Assessing the Peak-Period Thermal Conditions of Large Places of Worship in Ahmadu Bello University Main Campus Zaria, Nigeria

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ABSTRACT

One of the most gruelling challenges for the users of places of worship in the tropical hot regions is the extreme thermal discomfort during the peak activity periods. This study investigated the thermal comfort conditions of mosques and churches of ABU Zaria main campus. To fully understand the occupants' experience, the study applied an empirical field observations method to obtain primary data that was subsequently subjected to comparative analysis against the stipulated comfort zones for the location from a set of validated thermal comfort standards. The results show that the combined impact of air temperature, relative humidity and wind speed provided a comprehensive deduction that thermal comfort is such a great challenge to attain in the places of worship throughout the survey period. The average cases of temperature profile on a typical day of the hottest week recorded a temperature difference of +2.85 °C from the outdoor temperature in the ITN mosque, which is the highest record, while the lowest was +2.15°C on ABU Chapel. Worse cases were observed to be +4.50 °C in the hottest moments during Friday prayer in the ITN Mosque and +4.10 °C during the Sunday mass in OLQPP chapel. The study concludes that the design of crowded worship spaces requires a holistic approach of balancing the comfort indices with adequate natural ventilation and supplementary augmentation with mechanical systems.

Keywords: Religious Buildings, Thermal comfort, Thermal Comfort indicators, Comfort zone

1. INTRODUCTION

Mosques and Churches are essential components of a community's cultural and spiritual fabric. In the hot and dry climate, places of worship should be designed to provide a tolerable level of thermal comfort for the worshippers to attain composure and the essential focus required in the act of worship. Major religious activities that attract the highest occupancy rate in worshippers for both mosques and churches of the hot climate flow into the overheated periods of the day all year round (Azmi, Baharun, Arıcı, & Ibrahim, 2023; Vella, Martinez, Yousif, & Gatt, 2020). Although these worship places are used at various times throughout the day, in the hot and dry climates, worshippers experience challenges related to thermal discomfort during the peak periods which exerts so much pressure on energy requirements to cool the interior via the energy-consuming mechanical ventilation and air conditioning systems (Touma, & Ouahrani, 2017). Physical observation also revealed that these challenges often lead to worshippers' preference of observing the congregation in the outdoor portions of the worship centres rather than the designated interior spaces.

Within the Ahmadu Bello University (ABU) main campus and the research circle in general, studies on educational buildings are quite common on thermal performance and indoor environmental quality of lecture halls, classrooms, student hostels and even office buildings. This is as seen in studies by Garba (2011); Malgwi & Sagada (2014); and Abubakar & Ibrahim (2019). However, there appears to be a limited representation of the religious buildings that are equally essential in the fabric of every community. In its part, therefore, this study aims to specifically study the thermal conditions of large places of worship in ABU main campus in its peak period of use. This will set the stage for further endeavors like the avenue for calculation and design of sustainable mechanical means of ventilation to supplement the passive methods where thermal comfort challenges persist. It is also an endeavor that can primarily facilitate the employment of deep or conventional retrofitting of the older structures within the community to enhance their thermal insulation capabilities and necessary overhaul of its' fenestra systems. The aim of the study is to be achieved through the set objectives that include assessing the environmental factors of thermal comfort namely, air temperature, humidity and wind speed. Other factors that involve personal influences of thermal comfort are not within the scope of this study as it is only set out to detect the basic symptoms associated directly with the condition of the thermal zone in relation to the building fabric. Another objective is to identify the worst-case scenarios in thermal conditions of worship places on the campus and pave the way for subsequent possibilities of conducting demonstrative tests on the opportunities and benefits of building retrofitting as a corrective way of providing a remedy to the envisaged problem within the study area.

2. LITERATURE REVIEW

Thermal comfort is defined in the ISO 7730 (2005) and ASHRAE standards 55-66 (2020) as "the condition of the mind that which expresses satisfaction with the thermal environment". Szokolay (2008) states that thermal comfort occurs when there is a thermal equilibrium in the absence of regulatory sweating and the heat exchange between the human body and the environment. The most commonly used indicators of thermal comfort are air temperature and relative humidity because it is the easiest to feel or measure and people can rate them without any difficulty (Chen, Hua, Shi, & Ren, 2023; Wu, Fan, & Cao, 2023). Although internationally standardised; thermal comfort has been well perceived to be adaptive and psychological, and could not be exactly specified at a condition of temperature or relative humidity alone (Olesen, & Parsons, 2002). Several publicised studies have indicated that the state of comfort relies on a wide range of non-quantifiable factors such as mental states, occupant activity, clothing, state of health, acclimatisation and even age and gender (Ogunsote, 1991; Olesen, & Parsons, 2002). Among these psychological factors, the one most studied was the acclimatisation of people to a particular climate. Despite this established affirmation, it is of crucial importance that the primary environmental factors that form the basic frame for any thermal comfort evaluation are determined for every locality before proffering any passive or active design solution for such locations (Wu, Fan, & Cao, 2023).

Religious buildings mainly operate during the hottest part of the day, with occupants from every age group and gender. Research has shown that the thermal sensation of younger occupants of ages 22-25 prefers lower temperature in comparison with their elderly counterparts aged 67-73 (Schellen, van Marken Lichtenbelt, Loomans, Toftum, & de Wit, 2010). This denotes that, if the indoor environment is found to be comfortable for young adults in the hot season, then the rest of the older population will also find it to be comfortable; however, in the colder season this may not be the case as the younger demographics may stand the colder environment better. This is culled from numerous studies involving gender and level of activity synonymous with the case of religious buildings like that of Wu, Liu, Li, Kosonen, Kong, Zhou, & Yao, (2019); and Moossavi, (2014). Given these varying problems therefore, it is necessary that the first level of evaluation carried out in assessing the thermal comfort of buildings of mass occupation is to be able to determine/evaluate the air temperature and its combination with other thermal comfort variables like radiant temperature, relative humidity and air velocity. This will pave the way in facilitating the formulation of contextual local standards, appropriate passive design for thermal comfort, and aiding the design of supplementary mechanical ventilation and air conditioning.

2.1 Thermal Comfort Challenges in Crowded Places

Crowded interior spaces face more thermal challenges than offices and rooms with smaller occupants. Due to constrained airflow, ventilation in crowded buildings is hardly adequate due to the presence of stagnant pockets of heated stale air within the spaces (Chiguchi, Yamaguchi, Higashino, & Shimoda, 2016). An increased population in spaces cause body heat to be produced, raising indoor temperatures and jeopardising the efficiency of climate control systems (Aryal, Chaiwiwatworakul, Chirarattananon, & Wattanakit, 2021). This often brings about excessive reliance on energy-intensive air conditioning systems which can strain the energy requirement of any infrastructure. Typically, in densely populated areas, the diversity of the population adds another layer of complication. Individuals' comfort levels vary depending on their age, health, and personal preferences (Parsons, 2002). For this reason, obtaining a thermal comfort level that is suitable for everyone is a challenging objective for designers of crowded spaces like mosques and churches.

According to Wargocki, Sundell, Brundrett, Fanger, Gyntelberg, & Wouters, (2002); several thermal comfort indices help assess and maintain suitable conditions in interior spaces. These indices consider factors like air temperature, humidity, air velocity, clothing insulation, and metabolic rate to gauge comfort levels. One of the most typically used is the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). This was developed by Fanger, and it calculates the mean value of individual thermal sensations and estimates the percentage of occupants likely to feel dissatisfied. There is also the Adaptive Comfort Model that is tailored for naturally ventilated spaces; it recognises that occupants in hot climates may adapt to slightly higher temperatures and factors in variables such as outdoor climate, indoor air movement, and clothing to determine acceptable comfort ranges. Another tool used is the Universal Thermal Climate Index (UTCI), it evaluates the combined impact of air temperature, humidity, wind speed, and radiation on human comfort and provides a comprehensive understanding of thermal conditions, considering both physiological responses and the environment's influence.

For any form of assessment to be utilised in any thermal comfort design, it is of utmost importance to determine the comfort zone of that specified entity from any building typology. Establishing a comfort zone graphically represents the range of temperature and humidity conditions within which a majority of occupants feel comfortable (szokolay, 2008). This helps guide design choices for ventilation, insulation, and cooling systems and it requires discomfort indices to assess whether indoor conditions are better or worse than the outdoor climate, influencing crucial decisions regarding natural ventilation and cooling strategies. The most widely used index in this regard is the Operative Temperature (OT); it accounts for the combined influence of air temperature and mean radiant temperature in a space (Ogunsote, 1991; and Olesen, & Parsons, 2002). It also reflects how humans perceive thermal conditions, considering both convective and radiant heat exchanges. In hot climates with crowded interiors, balancing these indices with energy efficiency is crucial. Employing efficient HVAC systems, natural ventilation, shading devices, and reflective materials can help manage temperatures while adhering to thermal comfort standards. Regular monitoring and adjustments based on occupant feedback can ensure that these spaces remain conducive to well-being and productivity.

2.2 Comfort Zone; the Case of Zaria

A comfort zone is that thermal condition in which little or no effort is required by occupants to adjust their bodies to surrounding environmental conditions; it is the sum-total of heat or cold sensations experienced by occupants, within an occupant’s comfort zone (szokolay, 2008). Comfort zone standards are typically challenging to attain especially in the hot and dry climates. As stated by the Ministry of New and Renewable Energy (MNRE), 2020; hot-dry climatic regions are characterised by very high radiation levels, ambient temperature and relatively average humidity. Countries that are found in such climates are Nigeria, Niger, Egypt, Syria, Malaysia, Saudi Arabia, and the United Arab Emirates. According to NIMET (2018), the climate of Zaria is found to be hot and dry for most periods of the year. The mean daytime temperature of the location is about 38ºC, where the highest temperature is about 40ºC which is normally experienced between April and June while the temperature minimums are about 30ºC recorded in December and January; however, the annual average temperature of Zaria is 25.2°C with 6.1°C Fluctuation. (NIMET (2023).

According to ISO 7730 (2005) and ASHRAE standards 55-66 (2020), most people will be thermally comfortable in the following conditions;

i. Air temperature: heat periods (19ºC-24ºC) cold periods (18ºC-22ºC)

ii. Relative humidity: 40%RH-70%RH

iii. Air speed: 0.1-0.2 m/s, without creating draught

iv. Radiant heat: no direct exposure to the radiant heat source

Similarly, a more within-context study by Ogunsote, & Prucnal-Ogunsote, (2002); provided a summary which indicates that the optimum comfort limits using the Effective Temperature Index for Zaria (and by association, other parts of the country), are 20-25ºC; and that thermal stress is predicted based on average climatic data and not the experienced conditions of the thermal zone.

3. RESEARCH METHODOLOGY

3.1 Sampling Selection Criteria

Sampling was carried out purposefully using the size of the worship facility as the primary criterion. This is because it is the size that guarantees the rate of massive occupancy in the worship centres. The sampled buildings also fall under the category of places where the weekly general congregation is held; which is the Juma'at prayer for the Muslims and Sunday mass for the Christians. Two churches and two representative mosques were chosen for the study based on the relevance of their architectural and historical background. Within the campus therefore; the selected buildings are ABU Central Mosque as the sole Juma'at mosque on campus, ABU Chapel representing the largest church on campus, and Our Lady Queen of Peace Parish representing another denomination of large churches in the same vicinity. The second mosque selected is the Islamic Trust of Nigeria (ITN) Zaria Branch. Although the mosque is not located within the main campus, it is the closest alternative to the central core of the main campus and owes its occupation capacity to the staff and students of the university. It was largely considered for its large size in terms of space area and volume. It also presents a different set of variables for scrutiny as it differs from the ABU Central Mosque in terms of design, use of building materials and technique, and the fact that it has a double volume configuration.

3.2 Data Collection and Method of Assessment

An empirical field observation method was used to collect data on the environmental features of the sampled facilities, other physical observations include; the building form, volume, material properties, size, claddings and related fenestral systems. Onsite data was also collected and evaluated. All assessments were limited to environmental factors as indicators of the studied thermal conditions which include ambient air temperature, relative humidity levels, and the influence of the air velocity in the worship buildings. The Standards and Guidelines used as a yardstick for drawing conclusions on the results from conducted evaluations were the ISO 7730 and ASHRAE Standard 55.

The focus of the study is to assess the thermal condition of the places of worship on a worst-case scenario basis. According to Kazman, and Klein (2002); the worst-case scenario expresses the most problematic circumstances in carrying out assessments and guarantees adequate and efficient sampling steps required to reach any theoretical saturation (Kazman, and Klein, 2002). Therefore, as shown in Table 3.1; data was collected as outlined thus;

i. Typical week in the hottest month; According to NIMET (2023), the hottest week of the year was between the 29th of April to the 5th of May, 2023
ii. The main worship days of the hottest week, were Friday the 5th of May for the two sampled mosques and Sunday the 30th of April for the churches.
iii. The peak period of occupation for the mosques on the main worship day was from 1:00 pm to 2:00 pm; while for the churches it was from 8:00 am to 1:00 pm.
iv. Measurements were conducted at hourly interval between the beginning of the heated period of the day (7:00 pm) for the regular days, and at 30-minute intervals in the peak period of the main worship days.

Table 3.1: Outline of periods for data collection from the sampled buildings. Source: Field Study 2023

	Data collection periods		
Building	**Typical week**	**Worship day**	**Peak period**
Mosques	29th April To 5th May	Friday,5th May 2023	1:00 pm – 2:00 pm
Churches	29th April To 5th May	Sunday 30th April 2023	8:00 am-1:00 pm

3.3 Survey Instrument

The multi-purpose Kestrel 5500 data logger was primarily used for data collection. It is an ideal instrument that measures air velocity, temperature and relative humidity with sensory accuracy of 0.3m/s, 0.30oC and 1.6% respectively (Olanipekun, 2017; Abdullah, Salisu, & Dahiru, 2023). The positions of the measurement points for data collection to determine the level of thermal comfort were located according to ASHRAE (2020) which specifies that the height for evaluating comfort should be 1.5m above the floor level. This height is reasonable for standing during performing prayers. Certain precautions were taken while using this sensitive tool by not locating it close to walls or openings in the path of direct sunlight and frequent air movements, also caution was taken not to take readings near heat or moisture-producing sources. A tabular data recording strategy was used which was later copied to MSExcel spreadsheet to carry out all necessary computations.

4. FINDINGS AND DISCUSSIONS

4.1 Inventory of the Surveyed Places of Worship

The first building sampled for the study is the ABU Central Mosque. It is located in the main campus of the university and is the largest mosque within the community, accommodating the highest number of people, especially on Fridays when the Juma'at prayer is observed. For this study, only the central core was observed as the external core may present a different challenge for another area of thermal comfort study. It has a total floor area of 352m^2 which can accommodate up to about 360 worshippers at the peak period. It is largely made of reinforced concrete envelope with terrazzo floor and steel doors and windows with frosted glazing. The only mechanical means of ventilation recorded are the ceiling and wall fans distributed evenly around the prayer hall. Figures 1 and 2 show the exterior and interior views of the ABU central mosque respectively.

Figure 1: ABU central mosque (field work, 2023)

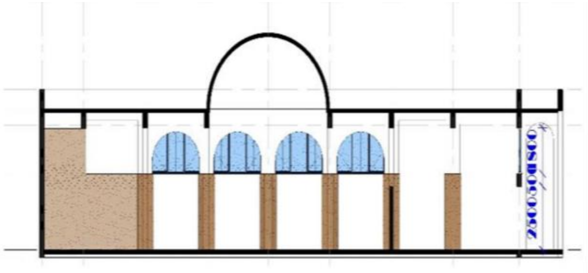

Figure 2: Section of ABU mosque (field work, 2023)

The second sample for the study is the mosque at the ITN centre. It is located in the ITN premises and is one of the largest mosques in Samaru Zaria. It is also a Juma'at mosque that has a square-meters of up to 1444 and can be occupied by over 1500 worshippers. The building materials are contemporary with long-span aluminium roofing on steel trusses insulated with P.O.P ceiling. The floor is covered with prayer mat and the windows are of aluminium casing with slightly tinted glazing. No air-conditioning units were recorded in the prayer hall however ceiling fans were found to be installed at all corners of the mosque. Figure 3 shows the Exterior view of the mosque, while Figure 4 shows the double-volume interior of the mosque.

Figure 3: ITN mosque (field work, 2023)

Figure 4: Interior of ITN mosque (field work, 2023)

As shown in Figures 5 and 6; Our Lady Queen of Peace Parish is a notable on-campus chapel located at the central hub of the university. It is the third facility sampled for the study. The chapel has an approximate area of about 385m^2 and can house up to 400 worshippers. The chapel is octagonal in shape and covered with long-span aluminium roofing with skylight windows at the pinnacle, the roof insulation is via P.O.P and Asbestos ceiling at appropriated portions of the building. Windows are of a large expanse of stained glass and the floors are also an alternation of granite and terrazzo for different areas. The pews are made out of timber faced with serial augmentation of wall and ceiling fans to provide a mechanical source of ventilation through the aisles.

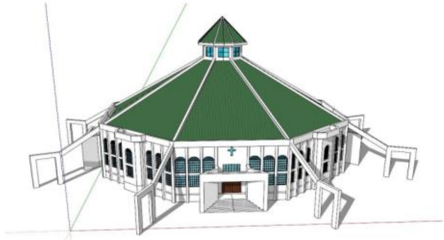

Figure 5: A model of OLQPP chapel (field work, 2023)

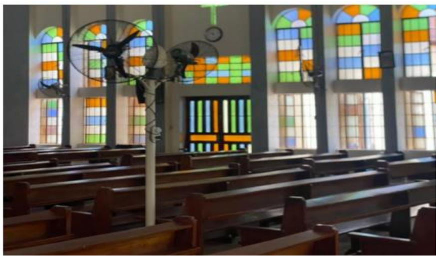

Figure 6: Interior of OLQPP chapel, (field work, 2023)

The fourth place of worship studied was the ABU chapel. It is the largest church on campus and has up to an area of 750m^2 which can be occupied by about 800 worshippers at a given time. The floor is of terrazzo finish, glossed wall painting and aluminium roofing sheets on steel trusses insulated by a ceiling made out of wooden strips. The pews are also made of polished wood and the doors and windows are made of steel with shielded with steel grills. The means of mechanical ventilation are also ceiling fans and standing fans arranged in sequence along the ceiling and walls. Figures 7 and 8 show the exterior and interior views of the ABU chapel respectively.

Figure 7: A.B.U Chapel (field work, 2023)

Figure 8: Interior ABU Chapel (field work, 2023)

Table 4.1 shows a summary of inventories from the four places of worship, it shows a lot of similarities in the use of building materials and technology; however, the finishes and interior claddings are quite different. Other differences between the samples include size, volume, shape and style/configuration of openings; there is also the presence of wooden furniture in the churches whereas the mosques only have their' floors covered with praying mats made chiefly out of wool and jute materials.

Table 4.1 Result of the Physical Inventory of the studied buildings; Source: Field Study 2021

Building	ABU Mosque	ITN Mosque	OLQPP	ABU Chapel
Floor Area m^2	352.3	1444	385	750
Wall (Mm)	Granite on plaster	Gloss on plaster	Gloss on plaster	Gloss on plaster
Floor/Covering	Terrazzo/Prayer	Marble/ carpet	Granite/Terrazzo	Terrazzo
Roof	Flat roof (357.3 m2)	Aluminium sheets	Aluminium sheets	Aluminium sheets
Ceiling	Concrete (slab soffit)	P.O.P	P.O.P/Asbestos	Wooden Strips
Window	Steel Casement	Aluminium Casement	Steel -Stained glass	Aluminium sliding
Doors	Folded Steel doors, frosted glazing	Aluminium swing, tinted glazing	Steel -Stained glass	Steel doors
Furniture	NIL	NIL	Timber	Timber
Cooling & Ventilation	ceiling fans and standing fans	ceiling fans and standing fans	ceiling fans and standing fans	ceiling fans and standing fans

4.2 Results from the Observed Thermal Conditions

Results from the recorded data are divided into air temperature, wind speed and relative humidity. The record is presented in maximum, average and minimum values to facilitate necessary inferences.

4.2.1 Temperature Profile

The outdoor dry bulb (ODB) temperature studied was typically high throughout the week with the maximum diurnal record being 33.08°C, where the daytime temperature reached up to 39.00°C on the 29th of April. Records show that the largest sample in terms of size, volume and extensive glazing is the ITN mosque which recorded the highest weekly average of 29.90°C and 38.15°C on the hottest day. The lowest is the ABU Chapel with 27.95°C on the hottest day advantaged by being flanked with vegetation at the southern flank against the hot setting sun of the evenings. Account of recorded values shown in Figure 9 across all samples illustrates the significant difference in temperature level on Sundays (day 1) for the churches and even higher records for the mosques on Fridays (day 6). This shows that higher temperatures were recorded in the thermal zones of the major worship days over the regular days. ABU and ITN mosques recorded the highest temperatures on Friday even though results show that the ODB is lower than Sunday for the two churches. In both results, it shows the higher level of discomfort that the occupants experience in the studied buildings on the major worship days over the regular days.

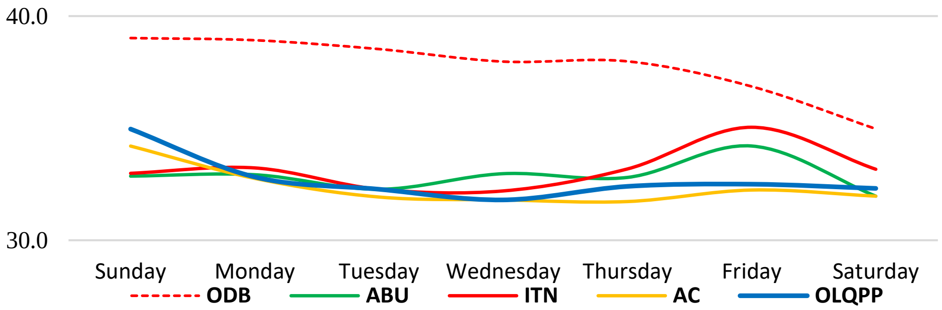

Figure 9: Temperature differences between regular days and peak periods: Field Survey, (2023)

Due to a tallying time of peak occupation, results for the temperature profiles of the mosques are presented simultaneously as shown in Table 4.2, the record for the mosques shows that; the maximum zone air temperatures were recorded during the peak period. The difference between the average record on the worship day and that of the regular day of the hottest week was approximately +2.60°C in the ABU Mosque, and about +2.85 in the ITN Mosque. Similarly, the recorded difference between the air temperature of the peak occupation period inside the prayer hall and that of the same hours of the regular day is about +4.02°C in the ABU Mosque, and about +4.50 in the ITN Mosque.

Table 4. 2 Result of the Field observation from the mosques; Source: Field Study 2023

	ABU Mosque			**ITN Mosque**		
Record	Min	Med	Max	Min	Med	Max
Temperature (°C); week	22.71	29.15	31.60	20. 90	29.90	33.00
worship day (7 am-9 pm)	23.00	32.75	37.85	22. 20	33.00	38.15
Peak period (12 pm-2 pm)	32.20	35.05	37.85	32.95	36.10	38.15
Humidity (%) day (7 am-9 pm)	48,00	47.22	67.80	45,00	52.20	68.20
Peak period	42.00	59.24	67.80	55.00	61.10	68.20
wind (m/s); day (7 am-9 pm)	0.45	0.8	1.0	0.4	0.9	1.1
Peak period	0.5	0.45	0.75	0.5	0.4	0.65

As observed from the field survey on the main worship days, the activity period for the churches starts from 7 am up till 9 pm. Records show different variations in the morning and afternoon worship sessions; however, as earlier iterated, this study is mainly concerned with the worst-case scenarios and the focus therefore was on the more challenging afternoon mass which coincides with the overheated periods of the day. As shown in Table 4.3, the temperature records from the churches show that; the maximum zone air temperatures were recorded during the peak period of the afternoon service. The difference between the average record on the worship day and that of the regular day of the hottest week was approximately +2.15°C in the ABU Chapel, and about +2.50 in Our Lady Queen of Peace Parrish. Correspondingly, the recorded difference between the air temperature of the peak occupation period inside the prayer hall during the service and that of the same hours of the regular day is about +3.90°C in the ABU Chapel, and about +4.10 in Our Lady Queen of Peace Parrish.

Table 4.3 Result of the Field observation from the churches; Source: Field Study 2023

	ABU Chapel			**Our Lady Q.P Parrish**		
Record	Min	Med	Max	Min	Med	Max
Temperature (°C); week	20.70	27.95	31.60	22.00	28.75	31.00
worship day (7 am-9 pm)	21.60	31.80	36.20	30.30	32.40	36.85
Peak period (12 pm-2 pm)	30.40	34.05	36.20	30.55	34.90	36.85
Humidity (%) day (7 am-9 pm)	56,00	51.10	63.70	57,00	49.20	61.10
Peak period	52.00	57.60	63.70	54.00	58.40	61.10
wind (m/s)**;** day (7 am-9 pm)	0.4	0.7	1.0	0.4	0.75	1.05
Peak period	0.55	0.45	0.75	0.45	0.4	0.7

4.2.2 Wind velocity

It was observed that the windows in the mosques have larger openings than in the churches, even though the glazing is more expanse in Our Lady Queen of Peace Parrish. Therefore, the wind velocity was found to be slightly higher in those samples. Throughout the experiment, the wind speed remained relatively constant in all the samples except for a slight drop during the peak occupation. The highest wind speed was recorded in the ITN Mosque at the rate of 1.1m/s after the congregation; however, during the congregation, it dropped to 0.40m/s. In all other samples range of wind velocity remained between 0.4m/s -1.0m/s throughout the day which shows that it was consistently below the comfort limit during the peak period.

4.2.3 Relative Humidity

Humidity was observed to be within acceptable comfort limits for most of the day with a slight increase beyond the upper limits towards the end of the day. Due to the excessive release of moisture through respiration, perspiration and movement, a higher humidity level was recorded during the peak occupancy period in all the samples. A higher humidity rise was recorded in the mosques due to the higher rate of occupancy; in all the samples humidity level ranged from 57.60% to 63.70%.

4.3 Peak Period Analysis

According to the adopted comfort zone from literature; air temperature for heat periods is between 20-25ºC, relative humidity must be within the range of 40%RH-70%RH and airspeed must not exceed the ranges of 0.1-0.2 m/s without creating a draught. Figure 10 shows the peak daily averages for all the studied buildings. The wide gap between the peak period and the thermal comfort threshold implies that the thermal zones are exposed to a large risk of heat stroke and that defines severe discomfort during the peak occupation period. The highest average peak period and the highest average daily temperature recorded for the ITN mosque were 36.10 ºC and 33.00 ºC respectively; which shows it suffers the highest level of discomfort amongst all samples. The least discomfort was recorded in the ABU Chapel with the highest average peak period and the highest average daily temperature of 34.05 ºC and 31.80 ºC respectively. Figure 11 shows that the daily records are also high throughout all samples, but the difference in the intensity between the peak period and the daily record show that severe discomfort is only experienced during the peak period.

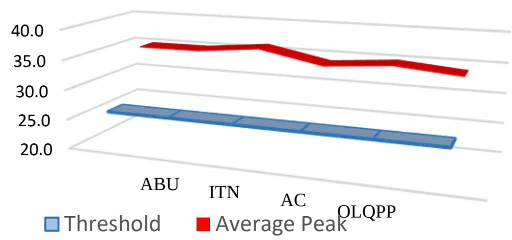

Figure 10: Daily peak on comfort threshold, (2023)

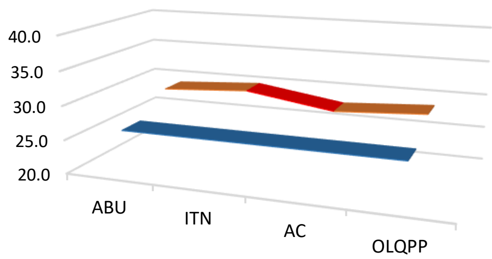

Figure 11: hottest week averages: field work, 2023

5. CONCLUSIONS AND RECOMMENDATIONS

The study affirms that major religious activities associated with the highest occupancy rate in mosques and churches take place during the overheated periods of the day as iterated by Azmi, Baharun, Arıcı, & Ibrahim, 2023. It was established that places of worship in ABU's main campus are subjected to high levels of discomfort during the heated periods of the hot season, which turns out to be more severe during the peak period of worship during the main worship days. This often lead to worshippers' preference of observing the congregation in the outdoor portions of the worship centres rather than the designated interior spaces owing it largely to the propagated influence of heat propagated by overcrowding as pointed out by Aryal, Chaiwiwatworakul, Chirarattananon, & Wattanakit, (2021); which exceeds beyond the comfort limit for Zaria as outlined by Ogunsote, & Prucnal-Ogunsote, (2002). This is as expressed by the findings from the study which categorically show thus;

1. The largest sample in terms of size, volume and extensive glazing (ITN mosque) recorded the highest weekly average of 29.90°C and 38.15°C on the hottest day respectively. While the lowest is the ABU Chapel with 27.95°C over the course of the week and 31.80°C on the hottest day.
2. The average cases of temperature record on a typical day recorded a temperature difference of +2.85 °C from the outdoor temperature in the ITN mosque, which is the highest record while the lowest was +2.15°C on ABU Chapel.
3. Worse cases were observed to be +4.50 °C in the hottest moments during Friday prayer in the ITN Mosque and +4.10 °C during the peak period during the Sunday mass in Our Lady Queen of Peace Parrish chapel.
4. The highest wind speed was recorded in the ITN Mosque at the rate of 1.1m/s while in all other samples, the range of wind velocity remained between 0.4m/s -1.0m/s.
5. A higher humidity was recorded in the mosques due to the higher rate of occupancy during the Friday prayer; the humidity level ranged from 57.60% to 63.70% in all sampled buildings.
6. The wide gap between the peak period and the thermal comfort threshold implies that the thermal zones are exposed to severe discomfort during the peak occupation period

In hot climates like that of Zaria therefore, it is recommended that the design of crowded interiors is carried out through an all-inclusive design procedure. As gathered from review of studies by Touma, & Ouahrani, (2017) and Youssef, Hamid, & Vatopoulos, (2017); to remedy thermal discomfort in crowded architectural spaces, there is need to improve ventilation by using natural airflow, ceiling fans, or HVAC systems. The studies also recommended the incorporation of shading devices and reflective materials on the entire building envelope to reduce heat gain and also to explore the implementation of evaporative cooling techniques, such as water features or misting systems. The study by Azmi, Baharun, Arıcı, & Ibrahim, (2023) also reiterated the need to use materials with high thermal mass to absorb and release heat gradually; additionally, there is need to control indoor humidity levels, as high humidity exacerbates discomfort.

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