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Network for Comfort and Energy Use in Buildings

The 6th Windsor Conference: ADAPTING TO CHANGE: NEW THINKING ON COMFORT

9-11th April 2010 Cumberland Lodge, Windsor, United Kingdom

Intelligent Energy Europe

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FIRST DRAFT TIMETABLE[1]

Friday, 9th April 2010

17:30 Registration

18:30 Drinks in the Drawing Room.

19:30 Dinner

20.30 Welcome by **Fergus Nicol**, NCEUB London Metropolitan University. UK

After Dinner Talks: (Chair Sue Roaf)
Ed Arens: University of California, USA
California Dreaming - Future directions for thermal comfort
Richard deDear, University of Sydney, Australia
New Thinking on the Pathology of Comfort

[1] Note that this is a preliminary timetable. It includes some 49 papers out of 72 submitted in abstract form which have been accepted for presentation. Authors are given either full (20min) or short (5 min + poster) presentation. The final versions of the papers will be available to members on the NCEUB website: http://nceub.org.uk/ We have listed first authors as presenting unless otherwise understood, please inform us of any errors. Numbers relate to the list of abstracts (available on NCEUB website).

Saturday 10th April 2010

08:30 Registration

09:00 - 11.00 SESSION 1. Comfort standards internationally
Chair: Michael Humphreys

Shahin Heidari, University of Tehran, Iran
Coping with nature: Ten years thermal comfort studies in Iran
Lorenzo Pagliano, Politecnico di Milano, Italy
Comfort Models and Building design in the Mediterranean Zone
(L. Pagliano and P. Zangheri)
Atze Boerstra, BBA Indoor Environmental consultancy, Holland
Personal control in future thermal comfort standards?
Chisthino Candido, Federal University of Santa Catarina, Brazil
Toward a Brazilian standard for naturally ventilated buildings: guidelines for thermal and air movement acceptability.
(C. Cândido, R. Lamberts, R. de Dear and L. Bittencourt)
Mohammad KOTBI, University of New South Wales, Australia
How to test Fanger's PMV model in a field study?
(Kotbi, King and Prasad)
Fergus Nicol, London Metropolitan University, UK
An overview of European Standard EN15251
(F. Nicol and M Wilson)

11.00 Coffee

11:20 – 13.20
PARALLEL SESSION 2a. Hot climates (1)
Chair: Ashok Lall ABL Architects, Delhi, India

Chen Huimei, South China University of Technology, P R China
Thermal Comfort Study in hot-humid area of China
(C. Huimei, Z. Yufeng, W. Jinyong and M Qinglin)
Hom B Rijal, University of Tokyo, Japan
Thermal adaptation in hot and humid outdoor conditions
(H.B. Rijal, R. Ooka, Y. Minami, T. Sakoi and K. Tsuzuki)
Oluwafemi Akande, Abubakar Tafawa Balewa University, Nigeria
Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate of Nigeria
(O. K. Akande and M. A. Adebamowo)
Amgad Farghal, Karlsruhe Institute of Technology, Germany
Enhancing the Adaptive Comfort Standard, a case study in a hot dry climate, Cairo, Egypt
(A Farghal and A Wagner)
Samira Zare Mohazabieh, Universiti Putra Malaysia
Thermal Comfort of Non-Malaysian Residents at Different Levels of a Multi-Storey Residential Building in Malaysia
(S Z Mohazabieh, E Salleh, M F Z Jaafar and N M Adam)
Madhavi Indraganti, India
Thermal Adaption and impediments: Findings from a field study in Hyderabad, India

PARALLEL SESSION 2b Comfort energy and buildings
Chair Adrian Pitts

Steven Firth, Loughborough University, UK
Natural ventilation in UK schools: design options for passive cooling

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Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate of Nigeria

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Abstract

Indoor thermal comfort is essential for occupants' well-being, productivity and efficiency. The hot-dry climate with its extremely high temperatures and intense solar radiation is becoming hotter and drier in this era of climate change and global warming. Thus providing for indoor thermal comfort and reducing energy use in buildings is becoming increasingly difficult. This has called for new ways of thinking and re-evaluation of the existing methods of tackling this problem. This research is based on a field survey comfort study conducted in Bauchi, in northern Nigeria during the dry and rainy seasons in 2009. Thermal comfort index is evaluated and compared with human responses. Findings indicate the need to review the fundamentals of the requirements for thermal comfort and adaptation by the occupants. Finally the paper concludes that findings should be presented in a format that would be useful and appropriate for architects to design climate sensitive residential buildings

Keywords: Thermal comfort; Residential buildings; Climate

1. Introduction

The primary function of all buildings is to adapt to the prevailing climate and provide an internal and external environment that is comfortable and conducive to the occupants. However, in this era of climate change and global warming, providing comfort for the occupants of a building is quite challenging and very fundamental. This is as a result of growing ranges of challenges now facing designers to provide buildings that will be fit and comfortable for the 21st century. Thermal comfort basically has to do with the temperature that the resident considers as comfortable to stay in. Indoor thermal comfort is achieved when occupants are able to pursue without any hindrance, activities for which the building is intended. Hence, it is essential for occupants' well being, productivity and efficiency. ISO 7730 as well as ASHRAE use the results of an extensive research carried by Fanger (1970) to define thermal comfort as that condition of mind which expresses satisfaction with the thermal environment. These definitions serve well for temperate climate for which it was developed. However, its use in the tropics is still very much challenged as the actual thermal comfort standards are based upon laboratory studies carried out in climatic chambers, ignoring the complex interaction between occupants and their environments that could affect their comfort.

Numerous field experiments have been performed in hot climates, but most of these have been in humid locations (e.g. de Dear and Auliciems, 1985; Auliciems and de Dear, 1986a, 1986b; Bush, 1990; de Dear *et al.*, 1991; and de Dear and Fountain, 1994). The result of neutral temperature of numerous field experiments performed in hot-humid climates is shown in table 1. Other hot-dry field experiments include those by Baker and Standeven (1994) in residential buildings during the summer in Athens, Greece. Their result indicated the importance of adaptive opportunity in order for building occupants to accept temperatures warmer than 24°C. As important as these studies are, their findings have not yet emerge into comprehensive and widely accepted guideline for tropical naturally ventilated buildings (Adebamowo, 2007). In reality, occupants are comfortable in wider range of conditions. This is because people are able to adapt to the environment that they are used to and also because several other factors could also contribute to the adaptation of their indoor environment.

Table 1: Result of neutral temperature of numerous field experiments performed in hot-humid climates

Year	Researcher	Building	Location	Neutral temperature of subjects	
1990	J.F. Busch	Office	Bangkok, Thailand	24.5 °C (ET) for AC buildings	28.5 °C (ET) for NV buildings
1991	R.J. de Dear, K.G. Leow *et al.*	Residential and office	Singapore	24.2 °C (To) for AC buildings	28.5 °C (To) for NV buildings
1994	R.J. de Dear, M.E. Fountain	AC Office	Townsville, Australia	24.2 °C (To) in the dry season	24.6 °C (To) in the wet season
1998	T.H. Karyono	Office	Jakarta, Indonesia	26.7 °C (To) for AC buildings	
1998	W. T. Chan *et al.*	Office	Hong Kong	23.5 °C (To) for AC buildings	
1998	A.G. Kwok	Classrooms	Hawaii, USA	26.8 °C (To) for AC classrooms	27.4 °C (To) for NV classrooms
2003	N.H. Wong *et al.*	Classrooms	Singapore		28.8 °C (To) for NV classrooms

Source: Hwang *et al.* (2006)

Meyer (2002) considers the relationship between indoor climate and climate change. Two schools of thought on indoor temperature research are reviewed: "one which sees indoor temperature as governed by a common and fixed human preference and the other as strongly influenced by highly variable habits and expectations". However, with the increased interest to reduce energy consumption in buildings, the complex interaction between occupants and their environment should be considered for 21st century buildings. Thus, the adaptive approach to thermal comfort was introduced (Nicol, 2004). The adaptive approach to thermal comfort is based on the findings of surveys of thermal comfort conducted in the field study. Field surveys concentrate on gathering data about the thermal environment and the simultaneous thermal response of subjects in real situations, interventions by the researcher being kept to a minimum. This kind of research uses statistical methods to analyze the data using the natural variability of conditions. The aim is to predict the combination of thermal variables (temperature, humidity and air velocity) which will be found comfortable. The thermal variables are measured at the same time as the subjective reactions are taken, where subjects taking part are asked in the survey to assess their thermal sensations. This assessment is generally known as the 'Comfort Vote' (Nicol and Humphreys, 2004).

Throughout northern Nigeria, such as Bauchi, there have been a few literature reports of field study on indoor occupants' comfort and residential thermal environment. However, there is only little information available concerning occupant comfort and residential thermal environment in Nigeria. Thus, the purpose of this study was to conduct a field study on indoor comfort and residential thermal environment in a tropical hot-dry climate of northern Nigeria. The specific study objectives are to measure and characterize thermal perceptions of occupants in their residence, compare observed and predicted percentage of dissatisfied (PPD) occupants and discern differences between the study area and other climate zones where similar studies have been performed.

2. Climate and location of study area

It is important to analyze the climate scenario for Bauchi state, Nigeria and understand the typical thermal behaviour of buildings. Bauchi is located in the north-eastern part of Nigeria at latitude 10° 17'N and longitude 9° 49'E. The climate is characterized by high temperatures and low humidity in the dry season. The diurnal temperature varies from an average daily maximum of 31.6°C to a daily minimum of 13.1°C. The mean relative humidity is highest in August (66.5%) and lowest in February (16.5%).The annual rainfall ranges from 600mm in the extreme northern parts to 1300mm in the southwestern part of the state (BSADP, 2002). The dry season occurs between October and April, while the rainy season occurs between May and September.

3. Methodology

3.1 Field Study

The field study was conducted in Liman Katagum in southern part of Bauchi metropolis. It was carried out with questionnaire surveys and field measurements on indoor thermal comfort and the nature of residential thermal environment during the dry and rainy season of 2009. This was carried out to get a variation measurement in terms of the indoor and outdoor temperature, relative humidity and air velocity. In the field survey, the questions asked on thermal sensations were based on the seven-point scale (ASHRAE scale from -3 to +3), representing the respondents comfort votes. At the same time, the following thermal variables were measured indoor; air temperature, relative humidity and air velocity. Considering the local climate characteristics, the survey was conducted in two extreme periods, dry and rainy seasons. The survey questionnaire and the application were designed according to standards ISO 7730 and ISO 10551 (1994).

3.2 *Subjects*

A sample size comprising of 206 subjects in sixty eight (68) naturally ventilated residential buildings in the study location were collected in both dry and rainy season. Table 2 shows the summary of the subjects of residential occupants in the study area. The subjects participating in the study were composed of 100 females (48.5%) and 106 males (51.5%). The percentages of residences with and without mechanical ventilation system (i.e. those using window(s) only) were 21% and 79%, respectively. The average age of all respondents ranges from 31- 49 years.

Table 2: Summary of the Subjects of Residential Occupants in the Study Area

Season	Dry Season	Rainy Season
Sample Size (Male/Female)	103 (53/50)	103 (53/50)
Gender (% of sample)		
Male	51.5	51.5
Female	48.5	48.5
Mean Age (year)		
Mean	31 – 49	31 – 49
(Minimum, Maximum)	(16, 70)	(16, 70)
Mean years living in local address		
Mean	10 – 15	10 – 15
(Minimum, Maximum)	(1 – 5, 20)	(1 – 5, 20)
Mean Height (m)		
Mean	1.66	1.68
(Minimum, Maximum)	(1.37, 2.01)	(1.37, 2.01)
Mean Weight (kg)		
Mean	61	65
(Minimum, Maximum)	(45, 84)	(45, 84)

The questionnaire covered several areas including demographics (name, gender, age, etc.), years of living in their current building and personal environmental control (Table 2). The questionnaire also included the traditional scales of thermal sensation (TSENS) and thermal preference. The TSENS scale was the ASHRAE seven-point scale ranging from cold (−3) to hot (+3) with neutral (0) in the middle. The three-point thermal preference scale used asked whether respondents would like to change their present thermal environment. Possible responses were "want warmer", "no change" or "want cooler".

3.3 *Measurement of indoor climate*

The following instruments were used to measure physical comfort variables; liquid crystal thermometers, wet and dry bulb hygrometer, and digital thermo-anemometer were used for collecting data of the indoor thermal environment. The thermal comfort variables were measured at 1.1 m height, while each respondent responded to the questionnaire. Each household was given questionnaires depending on the number of adults (i.e. from 16years old and above) in the family, three liquid crystal thermometers were hanged onto the wall at a height of 1.2m, one for the living room, another for the bedroom and the third one was hanged outdoor under a shaded wall. Likewise, two wet and dry bulb hygrometers were hanged on the wall one within and the other outside the building. Residents were required to fill the questionnaires while the research personnel recorded the environmental measurement thrice a day (7-10am, 12-3pm and 5-8pm). The content of the questionnaires mainly include resident's demographic and socio-economic characteristics, building characteristics, thermal comfort perception of the living spaces etc.

4. Results and Discussion

4.1 Environmental Parameters Data

The measurements basically captured three parameters mainly; air temperature, relative humidity and air velocity, which are required for computing thermal indices such as Operative Temperature (To) and Predicted Mean Vote (PMV).The statistical results of the environmental parameters data is shown in table 3 below. During the dry season, the indoor air temperature in the buildings were found to be between 21°C and 39°C with indoor relative humidity between 28% and 80% while in the rainy season, the indoor temperature in the buildings were found to be between 18°C and 29°C. These results show that the temperature and relative humidity exceeded the standard (ISO EN7730, 1994) for sedentary activity during the dry season. The temperature specified by the standard should be between 23°C and 26°C and relative humidity should be between 30% and 70%. The average air velocity was 0.13 m/s was within the threshold of < 0.2 m/s (ISO EN77304, 1994) for sedentary activity.

Table 3: Statistical Results of Parameters

	Dry Season			Rainy Season		
	Ave.	**Max.**	**Min.**	**Ave.**	**Max.**	**Min.**
Indoor Air Temperature (°C)	33.7	39.0	21	22.4	29	18
Outdoor Air Temperature (°C)	35.7	42.0	25	22.1	25	18
Indoor Relative Humidity (%)	50.4	80.0	28	68.4	75	35
Outdoor Relative Humidity (%)	45.2	75.3	18	65.8	85	55
Indoor Air Velocity (m/s)	0.13	0.50	00	-	-	-

4.2 Analysis of Votes

The results of the questionnaire survey of thermal comfort condition in the residential buildings include thermal sensation, thermal preference and assessment of humidity sensation. The equation that relates thermal conditions to seven point ASHRAE thermal sensation scale of, -3 (cold), -2 (cool), -1 (slightly cool), 0 (neutral), 1 (slightly warm), 2 (warm) and 3 (hot) known as the PMV index was used. The neutral temperature which is the temperature at which human body feel most comfortable, that means feel neither hot nor cold was determined. Theoretic neutral temperature is the temperature when PMV=0. Regression analysis of the testing thermal sensation and indoor air temperature for both dry and rainy season was performed and shown below (figure 1 and figure 2). The regression curves as shown in the figures below shows the high correlation (R2 = 0.8846 and 0.9119) between thermal sensation and indoor temperature. The regression equation for dry season is given as:

$$y = -10.2 + 0.357x \ (R^2 = 0.8846)$$

While the regression equation for rainy season is given as:

$y = -15.4 + 0.618x$ ($R^2 = 0.9119$)

Figure 1 and figure 2 shows that in dry season and rainy season the thermal neutral temperature is 28.44°C in dry season and 25.04°C in rainy season. Based on PMV (Predicted Mean Vote) evaluation index established by Fanger, the neutral temperature is 25.1°C in summer and 22.4°C winter.

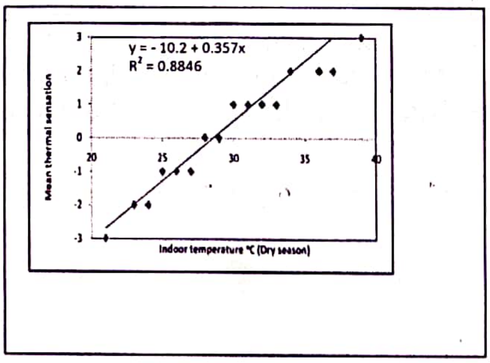

Fig.1: Thermal sensation scale against indoor air temperature in dry season

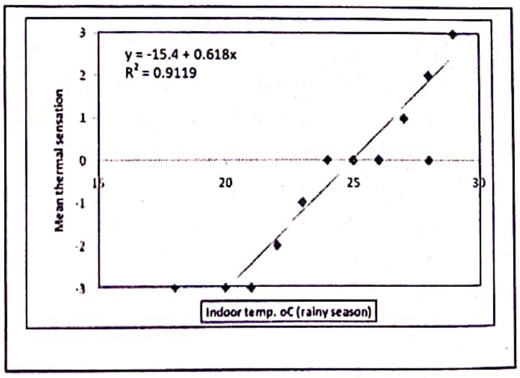

Fig.2: Thermal sensation scale against indoor air temperature in rainy season

The result indicates that in both seasons the testing neutral temperature is quite higher than the theoretic value by 3.34°C for dry season and 2.64°C for rainy season. This result likewise shows that the actual thermal comfort range is much wider than the theoretical calculated value. The difference in neutral temperature for both seasons between that established by Fanger may be attributed to climatic conditions which may affect subject's perception. It was also observed that there was a seasonal difference of 3.4°C between the dry and rainy season in comfort temperature. This is due to the fact that in the peak of rainfall both the indoor and outdoor temperature drops drastically.

The results of subjective responses to temperature (thermal sensation) are presented in figure 3. The results show that the majority of the respondents voted slightly warm sensation and neutral sensation.

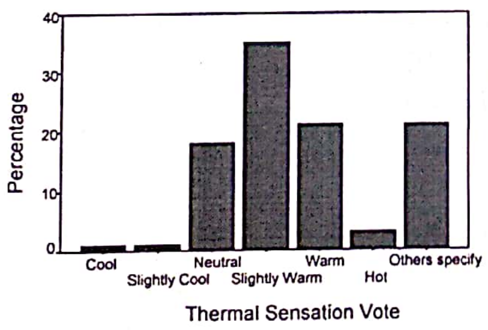

Figure 3: Thermal Sensation Vote

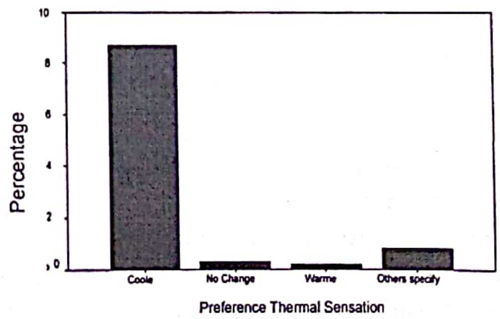

Figure 4: Preference Thermal sensation

The ASHRAE Standard 55 (2004) specified that an acceptable thermal environment should have 80% of occupants vote for the central three categories (-1, 0, 1). In this study, only 68% out of 79 respondents in the dry season while 51% out of 100 respondents in rainy season voted within the central three categories showing that the people were not in thermal acceptable conditions within their residences. The subjective scale used for thermal preference was the McIntyre scale (1982), which is -1 (cooler), 0 (no change) and 1 (warmer). The results of the subjective thermal preference amongst the respondents are presented in Figure 4. It can be seen that the respondent preferred to be cooler and no change.

Humidity assessment uses the subjective scale of -3 (much too dry), -2 (too dry), -1 (slightly dry), 0 (just right), 1 (slightly humid), 2 (too humid) and 3 (much too humid). The subjective responses on humidity are presented in Figure 5. It was observed that for the Overall votes, the occupants were not comfortable with the relative humidity, with 80% voted from very dry to slightly dry and 85% preferred that the humidity should be more humid (figure 6). Hence, the relative humidity was not comfortable for most of the respondents. Air movement uses the subjective scale of -3 (very low), -2 (low (still)), -1 (slightly low (still)), 0 (just right), 1 (slightly breezy), 2 (breezy). The results of the subjective response on air movement indicate that the majority voted 'very low' and 'low (still)'.This shows that they rejected the air movement in their residences.

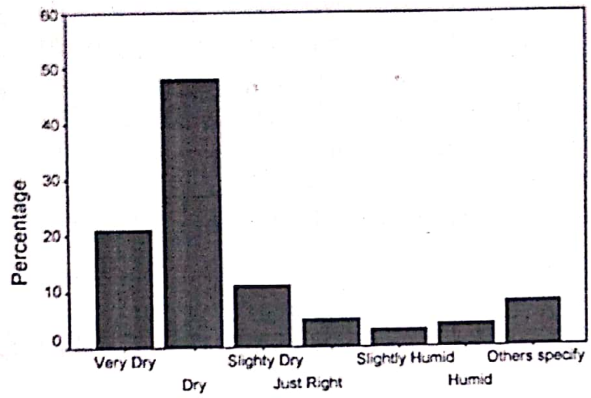

Figure 5: Humidity Sensation Vote

The subjective scale used for the Overall thermal comfort assessment is ASHRAE 7 point thermal sensation scale; -3 (much too cool), -2 (too cool), -1 (comfortably cool), 0 (comfortable), 1 (comfort-tably warm), 2 (too warm) and 3 (much too warm). The results obtained showed that 86% of the respondent voted in the three central categories (-1, 0, 1). In other words, thermal comfort conditions in all the residences were acceptable by majority of the respondents.

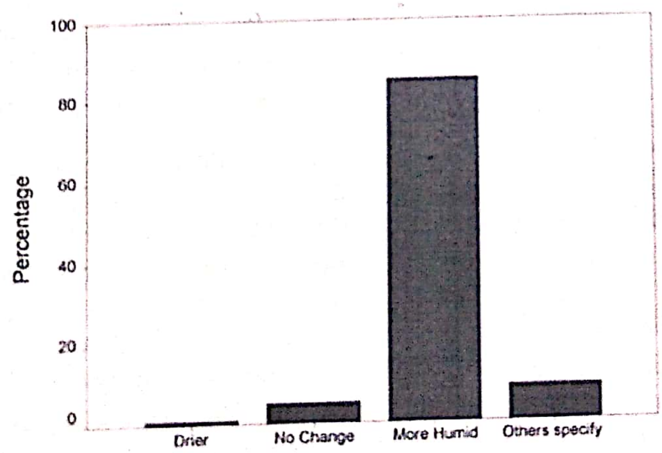

Figure 6: Preference Humidity Sensation Vote

4.2.1 Comparison of Findings with Previous Studies

The neutral temperature result obtained in the dry season from the present study can be compared to that of de Dear (1991) who found a neutrality operative temperature of 28.5°C for naturally ventilated apartments in Singapore and similarly Busch (1990) in his study in Thailand obtained neutral temperature of 28.5°C. Also the study conducted by Nyuk (2003) in Singapore, indicated that the regression analysis of mean PMV gave a neutral temperature of 26.1°C, and the TSV regression gave a neutral temperature of 28.8°C which is slightly higher than result obtained in this study with acceptable temperature range of 27.1°C to 29.3°C. Likewise, a similar study done in Sub-Saharan Africa Lagos, Nigeria by Adebamowo (2007) obtained a neutral temperature of 29.09°C in the warm humid climate giving a slight difference of 0.65°C to that obtained in this study in hot-dry climate of the same region. Similarly, a study conducted in rainy season between July and August by Ogbonna and Harris (2008) in a temperate dry climate of Jos, Nigeria, obtained a PMV regression that gave a neutral temperature of 25.06°C and a comfort range between 23.55°C and 26.57°C which is very close to the neutral temperature obtained in this study for rainy season. A comparison of the results of this study with that carried out by Adebamowo (2007) and Ogbonna and Harris (2008) indicates there is little or no disparity in thermal neutralities obtained in this tropical region.

4.2.2 Theoretical Explanation

In Nigeria the idea of adapting to the hot indoor temperature comes to play as the different social classes get used to the temperatures that exist in their homes. From this study it was observed that more than 80% of the respondents found their thermal indoor conditions acceptable, even though the thermal sensation votes, exceeded acceptable thermal conditions set by the ASHRAE standard (ASHRAE 55:2004). It was also found in this study that during the dry season, the respondents who felt neutral were not always satisfied with their thermal condition and most of them wanted their environment to be cooler. In the other hand, in rainy season, respondents who were satisfied with their thermal condition (prefer 'no change'), were not exactly 100% having neutral sensation.

The results obtained in this study are comparable with findings in the studies by Nyuk (2003) for classrooms in Singapore and Busch (1990) for offices in Thailand. The neutral temperature of 28.44°C with a comfort range of 25.5°C to 29.5°C shows the result obtained is in agreement with the result obtained from Nyuk (2003), de Dear *et.al* (1991) and Busch (1990). However, a study done in three climatically disparate Australian cities (Darwin, Brisbane and Melbourne) revealed that occupants of air-conditioned buildings tended to prefer them, whilst those in non air-conditioned buildings preferred to work in passively ventilated buildings - even when these recorded the hottest temperatures (de Dear and Auliciems, 1988). Some hindrances to good indoor temperature in the study area could be identified as (i) the types of clothing used in the tropics. (ii) the size and insufficient number of window openings that can provide adequate ventilation in the residences and (iii) low level ceiling height.

The study also showed that respondents in the hot dry climate such as northern Nigeria may have a higher heat tolerance since they accepted the thermal condition which exceeded the standard. This tolerance to relatively high temperatures is likely to be a result of adaptive activities, such as opening windows and removing clothes, which form part of the daily life in hot dry climates, as well as the homoeo-thermic mechanisms of the body. Indeed, the degree of adaptive opportunity can influence thermal comfort expectation. It is therefore convenient for naturally ventilated buildings in northern Nigeria to use fans (mechanically ventilated) and increase the size of their windows instead of using air-condition to improve the indoor thermal condition with the interest to reduce energy consumption in buildings. It is proven that the respondents are able to adapt to the environment that they are used to. Aghemabiese and Berko, (1996) have suggested that the wholesale adoption of air-conditioning as a primary cooling strategy throughout the developing world can be avoided. Given that many people from tropical climates are 'uncomfortable' with air-conditioning due to its energy consumption level and cost, more climatically and culturally sensitive future involving daily adjustment, clothing habits and climatically sensitive design are therefore advocated.

5 Conclusions

Indoor thermal comfort has been viewed as being highly dependent on the occupants and the way they see the environment. Baker and Steemers (1999) have discussed the issues of "comfort and thermal delight" as important to building design but not the "obsessive application of narrow 'optimized' environmental parameters". Indoor thermal comfort must be understood as a far more holistic experience dependent upon the interaction of many factors - including the variability and options that the environment offers and the ability of the occupant to determine these options. The challenge for building designers is to make room for "adaptive change with new thinking on comfort" in order to extend the 'comfort zone' and to accommodate climate change and global warming. Therefore, there is the need to review the fundamentals of the requirement for thermal comfort and adaptation by the occupants. Meanwhile, the above findings should be presented in a format that would be useful and appropriate for architects to design climate sensitive residential buildings that will provide comfort for the 21st century.

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