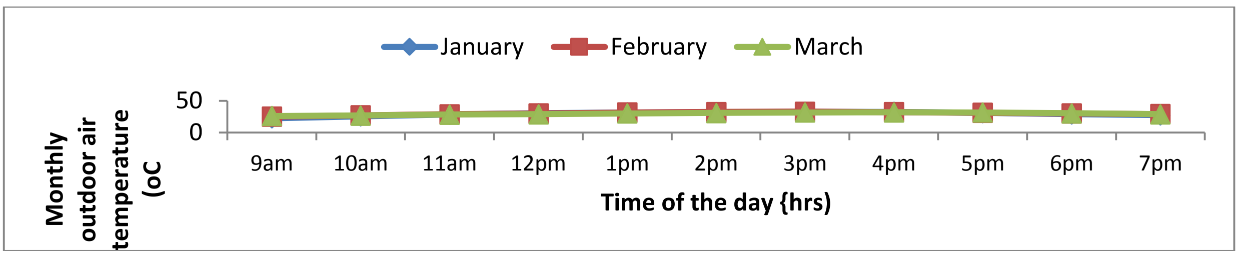
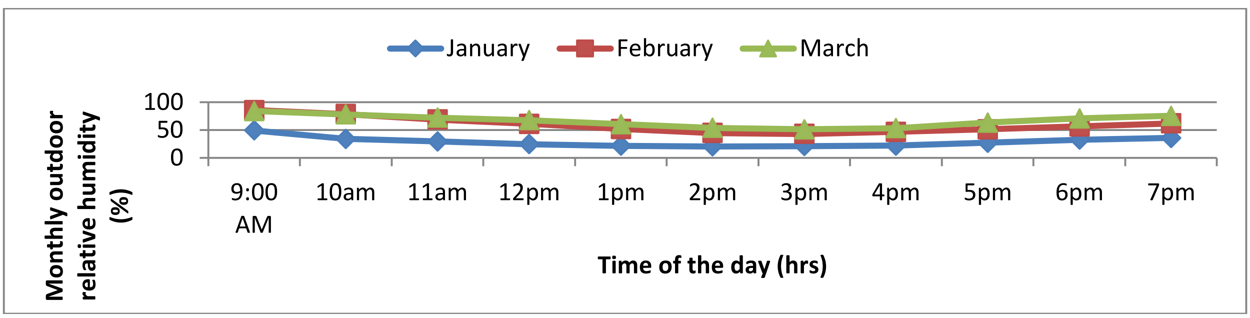
III. Results and Discussion

a) Environmental conditions in the surveyed hostel

i. *Outdoor climates*

Fig. 3 gives the physical data of outdoor climate during the survey period. The lowest temperature was recorded at 9 am in the morning, while the highest temperature was recorded at 4 pm in the afternoon (Fig. 3(a). Air temperature (ta) ranged between 22.5◦C and 32.9◦C (mean = 29.6◦C, STD = 2.50). Relative humidity (RH) fell within 20.36% and 85.82% (mean = 51.40%, STD = 19.83) (Fig. 3(b). The global solar radiation ranged from 0-788W/m2 (mean = 377.8 W/m2, STD=) (Fig. 3(c). In January, the outdoor air temperature (ta) ranged between 22.5oC and 32.6oC (mean =29.3oC, STD =3.21). Relative humidity showed low values in January and fell within 20.36% and 49.34% (mean = 28.86%, STD = 8.70. The global solar radiation ranged from 0-625 W/m2 (mean = 346 W/m2, STD =229). In February, the outdoor air temperature (ta) ranged between 25.1oC and 32.9oC (mean = 30, STD = 2.36). The relative humidity (RH) fell within 42.88% and 85.82% (mean = 59.01%, STD = 13.99). The global solar radiation ranged from 0-788 W/m2 (mean = 390 W/m2, STD =278). In March, the air temperature variations were narrower, averaging around 29.5oC with a minimum of 26oC and a maximum of 31.8oC. Relative humidity showed high values with a mean of 66.34% against 59.015% in February.





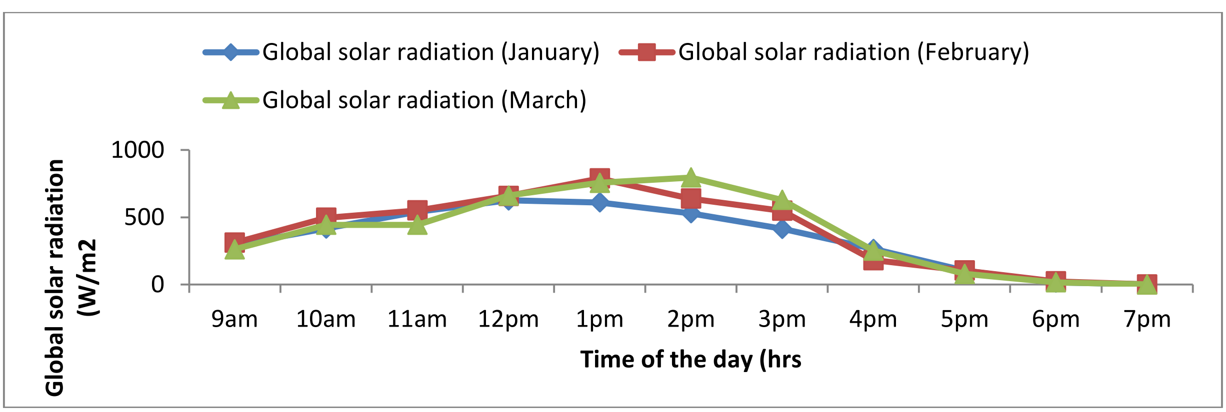


Figure 3 : The outdoor environmental variables of the respective days

ii. *Indoor climates: air temperature and relative humidity*

The measured hygro-thermal conditions reflect the occupants` space conditioning and ventilation preferences as well as the extent to which they will exercise environmental controls. Statistical summaries of measured physical parameters of indoor and outdoor climatic data are provided in Table 2 for the total data set broken down by months and by floors. For all data, the indoor air temperature ranged from 28.1oC to as high as 34oC (mean = 31.1oC, STD = 1.83). The relative humidity ranged from 30.8-75.5% (mean = 45.45%, STD = 12.64). In January, the air temperature was between 28.4oC and 33.5oC (mean=30.9oC, STD

= 1.71) with relative humidity (RH) readings between 31.8% and 71% (mean = 46.16%, STD =12.45). In February, air temperatures ranged from 28.1oC to as high as 33.7oC (mean = 31.1oC, STD = 1.86). The RH fell within 30.8% and 75.5% and 83.8% (mean = 45.72%, STD = 14.03). In March, the air temperature was between 28.5oC.and 34oC (mean =31.3, STD = 1.96). Table 3 shows the descriptive statistical summary of the measured environmental variables by floors. In general, second floor recorded higher mean air temperature value compared to the ground floor in all the months.

Table 2 : Descriptive summary of measured environmental variables on monthly basis

Month	Descriptive statistic	T_o (°C)	RH_o (%)	Global solar rad. (W/m2)	T_a (°C)	RH (%)	MRT (°C)
January	Mean	29.3	28.86	346.17	30.9	46.16	30.83
	Max	32.6	49.34	625.27	33.5	71	33.06
	Min	22.5	20.36	0	28.4	31.8	28.3
	STD	3.21	8.70	229.44	1.71	12.45	1.736
February	Mean	30	59.01	390.91	31.2	45.72	30.88
	Max	32.9	85.82	788.83	33.7	75.5	33.35
	Min	25.1	42.88	0.014	28.1	30.8	28.11
	STD	2.36	13.99	278.09	1.86	14.03	1.867
March	Mean	29.5	66.34	394.45	31.3	44.48	31.02
	Max	31.8	84.02	795.67	34	66.3	33.35
	Min	26	51.19	0	28.5	32.8	28.3
	STD	1.98	10.89	293.14	1.96	11.89	1.955
All months	Mean	29.6	51.40	377.18	31.1	45.45	30.92
	Max	32.9	85.82	718	34.0	75.5	33.06
	Min	22.5	20.36	0.005	28.1	30.8	28.3
	STD	2.50	19.83	263.36	1.81	12.64	1.795

Table 3 : Descriptive summary of measured indoor environmental variables by floors

Season Sample size	Descript. Statistics	Ground floor			Second floor			All floors		
		Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Ta(°C)	Mean	30.4	30.9	31.1	31.1	31.4	31.1	30.87	31.17	31.31
	Max	32	33.6	34	34	33.7	34	33.5	33.7	34
	Min	28.7	28.5	28.5	28.5	28.1	28.5	28.4	28.1	28.5
	STD	1.21	1.77	1.95	1.95	2.01	1.95	1.71	1.86	1.96
RH (%)	Mean	47.04	30.9	45.69	45.29	44.65	44.48	46.16	31.17	44.48
	Max	69.1	33.6	63.7	71	75.5	66.3	71	33.7	66.3
	Min	36.5	28.5	34.6	31.8	30.8	32.8	31.8	28.1	32.8
	STD	12.33	1.77	11.77	13.11	15.23	11.89	12.45	1.86	11.89
MRT (%)	Mean	30,11	30.62	30.75	30.99	31.1	31.23	30.55	30.85	30.99
	Max	31.67	33.25	33.65	55.16	33.4	33.45	32.26	33.3	33.55
	Min	28.4	28.21	28.21	28.11	27.8	28.3	28.25	28.3	28.25
	STD	1.208	1.749	1.933	2.056	1.99	2.008	1.586	1.855	1.961

Fig. 4 (a) shows the profiles of air temperature recorded during the field study. The lowest temperature was recorded at 9 am in the morning, while the highest temperature was recorded at 4 pm in the afternoon. In all the months, minimum and maximum air temperatures occurred at 9 am and 4 pm respectively. Observable there was minimum deviation of air temperature across the different months. In January the mean air temperature was 30.9oC, In February, it was 31.2oC and in March, it hovered around 31.3oC. The low change in temperature intervals was because for summer months the difference between mean radiant temperature and dry bulb temperature is less then 1oC and wind speed is less than 0.1 m/s. Besides, similar higher indoor air temperature conditions were experienced across the different months. According Djamila et al. [19] and Feriadi and Wong [20], the higher temperature variations observed are common with concrete structure in this climatic zone. From the temperature profile, it was observed for all the three months the temperature swings were between 4oC and 5.3o. According to Singh et al. [18] these temperature swings lie in permissible range for naturally ventilated buildings. In comparison, we recorded a slightly higher indoor temperature in February than that of January. The indoor temperature of February was marginally higher than that of January (on average 0.26). For about 91% the values of measured indoor air temperature were higher in February than that of January. Only one data deviated marginally (<1). Similar trend was observed between February and March. For more than 72% the values of measured indoor air temperature were higher in March than that of February. In about 23% it was higher in February than that of March. Fig. 4(b) shows the profiles of measured RH data. The highest humidity was recorded at 9:00 am and after 5:00 pm. For all data about 58% of RH data was within the 30% and 70%. In about 21% of the environments, the indoor RH was observed to be above 70%. Breaking down by months, it was observed that 63.6% of the measured relative humidity data was within the range of 30%-70% in January while 36.4% fell above 70%. In February, 81.8% of measured RH was in the range of 30%-70% and 18.2% fell above 70% beyond the higher comfort humidity limit. The relative humidity decreased about 10% in March compared with that of February. About 55% of the measured RH ranged between 30% and 70% and 45% of the relative humidity was more than 70%, beyond the higher comfort humidity limit.

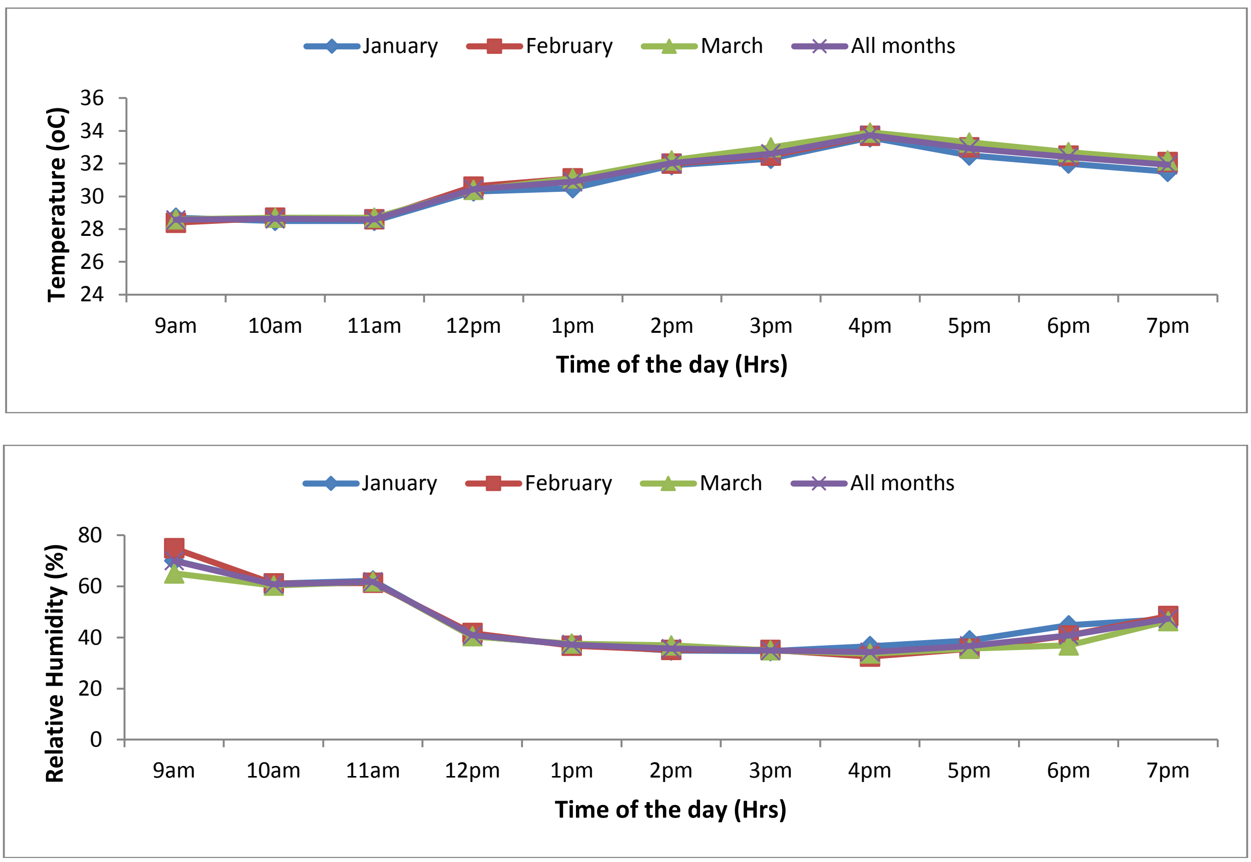


Figure 4 : Profiles of indoor environmental variables of the hostel

Fig. 5 depicted the comparison between ground and second floor across different months in terms of temperature. The ground floor was clearly performing better than the second floor. Its average temperatures were 30.4oC, 30.9oC and 31oC in January, February and March respectively, whereas the mean temperatures on second floor for these months were 31.1oC, 31.4oC and 31.1 respectively. The second floor on the average was 0.5 - 0.9oC warmer than the ground floor similar to Appah-Dankyi and Korateng [21] study in naturally ventilated classrooms in Accra, Ghana and Taylor et al. [22] in a rammed office building. The indoor air temperature on the ground floor correlated robustly with second floor (r =0.9808). For between 82-100% the measured temperature data on the second floor were higher than that of ground floor. This finding does not agree with the commonly held belief that the higher one goes the higher it becomes. The reason may be that during the monitoring period respondents were found cooking in their rooms instead of kitchenette provided for them. Inquiry shows the kitchenette is too small and far from their rooms. Therefore, in future design the issue of kitchen location must be addressed. However, both floors recorded air temperatures outside the upper and lower limits of the comfort zone. The diurnal variation in indoor temperature and relative humidity in these three months is very small (about 4-5.3oC and 20-42% respectively). In a study conducted in Japan, Indraganti et al [23] observed similar trend in all the office buildings surveyed.

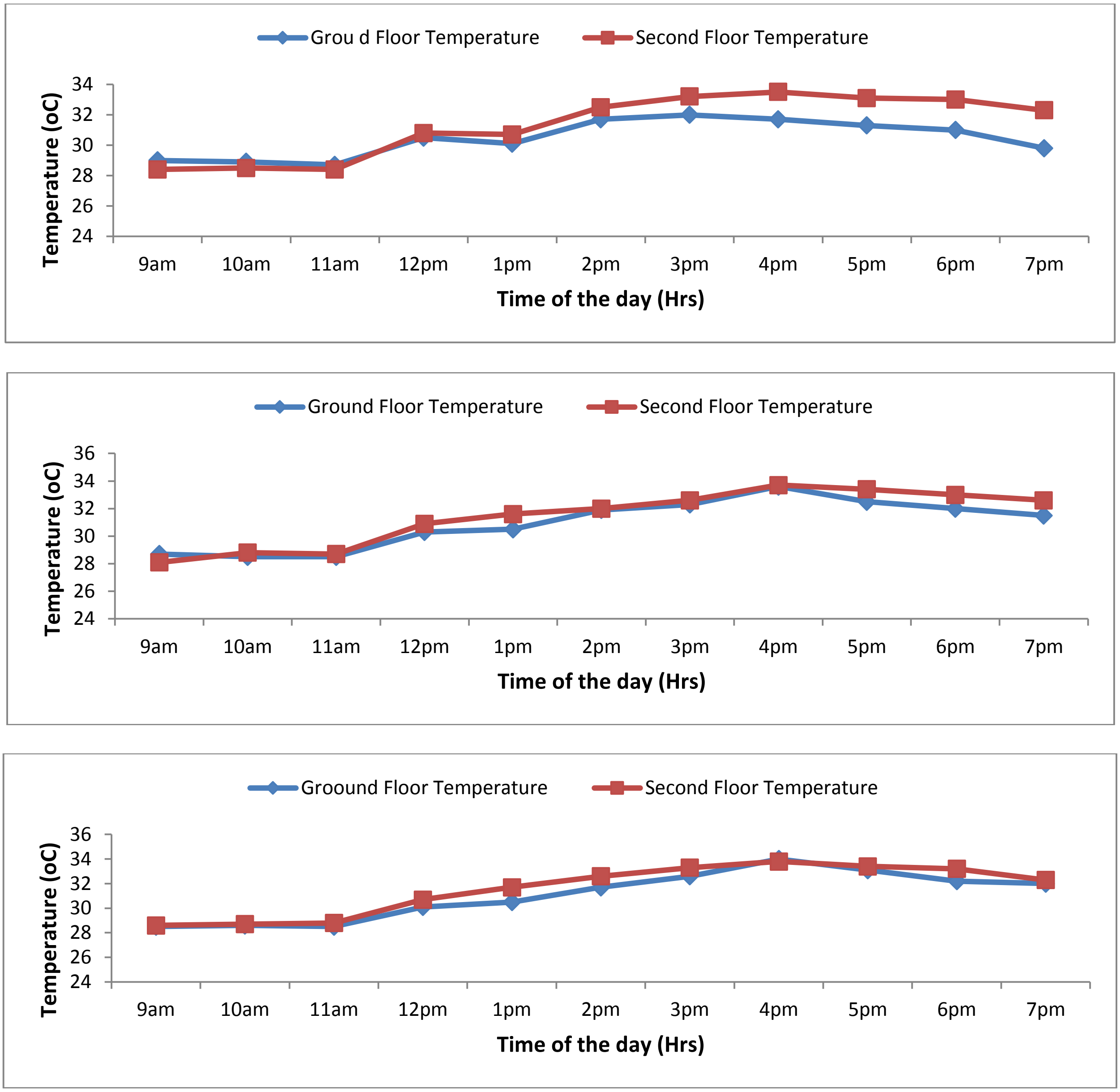


Figure 5 : Comparison of performance of indoor air temperature of ground floor and second floor

Fig.6 compared the performance of indoor relative humidity on both floors during monitoring period. The second floor performed better than ground floor throughout the survey period. Its mean relative humidities were lower than that of second floor. For example it was 45.3% as against 47.04% recorded on ground floor in January. Similarly, it was 44.65% compared with 46.16% found in February. Similar trend was observed in March and all months. For between 55-82%, the RH values on second floor were higher than that of ground floor. The second floor on the average was 1.7-2.4% less humid than the ground floor. The indoor air RH on the ground floor correlated robustly with that of second floor (r =0.9765).

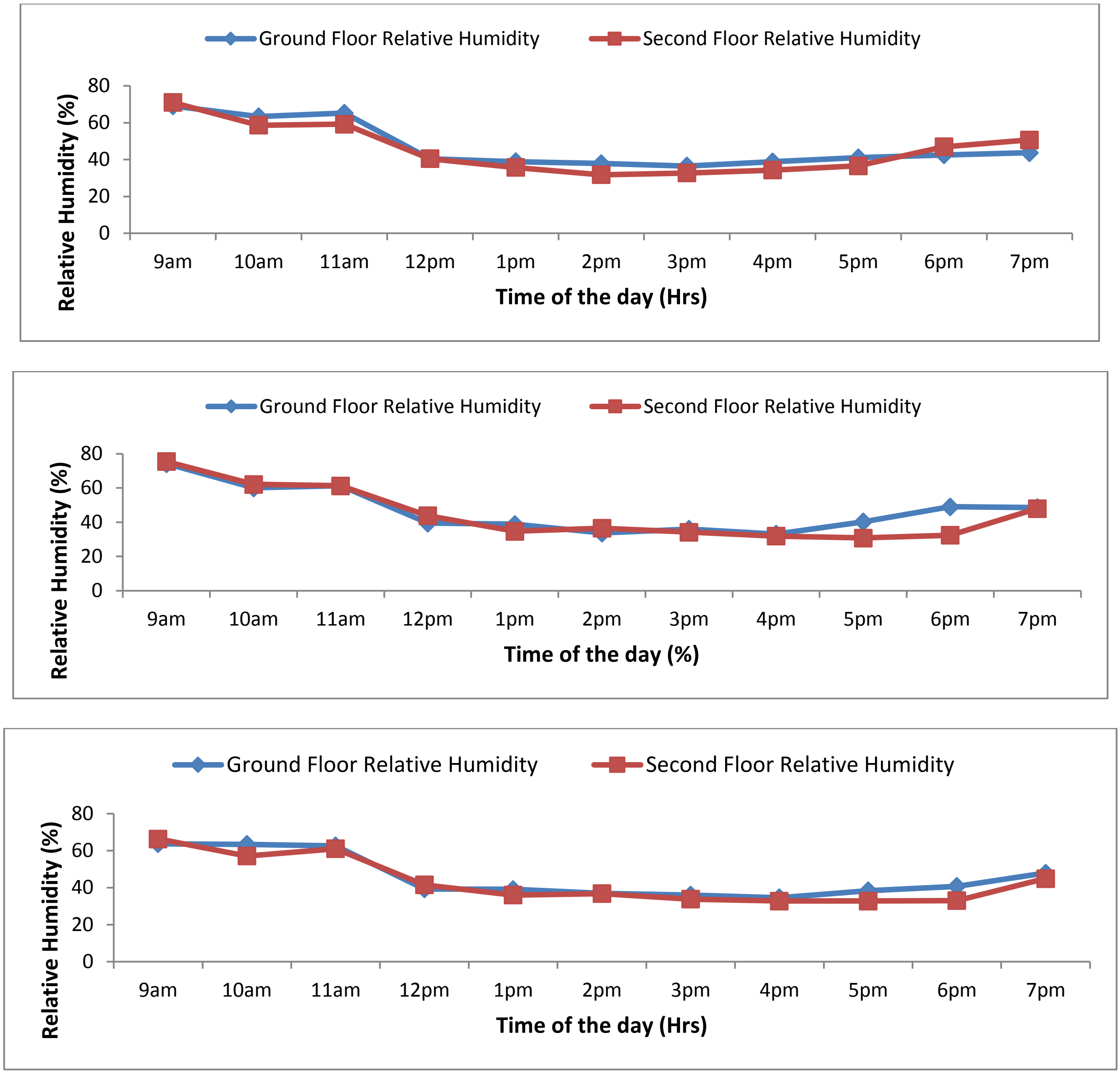


Figure 6 : Performance of ground floor RH compared with second floor RH

iii. *Indoor conditions: air velocity*

In hot season air movement will be an important factor in improving human thermal comfort. We have known from previous studies that air movement has a great influence on the respondents' comfort sensation and people require a higher level of air movement in order to feel comfortable. In this building, ventilation was primarily achieved through the use of windows and personal fans. The indoor air velocity was similar in all the months with the mean values of 0.02 m/s, evidently, the respondents in 100% of the environments were operating with less than 0.1 m/s air speed. Although they are naturally ventilated buildings, the air velocities in general are low.

The measured indoor environmental variables were compared with the ASHRAE standard 55 [24] and ISO 7730 [25] standard. These Standards used 23-26oC and 30-70% lines to delineate the air temperature and RH boundaries of comfort on the psychrometric chart. In relation to air velocity, the ASHRAE standard 55 suggested an air velocity between 0.18 m/s, and 0.25 m/s as the optimal air velocity for comfort. It also recommended increased air speeds to offset the elevated air temperatures. For a maximum indoor operative temperature increase of 3.0 K above comfort limits, it encouraged air speeds up to 0.8 m/s, with occupant control on the air speed. According to Wagner et al. [26] and Karyono [27] if NV buildings were designed correctly according to the local climate, for instance entirely protected from the direct sun`s radiation, which is common to the selected hostel, there would be a greater opportunity for naturally ventilated buildings to provide low indoor temperature. However, on the contrary, most of the measured air temperature in NV buildings especially in warm-humid climates showed that, in most cases none did fall within the acceptable

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standard [28-31]. Such conclusion was is in line with the findings of the present study. In comparison, in all cases, the values of indoor air temperature, relative humidity and air velocity were not within the comfort zone limits. The values of air temperature were higher than the maximum acceptable value; range of difference was between 2oC and 8oC. The values of air velocity were found to be away below the narrow range of 0.18 m/s and 0.25 specified in the ASHRAE Standard 55 and ISO 7730 standard. The reason may be that cross ventilation was found to be limited during this period because the outdoor temperature was very high. About 58% of measured relative humidity values were within the comfort zone limits. The results of this study seem to support the argument of [9, 32-33] that in warm-humid tropical climate the potential of NV buildings for sustainable thermal comfort is limited in hot season.

b) Measured subjective thermal responses

i. *Physical characteristics of the respondents*

A comprehensive profile of the respondents is shown in Table 4. The sample size varied each month; a maximum of 96 respondents voluntarily participated in the short-term survey. They were in the age group of 16-30 years with mean age of 24 years. They were Nigerian nationals from different ethnic group (Yoruba, Hausa, Igbo and Edos) living in the hostel for at least three month. Mean activity level of the group was found to be 1.06 met although respondents were observed to be either lying down/sleeping (0.7 met) or sitting passively (1 met) or sitting and working (1.2 met) and cooking (1.6 met). The mean clo value was 0.58, although individual respondent clo values varied from 0.42 and 0.73. The body surface area was estimated to be 1.65m^2.

Table 4 : Demographic characteristics of the respondents

N =96	Height (m)	Weight (kg)	Age (years)	Body surface area (m^2)	Clothing insulation (Clo)
Mean	1.68	58	19.6	1.65	0.58
STD	8.85	9.6	1.6	0.15	0.14
Maximum	1.92	92	27	2.14	0.73
Minimum	1.25	36	17	1.21	0.42

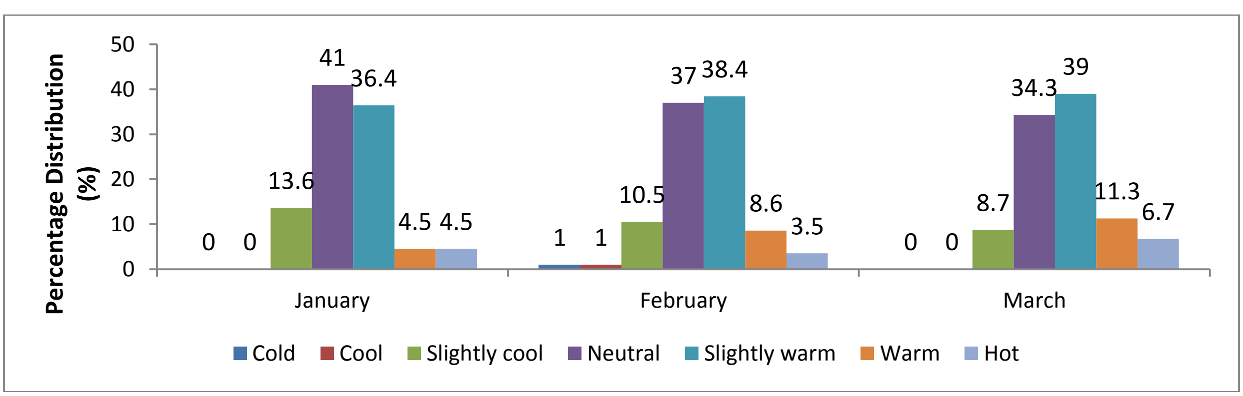
ii. *Thermal sensation, preference and acceptability*

Thermal sensation, preference and acceptability are the most important human responses to thermal environments and their relationships to a large extent determine the definitions of optimal conditions and acceptable ranges. By its literal sense, the term ''thermal sensation'' can be viewed as the interviewee's judgement of stimuli from the thermal environment to a certain extend. It is an important psychological expression relating to the feeling of warmth or coolth. On the other hand, thermal preference indicates what respondents preferred to be having in their environments. Thermal acceptability relates to a very important dimension of thermal comfort perception. It reflects several aspects pertaining to the occupant comfort: indoor and outdoor conditions, access and use of environmental control, hermal history, air quality, exposure etc.

The subjective feeling of warmth or coolth was measured using the ASHRAE thermal sensation scale. The respondents responded to the question "how do you feel the present temperature of this room" on a seven-point scale. Thermal preference was assessed from the questionnaire using the McIntyre scale of thermal preference through the question "at the moment, would you prefer warmer (+1), no change (0) or cooler (-1) environments. A direct question "do you accept the present indoor condition" to all respondents was used to ascertain their thermal acceptability. A comfortable subject usually voted within the central three categories (-1, 0, +1) of ASHRAE scale. The ASHRAE standard 55 [24] specified that the thermal acceptability should be defined as the condition where 80% of occupants vote for the central three categories (-1, 0, +1). Studies conducted by Zhang et al. [31] in NV buildings in hot-humid area of China and Zhang and Zhao [34, 35] carried out in a climate chamber under stead-state or dynamic, uniform or non-uniform conditions have shown that thermal sensation relationship varied significantly with the type of conditions. On the other hand, European SCATs project data base [36] observed that temperature changes that take place over a year in a building do not affect the overall assessment of environmental comfort in buildings. The frequency distribution of thermal sensation, preference and acceptability votes given across different months is shown in Fig. 7. It can be found through comparisons that the relationships obtained in the present study seem to support the observation of European SCATs project data base. All thermal sensation votes across the three months fell within the central three categories of the ASHRAE scale. Although, it showed some variations, the variations in TSV was very small (Fig. 7(a). In January, respondents were more comfortable (91%) when mean temperature was 30.9oC than in February (85.9%) when mean temperature was 31.2oC a difference of 0.3oC. Proportion voting within the comfort band on the sensation scale reduced to 82% in March when mean temperature was 31.3oC. The mean comfort vote of respondents (MTSV) was between neutral and slightly warm (MTSV = +0.45, +0.56, +0.73). These results showed that a perturbation of temperature produced a change in the sensation vote in the hostel. On the average, thermal sensation vote changed by 9% for every 0.4oC change in air temperature in the hostel. This indicated that respondents recorded a slightly lower sensitivity to the temperature rises. In the hot season, as the variations in the indoor air temperature are more important in this building, occupants can develop various human-environment relationships through thermal adaptation to local climate. This can be explained by the diversification of thermal experiences of occupants and the interactions between occupants and their environments as suggested by Nicol and Humphreys [37]. In comparison, Indraganti et al. [23] observed a unit sensation for every for 3.2K and 4.7 K perturbation in temperature in Chennai and Hyderabad, India. Similar trend was reported by Moujalled et al. [38] in France where on the average mean thermal sensation changed one unit for every 5oC of operative temperature in dry season.

According to Kwok and Chun [39], perhaps a more accurate measure of comfort is to ask what people prefer. Various distributions of respondents` votes are presented in Fig. 7(b). As found in many studies where respondents in naturally ventilated buildings expressed a preference to be cooler and wanted more air movement, it is clear to identify that a majority voted for the maintenance of ''cooler'' and ''no change'' environment. In January, the thermal preference votes show that 72.7% and 23.7% of respondents prefer cooler and no change environment. Incidentally, no respondent wanted warmer environment. In February, they also preferred air temperature on the cooler (73.5%) and no change (22.7%) categories despite accepting their thermal environment. However, 4.6% of the respondents still prefer the temperature to be warmer. In March, a preference for cooler (71.5%) and no change (23.2%) environments was evident, even though a significant number of subjects voted on the central three categories (-1, 0, +1). 5.3% still desired warmer environment. This in the opinion of the researcher were due to higher temperatures coupled with the insufficient air movement during the survey period, led to a psychological sense of `thermal comfort insecurity` in the occupants. As a consequence, they yearned for cooler environment irrespective of the current thermal sensation. The result confirms the tendency outlined by McIntyre`s research [40] who found that people of warm climates may prefer what they call a "slightly cool" environment and, on the contrary people of cold climates may prefer what they call a "slightly warm" environment.

Thermal acceptability is the percentage of the respondents to the questionnaire who found acceptable their thermal conditions. Various distributions of respondents` votes are presented in Fig. 7(c). Their responses are rather interesting. In January, almost 73% and 27% of the participants judged their environment to be acceptable and unacceptable. In February, 71% and 29% of the participants judged their environment to be acceptable and unacceptable. In March, just 75.2% found their environment thermally acceptable. It is generally expected that people voting comfortable (TSV = -1, 0, +1) accept the environment. Interestingly, 18%, 14.9% and 6.8% of respondents voting in the comfort band, especially, those voting "neutral" have also voted the environment unacceptable. According to Indraganti et al. [28], this complex pattern of acceptance is attributed to many reasons: lower expectations in some user groups, overall satisfaction with oneself and her immediate environment, age, health, availability/access to controls. These results indicate that most of the participants adjusted for the climatic variation and remained satisfied with the indoor thermal environment. An attempt was made to examine the subjective assessments of the indoor thermal conditions between the three sessions of the day: morning, afternoon and evening sessions. Fig. 7(d) shows that only the in morning, sessions (on the average, 82.9%) with mean thermal sensation votes of -0.4 can satisfy the above criteria. For evening session, 74.9% of respondents found that their environment condition was acceptable with a mean vote of -0.37, between neutral and slightly cold category. A lower percentage of 72.6% was found in the afternoon hours with a mean vote of +0.29.



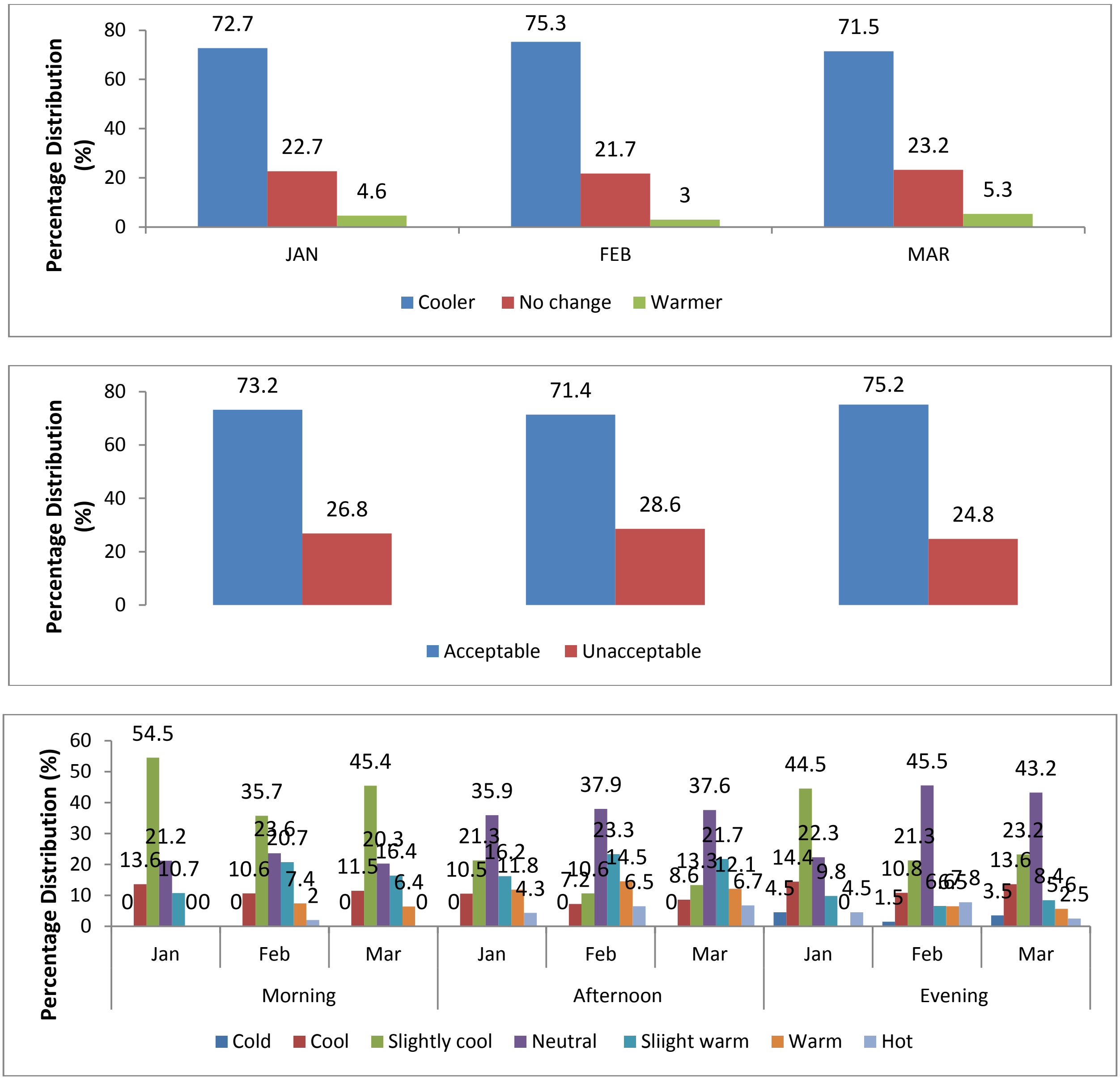


Figure 7 : Distribution of subjective response on thermal environment

iii. *Relative humidity sensation, preference and acceptability*

Fig. 8 presents the frequency distribution of RH sensation, preference and acceptability votes across the various months. Relative humidity was assessed using the 5-point Nicol relative humidity sensation scale ranging from -2 (moderately dry), -1 (slightly dry), 0 (neutral), +1 (slightly humid) and +2 (moderately humid). The frequency distribution of RH sensation is shown in Fig. 8 (a). In January, about 23% experienced moderately humid at the existing room conditions. About 41% of respondents perceived the air was slightly dry while 36.4% perceived the air neutral. In February, Similar patterns in relative humidity sensation as that of January were observed in February and March. Generally, the subjective responses to relative humidity were biased towards dry with the mean vote within the neutral and slightly dry category (MSV = -0.86, -0.88, -0.86). Fig. 8(b) shows the RH preference of respondents. It was noticed from the study that between 50% and 56% of respondents preferred to be neutral; between 13.5% and 20% respondents preferred to reside at slightly dry conditions. Up to 25% of the students preferred to reside in moderately humid conditions. The mean preference votes were biased towards the neutral and slightly dry category (MSV = -0.2, 0.-0.3). Fig. 8 (c) shows that on the average more than 85% of respondents accepted their relative humidity across the three months.

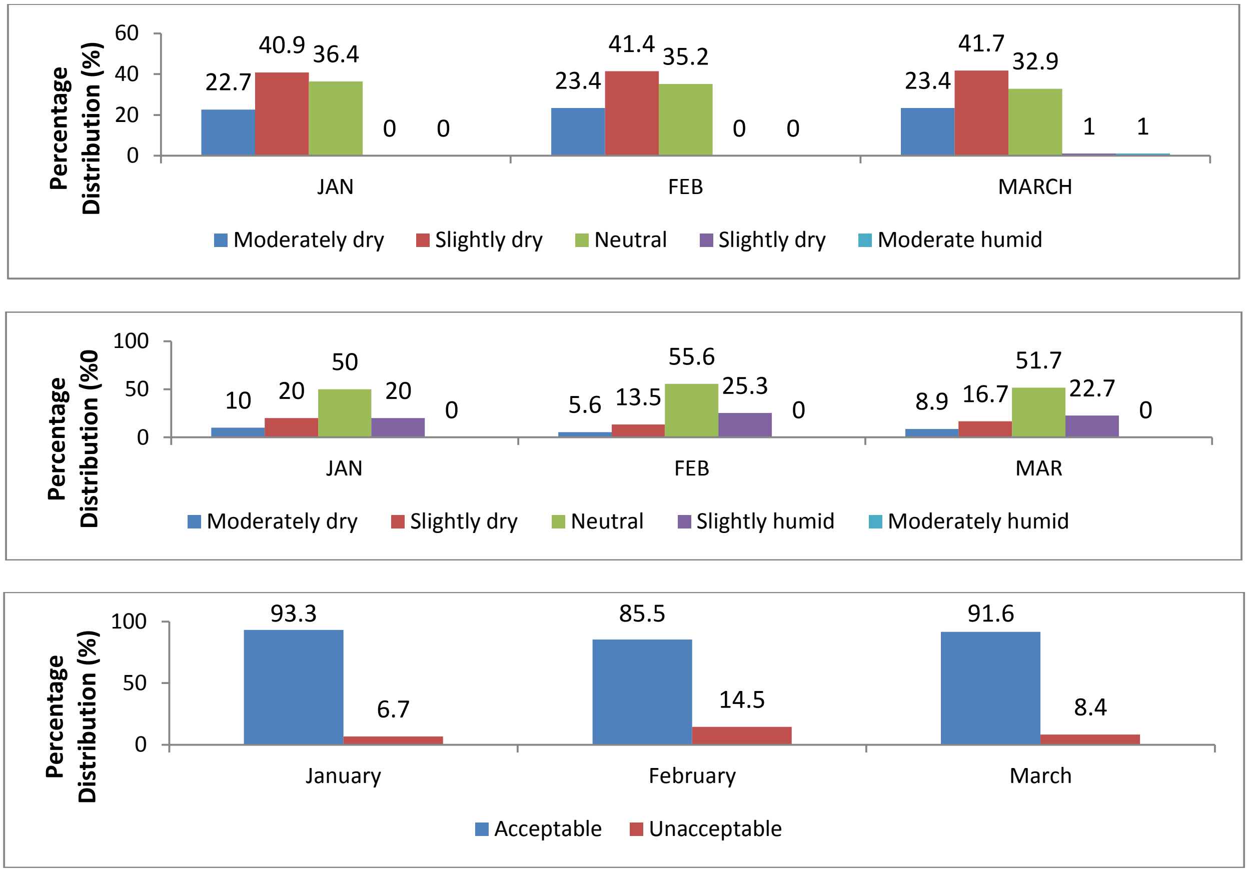


Figure 8 : Distribution of subjective response on relative humidity

iv. *Air movement sensation, preference and acceptability*

In the warm-humid climate of Ile-Ife, air movement plays a major role in achieving thermal comfort. Therefore, it is important to understand the hostel occupant`s perception, preference and acceptability for the actual indoor air movement in spite of low air movement data recorded. Fig. 11 presents the frequency distribution of air movement sensation (AMS), air movement preference (AMP) and movement acceptability (AMA) across the various months. Fig. 11(a) shows the indoor AMS votes of the respondents. AMS was assessed on Nicol five-point scale using the question "how is the air movement in this room?" with a vote of +2 indicating that the air velocity level in the hostel was high, a zero vote means that the respondents felt that the air velocity was just right. In January, 81% o of respondents claimed that the air was slightly high and just right. Only 19% reported that the air movement was low. In February, 75% of respondents sensed the air velocity as slightly high and just right. 25% of all respondents perceived that the air was slightly low. In March, 82.2% o of respondents perceived the air to be slightly high and just right. 17.8% of all respondents indicate that the air movement was slightly low. The mean air movement sensation (MAMS) votes were biased towards the neutral and just right category (MAMS = +0.2, +0.1, +0.2) giving the overall impression that the air was sensed okay.

The question "how do you prefer to have air movement in this room elicited responses on the air movement preference (AMP) on McIntyre three-point scale (Fig. 11(b). Most of the subjects (95.5%, 93.6%) indicate more air movement as their preference for air movement for the months of January, February and March respectively. A small portion (4.5%) of respondents desired no change in their thermal environment. Interestingly, no respondent wanted less air movement except in March where only 2.3% respondents preferred less air movement. The present results confirm previously findings that occupants in warm-climate would prefer more air movement and no change in their thermal environment [31, 41-42].

Air movement acceptability (AMA) was assessed on binary scale (acceptable and unacceptable). Figure 9(c) shows the indoor AMA votes of the respondents. In January, 93.3% and 6.7% of the participants judged air movement to be acceptable and unacceptable. In February, 85.5% and 14.5% of the participants perceived the air movement to be acceptable and unacceptable. In March, just 91.6% found their environment thermally acceptable. A large portion.

Figure 9 : Distribution of subjective response to air movement

c) Overall comfort conditions

During the study occupants were asked to judge the 'overall thermal comfort' based on their experience of room temperature, RH and air velocity. The recorded perception was analysed on Nicol`s five-point thermal acceptance scale as presented in Fig. 10. It was observed that above half of the respondents (56.5%) in January, 51.7% in February and 54.4% of this group in March felt slightly comfortable. More than 25% in January, 19.3% in February and 23.9% in March were comfortable at present room conditions. There were fewer votes noticed on uncomfortable and very uncomfortable categories. There was no vote on very comfortable state in all the months. The mean thermal comfort vote was within the slightly uncomfortable category.

From the above distribution of votes, it is possible to relate the votes of the various environmental parameters to that of overall thermal comfort (Figs. 7-10). Given the mean overall thermal comfort vote of slightly uncomfortable, the mean temperature, humidity and air movement votes were under the categories of neutral and slightly warm, neutral and slightly dry and neutral and just right respectively. This reinforces the idea that the occupants perceptions of thermal comfort indeed hinges on sensations of temperature, humidity and air movement, as illustrated in Fanger`s thermal comfort equation.

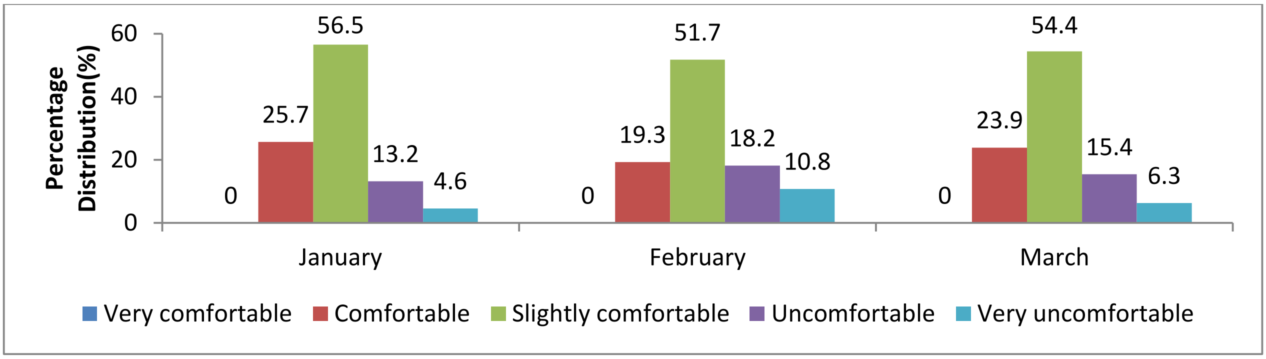


Figure 10 : Assessment of indoor environment based on overall thermal comfort

d) Relationship between measured physical thermal comfort parameters and TSV

A comparative analysis was performed to find out the relationship between actual survey vote and measured physical thermal comfort parameters. Studies have shown that no correspondence existed between the measured physical data and occupants' perceived votes in NV buildings especially in warm-humid tropical climate [20, 26, 43]. They also reported that occupants of NV buildings were thermally comfortable in a wider range of environmental conditions beyond what was recommended in ASHRAE standard 55 and ISO 7730 standard. Zhong et al. [44] and Huang et al. [45] observed that the capacity to control an indoor environment could improve the subject`s thermal comfort level and extend the acceptable range of thermal environment. That is more than 80% of the occupants will express satisfaction with the thermal condition. Such conclusion is in line with the findings of the present study. Comparison of physical measurement and TSV indicates that people can develop various human-environment relationships through thermal adaptation to local climate, resulting in different thermal neutral temperatures in various climates. We recorded higher indoor air temperatures beyond the recommended unit set by the standards for summer across the different months. On the contrary, occupants of the hostel found their thermal environment comfortable, acceptable and satisfied. This in our own opinion was due to adaptive behaviour, expectation and acclimatisation of occupants` of warm-humid climate to higher temperatures. The findings of this study seems to support the argument of previous researchers that thermal sensation vote in field study hinges primarily on the use, access and perceived access to the adaptive controls and several psychological parameters in addition [46].

e) Adaptation to achieve thermal comfort

Studies have shown that, in general, respondents in NV buildings preferred to employ environmental control (window opening) first before they resort to personal adjustment which involves some thermoregulation of their bodies [9, 17, 20, 47]. On the contrary, Indraganti [46] study in India revealed that occupants used the environmental control only when adaptation through clothing and/or metabolism was not sufficient or feasible. Again, Feriadi and Wong [20] add that in warm-humid climate the immediate cooling effect is mainly anticipated from higher wind speed through window openings. Hwang et al. [45] also observed that the habitual adaptation method of respondents is influenced by (i) the effectiveness of the adaptive control in relieving thermal discomfort (ii) availability and accessibility (iii) convenience (iv) cost. Other factors mentioned included sufficient window-wall-ratio (WWR). The results of this study seemed to compare favourably with the above findings. Fig. 11 shows the preference to use control features to restore thermal comfort state. While there were individual differences in the way people have adopted adaptive opportunities, the environmental control by opening the windows was highly preferred by respondents with the percentage of 77.4%, closely followed by wearing light clothes (77.3%). The used of fans, open door and close door as well as adjustment to window blind, showed the same percentage of 59.1%. Other favoured adaptive actions taking were cold food/drink (50%), change activity (47.6%) and partial opening of windows (46.4%). Moving out to cool place and usage of hand fan constituted 36.1%. The least favorable action was adjusting shading/sun control (27.3%). The high preference for the window opening, wearing light clothes and use of fan signifies that they were adequate and effective for the evaporation of skin moisture found at various humidity and temperature ranges observed during the survey. It also indicated that those adaptive actions are accessible and convenience for the occupants. The above finding can be used not only as information on the percentage of "likeliness" but also on the student`s preference in choosing various adaptive actions to make their living environment more comfortable. Certainly, for hostel building designers, this information is very useful so they would pay more attention to incorporating them into student housing design.

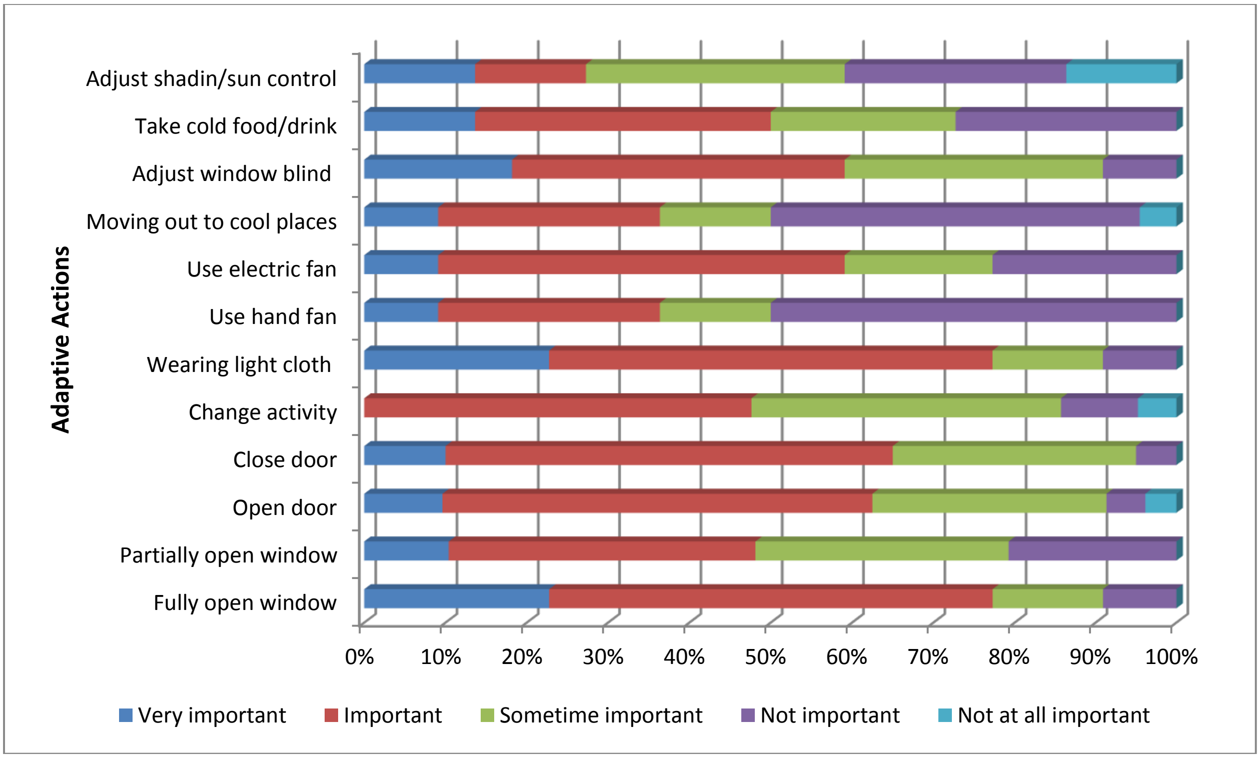


Figure 11 : Adaptive behaviour

Further analysis was carried out on the frequency of windows, window blinds and fan usage at different times of the day. The usage was divided into three time slots: morning (9–12 a.m.), afternoon (1–4 p.m.), and evening (5–7 p.m.). The results are presented in Fig. 12. Fig. 12(a) shows the preference to open their room window. The highest percentage of opened window was in the morning and afternoon with the value of 90.9% respectively. The percentage of occupants who opened the window in the evening is still very high (77.3%). If the usage of window is assumed to be indirectly related to indoor environmental condition then it implies that in the morning, afternoon and evening the indoor condition might be less comfortable.

The adjustment to window blind is much higher in the afternoon and morning with the percentage as high as 80.9% and 79.9%, respectively (Fig.12 (b). In the evening, the percentage was still relatively high with 68.2% respondents adjust their window blind. The reason may be that the outdoor/indoor was usually higher at that time. Another possible reason may be to allow natural light indoor.

The use of fans is significant to human comfort and is the most commonly used environmental control option [48]. It was observed that the usage of fan is much higher in the afternoon and evening with the percentage as high as 83.6% and 75.8%, respectively (Fig. 12 (c). This is because in the afternoon and evening, the outdoor/indoor is usually higher than that of the morning time. The frequently windless condition in these periods might be the reason for the high usage of fans that expected to improve uncomfortable indoor condition. Interestingly, Feriadi and Wong [20] found the use of fans occurring when the daily mean outdoor temperature was beyond 25oC. Fig. 11(d) shows the unique combination of the usage of various environmental controls at these times of the day.

f) Limitation to sustainable thermal comfort in the hostel

As stated in section 3.1.3 of this paper that if NV buildings were designed correctly according to the local climate, it will give such buildings a great opportunity to adapt to elevated temperatures. Also, the tendency for such buildings to provide lower indoor temperature is high. However, in this building, many issues, some of them contributed by the occupants hindered sustainable thermal comfort. Temperature excursions beyond the comfort limits were a daily feature in warm-humid climate of Ile-Ife during this season. Many of the windows and doors were found with limited accessibility as most of the windows were blocked due to arrangement of the indoor spaces. Profligate attitudinal disregard was observed towards the environment as occupants were found cooking in their rooms instead of the kitchenette provided for them. Finally, psychological preparedness of the subjects resulted in some display of thermal empathy

V. Conclusion

A dry season thermal comfort field measurement was performed in a naturally ventilated

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female hostel in Obafemi Awolowo University, Ile-Ife, Nigeria. The indoor environmental conditions, human responses and adaptation to thermal environment as well as hindrances to sustainable thermal comfort were systematically investigated in the present study. The key findings from this study are as follows:

- Objective measurement of the hostel showed that none of the measured data had thermal conditions falling within the comfort zone of ASHRAE standard 55. However, occupants found temperature range beyond the comfort zone comfortable, satisfying and acceptable.
- Respondents preferred cooler and no change environments and more air movement.
- A comparative analysis of ground floor and second floor performance showed that second floor indoor air temperature was higher than ground floor temperature.
- There was no much difference in thermal performance of the hostel across the three months as they exhibit similar trend.
- The investigation on thermal adaptation methods reveals that first preference of the respondents was window opening (77.4%), closely followed by wearing of light clothes (77.3%) and lastly the fan use
- Prominent among the barriers identified was the profligate attitudinal disregard towards the environment as occupants were found cooking in their rooms instead of the kitchenette provided for them.
- The results of the study show that occupants in warm-humid climate have a wider range of thermal acceptability than that specified by the ASHRAE Standard 55.

The study concludes that in warm-humid of Ile-Ife during hot season the desired for optimal thermal comfort in NV hostels may not be achieved. However, the availability of behavioural controls and mechanical ventilation system can help to improve thermal environmental conditions.

VI. Limitation of the Study

Our study represents a relatively small sample size (1) with 96 responses collected in the naturally ventilated hostel, which could cause misleading interpretations. However the general tendencies of thermal sensation and preference corroborate findings from studies in both offices and schools. In pursuing this research further, the researcher plan to expand the study to more hostels, conduct the study during the rain and harmattan months of the year, and make seasonal evaluations on perceptions of comfort.

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