Energy Performance Assessment of Air-Conditioners with Thermal Comfort Modelling in an Indoor Environment

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Abstract

Energy performance of air-conditioners at the University of Lagos is assessed, with regards to the thermal comfort consideration of the occupants. Using the regression of relevant thermal comfort parameters, the energy efficiency rating (EER) for air-conditioners in five (5) residential quarters, including Ransome-Kuti, Mbonu-Ojike, Baya Jidda, Ozolua, and High Rise; and five different commercial energy stocks, including the University Guest Houses Auditorium, Alumni Building (Guaranty Trust Bank), United Bank for Africa (UBA), Multi-purpose Hall A and the University Consult Building (First Bank), are analysed. The comparison of the thermal comfort responses from the five residential zones indicates that High Rise quarter has the highest predicted mean vote (PMV) of 1.45 and predicted percentage of dissatisfied (PPD) of 48.07 %. Among the assessed commercial energy stocks, Multi-purpose Hall A appears to have the best performance with the PPD of up to 10 % followed by First Bank with the PPD of 14 %. A thermal comfort analysis tool is proposed for the ongoing development of a smart campus, based on the efficient framework and demand side management of energy consumption in residential buildings. It is anticipated that this effective and user-friendly tool will contribute to the development of a reliable minimum energy performance standards (MEPS) for air-conditioning appliances and other energy appliances by the Standard Organization of Nigeria (SON).

Keywords: Appliances, buildings; cooling; heating; standards

Nomenclature

A_{Du}	index of the type of activity
C_{res}	heat exchange by convection in breathing
COP	coefficient of performance
EER	energy efficiency rating
E_{res}	evaporative heat exchange in breathing
I_{cl}	cloth index (clo)
h_c	convective heat transfer coefficient
h_r	mean radiative heat transfer coefficient
f_{cl}	the clothing surface area factor
$F_{0\rightarrow i}$	shape factor which indicates the fraction of total radiant energy leaving the clothing surface 0 and arriving directly on surface *i, i=1,2,...,n*
M	metabolic rate (met)
$M-W$	metabolic heat production (Wm^{-2})
MEPS	minimum energy performance standards
P_a	water vapour partial pressure, in Pascal (Pa)
P_w	vapour pressure of water in ambient air (Pa)
PMV	predictive mean vote
PPD	predictive percentage of dissatisfied
Q_{sk}	heat loss through the skin (Wm^{-2})
Q_{res}	heat loss due to respiration (Wm^{-2})
RH	relative humidity

s thermal load on the body (Wm^{-2})
t_a ambient air temperature (^oC)
t_{cl} the clothing surface temperature, in degrees Celsius (°C)
t_{eq} equivalent temperature, in degrees Celsius (°C)
t_o operative temperature (^oC)
t_r mean radiant temperature (^oC)
t_i temperature of the surrounding surface i, I = 1, 2,....,n
t_{sk} temperature of the skin (^oC)
v air velocity (m/s)

1.0 INTRODUCTION

In developing economy, sustainable energy economy is no longer limited to the development of policy towards the generation of sufficient energy for its growing population. Utilization policies, including the minimum energy performance standards (MEPS) for refrigeration and air-conditioning systems with the recommendation of appropriate standard and labelling for heating, ventilation and air-conditioning system (HVAC), represent the growing interests of stakeholders. For example, the technical committee for air-conditioners and heat pumps of the Standards Organization of Nigeria (SON) for the development and review of these standards have recently adopted the maiden standards (SON, 2017), including the NIS ISO 5151 (non-ducted air-conditioners and heat pumps – testing and rating for performance), NIS ISO 16345 (water-cooling towers – testing and rating of thermal performance), NIS ISO 15042 (multiple split system air-conditioners and air-to-air heat pumps – testing and rating for performance), NIS ISO 16358-1 (air-cooled air-conditioners and air-to-air heat pumps – testing and calculation methods for seasonal performance factors, Part 1: cooling seasonal performance factors), NIS ISO 16358-2 (air-cooled air-conditioners and air-to-air heat pumps – testing and calculation methods for seasonal performance factors, Part 2: heating seasonal performance factors), and NIS ISO 16358-3 (air-cooled air-conditioners and air-to-air heat pumps – testing and calculation methods for seasonal performance factors, Part 3: annual performance factors). However, it was generally agreed that these standards are subject to review, after adequate results of technical investigation about the geographical and seasonal variabilities, thermal sensations of residential and commercial users of the appliances, building type and environment factors, and behavioural patterns, are sufficiently captured. The urgency of developing standards in technically disadvantaged countries often necessitates the adoption of standards and labels, without comprehensive analytical framework of the energy stocks, engineering-economy analysis, life cycle-cost analysis, environmental impact assessment of the appliances, and empirical review of the stakeholders' inputs (Shi, 2015).

Unlike in Europe, North America and most developed countries where buildings are integrated with heating and air-conditioning systems, consumption of air-conditioners in most developing countries is considered a luxury. Grignon-Massé *et al.* (2011) proposed the combination of life cycle analysis and environmental impact assessment as a methodology for reducing the CO_2 emission from the consumption of air-conditioners in Europe. It was observed that the consumption of individual air-conditioners constitutes a fast-growing electrical end use. The Energy Efficiency Ratio (EER) and the Coefficient of Performance (COP) were assessed based on the climatic conditions, while the air-conditioner standard performance was evaluated at full capacity with an outside air temperature of 35 ^oC in cooling mode and 7 ^oC in heating mode (Grignon-Massé *et al.*, 2011). However, there is no justification for the consideration of two seasonal performance metrics for air-conditioners in tropical countries, like Nigeria.

Besides the consideration of thermal comfort of occupants of residential and commercial buildings, the implementation of the minimum energy performance standards (MEPS) for air-conditioners can be influenced by the need to reduce energy consumption. About 831 GWh savings on residential energy consumption was estimated as a result of the implementation of MEPS for room air-conditioners over a period of 10 years from around the year 2001 (Mahlia *et al.*, 2005). By the initiative of SON in Nigeria in 2016, the country can be seen to have joined the group of countries, like Singapore, Malaysia, China, Canada, United States, Britain, Japan, Philippines, Sri Lanka, South Korea, and some other countries (Mahlia *et al.*, 2005), that adopted ISO 5151 (or a domesticated variant of ISO 5151) for air-conditioners. In climates where regional and seasonal variations in the relationships between outdoor temperature and mortality are significant, performance ratings of residential and commercial air-conditioners, indoor thermal comfort, and cooling energy consumption have been reported to have direct implications for public health policy and practice (Willand *et al.*, 2016). Even in tropical regions like India and Nigeria, where residential and commercial buildings have been built of brick, with lime brick, dust mortar and, later on, cement-sand mortar, existing performance standards for air conditioners do not reflect the climate and regional variations within the countries (Pellegrinoa *et al.*, 2016). The thicknesses of walls, the applied shading systems (including verandas or porches), courtyard design, and roof insulation are part of shared guidelines for climate-responsive architecture.

Particularly in Nigeria, relative humidity of both the indoor and outdoor environment vary significantly throughout the year, resulting in an increased use of air-conditioners for acceptable thermal comfort. For example, the city of Lagos has an average outdoor temperature of $26.8 \pm 3.45\,^oC$ (the hottest month being in the month of March with $28.5\,^oC$, while the coolest month being in August with $25.02\,^oC$). The average annual relative humidity is 84.7 %; while the average monthly relative humidity ranges from 80 % in March to 88 % in June (ECOWAS, 2013). The building sector accounts for 40 % of the world's energy while the energy consumption of the commercial building is dominated by the power needed for cooling and heating. By considering the demands of several cooling and heating appliances, including hot-water tanks and electric/gas furnaces, in both residential and commercial energy stocks in major cities in Ontario, it has been predicted that the management of thermal comfort and indoor air quality accounts on average for approximately 47 % of the total energy demand (Ogedengbe *et al.*, 2011 and 2013). Independent studies have confirmed a consistent performance in residential and commercial buildings in major European countries, including Italy (Caldera *et al.*, 2008) and Norway (Satori *et al.*, 2009).

While the adaptive approach uses historical usage data for energy stocks, the energy balance approach, which is well characterized by the work of Fanger (1970) uses data from climate condition studies. Fanger's comfort equation has been established from experimental work Fanger (1970). His predicted percentage of dissatisfied (*PPD*) for an indoor climate is perhaps more meaningful and is determined from the predicted mean vote (*PMV*) for several positions in a room. The *PMV* model is the most commonly used method nowadays in practice to predict thermal comfort in the design of a building and is often used to evaluate discomfort in existing built environments. Unfortunately, demand side monitoring to improve the efficiency of heating and cooling in residential buildings has not included the assessment of the thermal comfort of the occupants.

This paper deploys a regression formulation of the thermal comfort parameters for energy performance assessment of air-conditioners within an asymmetrical environment, constituted by the residential quarters and some commercial buildings within the University of Lagos. The objective of this study is to develop an applicable model for the energy efficiency rating (*EER*) and coefficient of performance (*COP*) for air-conditioners in Nigeria, especially within residential and commercial building facilities in tertiary institutions. Useful guidelines towards the development of a reliable minimum energy performance standard (MEPS) for air-conditioners in Nigeria will be recommended.

2.0 METHODOLOGY

2.1 Experimental Design

Figure 1 shows the schematics of a typical energy stock and the configuration of space for experimentation. Reliable assessment of thermal comfort model combines both the behavioral and environmental variables, including the activities of the occupants; thermal resistance of the clothing; air temperature; mean radiant temperature; relative air velocity; and humidity, and the assessment of physiological variables, including thermal comfort zone of the occupants; and their metabolic heat (Meissner *et al.*, 2014). Using Fanger's comfort equation (Kim *et al.*, 2016), the predicted mean vote (*PMV)* represents a complex equation making a connection among environmental variables, thermal sensation, activity and clothing level, as shown in Eq.1 (Ho *et al*., 2011).

$$PMV = (0.352e^{-0.042}(M/A_{Du}) + 0.032)\,[(M/A_{Du})(1-\eta) - 0.35\,[43 - 0.061(M/A_{Du})(1-\eta) - P_a] - 0.42\,[(M/A_{Du})(1-\eta) - 50] - 0.0023(M/A_{Du})(44 - P_a) - 0.0014(M/A_{Du})(34 - t_a) - 3.4\times10^{-8}\times f_{cl}[(t_{cl}+273)^4 - (t_{mrt}+273)^4] + f_{cl}h_c(t_{cl}-t_a) \tag{1}$$

while the predicted percentage of dissatisfied (*PPD)* index predicts the number of people which are not satisfied in terms of thermal comfort. When the *PMV* value is known, the *PPD* can be found from Eq. 2:

$$PPD = 100 - 95e^{-(0.03353\,PMV^4 + 0.2179\,PMV^2)} \tag{2}$$

where

$$t_s = 35.7 - 0.032\left(\frac{H}{A_{Du}}\right)$$

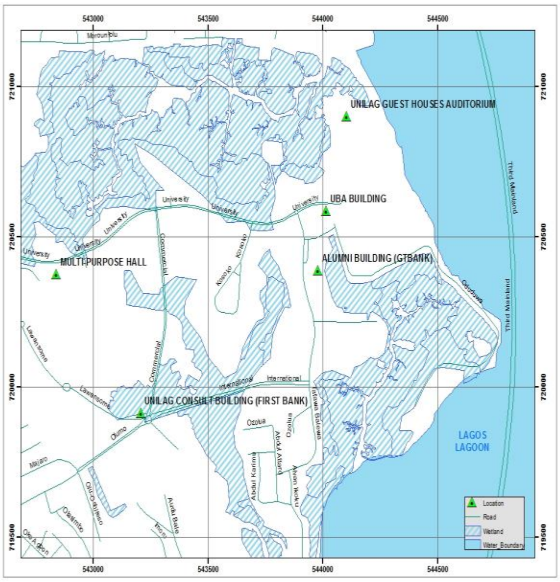
$$E_{sw} = 0.42A_{Du}\,[\left(\frac{H}{A_{Du}}\right) - 50]$$

f(t_{cl} , f_{cl}*) is the* type of clothing

f(η, V, M/A_{Du}*)* is the type of activity

f(V, t_a, t_{mrt}, P_a) are the environmental variables

(a) Residential Quarters



(b) Commercial Stocks

Figure 1: Zonal Mapping of the Energy Stocks, including (a) Five Residential Quarters; and (b) Five Commercial Energy Stocks

Table 1 indicates the psycho-physical ASHRAE scale with seven comfort levels that can be used as a measure for the thermal sensation. However, Sayigh and Marafia (1998) reported that the *PMV* provides the mean vote of average thermal sensation for a large group of people in a given environment.

Table 1: ASHRAE Thermal Sensation Levels (ASHRAE, 2005)

-3	-2	-1	0	+1	+2	+3
cold	cool	Slightly cool	neutral	Slightly warm	warm	hot

Assessment of thermal sensation within a built environment requires the use of relevant temperature variable. Chung *et al.* (2010) indicated considerable discrepancies in thermal comfort analysis that is solely based on air temperature, rather than the mean radiant temperature, for the calculation *PMV*. Therefore, thermal sensation balance is expressed as a function of the comfort factors in Eq. 3 (Fanger, 1970):

$$f(M, I_{cl}, v, t_r, t_a, P_w) = 0 \tag{3}$$

In order to define an explicit relation between the comfort factors, *the thermal load*, as an index of comfort, is defined as a remaining amount of each energy balance items. It represents any heat gain or loss from the thermally neutral state (Fanger, 1972) as in Eq.4.

$$S = (M - W) - (Q_{sk} + Q_{res}) \ (Wm^{-2}) \tag{4}$$

The heat loss through the skin is a sum of the sensitive heat losses (H) and the heat exchange by evaporation on the skin (E_c) and is given by Eq.5.

$$Q_{sk} = H + E_c \tag{5}$$

The heat loss due to respiration is a sum of the heat exchange by convection in breathing (C_{res}) and the evaporative heat exchange in breathing (E_{res}) and is given by Eq.6.

$$Q_{res} = C_{res} + E_{res} \tag{6}$$

leading to the complete expression of the thermal load as is in Eq.7.

$$S = (M - W) - H - E_c - C_{res} - E_{res} \ (Wm^{-2}) \tag{7}$$

where the terms H, E_c, C_{res}, and E_{res} correspond to the heat exchange between the body and the surrounding environment and are calculated from Eqs.8-11 (Fanger, 1972).

$$H = 3.96 \times 10^{-8} \times f_{cl} \times [(t_{cl} + 273)^4 - (t_r + 273)^4] - f_{cl} \times h_c \times (t_{cl} - t_a) \tag{8}$$

$$E_c = 3.05 \times 10^{-3} \times [5733 - 6.99 \times (M - W) - P_a] - 0.42 \times [(M - W) - 58.15] \tag{9}$$

$$C_{res} = 0.0014 \times M \times (34 - t_a) \tag{10}$$

$$E_{res} = 1.7 \times 10^{-5} \times M \times (5867 - P_a) \tag{11}$$

Based on the adopted Nigerian Industrial Standard (NIS ISO 5151) for air-conditioners (SON, 2017), the domestic thermal comfort model that assesses the *PMV* and *PPD* should reflect the standard rating conditions of the different regions within the country. The energy performance assessment of air-flow conditions (see **Table 2**) requires that tests shall be conducted under the selected conditions with no changes made in fan speed or system resistance to correct for variations from the standard barometric pressure. The tests shall provide for the determination of the sensible, latent and total cooling capacities as determined in the indoor-side compartment. Whereas, the energy performance assessment of both the maximum and minimum cooling conditions (see **Table 3**) requires that the tests shall be conducted with the equipment functioning at full-load operation. The test voltages shall be maintained at the specified percentages under running conditions. In addition, the test voltages shall be adjusted so that it is not less than 86 % of the rated voltage at the moment of restarting the equipment after the shutdown. For the minimum cooling condition, and at the end of a 4-hr test, any accumulation of frost or ice on the indoor coil shall not cover more than 50 % of the indoor-side face area of the indoor coil or reduce the airflow rate by more than 25 % of the initial airflow rate.

Table 2: Proposed Cooling Capacity Rating Conditions for Air-flow (SON, 2011)

Parameter	Standard Rating Conditions	
	T_1	T_3
Temperature of air entering indoor side:		
• Dry bulb	27 °C	29 °C
• Wet bulb	19 °C	19 °C
Temperature of air entering outdoor side:		
• Dry bulb	35 °C	46 °C
• Wet bulb	24 °C	24 °C
Condenser water temperature:		
• Inlet	30 °C	30 °C
• Outlet	35 °C	35 °C
Test frequency	Rated frequency	
Test voltage	Extended voltage range	

Table 3: Maximum and Minimum Cooling Performance Test Conditions (SON, 2011)

Parameter	Standard Rating Conditions		
	Maximum		Minimum
	T_1	T_3	T_1 and T_3
Temperature of air entering indoor side:			
• Dry bulb	32 °C	32 °C	21 °C[1]
• Wet bulb	23 °C	13 °C	15 °C
Temperature of air entering outdoor side:			
• Dry bulb	43 °C	52 °C	21 °C
• Wet bulb[a]	26 °C	31 °C	—
Test frequency[b]	Rated frequency		
Test voltage	90% and 110% of rated voltage with a single name-plate rating; 90% of the lower rated voltage and 110% of the higher rated voltage for units with dual or extended name-plate voltage		

a: The wet-bulb temperature condition shall only be required when testing air-cooled condensers which evaporate the condensate.
b: Equipment with dual-rated frequencies shall be tested at each frequency
1: 21 °C or the lowest temperature above 21 °C at which the regulating (control) device will allow the equipment to operate.

2.2 Air-Conditioners' Performance Measurement

Table 4 described the experimental field, including five (5) residential quarters for staff of the University of Lagos, and five (5) commercial facilities (see **Figures 1**). The two factors that were taken into consideration in order to evaluate the performance of the air-conditioners include the cooling capacity and the power consumption. Both factors depend on the ambient temperature and relative humidity. Therefore, discrete measurements of the air temperature and the mean radiant temperature data are collected for the sample rooms at different points, including head level, waist level and ankle level (for the air temperature); and ceiling level, floor level, west wall, east wall, south wall, and north wall (for the mean radiant temperature). The air speed and the relative humidity data are measured at the same points of measurement for the air temperature; while the activity level of occupants and their clothing levels are noted (being guided by **Tables 5 and 6**) about one hour before the commencement of the measurement exercise. The coefficient of performance (*COP*) is the ratio of cooling capacity and the equivalent power input to the compressor of the air conditioners and is given by Eq.12.

$$COP = \frac{Cooling\ Capacity}{Power\ Consumption} = \frac{Q_{out}}{W_{in}} \qquad (12)$$

Using regression analysis in the form of Eq.13,

$$y = f(x_1, x_2, \cdots, x_n) \qquad (13)$$

where *COP* and power consumption are predicted from the independent variables x, as ambient temperature and relative humidity becomes the predictor variables. It is required to find a suitable approximation for the true functional relationship between *y* and the set of independent variables, x_i's.

The second-order model recasts Eq. 13 as:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_{ii} + \sum_i \sum_j \beta_{ij} x_i x_j + \varepsilon \quad \text{for } i < j \qquad (14)$$

Figure 1 shows the coordinate of the field for experimental data collection in air-conditioned residential buildings and the commercial stocks located on the campus of University of Lagos. The campus is located on latitude 6°31`N and longitude 3°23`E, and bordered to the east and south by the Lagos lagoon. Generally, Lagos has its unique climatic characteristics with two distinct rainy seasons; the most intense season occurs between April and July, with a milder one from October to November. Lagos experiences a dry season during August and September, as well as between December and March.

Table 4: Description of the Experimental Field

Zones	Represented Residential Area	Different Commercial Stocks
1	Ransome-Kuti Close Staff Quarters	Multi-purpose Hall A (Jelili Adebisi Omotola Hall A)
2	Mbonu-Ojike Close Staff Quarters	Unilag Consult Building (First Bank)
3	Baya Jidda Close Staff Quarters	United Bank for Africa (UBA) Building
4	Ozolua Close Staff Quarters	Alumni Building (Guaranty Trust Bank)
5	High Rise Block ‘B’ Staff Quarters	University Guest Houses Auditorium

Occupied flats or quarters with installed air-conditioners are used to conduct measurements in order to obtain the required environmental conditions, which are used for the evaluation of the *PMV* and *PPD* for thermal comfort. In addition, the level of activity of the occupants is considered with other variables in order to calculate the thermal comfort level. ASHRAE standards 55-2004 list various activities with the metabolic rate expected from a healthy body. **Tables 5 and 6** extract relevant data from ASHRAE standards 55 for the occupant’s activities and clothing levels respectively.

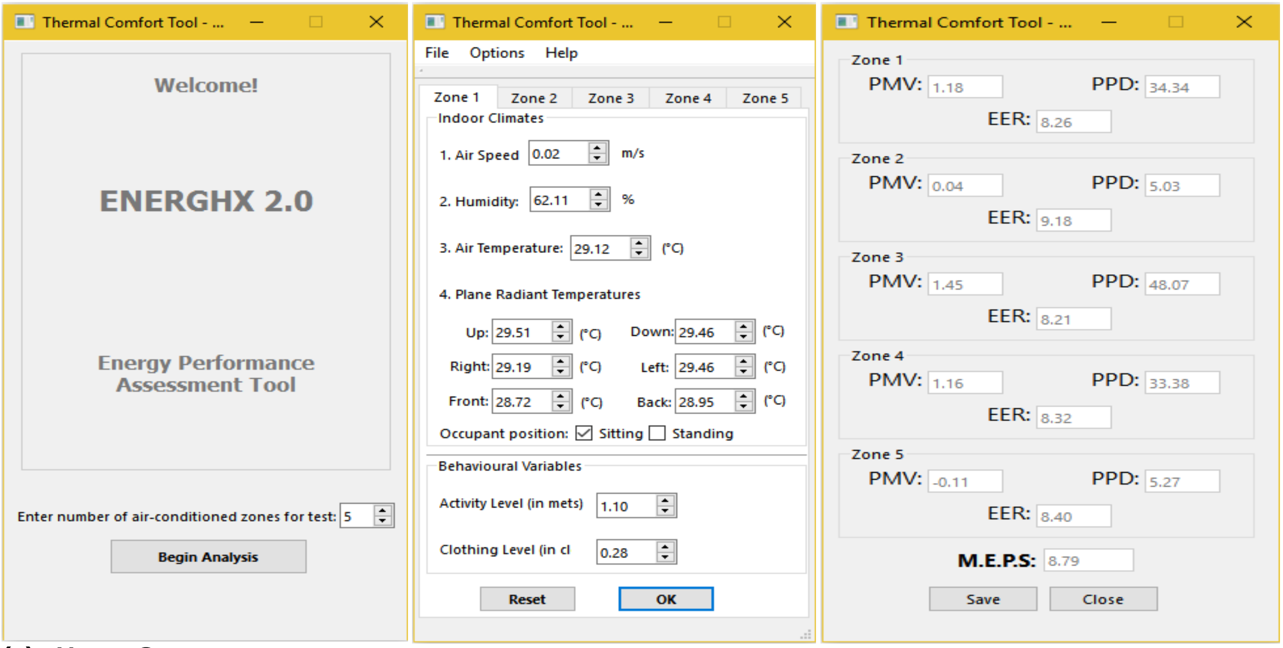
Table 5: Metabolic Rate for Occupant’s Activities (ASHRAE, 1992)

Activity	Metabolic rate (in mets)
Sleeping	0.7
Reclining	0.8
Seated, quiet	1.0
Standing, relaxed	1.2
Walking about	1.7
Medium activity, standing (shop assistant, domestic work, machine work)	2.0
Reading, Seated	1
Writing	1
Typing	1.1
Filing, seated	1.2
Filing, standing	1.4
Lifting/Packing	2.1

Table 6: Classification of Occupant’s Clothing (ASHRAE, 1992)

Clothing Description	Garments Included	clo
Trousers	Trousers, short-sleeve shirt	0.57
Trousers	Trousers, long-sleeve shirt	0.61
Skirts/Dresses	Knee-length skirt, short-sleeve shirt (sandals)	0.54
Skirts/Dresses	Knee-length skirt, long-sleeve shirt, full slip	0.67
Shorts	Walking shorts, short-sleeve shirt	0.36
Sleepwear	Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks)	0.96

The entire equations (Eqs. 1-11) that detail the thermal comfort modelling procedure, the iterative assessment of the adaptive temperature of the environment, and the development of the empirical auditing model are programmed with the C++ language. **Figure 2** visualizes the software tool with a graphical user interface (GUI), built within the *Qt* designer framework, which allows the development of widgets or dialogs in a what-you-see-is-what-you-get (WYSIWYG) manner. There are 3 different types of window screens in the project which display the home screen, the data entry form, and the results respectively.



(a) Home Screen **(b) Data Entry Screen** **(c) Result Screen**

Figure 2: Screenshot of the Audit Software Tool, showing (a) Home Screen; (b) Zonal Data Entry Screen; and (c) Result Screen

The GUI tool is effective and user-friendly, allowing easy data entering of the indoor climatic conditions as well as the behavioural variables in the various test zones. Based on the developed thermal comfort model, it proceeds to evaluate the room comfort indices and the air conditioner energy performance. The obtained *EER* values within the thermally comfortable zone are then averages and the MEPS are specified.

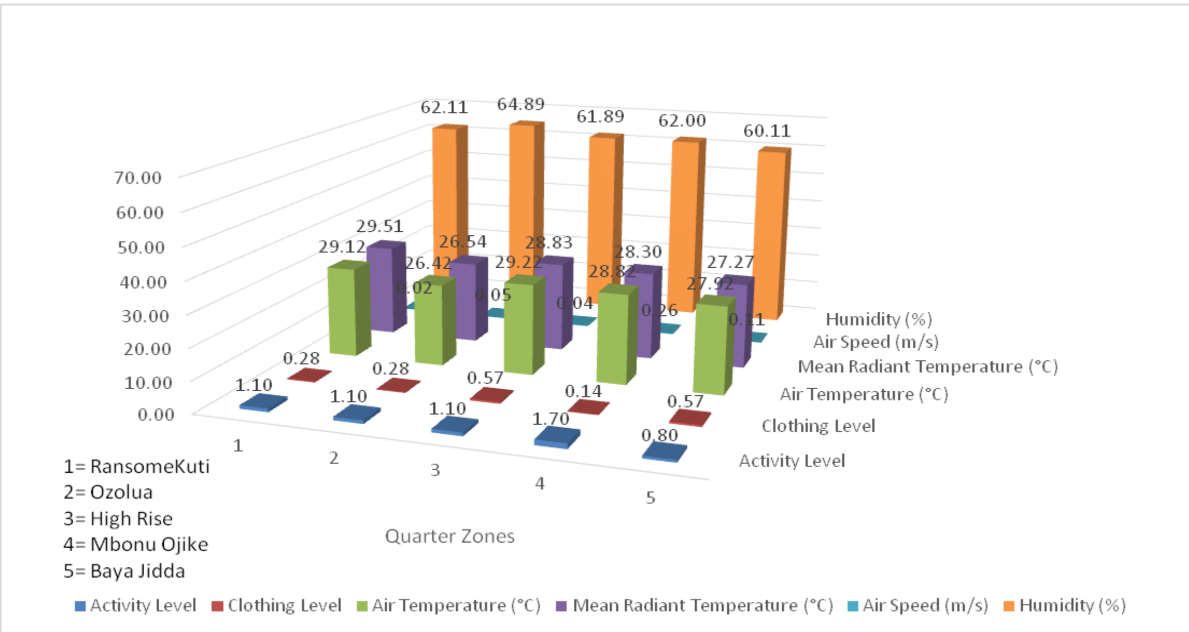


Figure 3: Thermal Level Assessment of the Five Residential Staff Quarters

3.0 RESULTS AND DISCUSSION

Figures 3 and 4 assessed the activity level, clothing level, air temperature, air speed and humidity within the five residential quarters. The measurements were taken in the late hours of the afternoon and evenings.

The mean radiant temperature was about 0.28° cooler than the mean air temperature of 28.30°C, probably due to the timing of most measurements in the afternoon and evening hours. Relative humidity was uniformly high throughout, with a mean of 62.2 %. Indoor air velocities were light with an average value 0.10 ms^{-1}. In the air-conditioned apartments, the mean clothing insulation value of 0.37 clo reflects the casual dress codes of students at the University, with the typical male ensemble consisting of shorts and t-shirt, while the typical female ensemble consisted of a light skirt and blouse. The mean metabolic rates estimated were approximately equal to 1.16 met, as occupants were mainly sitting and using their laptops or mobile devices.

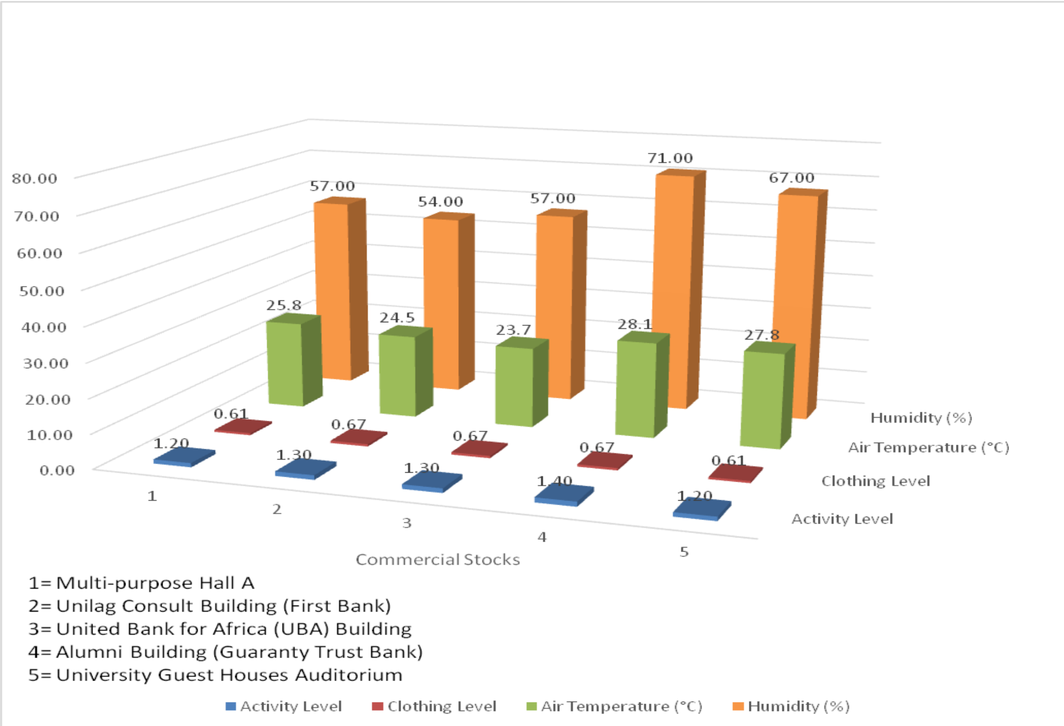


Figure 4: Thermal Level Assessment of the Five Commercial Energy Stocks

Using the Fanger's thermal comfort model, **Tables 7 and 8** predict the *PPD* and *PMV* indices for the 5 residential zones and the 5 commercial stocks respectively.

Table 7: Predicted PMV and PPD for the 5 Residential Zones

ZONE	RESIDENTIAL ZONES	PMV	PPD (%)
1	Ransome-Kuti Staff Quarters	1.18	34.34
2	Ozolua Staff Quarters	0.04	5.03
3	High-Rise Staff Quarters	1.45	48.07
4	Mbonu-Ojike Staff Quarters	1.16	33.38
5	Bayya-Jidda Staff Quarters	-0.11	5.27

Table 8: Predicted PMV and PPD for the 5 Commercial Stocks

ZONE	COMMERCIAL STOCKS	*PMV*	*PPD* (%)
1	Multi-purpose Hall A	-0.46	9.35
2	Unilag Consult Building (First Bank)	-0.65	13.94
3	United Bank for Africa (UBA) Building	-1.24	37.02
4	Alumni Building (Guaranty Trust Bank)	1.26	38.07
5	University Guest Houses Auditorium	1.05	28.14

ASHRAE standard 55 (1992) defines the comfort zone as a range of thermal environmental conditions, where greater than 80% of occupants expressed satisfaction. Therefore, the percentages of dissatisfaction will be less than 20 %. It implies that only the residential zones 2 and 5 are in the thermal comfortable range; while only the Multi-purpose Hall A appears to be most maintained in the acceptable comfort level, compared to other commercial energy stocks within the campus.

The thermal level assessment data from the five residential quarters are analyzed in order to obtain the empirical model for the *COP* and *EER* of air-conditioners. Using the linear regression analysis, corresponding functional relationship for *EER* based on their experimental results is proposed in Eqs. 15 and 16:

$$EER = (-11.50) + (0.3868)\,T_{am} + (0.1482)\,RH \tag{15}$$

$$COP = (-3.3705) + (0.1134)\,T_{am} + (0.0434)\,RH \tag{16}$$

The energy efficiency standard is calculated from the *EER* relation connecting the ambient temperature and the relative humidity. The values are inputted from the output of the thermal comfort analysis, given the desired *PMV*, as outlined earlier. Comparing the proposed model with that of Izham and Mahlia (2010), the *EER* of the air conditioners are evaluated as depicted in **Table 9**.

Table 9: Predicted *EER* of the Residential Air-conditioners

ZONE	ZONE	*EER* (Izham and Mahlia [29])	*EER* Proposed Model
1	Ransome-Kuti Staff Quarters	8.26	8.84
2	Ozolua Staff Quarters	9.18	8.31
3	High-Rise Staff Quarters	8.21	8.86
4	Mbonu-Ojike Staff Quarters	8.32	9.12
5	Bayya-Jidda Staff Quarters	8.40	8.17

Using measures of central tendency, the obtained *EER* values obtained in the comfort zone are compared as shown in **Table 10**. Mbonu-Ojike quarters have the highest level of thermal comfort from air-conditioners with an *EER* of 9.12, compared to the air-conditioners in the Ozolua quarters based on the proposed model.

Table 10: Measure of Central Tendency Based on Izham and Mahlia's Model

MEASURE	*EER*
Mean	8.79
Median	8.79
Maximum	9.18
Minimum	8.40

5.0 CONCLUSION

A graphical user interface (GUI) tool was developed for energy performance assessment of buildings' indoor climatic conditions as well as the behavioural variables in the various test zones. The thermal comfort of the five residential zones was obtained using the *PMV* and *PPD* indices of Fanger's model. It was observed that only 40 % of physical measurements of air-conditioned rooms fell within the thermal comfort zone. It was observed that assessment based on *PMV* and *PPD* metrics reveals that only Ozolua and Biyya Jidda residential quarters are in the thermal comfortable range; while only the Multi-purpose Hall A appears to be most maintained in the acceptable comfort level, compared to other commercial energy stocks within the campus. Within this comfort zone, the *EER* of the air conditioners were evaluated from the operational model for room air conditioners. The obtained values were compared using measures of central tendency. The MEPS is specified to be 8.79, suggesting the best performance at the Mbonu Ojike residential quarters. In reality, there was a significant seasonal change in both outdoor and indoor atmospheric factors, based on prevalent climatic conditions in the test environment. This variation in the outcomes of thermal comfort level from air-conditioners suggests 8.79 as the recommended *EER* for air-conditioners to be supplied into residential quarters at the University of Lagos. Data about subjective comfort sensation should also be considered through multiple choice questionnaires distributed to the occupants, in order to find a correlation between experimental data measured by the instruments and the subjective responses of the occupants. This will ensure precise evaluation of occupants' thermal comfort and specification of appropriate MEPS.

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CONFLICTS OF INTEREST
The authors declare no conflict of interest.

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