

## THERMAL COMFORT IN A NATURALLY VENTILATED LARGE SPACE BUILDING IN MAIDUGURI, BORNO STATE

By

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[sulaimonshodiya@yahoo.com](mailto:sulaimonshodiya@yahoo.com); [shodiya@unimaid.edu.ng](mailto:shodiya@unimaid.edu.ng)**ABSTRACT**

*In a hot climate like Maiduguri, one of the conventional approaches for providing comfortable environment is the use of natural ventilation. In some cases, this strategy does provide the suitable thermal environment in a large space building such as the mosque. This study evaluated the thermal comfort of a naturally ventilated large space building, the university of Maiduguri (unimaid) central mosque in Maiduguri, Borno state during different times of daily prayers. The field study was conducted in 16th December 2015 (harmattan season) and April 2016 (hot season) during subuh, zuhr, Asri, Magrib and Ishai prayer times. During these days, the objective measurement using LUTRON ABH-4224 Cup Anemometer instrument and subjective assessment using questionnaire were accomplished. The objective parameters measured were air temperature, relative humidity and air velocity and the subjective responses concern the thermal condition of the respondents. Through linear regression analysis, Predictive Mean Vote (PMV) model was developed. The results obtained showed that majority of the worshippers found the thermal condition unacceptable in the naturally ventilated mosque even though the thermal sensation exceed the one specified by ASHRAE standard 55. Also, from the PMV model developed, the comfort range of temperature was found to be between 29.6 to 32.8°C and the neutral temperature was found to be 31.2°C.*

**Keywords:** Thermal comfort, Thermal environment, Large space building, Predictive Mean Vote.

**INTRODUCTION**

Large spacious buildings are usually constructed in the cities in all over the world including Maiduguri, Borno state in Nigeria. The large space buildings such as mosque (place of worship for the Muslims), sports hall, cinema hall, meeting rooms etc, are distinguished from the other occupied buildings in terms of nature of design and energy consumptions. As a result of the small nature of the small space buildings, the energy consumptions are generally smaller than the large space buildings (Xu, 2002). Furthermore, the complexity of the inflow air and its distributions in the large space buildings make the energy consumptions to be on the high side. The large space buildings usually create a problem such as air flow, air temperature and

relative humidity which affect the thermal comfort of the building (Al-Homoud, Abdou, & Budaiwi, 2009).

In a hot and humid climate, natural ventilation is one of the strategies used for providing thermal comfort. The ventilation is serving two purposes, viz-a-viz, to provide good indoor air quality (IAQ) and to provide an appropriate air temperature by heat transfer mechanism (Chen, 2009). Though, the ventilation is recommended for the thermal comfort, however, it may not provide the necessary comfort in the environment due to the instability of the wind speed and obstacles in the surroundings (Ji, Lomas, & Cook, 2009). This means that in a place with unstable wind speed like Maiduguri, natural ventilation may not satisfactorily solve the

problem of thermal comfort of large space buildings such as the mosque (Chow, Fung, & Wong, 2002).

Mosques are distinguished from other types of buildings by having an intermittent operation schedule. They are partially or fully occupied five times a day and the maximum occupancy is expected to occur on Friday prayers. Buildings with intermittent occupancy may not perform the same thermally as typical commercial and residential facilities. There are limited researches in this area that has been carried out and the thermal comfort conditions and perception of occupants that have been investigated (Hussin, Salle, Chan, & Mat, 2014; Mishra & Ramgopal, 2014; Shodiya, Omarou, Quadri, & Muhammed, 2015).

The objectives of the present study includes: determining the insulating factor due to clothing (clo-values); the comfort temperature range and the neutral temperature based on the Predictive Mean Vote (PMV) model to be developed. Many studies have been conducted to investigate the indoor thermal comfort in buildings using the PMV approach such as; (Hussin, et al., 2014; Shodiya, et al., 2015) - Thermal Comfort and Occupant Satisfaction in a Mosque. This study will also adopt the PMV approach to assess the thermal comfort of the naturally ventilated university of Maiduguri (unimaid) central mosque.

## METHODOLOGY

Thermal comfort was evaluated in the naturally ventilated mosque (Unimaid Central Mosque) for daily prayer mode. The selected mosque is located at latitude and longitude of  $11^{\circ} 50'N$  and  $13^{\circ} 09'E$  respectively, University of Maiduguri, Borno state. The data were collected on 16<sup>th</sup> December 2015 and 15<sup>th</sup> April 2016

representing the harmattan season (cool) and the summer season (hot) respectively. Worshipper's thermal comfort were evaluated and observed during daily prayer time modes of *Subh, Zuhr, Asr, Magrib and Isha*. These involved collection of environmental indoor measurement and questionnaires among worshippers.

## Case Study

The selected mosque is the Unimaid Central Mosque is the community mosque in the university. The mosque was built in the year 1983/84 and was constructed based on a square plan. The total built up area of the mosque is  $640 \text{ m}^2$  and the wall height is 6m. The east facing wall is oriented towards the direction of holy city, Mecca, and contains one door incorporated in a partial glass wall. Also, the wall facing the Northward and Southward are built with partial glass walls incorporated with single door each for entrance and twelve small incorporated windows on each side. The wall facing westward is built with no door or window. The doors and windows dimensions are 2.5m by 1.4m and 0.35 by 0.23 respectively. All the windows are installed for ventilation purposes. The mosque has a roof that is constructed together with one big dome located at the centre of the mosque. The mosque and its surrounding can occupy approximately 2000 worshippers. The floor area is furnished with carpet that has some patterns for the *saffs* (row) parallel to the *Qibla* wall (eastward). The distance between each *saff* is about 1.2m. Figure 1 shows the outside view of Unimaid Central Mosque. Also, Figure 2 and 3 show the worshippers' standing and sitting mode during prayers. Likewise, Figure 4 shows worshippers sitting after prayer.



Fig: 1 Unimaid Central Mosque view



Fig: 3 Daily prayer mode (sitting)



Fig: 2 Daily Prayer Mode (standing)



Fig:4 Worshippers after performing prayer

### ***Instrument for Data Collection***

The survey questionnaire consists of three sections (a) demographic background (b) clothing (c) current thermal comfort. The questionnaire was developed and adopted from a previous study, Hussin et al., (2014) where worshippers can feel free to evaluate their thermal environment in the mosque. In addition, the clothes types were also obtained from the survey and cloth value (clo) was estimated based on clothes assemblies references in ISO-7730, (2005). ASHRAE seven point thermal sensation scale (+3 to -3) was included in questionnaire, to assess the actual mean vote (AMV) or thermal sensation vote (TSV) reflecting the qualitative thermal sensation of the worshippers. The control point is based on ASHRAE acceptable thermal environment for general comfort where  $PPD < 20\%$  or  $(-1 < PMV < +1)$  and the recommended thermal comfort

temperature range is between  $22.5 - 26.0^{\circ}\text{C}$ , ASHRAE Standard-55,(2013).

### ***Objective Measurement***

Measurements of indoor climatic conditions were made with a portable meteorological instrument known as LUTRON ABH-4224 Cup Anemometer. Air velocity, air temperature and relative humidity were measured using the instrument. The equipment set up had been tested before starting the measurements. The instrument was installed at the height of 1.1m above from floor level and located at fixed position in the main prayer hall (between saff 6 & 7). The height level proposed by ASHRAE Standard-55 (2013) for light activity-standing/sitting, is almost suitable condition to worshippers during performance of the daily prayers. Figure 5 shows LUTRON ABH-4224 Cup Anemometer used

for measuring the air temperature, air velocity and relative humidity at unimaid central mosque.

LUTRON ABH-4224 Cup Anemometer



Fig: 5 Measurement activities at Unimaid central mosque

## RESULTS AND DISCUSSION

### *Demographic Information*

The worshipper's demographic information which includes the worshipper's categories and ages is given Table 1 and 2 respectively. The number of respondents was 100 people and all of them were male.

They included 7.2% from mosque committee, 13.4 % from close community university staffs and 79.4 % from students. Their ages range from 15-20 (18.6 %), 21-26 (60.4 %), 27-35 (13.6 %), 36-46 (7.4 %) and 46 above (0 %).

Table 1: Worshipers Categories

	<i>Subh(%)</i>	<i>Zuhr(%)</i>	<i>Asr(%)</i>	<i>Magrib(%)</i>	<i>Isha(%)</i>
Mosque committee	4	8	7	11	6
University staff	11	19	14	15	8
Students	85	73	79	74	86

Table 2: Worshippers Ages

	15-20	21-26	27-35	36-46	46 above
Subh	16	68	9	7	0
Zuhr	26	59	11	4	0
Asr	16	73	8	3	0
Magrib	20	59	12	9	0
Isha	15	43	28	14	0

### Clo Value /Clothing insulation

The common clothes worn by the worshippers during performance of daily prayers at Unimaid central mosque including the clo values is given in Table 3. The most common clothes indicated is traditional caftan and cap having 51.9% during subh prayer while 43.9% and 40.9% during magrib and isha prayers respectively. At noon (zuhr prayer), most of the respondents were students and some lecturers and they wore the normal working attire of long sleeve shirt paired with trousers. Thus, during zuhr prayer, 24.2% of respondents wore this clothes compare to traditional caftan and cap which is 19.7%.

Figure 6 shows that there is no correlation ( $R^2 = 0.2927$ ) between worshippers clothing and operative temperature (OPT) when they attended the mosque.

There are several factors involved regarding this situation. Firstly, the climatic condition which is in most time hot except during harmattan season, and secondly the requirement of Muslim attire when performing the prayer. In Islam there is no limitation to the type of attire when visiting the mosque for performing prayers except that it must cover the basic *aurat* (men: from knee to navel; women: the whole body except the face and the two palms) and be clean from dirty. Thirdly, the mosque is strategically located (proximity to houses). The traditional caftans and caps were the most common attire worn by the worshippers especially during subh, magrib and isha prayers. The same situation was reported Hussin et al., (2014) in Malaysia where it was found that the worshippers wore customary attire during prayers at the mosque.

Table 3: Common clothes worn by worshippers during daily prayer

Description	Percentage (%)	Clo value
Trousers, Short-Sleeve Shirt	9	0.57
Trousers, Long-Sleeve Shirt	26	0.61
Knee-Length Skirt, Long-Sleeve Shirt, Long-Sleeve Sweater	4	1.04
Athletic Sweat Shirt, Long-Sleeve Sweatshirt	2	0.74
Kaftan and Cap	37	0.89
Native Cloth and Hijab	6	1.57
Ankara, Vail	3	0.69
Kaftan without cap	11	0.72
Kaftan and Cap	2	1.37

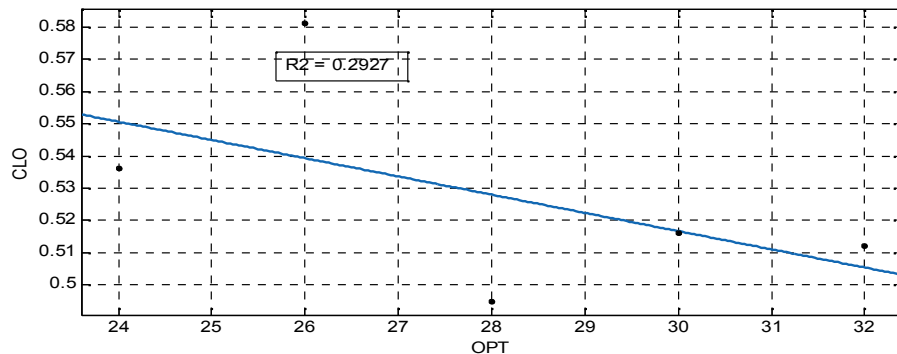


Fig 6: Clo Value and Relation to Operative Temperature

### Indoor Climatic Conditions

The daily pattern of the average indoor climatic conditions in the central mosque starting from *Subh* to *Isha* prayers are illustrated in Figure 7 - 9. It is observed that the indoor ambient temperature, relative humidity and air velocity in unimaid central mosque have unique

patterns. Air temperature was generally reduced when the air velocity increased as shown in Figure 7 during these prayer times. The same observation can be made for relative humidity and temperature (Figure 8) and so also for the relative humidity and air velocity (Figure 9).

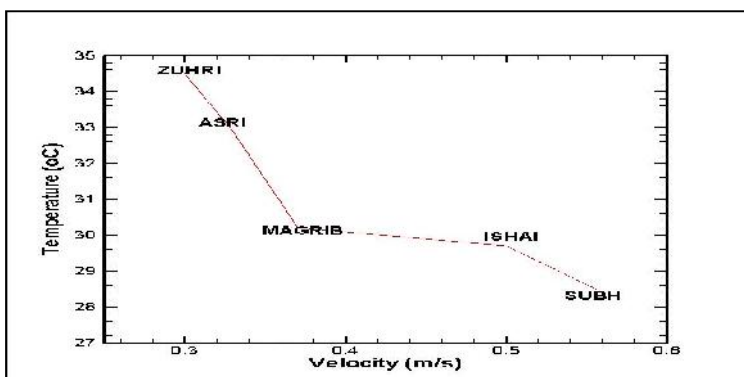


Fig. 7: Relationships between Temperature and Velocity

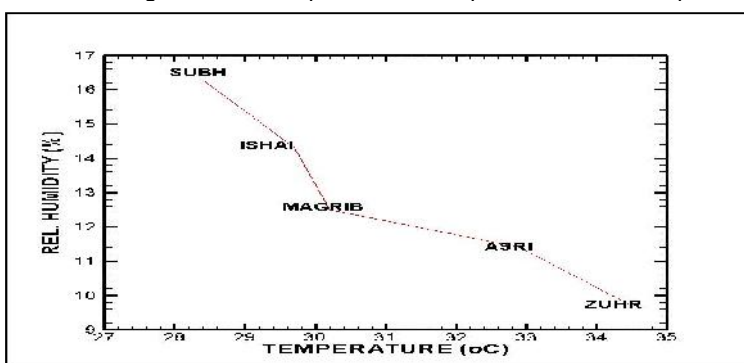


Fig. 8: Relationships between Relative Humidity and Temperature

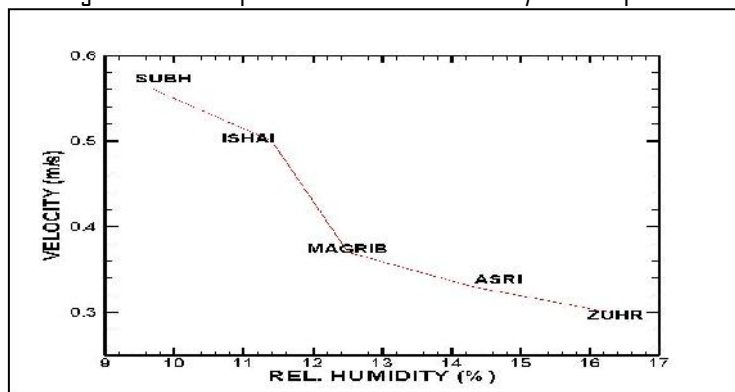


Fig. 9: Relationships between Velocity and Relative Humidity

### Worshippers' Thermal Sensation

The results of thermal responds of the worshippers based on ASHRAE seven-point thermal sensation scale (ASHRAE Standard-55 (2013) were shown in Figure 10. Most of the votes for the prayer times indicate hot thermal sensations, which reflect that the worshippers felt hot with their environment instead of normal. At observation times, operating temperatures

(OPT) range were from 28.4-30.9 °C (*Subh*), 34.5-39.2 °C (*Zuhr*), 32.9-34.1 °C (*Asr*), 30.2-32.8 °C (*Magrib*), 29.7-31.1 °C (*Isha*) respectively. Since the indoor OPT was slightly higher, the thermal sensation votes show that the majority of the worshippers did not accept their thermal environment (Figure 10). The same situation was reported by Hussin et al., (2014) in the mosque buildings.

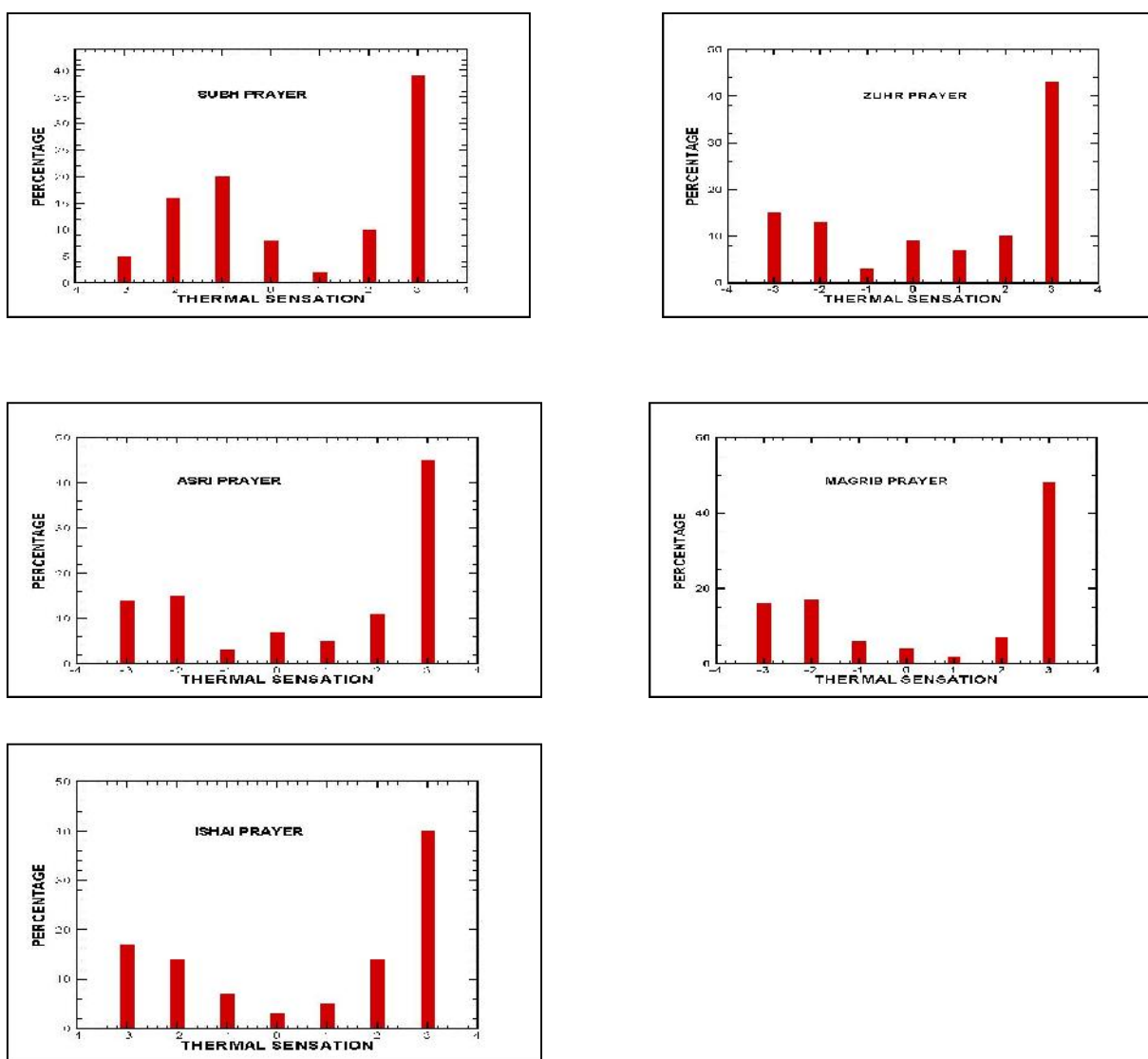


Figure 10: The worshippers' thermal responses based on ASHRAE seven-point thermal sensation scale

Thermal preference of worshippers when exposed to the indoor thermal environment was evaluated. Worshippers were asked if they preferred to change the thermal environment they were experiencing. The results show that majority of worshippers preferred to change their thermal environment to cool during prayer times. Similar result was reported by Hussin et. al. (2014) in Malaysia case where most of the respondents preferred to change their thermal environment to cool.

### ***Neutral Operative or Comfort Temperature***

The neutral temperature is the temperature at which most people vote for "neutral" in the seven point of ASHRAE scale. Figure II shows the regression of PMV on operative temperatures for naturally ventilated mosque in Unimard. From the Figure, the neutral temperature is found to be 31.2°C and the comfort temperature range is between 29.6 to 32.3°C.

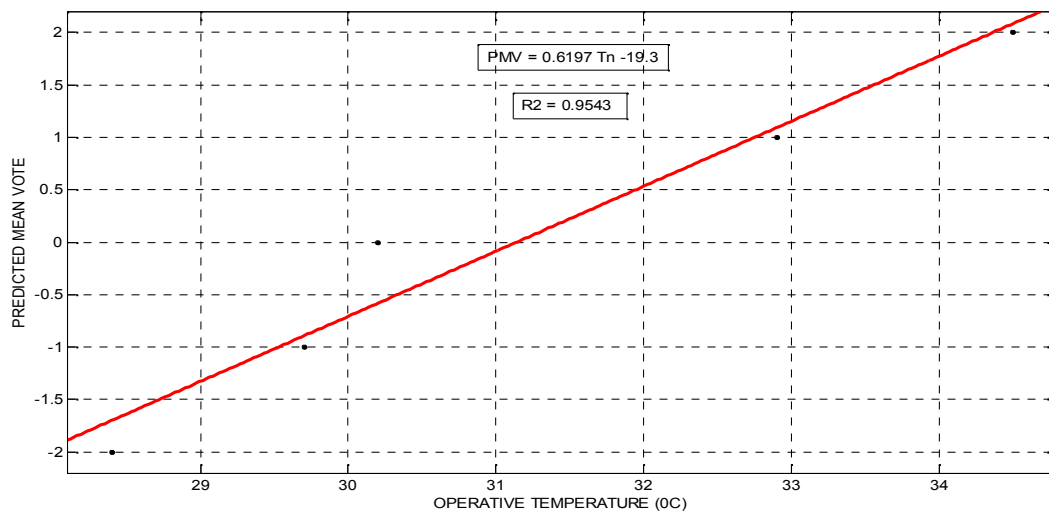


Fig. II Regression of PMV on operative temperatures for naturally ventilated mosque in Unimard

### **CONCLUSION**

It was found that from the objective measurements of the naturally ventilated unimaid central mosque building, the measured data do not fall within the comfort zone of ASHRAE Standard 55. However, some of the worshippers in the buildings found the range of temperatures acceptable. The neutral temperature was found to be 31.2°C and the comfort temperature range is between 29.6 to 32.3°C. On the Subjective measurement, the subjective responses showed that majority of the worshippers voted unacceptable/unsatisfied. The study also showed that

the worshippers in the hot environment such as Maiduguri may have a higher heat tolerance since some of the worshippers accepted the thermal environment which exceeded the ASHRAE standard. It is therefore pertinent to conduct a research using fans (mechanical ventilation) coupled with natural ventilation in Maiduguri mosque buildings. The research is on the interest of reducing the energy consumption in buildings. i.e., instead of using air-conditioning system which is more energy consuming, for thermal comfort, mechanical ventilation and natural ventilation can be used.

### Acknowledgement

We really appreciate the efforts of the university of Maiduguri central mosque committee members for their cooperation, and the worshippers for their continuous support and participation during the field study. Also we gratefully acknowledge Mallam Abbas Mohammed Gisilambe, head of ARID research and disaster management, department of geography, university of Maiduguri, for providing us with the measuring instrument.

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