Assessment of Passive Design Strategies for Sustainable Thermal Comfort

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ABSTRACT

The aim of this study was to assess the thermal comfort level of middle-income housing in Uyo, Akwa Ibom State. The researcher adopted a descriptive survey research design, using the population of all middle-income housing residents. A sample of 200 respondents was randomly selected for questionnaire administration, while 5 houses were used for physical measurement. Besides the questionnaire tagged "PASSIVE DESIGN STRATEGIES FOR SUSTAINABLE THERMAL COMFORT QUESTIONNAIRE (PDSSTCQ)," several other instruments were used for data collection, including liquid crystal thermometers, Wet and Dry Bulb hygrometers, anemometers, and the CBE Thermal Comfort Tool. The variables were subject to descriptive analysis, One-Way Analysis of variance, and Pearson Product Moment Correlation Analysis at a 0.05 level of significance and 198 degrees of freedom. The results (calculated F-values of 5.95, 4.44, 3.63, and 2.88) were greater than the critical F-value of 2.37, and 0.69, which was greater than the critical r-value of 0.139, were significant, which therefore means that there is a significant influence of the level of housing occupied on the level of comfort satisfaction of the occupants with respect to the physical measurement of the following components of thermal comfort: TWC, MRTC, TDC, and GTC. The result also showed that there is a significant relationship between the architectural features of the building and the effectiveness of natural ventilation and thermal comfort. The researcher recommended that Architectural features that promote thermal comfort should be used for buildings in order to make the occupants comfortable.

KEYWORDS: Thermal Comfort, Natural Ventilation, Architectural Features

Introduction

Many housing facilities, mostly in Africa, have been built relying on natural climatic conditions for occupancy comfort throughout the year, which has brought about discrepancies amongst users (Hazim, 2010). While natural ventilation can provide thermal comfort in some climates, a gap in thermal comfort improvement strategies in naturally ventilated buildings still exists to enhance suitable thermal conditions in buildings, thus avoiding occupant dissatisfaction, low productivity, and overall building performance (Wang, 2006). Globally agreed upon, Fanger (1970) defines thermal comfort as the condition of the mind that expresses satisfaction with the thermal environment. Thermal comfort is said to be achieved in a building when the highest possible percentage of all occupants are thermally comfortable. The concept of natural ventilation doesn't seem complicated, but it's a challenge to design naturally ventilated buildings due to the fact that natural ventilation is difficult to control since it is a medium of passage for solar latent loads from the external environment. Natural ventilation efficiency and building thermal comfort are affected by both internal and external factors (Cai and Wai, 2010). According to Hazim (2010), Natural Ventilation is where the airflow in a building is a result of wind and buoyancy through openings or cracks within the building envelope. Naturally ventilated buildings in some climates can operate for the entire cooling season within adaptive comfort constraints without mechanical cooling.

Linden (1999) defines natural ventilation as the process of supplying and removing air through an indoor space without using mechanical systems. It refers to the flow of external air into an indoor space as a result of pressure or temperature differences. There are two types of natural ventilation that occur in buildings: wind-driven ventilation and buoyancy-driven ventilation. While wind is the main mechanism of wind-driven ventilation, buoyancy-driven ventilation occurs as a result of the directional buoyancy force that results from temperature differences between the interior and exterior (Linden, 1999). However, the two types could be combined, and it is called combined wind and buoyancy.

Heiselberg (1990), also defines natural ventilation as:

- Single-sided ventilation, where the ventilation rate is limited to zones close to the openings. Wind turbulence and thermal buoyancy are the main driving forces. In comparison with other principals, lower ventilation rates are registered with single-sided ventilation.
- Cross ventilation occurs when two or more openings on opposite walls of a building cover a zone. The openings are usually windows or vents. The effect of cross ventilation is dependent on wind pressure and opening size.
- Stack ventilation is where buoyancy-driven flows are larger. It relies on two principles that take advantage of air density, i.e., as warm air rises to the exit, the warm air is replaced by cool air, hence ventilation. Here, ventilation openings are at both high and low levels.

According to Design Builder (2010), two approaches, scheduled and calculated natural ventilation, can be used to model infiltration and natural ventilation:

- Scheduled natural ventilation is when natural ventilation and infiltration change rate are defined for each zone using a fixed parameter of maximum

ACH (infiltration air change rate), and the infiltration is always scheduled. Infiltration is defined under air tightness, and airflow is considered to be included in the natural ventilation set value. Scheduled natural ventilation is used if one is able to estimate natural ventilation and infiltration rates.

- Calculated natural ventilation is when natural ventilation and infiltration are calculated based on vents, window openings, cracks, buoyancy, and wind-driven pressure differences. Calculated natural ventilation is used if one intends to estimate the real natural ventilation and infiltration. Though considered the lowest-cost option, a challenge in this strategy is that at times occupants neglect or forget to open and close the windows when the outdoor conditions vary in an unpredictable manner, hence leading to thermal comfort problems (WindowMaster, 2012).

Wang and Wong (2006) found that due to the global emergence of energy shortages, climatic changes, and sick building syndromes associated with the common usage of air conditioning, authorities worldwide have recognized the necessity of finding strategies that can cultivate a more sustainable design with satisfactory indoor thermal comfort. This has led to a growing interest in low-energy cooling strategies that take advantage of natural ventilation, which has the potential to reduce first-cost and operating costs for commercial buildings while maintaining ventilation rates consistent with acceptable indoor air quality. So thermal comfort Models should be able to, at best, help architects and other building engineers in the design process. Comfort has been defined as 'the condition of mind that expresses satisfaction with the environment'. The indoor environment should be designed and controlled so that occupants' comfort and health are assured (Busch, 1992). Although comfort models mostly talk about indoor climate, both indoor and outdoor climate should be taken into consideration not only in urban design but also in buildings since most people spend their time in both buildings and urban spaces. So, both indoor and outdoor comfort are matters of attention for architects and urbanists.

Looking back to the history of thermal comfort and climatic design, it shows that there may be a combination of comfort zone definition models, like Fanger or adaptive, with design advice models like Mahoney for architects. The new climatic design model will need more flexible comfort conditions with different clothing and activity levels, together with an improved number of design advices to cover more parts of the architectural design process (Baker, 1995). Also, the model needs to have a look at outdoor comfort as well, to allow architects to think about open and semi-open spaces in their buildings. In many examples before the industrial revolution, not only indoor climate but also outdoor climate with shading, vegetation, and water surfaces were controlled. The urbanization process has a profound impact on the thermal environment. The excessive heat aggregated in densely built urban areas is attributed to a number of factors, including changes in urban geometry and substrate materials, losses in vegetative cover, anthropogenic heat, air pollution, and so on. The thermal discomfort, particularly in the summer months, could thus be aggravated. The outdoor thermal comfort level is closely associated with the use of urban open spaces.

In sub-tropical climates featuring very hot and humid summer months, urban dwellers tend to use outdoor spaces only when the thermal comfort level is close to neutral (Lin et alfor., 2010). Otherwise, in big cities such as Hong Kong and Shanghai, people mostly stay in air-conditioned indoor spaces during hot hours for shelter from the often intolerable heat. An indoor lifestyle may lead to a number of problems; for example, it can increase buildings' cooling energy consumption, have negative consequences on the physical and mental health of occupants, and result in a less vibrant and socially sustainable city space. In addition, in high-density urban areas, the indoor environment that relies on mechanical means for ventilation could aggravate the spread of infectious diseases, for example, the SARS outbreak in Hong Kong. The main aim of this study is to assess the thermal comfort of middle-income housing in Uyo, Akwa Ibom State, Nigeria. Specifically, the study sought to examine the comfort satisfaction of the occupants of middle-income housing in the study area and also examine the architectural features of the buildings in relation to the effectiveness of natural ventilation in the study area.

Materials and Methods

Study Area

The study area is Uyo, the capital city and State Headquarters of Akwa Ibom. Uyo metropolis encompasses Uyo Local Government and some parts of Uruan, Itu, Ibesikpo, and Nsit Ibom Local Government Areas. Uyo lies between latitude 50.55 North and longitude 80 East. This is within the equatorial rain forest belt, which is a tropical zone that houses vegetation of green foliage from trees, shrubs, and oil palm trees. In Uyo metropolis, there are well-designed buildings that are the products of competent architects. The buildings range from residential bungalows to maisonettes, offices, and churches. History has it that Uyo indigenes were among the first set of people in the Ibibio land to be exposed to the Western Education called the white man’s Education". They benefited from this gesture so much that many had the opportunity to be formally educated by the white missionaries as far back as the 19th century. There is then no gain in the fact that the literacy level in the area is quite high. Many tertiary institutions have been established in the area. These include the University of Uyo, Uyo City Polytechnic, the Corporate Institute of Research and Computer Science, the Contemporary Institute of Technology, etc. On the whole, the people are generally quite literate. With the status of Uyo as the Capital City of Akwa Ibom State and its high development index, there has been an influx of people, resulting in an increase in population and high demand for housing accommodation.

Methods

The study adopted a descriptive survey design. The population of the study consisted of all middle-income housing in Uyo Metropolis. The respondents in the study consisted of 200 household heads that were selected randomly from all the households in Uyo metropolis using a simple random sampling method. The instruments used to measure physical comfort variables were: liquid crystal thermometers, Wet and dry bulb hygrometers, anemometers for collecting data on the indoor thermal environment, The CBE Thermal Comfort Tool (a computer model program), and a questionnaire tagged "PASSIVE DESIGN STRATEGIES FOR SUSTAINABLE THERMAL COMFORT QUESTIONNAIRE (PDSSTCQ)". The principal source of data used was from both primary and secondary sources.

Results and Discussions

Hypothesis One: Comfort satisfaction was measured using physical measurements of thermal comfort in and around the premises. The results from the physical measurement of thermal comfort are presented in tables 3.1 and 3.2, respectively. In order to test the hypothesis, two variables were identified as follows:

1. Level of housing occupied as the independent variable
2. Level of comfort satisfaction of occupants as the dependent variable.

One-way analysis of variance was used to analyse the data in order to calculate the F-value (see Tables 3.1 and 3.2).

Table 3.2 shows a calculated f-value of (2.88, 5.95, 0.84, 1.21, 3.63, and 4.44) for TDC, TWC, RH_PEPC, AIR_VEL, GTC, and MRTC, after being tested for significance at the 0.05 alpha level with (2 and 197) degrees of freedom. From the results of the above analysis, four parameters (TWC, MRTC, TDC, and GTC) were observed to be significant, being that their respective calculated F-values (5.95), (4.44), (3.63), and (2.88) were greater than the critical F-value of (2.37), while (1.21) and (.84) for AIR_VEL and RH_PEPC were not significant as they were less than the critical f-value (2.37) at 0.05 alpha level with (2 and 197) degrees of freedom. Hence, for TWC, MRTC, TDC, and GTC, the results were significant. The result therefore means that there is a significant influence of the level of housing occupied on the level of comfort satisfaction of the occupants with respect to the physical measurement of the following components of thermal comfort: TWC, MRTC, TDC, and GTC.

Furthermore, it was deemed necessary to be more explanatory of the descriptive statistics of the above components of thermal comfort, (see table 3.3) It should be noted that the Sensation in table 3.3 was determined using the CBE Thermal Comfort Tool (ASHRAE Standard 55-2013) with Metabolic rate value of 1.2 met and Clothing level of 0.5 Clo. The Metabolic rate of 1.2 met is for a light activities standing, while the Clothing level of 0.5 Clo is clothing ensembles and garments of knee length skirt, short sleeved shirt, panty hose, and sandals.

TABLE 1: Descriptive statistics of the level of housing occupied on the level of comfort satisfaction of occupants

		N	X	SD
TDC	CASE STUDY 1	110	27.23	.61
	CASE STUDY 2A	110	27.49	.96
	CASE STUDY 2B	110	27.19	.77
	CASE STUDY 3	110	27.63	.81
	CASE STUDY 4	110	27.49	1.44
	CASE STUDY 5	110	27.80	2.79
	Total	660	27.47	1.45
TWC	CASE STUDY 1	110	24.54	1.50
	CASE STUDY 2A	110	24.93	1.25
	CASE STUDY 2B	110	24.72	1.46
	CASE STUDY 3	110	24.86	1.33
	CASE STUDY 4	110	24.53	.90
	CASE STUDY 5	110	25.37	1.51
	Total	660	24.82	1.36
RH_PERC	CASE STUDY 1	110	81.12	11.03
	CASE STUDY 2A	110	81.43	9.96
	CASE STUDY 2B	110	82.39	10.17
	CASE STUDY 3	110	80.37	10.32
	CASE STUDY 4	110	79.59	11.11
	CASE STUDY 5	110	81.34	13.05
	Total	660	81.04	10.98

AIR_VEL	CASE STUDY 1	110	.42	.21
	CASE STUDY 2A	110	.42	.19
	CASE STUDY 2B	110	.43	.19
	CASE STUDY 3	110	.37	.24
	CASE STUDY 4	110	.38	.27
	CASE STUDY 5	110	.42	.26
	Total	660	.41	.23
GTC	CASE STUDY 1	110	27.68	.58
	CASE STUDY 2A	110	27.92	.76
	CASE STUDY 2B	110	27.58	.81
	CASE STUDY 3	110	27.98	.84
	CASE STUDY 4	110	28.63	5.22
	CASE STUDY 5	110	28.42	1.31
	Total	660	28.03	2.31
MRTC	CASE STUDY 1	110	28.21	.69
	CASE STUDY 2A	110	28.35	1.04
	CASE STUDY 2B	110	28.05	.98
	CASE STUDY 3	110	28.32	1.13
	CASE STUDY 4	110	28.46	1.56
	CASE STUDY 5	110	28.76	1.53
	Total	660	28.36	1.21

Source: *Authors Field Survey, 2016*

TABLE 2: One-way Analysis of Variance of the Influence of the level of housing occupied on the level of comfort satisfaction of occupants

		Sum of Squares	df	Mean Square	F	Sig.
TDC	Between Groups	29.737	5	5.947	2.88	.014
	Within Groups	1349.971	654	2.064		
	Total	1379.708	659			
TWC	Between Groups	53.297	5	10.659	5.95	.000
	Within Groups	1172.169	654	1.792		
	Total	1225.466	659			
RH_PERC	Between Groups	507.539	5	101.508	0.84	.521
	Within Groups	78941.436	654	120.706		
	Total	79448.976	659			
AIR_VEL	Between Groups	.314	5	.063	1.21	.305
	Within Groups	34.074	654	.052		
	Total	34.388	659			
GTC	Between Groups	94.422	5	18.884	3.63	.003
	Within Groups	3406.860	654	5.209		
	Total	3501.283	659			
MRTC	Between Groups	31.626	5	6.325	4.44	.001
	Within Groups	930.988	654	1.424		
	Total	962.614	659			

***Significant at 0.05 level; df = 2 & 197; critical F-value= 2.37**

Source: *Authors Field Work, 2016*

Table 3: Standard Effective Temperature, Comfort Sensation, Cooling Effect, Based on Summary of Results of Physical measurement by Case Study

Case Study	Mean Temp. (℃)	Mean Rel. Humidity (%)	Mean Air Velocity (m/s)	Mean Radiant Temp (℃)	Set (℃)	Cooling Effect (℃)	Sensation
Case Study 1	27.20	81.10	0.42	28.20	26.80	2.3	Neutral
Case Study 2a	27.50	81.40	0.42	28.40	27.20	2.2	Slightly Warm
Case Study 2b	27.20	82.40	0.43	28.10	26.7	2.3	Neutral
Case Study 3	27.60	80.40	0.37	28.30	27.5	2.0	Slightly Warm
Case Study 4	27.50	79.60	0.37	28.30	27.4	2.1	Slightly Warm
Case Study 5	27.50	81.40	0.42	28.80	27.4	2.3	Slightly warm

Source: *Authors Field Work/Computer Simulation of the Field Survey, 2016*

ASHRAE Standard 55-1992 Adenda 1995 suggests that the summertime comfort zone ranges from about 23.5 at 25% relative humidity to about 26 at 60% relative humidity. The theoretical models (PMV, Predictive Mean Vote) predict comfort zones that are independent of local thermal conditions, while the adaptive models predict comfort zones that are dependent on local thermal conditions. The adaptive models, however, usually predict comfort zones that are closer to the field of study results. For instance, comfort was experienced at a temperature as high as 32 at over 85% relative humidity in Bangladesh (Mallick, 1996) and within higher ranges of temperature and relative humidity of 25–31.5 and 62.2–90% relative humidity in Thailand (Jitkhajornwanich, 2006). It is pertinent to note that the body's tolerance to relatively high temperatures and humidity is a result of adaptive activities such as opening windows, removing clothes, and homoeothermic mechanisms. The adaptation process of opening windows is for the purpose of increasing air movement in the occupied space so as to increase people’s convective and evaporative heat transfer rates.

The results of the statistical analysis in Table 3 support the above views as it presents the indoor mean air temperature and humidity ranges between 27.2 and 27.6 and 79.6% and 81.4% above the ASHRAE Standard 55 ranges of 23.5 and 26 and 25% and 60%. However, although the relative humidity exceeded the standard, the occupants of the building on survey felt slightly comfortable with the thermal comfort level they had found themselves at. Also, in the study, it was found that the standard rate of ventilation, which is 0.02 m/s, has been exceeded by a range of 0.37–0.43 m/s.These values are good for creating adequate indoor velocities. These findings agree with the opinion of Tantasavardi et al. (2007), who stated that wind-driven natural ventilation is easier to achieve because it only needs a low wind speed to create adequate indoor air velocity that helps people's heat transfer by means of evaporation. In the study, the level of satisfaction with thermal comfort achieved by occupants, despite the air temperature and humidity level, was above theoretical model standards as a result of probable passive design strategies applied to the buildings. These Include:

1. Landscape features and vegetation such as trees, shrubs and grasses. Also non-use of concrete flooring or coal tarred surfaces.
2. Building form and envelope design:

- Design with a relatively narrow plan form to facilitate the passage of air.
- Orientation of the building to maximize their exposure to the required wind direction, and cross ventilation.
- Extension of eaves such that it can trap and channel the wind into the building.

3. Proper placement of internal partitions to channel air through the occupied zone.

Further tests were carried out using the Psychometrics Chart to compare thermal Sensation in Case Studies 1, 2A, and 2B (see figure 1); thermal sensation in Case Studies 3, 4, and 5 (see figure 2); the effect of air speed on thermal comfort of Case Study 1 buildings at assumed 0.1 m/s (see figure 3); the effect of air speed on thermal comfort of Case Study 1 buildings at 0.42 m/s (see figure 4); the effect of air speed on thermal comfort of Case Study 2B buildings at assumed 0.1 m/s (see figure 5); and finally, the effect of air speed on thermal comfort of Case Study 2B buildings at 0.43 m/s (see figure 6). It should be noted that in the chart, the shaded portion is the acceptable comfort zone, while the red circular pointer indicates the point of comfort.

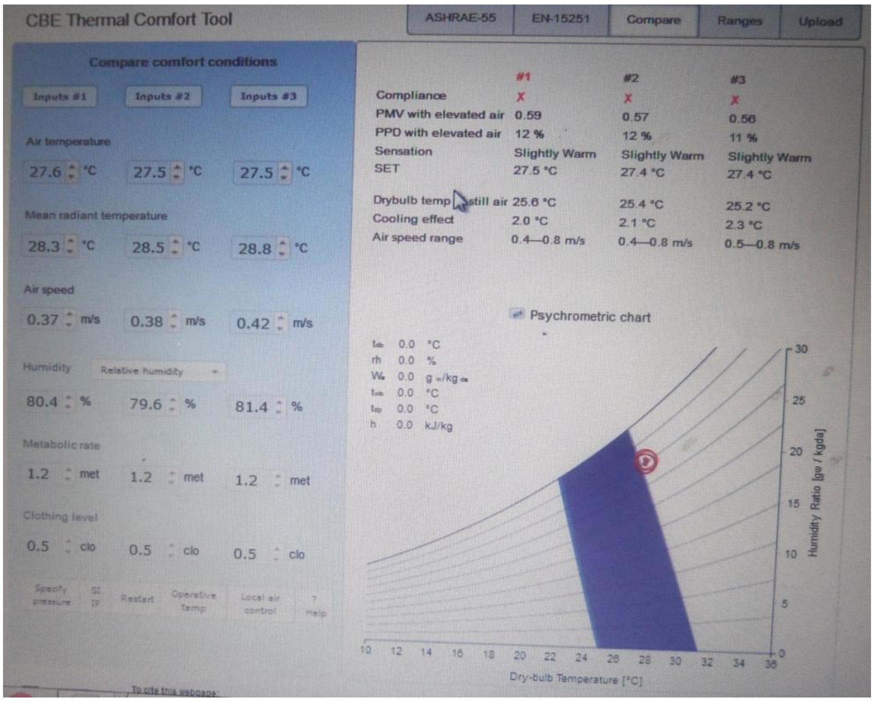
Figures 1 and 2 further explain that the best thermal comfort level was achieved in Case Studies 1 and 2. Figures 3 and 4, however, explain that at a low wind velocity of 0.1m/s in the same building, thermal comfort cannot be achieved.

	Inputs #1	Inputs #2	Inputs #3
Air temperature	27.2 °C	27.5 °C	27.2 °C
Mean radiant temperature	28.2 °C	8.40 °C	28.1 °C
Air speed	.42 m/s	.42 m/s	0.43 m/s
Humidity	81.1 %	81.4 %	82.4 %
Metabolic rate	1.2 met	1.2 met	1.2 met
Clothing level	0.5 clo	0.5 clo	0.5 clo

	#1	#2	#3
Compliance	✓	✗	✓
PMV with elevated air	0.43	0.52	0.42
PPD with elevated air	9 %	11 %	9 %
Sensation	Neutral	Slightly Warm	Neutral
SET	26.8 °C	27.2 °C	26.7 °C
Drybulb temp at still air	24.9 °C	25.3 °C	24.9 °C
Cooling effect	2.3 °C	2.2 °C	2.3 °C
Air speed range	0.4—0.8 m/s	0.4—0.8 m/s	0.4—0.8 m/s

t_{db}	25.9 °C
rh	77.3 %
W_a	16.2 g_w/kg_{da}
t_{wb}	22.7 °C
t_{dp}	21.4 °C
h	41.4 kJ/kg

Fig. 1: *Psychometrics Chart Comparing thermal Sensation in Case Study 1, 2A, & 2B*
Source: *Author's Computer Simulation of the Field Survey, 2016*

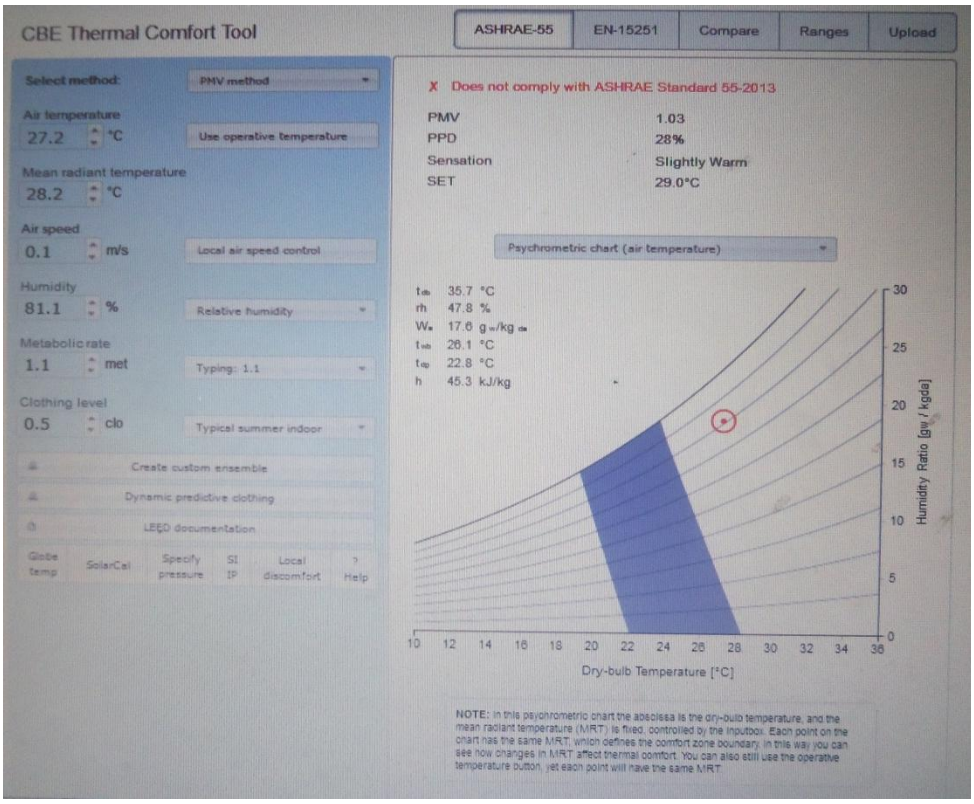


	Inputs #1	Inputs #2	Inputs #3
Air temperature	27.6 °C	27.5 °C	27.5 °C
Mean radiant temperature	28.3 °C	28.5 °C	28.8 °C
Air speed	0.37 m/s	0.38 m/s	0.42 m/s
Humidity (Relative humidity)	80.4 %	79.6 %	81.4 %
Metabolic rate	1.2 met	1.2 met	1.2 met
Clothing level	0.5 clo	0.5 clo	0.5 clo

	#1	#2	#3
Compliance	✗	✗	✗
PMV with elevated air	0.59	0.57	0.56
PPD with elevated air	12 %	12 %	11 %
Sensation	Slightly Warm	Slightly Warm	Slightly Warm
SET	27.5 °C	27.4 °C	27.4 °C
Drybulb temp at still air	25.6 °C	25.4 °C	25.2 °C
Cooling effect	2.0 °C	2.1 °C	2.3 °C
Air speed range	0.4—0.8 m/s	0.4—0.8 m/s	0.5—0.8 m/s

t_{db} 0.0 °C
rh 0.0 %
W_a 0.0 g_w/kg_{da}
t_{wb} 0.0 °C
t_{dp} 0.0 °C
h 0.0 kJ/kg

Fig. 2: *Psychometrics Chart Comparing Thermal Sensation in Case Study 3, 4 &5*
Source: *Author's Computer Simulation of the Field Survey, 2016*



Select method: PMV method
Air temperature 27.2 °C
Use operative temperature
Mean radiant temperature 28.2 °C
Air speed 0.1 m/s
Local air speed control
Humidity 81.1 %
Relative humidity
Metabolic rate 1.1 met
Typing: 1.1
Clothing level 0.5 clo
Typical summer indoor

✗ Does not comply with ASHRAE Standard 55-2013

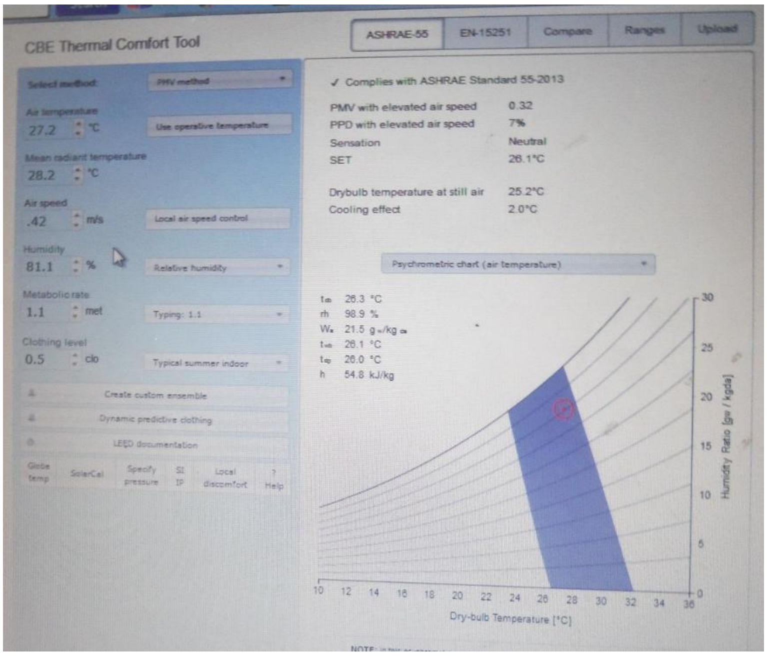
PMV	1.03
PPD	28%
Sensation	Slightly Warm
SET	29.0°C

Psychrometric chart (air temperature)

t_{db} 35.7 °C
rh 47.8 %
W_a 17.6 g_w/kg_{da}
t_{wb} 26.1 °C
t_{dp} 22.8 °C
h 45.3 kJ/kg

NOTE: In this psychrometric chart the abscissa is the dry-bulb temperature, and the mean radiant temperature (MRT) is fixed, controlled by the inputbox. Each point on the chart has the same MRT, which defines the comfort zone boundary. In this way you can see how changes in MRT affect thermal comfort. You can also still use the operative temperature button, yet each point will have the same MRT.

Fig. 3: *Effect of air speed on thermal comfort of Case Study 1 building at assumed air velocity of 0.1m/s*
Source: *Author's computer simulation of the Field Survey, 2016*



CBE Thermal Comfort Tool

Select method: PMV method
Air temperature 27.2 °C
Mean radiant temperature 28.2 °C
Air speed .42 m/s
Humidity 81.1 %
Metabolic rate 1.1 met
Clothing level 0.5 clo

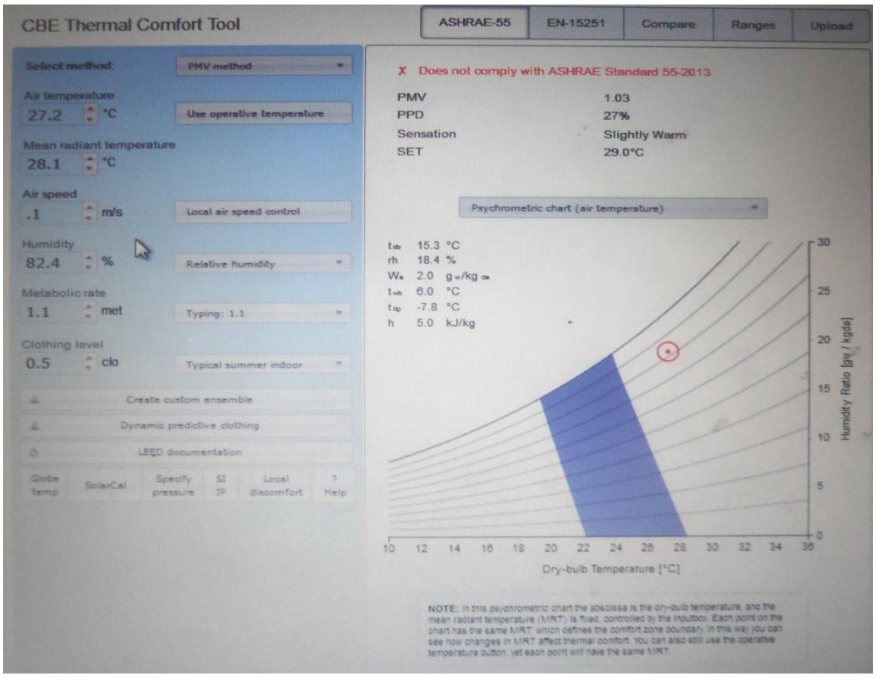
✓ Complies with ASHRAE Standard 55-2013

PMV with elevated air speed 0.32
PPD with elevated air speed 7%
Sensation Neutral
SET 26.1°C

Drybulb temperature at still air 25.2°C
Cooling effect 2.0°C

t_{db} 26.3 °C
rh 98.9 %
W_a 21.5 g w/kg da
t_{wb} 26.1 °C
t_{dp} 26.0 °C
h 54.8 kJ/kg

Fig. 4: Effect of air speed on thermal comfort of Case Study 1 building at assumed air velocity of 0.42m/s
Source: *Author's Computer Simulation of the Field Survey, 2016*



CBE Thermal Comfort Tool

Select method: PMV method
Air temperature 27.2 °C
Mean radiant temperature 28.1 °C
Air speed .1 m/s
Humidity 82.4 %
Metabolic rate 1.1 met
Clothing level 0.5 clo

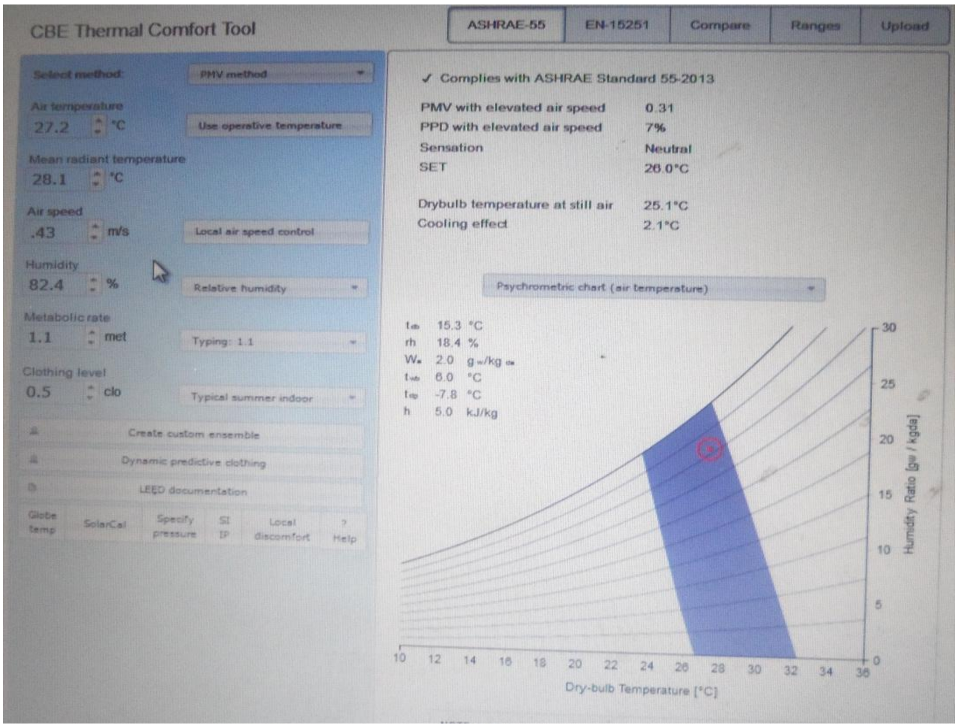
X Does not comply with ASHRAE Standard 55-2013

PMV 1.03
PPD 27%
Sensation Slightly Warm
SET 29.0°C

t_{db} 15.3 °C
rh 18.4 %
W_a 2.0 g w/kg da
t_{wb} 6.0 °C
t_{dp} -7.8 °C
h 5.0 kJ/kg

NOTE: In this psychrometric chart the abscissa is the dry-bulb temperature, and the mean radiant temperature (MRT) is fixed, controlled by the inputbox. Each point on the chart has the same MRT, which defines the comfort zone boundary. In this way you can see how changes in MRT affect thermal comfort. You can also still use the operative temperature button, yet each point will have the same MRT.

Fig. 5: Effect of air speed on thermal comfort of Case Study 2B building at assumed air velocity of 0.10m/s
Source: *Author's Computer Simulation of the Field Survey, 2016*


CBE Thermal Comfort Tool

Select method: PMV method
Air temperature 27.2 °C
Mean radiant temperature 28.1 °C
Air speed .43 m/s
Humidity 82.4 % Relative humidity
Metabolic rate 1.1 met Typing: 1.1
Clothing level 0.5 clo Typical summer indoor

✓ Complies with ASHRAE Standard 55-2013

PMV with elevated air speed	0.31
PPD with elevated air speed	7%
Sensation	Neutral
SET	26.0°C
Drybulb temperature at still air	25.1°C
Cooling effect	2.1°C

Psychrometric chart (air temperature)

Fig. 6: Effect of air speed on thermal comfort of Case Study 2B building at assumed air velocity of 0.43m/s
Source: Author's Computer Simulation of the Field Survey, 2016

Hypothesis Two: The null hypothesis states that there is no significant relationship between the architectural features of the building and the effectiveness of natural ventilation and thermal comfort. In order to test the hypothesis, two variables were identified as follows:

1. Architectural features of the building as the independent variable
2. Effectiveness of natural ventilation and thermal comfort as the dependent variable

Pearson Product Moment Correlation analysis was used to analyze the data. (See Table 4).

Tables 4 and 5 present the obtained r-value of 0.69. This value was tested for significance by comparing it with the critical r-value (0.139) at the 0.05 level with 198 degrees of freedom. The obtained r-value (0.69) was greater than the critical r-value (0.139). Hence, the result was significant. The result therefore means that there is a significant relationship between the architectural features of the building and the effectiveness of natural ventilation and thermal comfort.

TABLE 4: Pearson product moment correlation analysis of the relationship between environmental arrangement with building openings and the effectiveness of natural ventilation with thermal comfort

Variable	∑x ∑y	$\sum x^2$ $\sum y^2$	∑xy	r
Environmental arrangement (X1) Effectiveness of natural ventilation and thermal comfort (y)	1560 1880	17000 18280	14160	-0.29*
Building openings(X2) Effectiveness of natural ventilation and thermal comfort (y)	2080 1880	22800 18280	19120	-0.51*

***Significant at 0.05 level; df = 198; N = 200; Critical r-value = 0.139**

TABLE 5: Pearson product moment correlation analysis of the relationship between architectural features of the building and the effectiveness of natural ventilation and thermal comfort

Variable	∑x ∑y	$\sum x^2$ $\sum y^2$	∑xy	r
Architectural features of the building (XI) Effectiveness of natural ventilation and thermal comfort (Y)	1920 1880	18560 18280	18240	0.69*

***Significant at 0.05 level; df = 198; N = 200; Critical r-value = 0.139**

Discussions

The result of the data analysis in Table 2 was significant due to the fact that the calculated F-value (5.13 from comfort satisfaction in the questionnaire) and (11.96, 8.18, 3.82, and 3.40 from physical measurement of thermal comfort components as TWC, MRTC, TDC, and GTC) were greater than the critical F-value of (2.37) at the 0.05 level with (2 and 197) degrees of freedom. The result implies that there is a significant influence of the level of housing occupied on the level of comfort satisfaction of the occupants. The result was in agreement with the findings of Wang (2006), who stated that whilst natural ventilation can provide thermal comfort in some climates, a gap in thermal comfort improvement strategies in naturally ventilated buildings still exists to enhance suitable thermal conditions in buildings, thus avoiding occupant dissatisfaction, low productivity, and overall building performance. The significance of the result caused the null hypotheses to be rejected while the alternative one was accepted.

The result of the data analysis in Table 4 was significant due to the fact that the obtained r-values (-0.29) and (-0.51) were greater than the critical r-value (0.139) at the 0.05 level with 198 degrees of freedom. The results imply that environmental arrangement and building openings have a significant relationship with the effectiveness of natural ventilation and thermal comfort. The results were in agreement with the findings of Spagnolo and de Dear (2003), who reviewed the studies on the thermal comfort of outdoor conditions and questioned whether the theory developed for an indoor environment can be applied to an outdoor environment without modification. They also discover that outdoor comfort indices based on the energy balance of the human body should also use meteorological variables (air temperature, humidity, radiation, and wind speed) and human factors (clothing and metabolism). The significance of the result caused the null hypotheses to be rejected while the alternative one was accepted.

The result of the data analysis in Table 5 was significant due to the fact that the obtained r-value (0.69) was greater than the critical r-value (0.139) at the 0.05 level with 198 degrees of freedom. The result implies that there is a significant relationship between the architectural features of the building and the effectiveness of natural ventilation and thermal comfort. The result was in agreement with the findings of many experts in the area of study. The significance of the result caused the null hypotheses to be rejected while the alternative one was accepted.

Conclusion

Based on the findings of the research work, the researcher deems that many passive design strategies adopted by middle-income housing owners in Uyo, Akwa Ibom State, are not adequate enough for the subsisting thermal comfort of the occupants. The level of comfort perception of occupants is significantly different based on the level of housing occupied. There is a significant influence of the level of housing occupied on the level of comfort and satisfaction of the occupants. Furthermore, environmental arrangements and building openings have a significant relationship with the effectiveness of natural ventilation and thermal comfort. Finally, there is a significant relationship between the architectural features of the building and the effectiveness of natural ventilation and thermal comfort.

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