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Computing the Operative Temperature in Selected Hospitals' Outdoor Spaces in Abuja, Nigeria

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ABSTRACT

Outdoor thermal comfort studies have been understudied especially within the hospital settings. In tropical African continent which records high temperature range, poses a great challenge to human health, and by koppens climate classification, Abuja is within the tropical savannah climate. The study therefore aims at establishing the Operative Temperature (T_{Op}) of users within the outdoor spaces of selected hospitals in Abuja, Nigeria. The study employed a mixed-method approach with field measurement of microclimatic parameter carried out in the dry seasons using data loggers, alongside observation of behaviors within a specified time range, 9:00 am – 12:00 pm, 12:00 pm – 3:00 pm and 3:00 pm – 6:00 pm for each of the studied days. A closed ended questionnaire was employed to survey the user's perception within the outdoor spaces. Climatic data from NIMET was also collected as a comparative assessment with ASHRAE standard 55. The study showed that, T_{Op} exceeds the standard in the dry season having a value of 32.93^0C, the Physiological Equivalent Temperature (PET) index at this value indicates a warm sensation. The study concludes that, the design of outdoor spaces within these hospitals were not given due consideration which have resulted in high value of T_{op} recorded and recommends the designing of outdoor spaces to be an integral part of the design stage with the inclusion of landscapes and covered outdoor spaces within the hospitals' outdoor spaces.

Keywords: ASHRAE standard 55, effective temperature, hospital, outdoor spaces, thermal comfort, thermal stress.

INTRODUCTION

The rise in climate change in recent time resulting from global warming stresses the need for concerted efforts by governments, professionals, and researchers to propose solutions to the challenges by way of reducing the depletion of the atmosphere. The Intergovernmental Panel on Climate Change (IPCC, 2022) warns on the hazard and threat faced by the depletion of the ozone and fears that the 1.5^0C temperature rise mark may soon be reached, with its devastating effects on lives and health. These challenges are severe within the tropic regions globally and have great impact the physiological behavior of individuals. (Leal et al., 2021).

Thermal comfort is defined as the state of satisfaction, the feeling of well-being the human body gets when in contact with the environment, an expression of the mind which is subjective (British Standard BS EN ISO 7730, 2005). It is also defined as the condition of the mind at a particular time within an environment that expresses satisfaction (ASHRAE Standards 55, 2021).

Outdoor thermal comfort studies are dynamic, as such indices indices such as the Standard Equivalent Temperature (SET), Physiological Equivalent Temperature (PET), and Predictive Percentage Dissasstisfaction (PPD) have been put up to make inference on the performance of the outdoor environment with respect to thermal comfort. (Kotharkar, et. al.

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2022). The ET makes use of climatic parameter such as Relative Humidity, Air Temperature, and Wind speed to make empirical evidence of the thermal stress within such an outdoor space base on the ASHRAE standard 55 standard (2021). It is of important to note that ET condition within hospitals outdoor space is a concern as it pose challenge to all category of users within such space.

Thermal comfort studies have globally concentrated more on urban neighborhoods, commercial areas, and residential areas, leaving out healthcare facilities which house a number of vulnerable populations found within these outdoor spaces (Wu, et. al. 2025). These spaces are mostly found to be paved walkways, with few vegetation, inadequate shading consideration as a result of poor design criteria. In Nigerian cities especially Abuja, found within the tropical climate, these intense heat gain and its aftermath on health cannot be overemphasized. The study evaluates the extent to which Effective Temperatures fall within or beyond acceptable thermal comfort thresholds within the hospital's outdoor spaces for the diverse groups of users.

The healthcare facilities serve in providing care for the inherently vulnerable individuals like patients, visitors and health workers, who all interacts with the outdoor space. The spaces within these facilities are interconnected by outdoor spaces which serves as transition spaces and are most times used as waiting areas or recuperation spaces by patients. These category of users have been found not only to be faced with mere thermal discomfort within the outdoors but also a measure of exhaustion, and in extreme cases heat stroke, (WHO, 2021). therefore, the thermal environment in hospitals outdoors needs empirical assessment to meet the global acceptable standard.

LITERATURE REVIEW

Review of Hospital System in Nigeria

The healthcare system in Nigeria is categorized into three (3) for efficient and effective delivery (https://hfr.health.gov.ng). The Primary Health Care (PHC) is at the lowest end of these categories, dedicated to reach the rural areas, and falls within the responsibility of the local government. The Secondary Health Care (SHC), also classified as Public Secondary Hospitals (PSH), is placed at the state level, and cares for patients with a graver ailment. These have more facilities with specialized departments put in place to meet the needs of a larger populace. These facilities take more influx of patients as their responsibilities range from outpatient department (OPD) to inpatient. They carry out diagnostic tests and make referrals as the need arises. The management and supervisory roles are placed at the Tertiary Healthcare, which is the third tier. They are placed at the Federal Government level, where referral cases are treated. They also serve as administrative wings to other healthcare facilities, most of which are specialist hospitals. (Ayo, et al., 2023).

The rise in the global population have also seen its replication in Nigeria over the last decades (Sagir et al., 2021), the need to meet the health challenge pose by this rise is imminent. The healthcare facilities (hospitals) are places meant for provision and not only for treatment of diseases, it serves as training facilities and educating on health and well-being. These facilities have experience pressure in term of usage and weigh down on its infrastructures, ranging from poor design of outdoor spaces (architectural features) which were put in place for a sustainable environment to healthcare provision and affordability (Whear, et al., 2019; Alfa, et al., 2019).

The concept of Outdoor Thermal Comfort study

Outdoor thermal comfort study has previously been left out in the field of thermal study till recent time when it began to gain recognition as a result of negative gains in global climatic data and its impact on the environment. The study has identified and recognized various indices of assessment in different clime in the past decade, has emerged and applied in making decisive inferences on outdoor environment (Tau, et. al., 2022). The ASHRAE standard 55, (2021), identifies these indices base on Fangers model, (Fanger, 1970) which assess one personal experience in an outdoor environment while involve in certain activities using the Predicted Mean Vote, (PMV) and the Predicted Percentage of Dissatisfaction (PPD).

However, with the complex nature of the outdoor environment, other factors such as clothing insulation have been factored in, as influenced by the solar gain from the clothing an individual might be wearing. Other consideration was the physiological adaptation with the introduction of the Physiological Equivalent Temperature (PET) by Hope, (1999), which takes base in the Munich Energy Balance Model for Individuals (MEMI) is measured in Celsius, integrating variables like air temperature, mean radian temperature, wind speed, and vapor pressure to make inference on an individual's physiological stress.

The Universal Thermal Climate Index (UTCI) is the most recently used which accounts for a combination clothing and adaptation within the environment. The Standard Effective Temperature (SET*) was derived from the two-node of human thermoregulation (Gagge, et. al., 1986), initially for the study of indoor thermal comfort but further modified for outdoor thermal comfort assessment. The Effective Temperature (ET) presents a relevant assessment in tropical climates as it makes reference to humidity, a sensitive factor that quantifies thermal stress within an environment (Gao, et. al., 2018). A further modification as Standard Effective Temperature (SET), takes into consideration an isothermal environment where relative humidity (RH) equals 50% and windspeed is less than 1.5m/s and air temperature as mean radian temperature (T_{mrt}) (Blazejczyk et. al., 2012).

Implications of Effective Temperature in Hospitals Outdoor Spaces

The human body is designed in such a way to act as a balance between the severe outdoor climatic conditions and what is known is felt inside. Climatic conditions such as the relative humidity, winds speed and air temperature have great effect on the health of individuals especially those with diagnosed with cardiovascular disease (Du, et. al., 2024).

Scientifically, the human system response to any form of climatic changes within an environment by way of sweating to bring about cooling of the body or shivering through thermoregulatory in the case of severe cold (Hymczak et al., 2023) These changes condition needs to be balanced from the environment. The presence air temperature, relative humidity and wind speed within an environment can bring about an elevated operative temperature if not put to check leading to aggravated cardiovascular events, respiratory and heat related illness among individual. (Ju, et. al., 2025)

With the presence of different category of users within the hospital outdoor spaces which includes the elderly, the risk as their age gets to have negative impact on their and subsequently on the thermoregulatory action of their body system becomes high. (Jingwen, et. al. 2022). Some individuals react differently to specific medications which by extended stay under unshaded spaces become vulnerable in such environment showing associated symptoms of fatigue, dehydration, and heat related illnesses.

Types of Outdoor Spaces

The built-up environment is connected by different transition spaces from the outside to the main habitable and live-able spaces, they can be defined as spaces that are parts of a building surroundings, which are not entirely enclosed and serves other functions to users as an extension of activities. These spaces are seen as sites, parks, gardens, terraces, patio and courtyards, (Dukajovic, et al., 2017). Table 1 discusses some features of some outdoor spaces.

From literature the impact of these spaces like the courtyards cannot be over emphasized in different climatic regions taking into consideration the aspect ratio which refers to height, or the depth of the courtyard and the width or span of the courtyard for ventilation and lighting, and social engagements (Elnabawi, and Hamza, 2020) which creates a lot of varying differences within the spaces they are found, the amount of shade they provide further enhances the performance of the microclimate and consequently on the users' thermal comfort. (Soflaei, et al., 2017; Salameh, 2024).

Therapeutic Potential of Hospitals Outdoor Space.

Dating back the 20th century, literature reveals the importance of HOS as a means of creating an organized way of making patients more comfortable, which is preferred to the economical, technological demands (Giofre, & Dukanovic, 2016). This im-balance in the creation and maintenance of HOS has impacted negatively on both healthcare workers visitors, and patients. A good HOS need to be created to ensure other restorative potentials are employed as the hospital environment is not only meant to eradicate diseases but also has a role in balancing physical, mental, and social wellbeing, (WHO, 2021). Dukanovic et al. (2017) cited the restorative and the psycho-evolutionary theories of Kaplan and Kaplan, 1989, and Ulrich, 1984; 2001 respectively in relation to human and nature to positively impact human health by way of restoration.

Research has linked exposure to well-designed hospital outdoor environments with reduced selfreported pain levels, lower anxiety and depression scores, decreased reliance on analgesic medication, and shorter hospital stays (Ulrich, 1984) It was concluded that the interaction with natural elements within an environment constitute a positive distraction to the patients and thereby reducing their length of stay in hospital. According to Ulrich et al. (2004), A well landscaped HOS with a feel of greenery, fresh air contributes to a short- and long-term recovery, as human beings will prefer to interact with nature, to release every unwanted negative energy than to be kept concealed in a space. As such, in improving the health and wholeness of patients and caregivers (staff and visitors), a good management and sustainability of healthcare facilities that influence clinical result must be maintained (Ulrich, et al., 2008).

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Table 1: Some outdoor spaces.

S/No	Outdoor Spaces	Image	Description
1	Car parks		These are spaces primarily designed to offer safety for vehicular parking, but also serves as passageways for pedestrians. They are often laid over in bitumen, concrete or interlocking stones.
2	Corridors		These connect spaces within a facility, in most cases, one end is open to nature. They are covered at the top and stand on columns, either, steel, concrete or wood.
3	Courtyards		They are open spaces within buildings that connect other spaces and are mostly open to the sky and serve social and cultural functions.
4	Gardens		These spaces are made up of green areas with flowers, shrubs, trees that are calming and aesthetically pleasing to the eye.
5	Pergolas		These spaces are designed purposely to serve extra activities within a structure to provide shade with seating arrangement, they are covered and open on the sides.
6	Walkways		Walkways are connecting features found within buildings linking one unit to another and open on all sides. They could be paved, in most cases left natural.

Source: Researchers' fieldwork (2024).

Hospitals outdoor spaces (HOS) in tropic climates

The therapeutic potentials of HOS in tropical climates, are often undermined especially within the outdoor due to the intense temperature in the better part of the day that render them unfriendly for healthy activities. Poorly shaded courtyards, unventilated walkways, and heat-absorbing hard landscapes that create an unpleasant microclimatic environment that discourage outdoor use, effectively denying patients, visitors, and staff the restorative benefits that well-designed outdoor spaces are intended to provide (Achouri et. al, 2024).

Though, indices exist for outdoor thermal comfort assessment, one that relies on humidity and correlates closely with subjective thermal stress vote is the ET where both humidity and solar radiation constitute dominant thermal stressors (Swetika et. al. 2025). Studies from hot-climate countries including Israel, Australia, and Saudi Arabia have documented the deterrent effect of thermal discomfort on the use of hospital outdoor spaces, noting that occupancy rates in outdoor hospital areas decline sharply when thermal stress indices exceed moderate levels (Naushin, et. al., 2026).

MATERIALS AND METHODS

Study Area

Abuja, one of the Municipal Area Councils, (AMAC) is the Federal Capital Territory (FCT) of Nigeria, (Obiadi, et al., 2019) (Figure 1), located on coordinates with latitudes 4^0N, 14^0N and longitudes 3^0E, 15^0E, covering approximately 8,000 square kilometers (Chijioke et. al., 2021) is locate within the tropical savanna climate zone (Köppen–Geiger Aw classification), Abuja experiences two thermally distinct but consistently warm seasons. The dry season, spanning approximately November to March, is marked by intense solar radiation, the wet season, from April to October, brings elevated humidity levels, reduced wind speeds, the vegetation in the area moderates the urban heat island effect with decreased vegetation linked to increased land surface temperatures. (Koko, et. al., 2021).

The area experiences dicers social and health challenges such as child survival practices and malnutrition among children, (Ajike, 2023), and the rising occupational health and safety of the populace in this region poses a great concern (Adekiya, et. al., 2022).

Research Design

A mixed-method approach was employed in outdoor thermal comfort research which necessitate its use in this study to demand feedback from users (Lai et al., 2020; Arrar, et al, 2022) with regards to outdoor space use and the sustainability of the built environment (Shari and Soebarto, 2012). Similarly, Amaratunga, et al (2002) states that, in achieving a suitable data analysis, the two methods should be considered as they play complimentary role to each other. This, therefore, necessitated the research to adopt the approach.

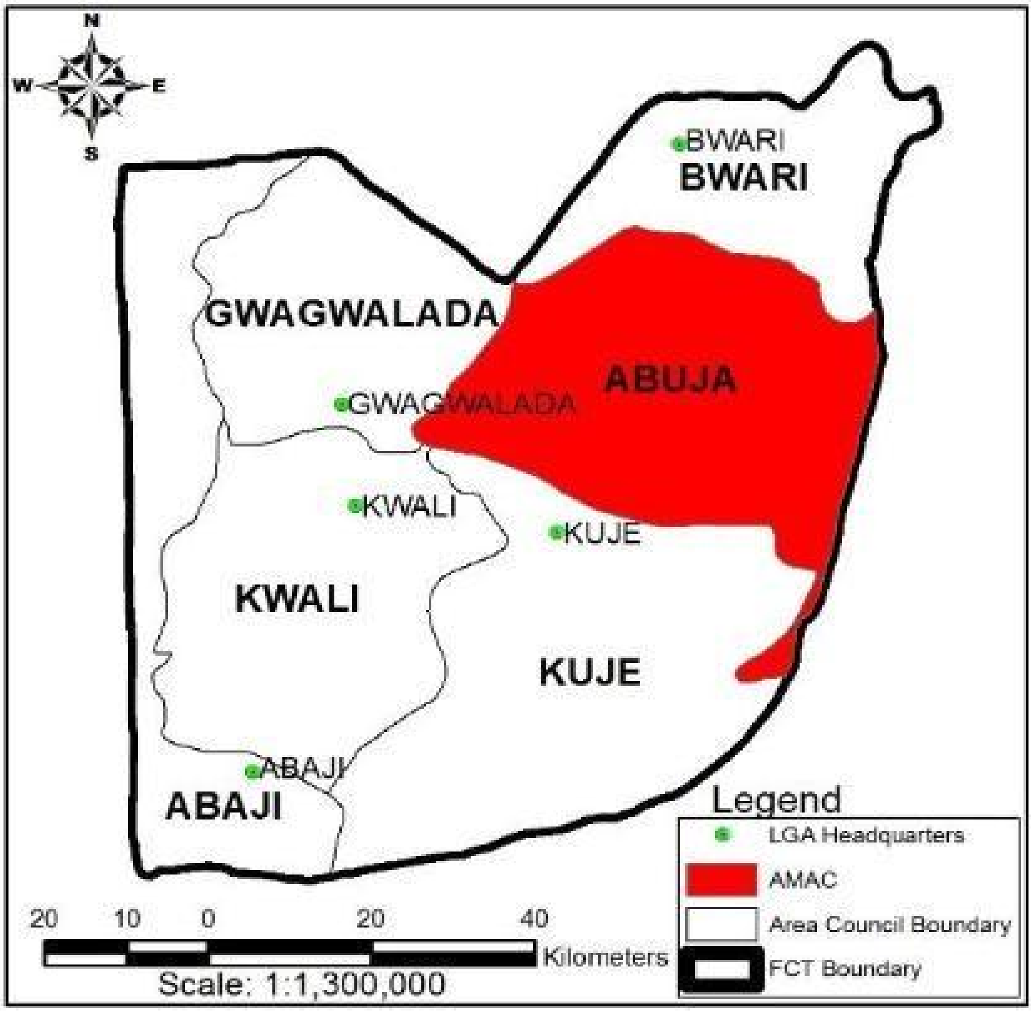

Figure 1: Federal Capital Territory (FCT) showing the Abuja Municipal Area Council (AMAC).

Source: Orisakwe et al., (2017)

In generating the qualitative data for this research, three (3) hospitals were selected purposively due to the availability of outdoor typology of space, H1, H2, and H3. An observation schedule was designed to capture the various behavior within the outdoor spaces alongside image capturing using Canon (Model SX50HS) digital camera. The quantitative data was obtained by the administering a total of 385 closed ended questionnaire of which 343 were collected and analyzed for the study. For field measurement, air temperature was measured on-site using I-button data logger, multifunctional air quality detector (model D9) was used to measure relative humidity, while a hand-held anemometer was used to measure wind speed on-site Figure 2, that are necessary for study. Measurement was taken systematically at the interval of three (3) hours, 9:00 am – 12:00 pm, 12:00 pm – 3:00 pm and 3:00 pm – 6:00 pm for each of the studied days.

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Air temperature detector MD9

Hand held anemometer

I-button data logger

Hobo data logger

Figure 2: Instrument set up for the study **Source:** Researchers' fieldwork (2024).

RESULTS AND DISCUSSION

The international standards of evaluation

The American Society of Heating, Refrigerating, and Air-conditioning Engineers, (ASHRAE) set out standards that are useful in various fields of engineering and environmental studies to aid uniformity of research across the globe. Since thermal comfort is a perception of the mind that expresses satisfaction (ASHRAE 55, 2021), it therefore implies that subjective assessment such as thermal preferences, thermal sensation, thermal comfort votes are valid for assessment on a 7-point thermal comfort scale. (Shooshtarian and Ridley, 2016a).

Table 2: ASHRAE thermal comfort scale.

Thermal Response	Assessment Rating
Hot	+3
Warm	+2
Slightly warm	+1
Neutral	0
Slightly cool	-1
Cool	-2
Cold	-3

Source: ASHRAE 55 Standard (2021).

Microclimatic parameter vote

Outdoor thermal comfort perception was assessed to derive the preferred thermal comfort of the respondents. Using a three (3) point Likert scale (Higher, Unchanged, and

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Lower) to make inference. It was observed that 90.4% of the respondents prefer the air temperature to be lower, 6.7% would prefer it higher while 2.9% settled for unchanged with a mean value of 2.8. This implies that the respondents agreed that the air temperature should be lower. Table 3 reflects the percentage choice of respondents within the hospitals outdoor space. 63%of the respondents prefer the wind speed to remain unchanged, while 37% would prefer a stronger wind speed. A mean value of 1.63 implies that the respondents preferred that the wind speed should remain unchanged. For relative humidity, 58.6% of the respondents said they would prefer it remained unchanged, 41.4% agreed that it should be lower with a mean value of 1.59 which implies that the respondents agreed that the relative humidity remained unchanged. Figure 3 further expresses these responses graphically.

Table 3: Outdoor thermal parameter vote.

Parameters	**Scale**	**Frequencies**	**Percentages (%)**	**Mean value**
Air Temperature	Higher	23	6.7	
	Unchanged	10	2.9	
	Lower	310	90.4	**2.84**
Wind Speed	Higher	127	37	
	Unchanged	216	63	
	Lower	0	0	**1.63**
Relative Humidity	Higher	142	41.4	
	Unchanged	201	58.6	
	Lower	0	0	**1.59**

Lower	**Unchanged**	**Higher**
1	**2**	**3**

Source: Researchers' fieldwork (2024).

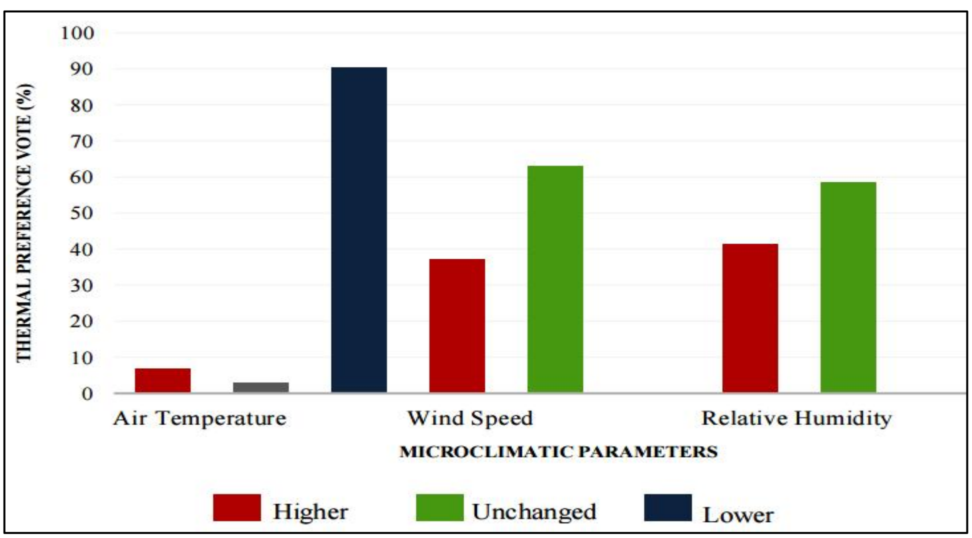

Figure 3: Thermal preference vote Source: Researcher's fieldwork (2024).

Preferred Outdoor Air Temperature

Outdoor air temperature is one of the major parameters that affect thermal comfort outdoors. The study observed the perception of users while involved in activities and assesses their desired air temperature within the space. Table 4 is an analysis of the responses to the air temperature choice base on the ranges for each of the hospitals for studied. For H1, 49.4% preferred the air temperature between the ranges of 25^{0}C – 30^{0}C and 28.6% of respondents preferred it less than 25 ^{0}C. H2 recorded the highest number of respondents who preferred it within the range of 25 ^{0}C– 30 ^{0}C, which is 56.6% of all the respondents. It also recorded 21.6 ^{0}C respondents who favored less than 25 ^{0}C, leaving a total of 78.2% for respondents who would prefer the air temperature to be less than 30 ^{0}C during the study. Whie for H3, the lowest choice recorded was found to be between ranges of 35 ^{0}C – 40 ^{0}C having 1.6%, while the highest had the range of 25 ^{0}C– 30 ^{0}C.

Table 4: Air temperature assessment.

Air Temperature (^{0}C)	Gwarimpa **H1** (%)	Maitama **H2** (%)	Nyanya **H3** (%)	Total
< 25	22 (28.6)	31 (21.6)	37 (30.1)	90
25 – 30	38 (49.4)	81 (56.6)	66 (53.7)	185
30 – 35	11 (14.2)	17 (11.9)	18 (14.6)	46
35 – 40	6 (7.7)	12 (8.5)	2 (1.6)	20
> 40	0 (0.0)	2 (1.4)	0 (0.0)	2
Total	**77**	**143**	**123**	**343**

Source: Researchers' fieldwork (2024).

Physiological Equivalent Temperature (PET)

This index is widely applicable in hot regions for outdoor studies Patle and Ghuge, (2024). It is the immediate air temperature surrounding an individual at which the energy capacity is sustained by a combination of the core temperature, the skin temperature and the sweat rate within the environment. This index takes into account the human vessels regulatory activities (Coccolo et. al., 2016; Chen and Matzarakis, 2017). The PET scale reflects the judgment from the various temperature recorded within an environment, Table 5, ranging from extreme heat to extreme cold thermal responses. It also considers the neutral point on the scale for a comfortable situation.

Microclimatic Parameters Analysis

In assessing the operative temperature range for the outdoor thermal comfort, field data collected for air temperature, relative humidity and wind seed were compared with data collected from the NIMET base station over the same period and seasons, which further validate the on-site measurements for the analysis. Figure 4 shows the data collected for both the wet season and dry season for which the mean scores were computed and plotted graphically as shown. The similarity from the line graph curve further confirms the validity of the filed data, and shows a good relationship between the two.

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Table 5: PET Scale.

PET ^{0}C	Thermal Perception	Grade of physical stress
>41	Very Hot	Extreme heat stress
35 to 41	Hot	Strong heat stress
29 to 35	Warm	Moderate heat stress
23 to 29	Slightly warm	Slight heat stress
18 to 23	Neutral (Comfortable)	No thermal stress
13 to 18	Slightly cool	Slight cold stress
8 to 13	Cool	Moderate cold stress
4 to 8	Cold	Strong cold stress
< 4	Very cold	Extreme cold stress

Source: Chen and Matzarakis, (2017).

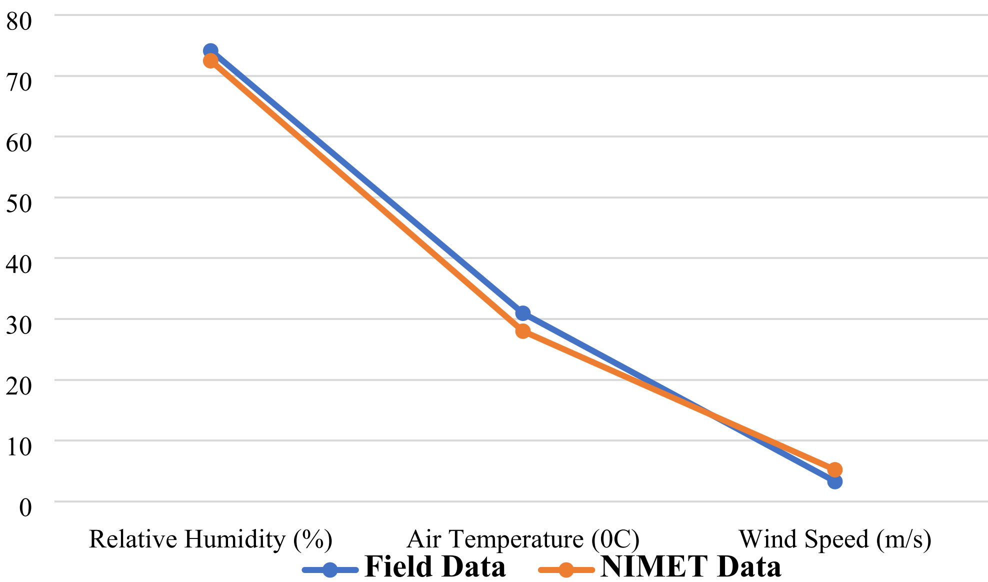

Figure 4: Comparing Field data and NIMET data Source: Researcher's fieldwork (2024).

The mean values from the field measurement of microclimatic parameters were used to calculate the Mean Radian Temperature (T_{mrt}) Matzarakis, et. al., 2010b; Guoa et. al., 2019), a value needed to compute for the Operative Temperature (T_{Op}). The prevailing mean temperature was taken as the mean computed from NIMET data. From the inputted values, the Operative Temperature (T_{Op})

was derived to be 32.93^{0}C for the study which is warm and moderate heat stress, as given on the

PET scale. Table 6 summarizes the mean of all measured parameters.

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Table 6: Overall mean of variables.

Air perature (^{0}C)	Relative Humidity (%)	Wind Speed (m/s)	Mean Radiant perature (^{0}C)	Operative perature (^{0}C)	Prevailing Mean Outdoor perature (^{0}C)
30.96	**74.13**	**3.18**	**49.70**	**32.93**	**28.00**

Source: Researchers' fieldwork (2024).

CONCLUSION

The dynamic nature of outdoor environment has made the study within outdoor space quite challenging. However, these challenges must be faced head on. Amongst the microclimatic variables that makes the outdoor space unconducive, relative humidity, air temperature and winds speed were study to compute for the operative temperature (T_{Op}) within the studied areas. The study reveals that operative temperature given by ASHRAE 55 standard (2021) for upper limit temperature outdoors for any activity was exceeded within the studied areas. Despite these challenges, the users still find adaptive ways to make use of the outdoor spaces as they go about their various activities. In the quest for a better and sustainable environment, outdoor spaces, especially within a micro-setting, cannot be overlooked as most activities happen within these spaces more often than in the general outdoor spaces like parks that often experience usage only base on occasions. The design of these spaces within the hospitals settings as an integral part and followed to construction and implementing will go a long way in making a more friendly outdoor spaces within the hospitals and hence improve on the operative temperature (T_{Op}) which further reduces the risks of heat related illness.

Sustainability within the confines of the built environment suggests that all outdoor spaces of hospital be inclusively designed. One of the major observed setbacks in the use of the outdoor space is the lack of inclusiveness of design**.** The outdoor spaces observed appear to be disjointed spaces which were set into use as an afterthought, or as the need arises. This pattern further proves the need for such spaces to be designed with the consideration of the end users' adaptive behaviours within the hospital outdoor spaces. An awareness campaign should be launched, on the hazards of the heat related illness that users are vulnerable to within these spaces.

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