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A Comparative Study of Urban and Rural Thermal Comfort in Residential Buildings Located in Umuahia and Eziala Nsuluin Abia State Nigeria

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Abstract
The paper presented a field study of occupants' thermal comfort and residential thermal environment conducted in an urban and a rural area in Abia State Nigeria. The study was carried out in the summer 2016. 50 naturally ventilated urban residences and 55 also naturally ventilated rural residences were studied. A comparative analysis was done using results from urban and rural residences. The mean thermal sensation vote of rural residences is approximately 0.4 higher than that of urban residences at the same operative temperature. Thermal sensation vote calculated by Fanger's PMV model did not agree with those obtained directly from the questionnaire data. The neutral operative temperature of urban and rural residences is 26.2°C and 24.5°C, respectively. Percentage of acceptable votes of rural occupants is higher than that of urban occupants at the same operative temperature. It suggests that rural occupants may have higher cold tolerance than urban occupants for their physiological acclimatization, or have relative lower thermal expectation than urban occupants because air-conditioners are not used in the rural area. The study will help researchers in formulating thermal standards for naturally ventilated buildings in rural environments.

Keywords: *Comparative analysis, Urban thermal comfort, Rural thermal comfort, Thermal sensation.*

Background to the Study

Han et al; (2009) noted that in recent years, many researchers studied residential thermal environment and occupant comfort in urban residences in different climatic zones. Scholars who have done researches in thermal comfort in rural areas include Bush (1992), De Dear (1994,1998), Nicol (1999) and Fato et al (2004) to mention a few. The researches were tailored on how to improve people's living conditions in rural residences. This study seeks response to the following questions: what is the difference in occupants' thermal comfort between urban and rural residences in Abia State, and should we provide the same residential thermal environment for rural and urban residences in Abia State.

It is well known that the lifestyle and economic status of individuals in rural areas are different from those in urban areas in Abia State. For example, air- conditioning is not popular in the rural areas, and this makes occupants living in rural areas to expect less thermal comfort than those living in urban areas. Fanger and Toftum (2008) introduced expectancy factor to explain the difference between non- air-conditioned buildings in regions where the weather is warm only during the summer and where there are none or few buildings with air- conditioning and regions with same or similar environmental conditions but widespread use of air –conditioning. The expectancy factor is 0.7-0.8 with few air –conditioned buildings and 0.8-0.9 where there are many air –conditioned buildings. Moreover, thermal adaptive theory indicates that behavioral adjustment, past thermal history and expectations, influence occupants' thermal comfort Brager et al (1998).

It is evident that there are many differences between urban and rural occupants 'comfort because of their different economic conditions, lifestyle, context factors, physiological acclimatization and expectation.Brager et al, (1998) however, to the best of knowledge, there is little information available concerning the occupant's comfort and residential thermal environment in rural areas. Thus, major reasons of this study are comfort and residential thermal environment in the rural area through field studies, and a comparative and statistical analysis of urban and rural occupants' thermal comfort. This will be of assistance in recommending sustainable thermal standards for buildings in rural areas in Abia State in future.

Methodology

Building Types and Envelope Characteristics

Umuahia a typical warm humid city, the capital of Abia State was selected as the urban site for the study. Eziala Nsulu, a village about 30km away from Umuahia, was selected as the rural site. The outdoor meteorological conditions of the two areas are very similar: hot summers and heavy rains. There are two common types of buildings in the rural area; earth and brick-masonry. The envelopes of earth buildings are rammed earth walls. In the urban area, are brick-masonry buildings and cavity walls made of brick and cement mortar. Also there are reinforced- concrete buildings made of aerated concrete blocksor hollow bricks. During the summer months, occupants of naturally ventilated buildings, in rural and urban areas make use of oscillating fans for cooling. All residences both in the rural and the urban areas were investigated in this study without installing central HVAC systems or any mechanical ventilated systems.

Samples

A sample size of 200 subjects in 105 different residences of the urban and rural areas participated in the study. Occupants of 50 residences in Umuahia urban and 55 in rural Eziala Nsulu responded to the summer surveys. The subjects participating in the survey were composed of 105 females (52.5%) and 95 males (47.5%). The average age of all respondents is 35.0years old, ranging from 15 to 65. The questionnaire covered several areas including demographics (sex, gender, height, age, etc.), years of living in their current places, economic condition, educational level and measures for improving residential thermal environment and advancing occupants' thermal comfort level. The questionnaire also included the traditional scales of thermal sensation and thermal preference, current clothing garment and metabolic activity checklists. The thermal sensation scale was the ASHREA seven- point scale of warmth ranging from cold (-3) to hot (+3) with neutral (0) in the middle. The thermal preference scale is a three- point scale with the following options: (1) “want warmer”, (2) “no change “and (3) “want cooler”. Intrinsic clothing insulations were estimated using the garment values published in ISO 7730. Metabolic rates were assessed by a checklist of residential activities databases published in ASHRAE standard 55-19922.

Measurement of Indoor Climate

Swema 3000, multi-purpose test system for professional measurements in indoor climate, was utilized in this study. The multi-purpose swema 3000 is ideal in a broad range of applications, including indoor climate, thermal comfort, air-conditioning and ventilation. Moreover, Swema 3000 incorporates powerful built-in calculation and documentation features that vastly simplify field study. Three probes are equipped with Swema 3000, Swa03 probe measures air velocity and temperature with sensory accuracy of ±0.3m/s, ±0.3°Crespectively. Hygroclip S probe measures relative humidity (RH) and temperature with sensory accuracy of ±1.6%, ±0.3°C, respectively. SWAT probe measures globe temperature with sensor accuracy of ±0.3°C.

Three points were measured in a room along the diagonal. The field investigator measured thermal comfort variables (ambient air temperature, relative humidity velocity and globe temperature) at the 0.1, 0.6 and 1.1m heights while each respondent filled in the questionnaire. Operative temperature (T_o) was calculated as the average of air temperature and mean radiant temperature. This method followed Han et al; (2009), in a similar study of thermal comfort in urban and rural location in China.

The calculation of thermal comfort indices was done applying de Dear et al; (1998) ASHRAE research project RP- 884 and calculating the environmental comfort indices with fountain model of thermal sensation (Fountain et al; 1996) and using data from the questionnaire responses and thermal variable measurements obtained from the field study.

Results and Discussion

Outdoor and Indoor Climate Environments

During the investigation period, the mean daily maximum temperature for both the urban and rural areas was in the range of 26.1-24.4°C. Meanwhile, the mean daily maximum relative humidity was in the range of 78% - 70%. Outdoor climatic variables (air temperature, relative humidity and air velocity) were collected from Nigerian Metrological Institute (NIMET) Abuja.

Statistical summaries of the indoor measurement and comfort indices for the residences of the urban area and the rural areas in the 2015 summer. Mean RH values were in the range of 30.77 – 76.78% urban residences and 68.04 – 85.57% in rural residences. The mean air velocity (average over the three heights) was 0.05 m/s in both places. Operative temperature fell within the 6 – 17°C range. The predicated mean vote (PMV) fell within – 2.23 to 0.96 in urban residences and – 1.78 to 0.74 in rural residences. The PMV value is increased by 0.17 and 0.46 for each degree increase of the operative temperature in the urban and rural residences, which were obtained from a linear regression. Mean predicted percentage of dissatisfied (PPD) fell in the range of 5 – 86.5% in urban residences and 5 – 66.2% in rural residences.

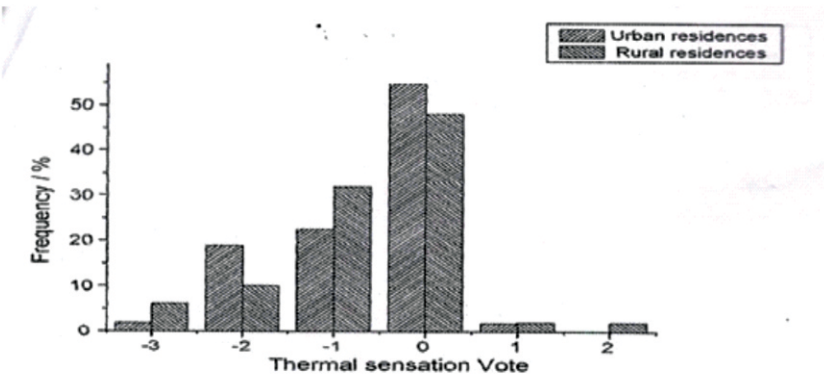

Fig. 1. Frequency of thermal sensation vote

Thermal Comfort and the Questionnaire

The frequency distribution of thermal sensation vote of the urban and rural area is given in Fig 1. The mean thermal sensation votes of urban and rural area, range from – 1 (slightly cool) to 0 (neutral), are 77.3 and 80%, respectively; most of thermal sensation votes were equal to zero. Mean thermal sensation votes (MTSV) obtained directly from questionnaires and PMV calculated by Fanger' PMV model (Fanger 1970).

Thermal Preference – Urban and Rural Residence

Thermal preference is assessed directly according to the answers of the question: "at the present time, would you prefer to want warmer, no change or want cooler?" The frequency distribution of thermal preference of the urban and rural residence is given in Fig. 2. Among the urban occupants 67.9 and 32.1% voted

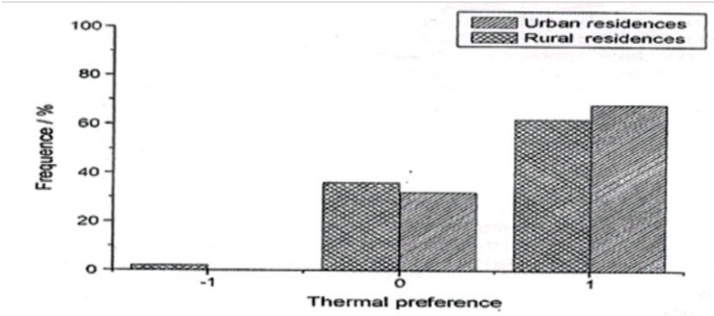

Fig. 2. Frequency of thermal preference

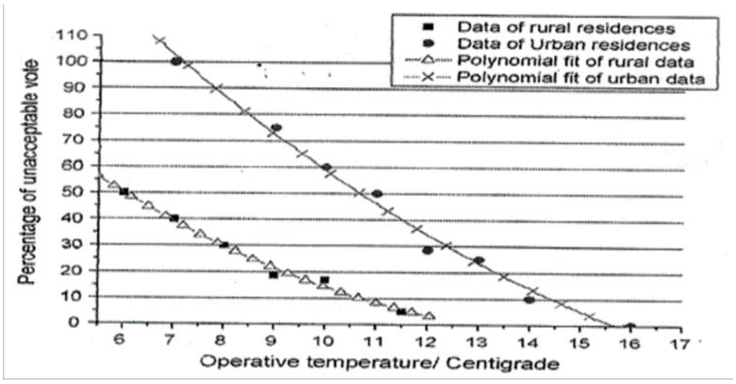

Fig. 3. Comparison of thermal acceptability between rural and urban residence

For "want warmer" and "no change" respectively. Importantly, no respondent voted for "want cooler". Among the rural occupants 62 and 36% voted for "want warmer" and "no change". It shows that the percentage of the rural occupants voting "no change" is a little more than the percentage of the urban occupants.

Thermal Acceptability – Urban and Rural Residences

Thermal acceptability is a quite controversial aspect of thermal comfort because it can be defined with reference to different scales. Four acceptability ratings based on different scale are compared by Fato et al. (2004). Thermal acceptability for this paper is obtained directly from the occupants who answered "acceptable "to the questionnaire when asked whether their thermal conditions were acceptable or not. The percentage of actual unacceptable votes for each half-degree operative temperature. Fig.3 shows the comparative results of thermal acceptability between the rural and urban residences. Results indicate that the percentage of unacceptable votes of urban residence is higher than the rural residences at the same operative temperature, while the percentage of acceptable votes of rural occupants is higher than the urban occupants at the same operative temperature, which indicates that the tolerance level of the rural occupants is higher than the urban occupants. In addition, the frequency distribution of thermal acceptability of theurban and rural residence is given in Fig.4. Urban occupants vote is 68 and32% for “acceptable” and “unacceptable “, respectively.

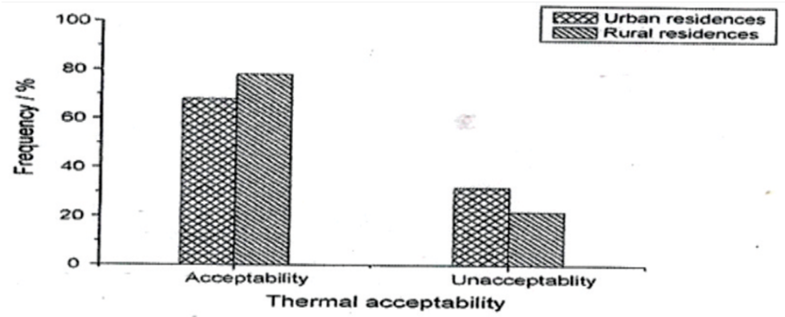

Fig. 4. Frequency of thermal acceptability

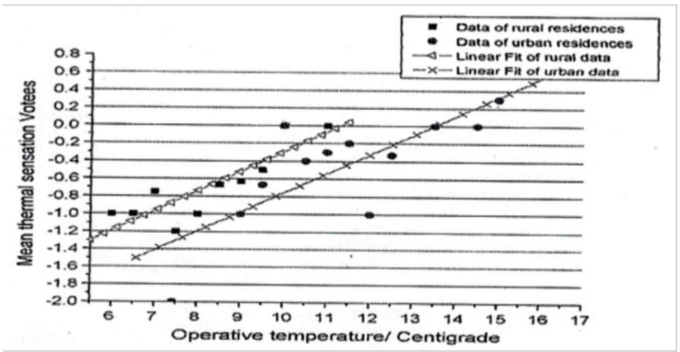

Fig. 5. Comparison of thermal sensation vote between the rural and urban residence.

Thermal Sensation Vote of Urban Residents and Rural Residents

MTSV for half-degree operative temperature bin in the urban and rural residence was obtained directly from the questionnaires according to ASHRAE seven-point scale. Fig. 5 compares mean thermal sensation vote between the urban areas. The figure indicates that the mean MTSV of the rural area is approximately 0.4 higher than that of the urban area at the same operative temperature. The mean MTSV of the rural area is higher than that of the urban area at the same operative temperature, and the neutral operative temperature for rural residences is lower than that of urban residences. One possible reason is that the occupants in the rural area have stronger ability to tolerate cold than those in the urban area because of their physiological acclimatization or past thermal history. The other reason that expectations of the rural area occupants is lower than that of the urban area occupants considering their economic level. Statistical data from questionnaires shows that the occupants' incomes of the rural area are far below that of the urban area, which leads to the following conclusion: occupants of the rural area have relative low expectation for their thermal comfort. This agrees with Fanger's study, who has introduced an expectancy factor in non-air-conditioned buildings in warm climates Fanger and Toftum (2002).

Relationship between MTSV and PMV

MTSV for half-degree operative temperature bin in the urban and rural residences was obtained directly from the questionnaires. PMV for half-degree operative temperature bin in the urban and rural residence was calculated by Fanger's PMV model. The relationship between MTSV and PMV is given in Fig. 6. The linear regression line of MTSV and PMV was significant (prob< 0.0001,R^2 = 0.75) and standard error on the regression coefficient was0.32. The fitted equation was:

$$MTSV= 0:78PMV - 0:11 \quad (-3\leq PMV\leq 0)$$

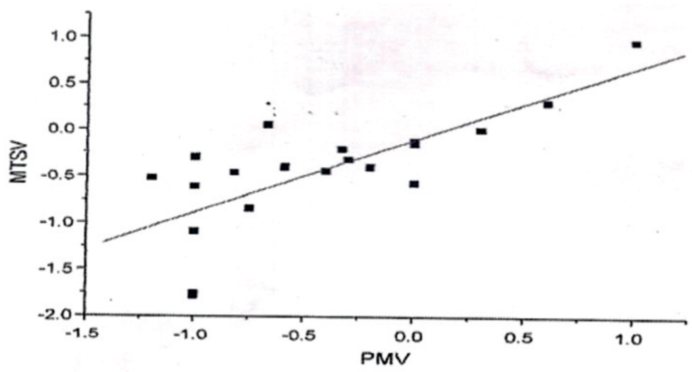

Fig.6. Relationship between MTSV and PMV

An interesting phenomenon is observed from this equation. If PMV equals to -1, the MTSV is -0.89. MTSV is higher than PMV, which implies that Fanger's PMV heat balance model with six key parameters does not describe exactly occupants' thermal sensation under natural ventilated environment. Thermal adaptability such as context factors, expectations, behavioral adjustments and so on should be considered at the same time.

Personal Environmental Control and Indoor Air Quality (IAQ)

The availability and appropriate use of controls in a building allows occupants to modify the internal environment. In naturally ventilated buildings, control over indoor temperature and ventilation can be obtained by applying typical strategies/ controls such as opening windows, doors, ventilators, etc. however, for extreme conditions, air-conditioners may be used to improve indoor thermal environment. The data of the study show that 94% of rural residence occupants make use of hand fans.

However, only 28% occupants in the urban area use air-conditioners and others use fans. The different percent of improving thermal environmental methods indicates that the electric energy consumed by the urban area is much more than that in the rural area. Indoor air quality problems between the rural and urban residences are quite different. The indoor air pollution source in rural areas is fuel burning but indoor air pollution sources in urban areas include outdoor pollution from industrial sources and traffic and building and recordation materials. The main contaminants in urban area are volatile organic compounds (VOCs), formaldehyde, benzene, etc. but the main pollutant in rural areas is particulate matter (PM), carbon dioxide (CO_2) , carbonic oxide (CO), sulfur dioxide (SO_2) and so on, Wang et al. (2007). In the rural area, carbon dioxide (CO_2) concentrations in all rooms were lower than the national standard, but PM and SO_2 concentrations in many rooms were higher than the standard because of the pollutant source of timber fuel.

Possible Improvements of the Housing Thermal Environment

Because of increased use of air-conditioning consuming plenty of electric energy and creating a serious peak electricity load problem, people environment and occupants' thermal comfort. Santamouries et al. (2007) have summarized the recent progress on passing cooling technique in the residences of low-income households. As a rule, passive cooling techniques, (2) solar and heat protection techniques and (3) heat dissipation techniques. Improving urban micro-climate technique may involve increasing green spaces in urban environments, planting roof and wall for an ecologic way to improve the indoor thermal environment, and using reflective or cooling materials. Solar and heat protection may involve switch-able glazing technology, using reflective coatings on the roofs, solar control and shading of building surface, thermal insulation, etc. in heat dissipation techniques include ground cooling system, natural ventilation techniques, hybrid ventilation system, night ventilation, wind tower, using oscillating or ceiling fans, etc. in china, the commonly used passive techniques in the summer are increasing green area in the urban planting roof and wall, thermal insulation natural, ventilation, oscillating or ceiling fans, etc. in winter, the commonly used passive techniques are wall insulations, using carbon basins and electric heaters, etc. in addition, air-conditioners for cooling and heating are far more popular in the urban area than rural area.

Conclusions

This study investigated thermal environment and comfort of residences between the urban and rural in Abia State in South Eastern Nigeria. The study concluded that occupants thermal sensation responses in houses of the urban area are different from those in residences of the rural area. Mean thermal sensation vote of the rural area is 0.4 higher than that of the urban area at the same operative temperature. Moreover, the percentage of acceptable votes of rural occupants is higher than the urban occupants. The difference is attributed to the occupants in the rural area having relative lower expectation than the occupants in the urban area. The other possible reason is that the occupants of the rural area have stronger ability to tolerate cold than the occupants of the urban area because of their physiological acclimatization or past thermal history. Low expectation and ability to tolerate low temperatures by the rural subjects may explain the observed, difference.

The mean PMV calculated by Fanger's model is higher than the MTSV obtained from the questionnaire data. The difference is attributed to the different combination of the objective and subjective conditions that have not been considered in Fanger's model.

The comparative results of this field survey can be helpful in recommending the sustainable thermal standards for buildings in the rural area.

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