Innovations

Analysis of Thermal Comfort in Naturally Ventilated Hostel Buildings in Delta State University of Science and Technology

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Abstract : *The discomfort of indoor environmental condition in occupied spaces in Hostel buildings has escalated due to combined effect of high solar radiation and humidity levels in the warm-humid climate which is an impact from climate change. The discomfort faced by occupants of buildings are less effective air flow; which cannot ensure personal thermal comfort and expel moisture that can impact on the indoor environmental performance. As a result, these have contributed to use of artificial means to provide a comfortable thermal environment at high energy consumption. This paper reports on the investigation using questionnaire to analyse the thermal comfort in naturally ventilated Hostel buildings. Occupants were asked to assess environmental conditions in terms of thermal comfort by filling in the questionnaire. The Analysis of Variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the occupants thermal comfort performances in the Hostel building. The result shows that thermal comfort of the occupants is influenced by the ventilation potential in the Hostel building. The use of natural ventilation potentially reduces the operational and the maintenance cost needed for mechanical system. Recommendations were made for effective ventilation to improve occupant's thermal comfort.*

Keywords: *Climate change, Thermal comfort, Natural ventilation, Warm humid climate, and Energy consumption.*

1. Introduction

Thermal comfort is strongly related to thermal balance between the body's heat generations and the release of body heat into its surroundings. Human body continuously produces heat due to metabolic activities which is used as work and dissipated to surrounding to maintain the body temperature (achieve body thermal balance). A state of thermal balance of the body is when heat gains and losses to its surrounding are at equilibrium rate. Baker and Steemers (2000) stated that heat loss to the environment occurs predominantly by three mechanisms (radiation, convection and evaporation) and to a much lesser extent by conduction. Heat transfer between human body and its surrounding in a normal comfort condition. Basically, our body constantly produces heat from the consumption and digestion of food and the processes are known as metabolism of the energy produced in the body. There are only about 20% of energy produced in the body is utilized in useful work while remaining 80% must be dissipated to the environment (Baker & Steemers, 2000). Heat must be continuously dissipated and regulated to maintain normal body temperature at around 37°C. Insufficient heat loss leads to overheating called *hyperthermia*, and excessive heat loss results in body cooling which is called *hypothermia*. An internal body temperature less than 28°C can lead to serious cardiac arrhythmia and death; and temperature greater than 46°C can cause irreversible brain damage. Therefore, the careful regulation of body temperature is critical to maintain body comfort and health (ASHRAE, 2009).

2. Literature Review

Basically, thermal comfort conditions considered the six basic parameters which are classified into two major variables such as environmental variables; and personal variables. These parameters can influence thermal condition and the integrated influence of these six parameters can determine thermal comfort responses.

Table 1: Thermal comfort

Environmental variables	Personal variables	Contributing factors
Air temperature	Metabolic rate (activity)	Food and drink
Air movement	Clothing	Acclimatization
Humidity		Body shape
Radiation (*can be referred to as mean radiant temperature)*		Subcutaneous fat
		Age and gender
		State of health

Source: (Auliciems & De Dear, 1986)

However, the variables that affect heat dissipation from the body (thermal comfort) are grouped into three sets as shown in Table 1 (Auliciems & De Dear, 1986).

- **Air temperature**

Temperature is easily measured and alternatively called air temperature or dry bulb temperature which is measured by an accurate thermometer or thermocouple. When measuring air temperature, the thermometer should be shielded to reduce the effects of direct radiation. It is found that in most cases a reasonably comfortable environment can be maintained when two or three of parameters are controlled (Atolagbe, 2014).

- **Mean radiant temperature**

Mean radiant temperature can be defined as the temperature of an imaginary isothermal enclosure with which a human body would exchange the same radiation as with the actual environment (Olanipekun et al., 2014). Equation 1. shows the mean radiant temperature:

$$T_{mrt} = T_g + 2.35\,(v)^{0.5}\,(T_g - T_a) \qquad \text{......................(1)}$$

Where; T_{mrt} = mean radiant temperature

T_a = air temperature (dry bulb temperature)

T_g = globe temperature

V = relative air velocity

- **Air velocity**

Continuously moving air is one of the requirements for thermal comfort. It is not only effective in evaporating perspiration but also in speeding convection heat loss from the skin (Allard, 2002; Anunobi et al., et al., 2015). Olanipekun et al., (2014) pointed out that air movement increases human comfort in warm humid climates at air speeds of between 0.4–3 m/second. It indicated that air flow of 1 m/second will reduce an air temperature of 30° C to an effective temperature of 27° C.

- **Relative humidity**

Relative humidity is the ratio of mass of water vapour in the air to the mass of water vapour when the air is in saturated state. Raising relative humidity reduces the ability to lose heat through perspiration and evaporation, so that the effect is similar to raising the temperature. Excessively high or low relative humidity can produce discomfort, while high relative humidity can promote the growth of microbial contaminants that harmful to occupant's health (Baker & Steemers, 2000).

- **Clothing insulation**

Clothing insulation is measured in units of 'clo' (Atolagbe, 2014). Clothing, through insulation properties, is an important modifier of body heat loss and comfort. If clothing does not provide enough insulation then the wearer may be at risk in the very cold conditions. For dry insulation a value of 1 Clo is defined as providing an insulation of $0.155 m^2 K/W$ (Adebamowo et al., 2010).

- **Metabolic rate**

Metabolism determines the rate at which energy is converted from chemical to thermal form within the body, and blood circulation controls the rate at which the thermal energy is carried to the surface of the skin. The energy generated by occupant's metabolism varies considerably with that occupant's activity. A unit to express the metabolic rate per unit of body surface area is the 'met', which is defined as the heat produced by a sedentary person and is given the values of 58 Watts produced for every square metre of the body surface area (i.e. 1.0 Met = 58.2 W/m2) (Adebamowo et al., 2013; Olanipekun et al., 2014).

1.2 Study Area

The study area is Delta State University of science and Technology, Ozoro, Nigeria. The Ozoro town is in warm humid climate zone with long wet season lasting from March to October that alternates with a shorter dry season that last from November to February. The climate is influenced by two prevailing air masses namely the south-west monsoon wind and then North-East trade wind. Annual rainfall in the Asaba area is up to 2500mm with double peak rainfall regime which takes place both in June and September. Annual average temperature is about 27^0C with no marked seasonal departure from the average. The natural vegetation of the area is rainforest with swamp forest occurring in flat-floured valleys and adjoining low lying areas that are seasonally or permanently water logged (NiMet 2006).

3. Research methodology

The research was carried out through obtaining data with the questionnaire survey to access the effect of indoor air temperature on thermal comfort of the occupants in naturally ventilated Hostel buildings. Occupants were asked to assess environmental conditions in terms of thermal comfort by filling in the questionnaire. The contents of the occupant questionnaire were developed from previous research on post-occupant evaluation by well-established researchers (Nicol, 2004; Baker and Steemers, 2000). In this questionnaire, occupants were asked to judge how they felt about the thermal environment on a typical 7-point ASHRAE sensation scale. Furthermore, occupants were asked to judge the acceptability of and preference for thermal conditions. A direct acceptability question asked occupants to gauge whether the current thermal condition was 'acceptable' or 'unacceptable'. The McIntyre preference scale (Right now I want to be: cooler, warmer or no change) was used to investigate occupant preferences.

3.1 Characteristics of monitored building

The characterizations of the monitored buildings were based on naturally ventilated Hostel buildings within the university campus. In order to have adequate sample size required in addressing the research questions, sampling of the occupants of naturally ventilated Hostel buildings were carried out.

Plate 1: Naturally ventilated Female Hostel, Delta State University of Science and Technology, Ozoro

Plate 2: Naturally ventilated Male Hostel, Delta State University of Science and Technology, Ozoro

4. Data Presentation and Analysis

The data generated from the questionnaire are sorted and arranged a way that is adequately fit for statistical analysis and interpretation using tables, bar charts, graphs, frequency distributions and percentages.

Question 1: Occupant thermal comfort level

This question was asked for respondents to indicate their level of thermal comfort. The Table 2; shows the thermal comfort level distribution of the respondents. The result has shown that about 1.42%of respondents were much too cool, 5.23% too cool, 3.33% cool, 7.14% ok, 20.00% warm, 53.33%

too warm and 10.50% much tool warm. This shows that more of the respondents are feeling too warm.

Table 2: Thermal comfort level distribution

Thermal comfort level	frequency	percentage
Much too cool	3	1.42%
Tool cool	11	5.23%
Comfortably cool	7	3.33%
Neither cool nor warm	15	7.14%
Comfortably warm	42	20.00%
Too warm	112	53.33%
Much too warm	20	10.50%
Total	**210**	**100%**

Source: Field work (2024).

Question 2: Occupant preference of air movement, (how would you like to have the air movement.

This question was asked to know the distribution of how respondent would like to be (occupant preference of air movement). The Table 8; shows the occupant preference of air movement. The result has shown that about 3.53% of respondents prefer slower, 5.38% exactly how it is now, and 91.07% prefer faster air movement. This shows that more of the respondents prefer air faster air movement.

Table 3: Occupant preference distribution of air movement

Occupant preference of air movement	frequency	percentage
Slower	12	5.71%
Exactly how it is now	18	8.57%
Faster	180	85.71%
Total	**210**	**100%**

Source: Field work (2024).

Question 3: occupant acceptability of the temperature

This question was asked to know the distribution of respondent's acceptability of the temperature. The Table 4 shows the temperature acceptability distribution of the respondents. The result has shown that about 19.52% of the respondents accepted it while 80.48% of the respondents did not accept the indoor temperature. This shows that more of the respondents did not accept the indoor temperature.

Table 4: Temperature acceptability distribution

Temperature acceptability	frequency	percentage
Acceptable	41	19.52%
Not acceptable	169	80.48%
Total	**210**	**100%**

Source: field work (2024).

The result in table 5; reported the p-value result for the ANOVA analysis on occupant's thermal perception in naturally ventilated hostel buildings in the study area.The result is said to be significant if p-value is less than 0.05 significant level. The result reports a p-value of 0.000 with an F-value of 34.335. We therefore reject the null hypothesis and accept the alternate hypothesis stating that occupant's thermal perception significantly differ in naturally ventilated Hostel buildings in the study area.

Table 5: The ANOVA analysis result on occupant's thermal perception in naturally ventilated Hostel buildings in the study area

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11.903	4	2.976	34.335	.000
Within Groups	.867	10	.087		
Total	12.769	14			

Source: ANOVA analysis output, SPSS 25

5 Discussion of results

Comfort threshold in warm humid climates like that of Ozoro, would be limited by high humidity, which will restrict the evaporative heat loss from the skin and cause discomfort (Fanger, 1970; Heiselberg,et al., 2001; Szokolay, 2004). But increasing the air flow speed around occupants can boost the evaporative heat loss from the skin; it would replace the humid saturated air around the skin with fresh and unsaturated air (Boutet, 187; Diogu & Okonkwo, 2005; Szokolay, 2004; CIBSE, 2006). So, increasing air flow speed can help occupants to achieve thermal comfort.

Thermal comfort would be influenced by the ambient environment, cultural context and occupant experience. People would adapt and tolerate the local climate condition when they live in this region for a long time. Thus, people who live in the warm humid climate can accept a higher humid and hot environment than those people from other climate conditions. Givoni (1998) explained that it is because of the acclimatisation. In the warm humid climate, the upper boundary of acceptability of humidity and temperature is higher than the comfort threshold upper limit of 26°C identified by ASHRAE (2004).

6 Conclusions

Air movement can increase the heat convection between the human body and the ambient environment, so that it takes away the heat by evaporating perspiration. The average skin temperature is 32°C-34°C when people are doing light activity, and the physical evaporation rate is based on air velocity and vapour press. The increase of air velocity can speed up the evaporation rate; while the evaporation rate will be decreased merely under high vapour pressure. Providing a cooling effect by increasing air movement can be achieved as the air temperature is lower than skin temperature. Therefore, providing air movement is an important method to reduce cooling load and achieve thermal comfort, especially in warm humid climates.

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