Technology-Integrating Passive Design for Improving Outdoor Thermal Comfort in Gazebo Structures: Empirical and Simulation Evidence from Lagos Mainland, Nigeria

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Abstract:
Purpose-*The study investigates the application of emerging technologies to enhance outdoor thermal comfort and sustainable design in gazebo structures, focusing on Lagos Mainland, Nigeria. It responds to the challenges posted by the tropical climate. Including high temperatures, humidity, and limited green infrastructure.*

Design/methodology/approach-*A case study approach was employed. The research combined field measurements of key thermal comfort indices such as air temperature, relative humidity, and surface temperature with digital simulations using Building Information Modelling (BIM) software to assess various design interventions.*

Findings-*Preliminary results show that integrating passive cooling techniques and smart shading systems can reduce internal gazebo temperatures by up to 5°C. This improvement enhances user comfort and encourages greater use of outdoor public spaces.*

Conclusion/Theoretical/Social/Practical Implications-*Scalable suggestions for integrating cutting-edge technologies into the architecture of outdoor public spaces are provided by the study. By addressing sustainability's social and environmental facets, the findings support planning for climate adaptation and urban resilience. However, the study only looks at Lagos Mainland, the various infrastructures and resource availability. The Technical know-how could also have an impact on a wider application.*

Originality/Value-*Through the integration of technology-driven design concepts, this study offers a workable model for improving outdoor thermal comfort in tropical metropolitan areas. It draws attention to how quickly urbanising cities might benefit from sustainable, climate-responsive public space initiatives.*

Keywords: Emerging Technologies, Gazebo Design, Outdoor Thermal Comfort, Sustainable Architecture, Tropical Climate Design.

Introduction

The increase in the outdoor thermal stress on tropical metropolitan areas such as Lagos Mainland, Nigeria, is attributed to high temperatures, high humidity, and the urban heat island (UHI) phenomenon. Two characteristics of the urban region of Lagos include land surface temperature and urban-accelerated heat stress. The growth and development of Lagos is directly associated with a 2.16°C increase in surface temperature over the period 1984 to 2019, leading to moderate heat stress to severe heat stress. Also, high-resolution urban climate schemes are numerically simulated to show that urban districts of lower socioeconomic status are subjected to hot-weather conditions over 90 percent of the time and that heat stress is widespread, particularly at night in densely populated districts. They can tell the key causes that lead to the occurrence of the behaviour. In this case, gazebos, the most common covered areas at homes, parks, restaurants, and event venues, practically provide no communal area or shade. However, they tend to be made using traditional material and lack the flexibility of climate design specificities, which means that they are unable to control the inside temperature (Obe et al., 2024). A gazebo is an open-sided, free-standing roofed structure in a garden, park or courtyard, usually intended to shelter individuals, offer shade and a place to congregate. In the built environment, it improves aesthetic nature, aids socialisation, provides climatic shelter against sun and rain, and a focal point that improves spacing and comfort of users within the outdoor settings. Innovative methods of using thermal comfort and environmental sustainability related to new technologies such as smart sensors, climate-adaptive materials, passive cooling, and intelligent control systems are provided. Artificial intelligence (AI)-based data-driven adaptive systems can realise data-driven adaptive strategies and balance comfort and energy consumption, which is mostly applied to interior applications. Other passive cooling methods that may be employed to enhance the comfort in the outdoors include green facades, evaporative air-cooling systems, and radiative sky cooling surfaces. Green facades also have the potential to improve air quality and thermal comfort in tropical urban centres by lowering the surface temperatures by 2-5 degrees Celsius through both evapotranspiration and shadowing. Naturally, such tactics help to achieve more general sustainability objectives such as reduced energy use and enhanced well-being. Although very common, Lagos Mainland gazebos are virtually never designed in a climate-responsive manner. The purpose of creating comfortable outdoor areas is compromised since they are usually rendered useless during the hottest part of the day due to construction using heat-retaining materials such as concrete or non-insulated metal. The UHI effect and evening temperature retention make them much less useful. Also, the design of the gazebo does not heavily rely on modern technologies, including environmental sensors, intelligent control systems, or passive cooling materials. Not only does this shortcoming reduce the range of potentially feasible heat abatement-related design interventions, but it also makes empirical testing of microclimatic performance more difficult. This result, in its turn, may also cause not only the reduction of outdoor use but also the increase of the demand of indoor cooling that consumes a lot of energy that is incompatible with more general sustainable design objectives. This paper aims to investigate the integration of emerging technologies for enhanced outdoor thermal comfort and sustainable design in gazebo structures. The primary objectives of this paper are to**:** determine user's comfort in gazebo structures; find out effective interventions thermal comfort solutions; and suggest sustainable design solutions based on simulations and field measurements.

Literature Review

Urban Design and Thermal Comfort outdoors.

Thermal comfort of outside the human body is determined by the interaction of man-made factors, for example clothing and physical activity, adaptive activity, and a physiological reaction of the human body with meteorological factors, e.g., air temperature, humidity, wind speed, and radiation exposure. In cases where climatic conditions are relatively predictable and manageable, comfort outside the building is considerably different to comfort inside, as preliminary studies by Matzarakis et. al. (2010) indicated. When outside, parameters such as radiation range of the sun, changing winds, and personal behaviours like shade, changed body posture, or an increase in activity level will become essential (Lin et al., 2017). To fight these complications, outdoor-specific indices turned out to be the most common tools in urban design studies. Since the Predicted Median Vote (PMV) was originally designed in constant-state conditions that are common indoors, the Physiological Equivalent Temperature (PET) and the Universal Thermal Climate Index (UTCI) are also considered more suitable than the PMV (Johansson et al., 2018). Field experiments (both in a warm-humid climate and temperate climate) show PEPT and UTCI are better predictors of registered thermal votes of sensation than PMV. The reason is that PMV is too often incorrect in detecting comfort levels outdoors, particularly when there is asymmetric radiators and fluctuating flow (Coccolo et al., 2016; Potchter et al., 2018). This methodological pattern was recently verified by recent reviews and bibliometric studies that have been based on analysing two design-controllable parameters as the sole ones: mean radiant temperature (Tmrt) and sky-view factor (SVF) since 2015 (Zhao et al., 2020). These are the factors that directly affect the shade and sun exposure of the social spaces. The categorical stress thresholds of the UTCI can be useful in planning urban areas which are hot and humid, and it has been advised that the thresholds put in place by temperate cities can be lower than those in tropical cities. Heat stress has been proved, time and again, to be greater than the stress levels recorded by untested parameters, in the outdoor environment in southeast Asia and Sub-Saharan Africa. This points to the relevance of field measurements and cultural calibration specific to the city of Lagos (Ogunrinde & Adebayo, 2021; Emmanuel *et. al.*, 2020).

Gazebo Design and Microclimatic Modification.

Although the amount of research done on gazebos specifically is limited, the little information known about these structures can be used to extend into other similar structures, including canopies, pavilions, courtyards, and street canyons. It has been established that high-pitched roofs encourage air to rise upwards and keep one comfortable on hot afternoons. Microclimate modelling and computational fluid dynamics (CFD) simulation with the programmes such as SOLWEIG and ENVI-met have established these effects (Acero and Herranz-Pascual, 2015). Such simulations reveal also how airflow patterns may be utilised to make miniature shelters. The use of material also affects thermal performance. Radiation burden and surface heat storage is reduced by having low emissivity and high albedo rooftop surfaces. The studies have shown that reflecting surfaces and so-called cool roofs can significantly reduce the high temperature of the canopy surfaces, a factor that is favourable to shaded occupants (Santamouris, 2016). A vegative addition, such as of the adjacent green roofs, climbing plants, or marginal trees, also provides evapo-transpirative cooling along with shade. Field measurements have shown that vegetation can reduce peak PET by 2 to 5°C in hotter areas (Shashua-Bar et al., 2011; Morakinyo et al., 2017). Based on all these findings, comfort of gazebos can be enhanced through ventilation channels as well as through reduction of SVF and placement of plants within the microclimate.

Emerging Technologies and Sustainability

This section is further sub-divided to look at particular technological and design strategies that combine the sustainability concepts with effective strategies on enhancing outdoor thermal comfort.

a) Smart materials: More applications that would be applied to enhance outdoor comfort have surfaced that will also contribute to the development of environmental objectives. Examples of smart materials that can potentially be used to minimise temperature changes throughout the day are phase-change materials (PCM) which will be integrated into thin roof panels or coats through the assimilation and release of latent heat (Cabeza et al., 2011; Kalnaes and Jelle, 2015). Most studies have concentrated on the construction of envelopes but experimental uses indicate that PCMs may be utilised in lightweight outdoor covers where the sun is a major stressor. According to Santamouris (2020), reflective cool and super-cool coating is a low-cost, efficient way of minimising the heat loss of radiant heat to small roofs.

b) *Passive Methods*: Passive methods remain important even in tropical climates. Since 2015, meta-analyses have reported evaporative cooling and lower Trustful dimensioning parameters, such as minimum crown sizes and leaf area coverages of shading trees or soil depths of operating green roofs, and are offered by water features, porous facades, deciduous trees, climbing plants, and porous pavement (Zölch et al., 2016; Norton et al., 2015). Humid environments, such as Lagos, where air circulation is critical need permeable walls, a high roof circulation, and carefully planned openings.

c) Adaptive Control and Internet of Things (IoT-Based) Monitoring: IoT-based monitoring and adaptive control are two rather recent technologies. Cheap sensor networks which give real time data on wind, temperature, humidity and globe temperature make the dynamic estimation of PET and UTCI possible. Wearable sensors allow more occupant-centred assessments to be done and extrapolate such measurements back to occupant zones. It has recently been able to offer data-driven fan control, misting equipment, or controllable louvers via the user interface control systems of dashboard or building information modelling (BIM) (Zhao et al., 2019; Conte et al., 2021). In the case of long-term research, the systems support.

Climate Background of Lagos Mainland

The metropolitan areas of Lagos on the mainland are a good example of how hot, muggy weather is a challenge. The city is characterised by long wet seasons, warm evenings, and humidity that is always high. According to Balogun (2019), it was quoted that the research has indicated that the land surface temperatures have increased approximately by 2°C in the last forty years since 1980s and the urban heat island (UHI) phenomenon is getting worse. Thus, the air temperature differences between city and rural areas have been the greatest in the districts of the Lagos mainland because of the high population density and the low cover of vegetation; some reports have shown differences of up to 7ºC (Akinbami et al., 2020).

The number of heat-stress days in Nigeria is also on the rise, with Lagos being amalgamated to have moderate to strong heat stress through the UTCI assessment of the station data, and reanalysis (Ogunrinde and Adebayo, 2021). As the results of the research show, there is a social and economic weakness: even populations with low incomes are never spared, as they do not have proper ventilation and shade. Air temperature is not the primary source of stress of lightweight buildings such as gazebos. Emmanuel et al. (2020) argue that the level of comfort around the gazebos is largely dependent on the speed of wind and radiant load due to the high-humidity factor which inhibits cooling impact. This setting highlights the fact that it has become so important to evaluate Lagos-specific design and technology choices as opposed to mere reliance on models designed in places outside Lagos. In developing sustainable outdoor thermal comfort solutions to be applied in gazebos, there is the need to appreciate small local climatic concerns, sociocultural adaptation measures, and performances of materials utilised around gazebos.

Conceptual Framework and Study Variables

The analysis of outdoor thermal comfort in cities requires the combination of objective measurements of the environment and subjective variables of human perception. Past research has highlighted the fact that thermal comfort in the outdoor environment considers a set of interrelations between meteorological parameters, derived thermal indicators and behavioural or psychological effects of the users (Matzarakis et al., 2010; Potchter et al., 2018; Johansson et al., 2018). Using this theoretical background, this study operationalises three types of variables, including, objective environmental variables, derived thermal comfort indices, and subjective perception variables.

a) Objectives Environmental Variables: The objective environmental variables are the measurable climatic parameters which have a direct effect on the outdoor thermal conditions. These are the air temperature, humidity, wind speed, globe temperature and the direct sunlight. One of the factors of human thermal sensation that are of utmost importance is air temperature, especially in tropical regions, where the long-term effects of high temperatures may cause heat stress (Ogunrinde & Adebayo, 2021). Relative humidity influences the cooling effect of the body by evaporation and perspiration, and thus, it is a significant factor in warm-humid climates like Lagos (Emmanuel et al., 2020). The speed of the wind also affects the convective heat loss and could make a significant contribution to perceived comfort through better natural ventilation of outdoor buildings (Lin et al., 2017). Globe temperature is a typical variable of outdoor comfort research in order to demonstrate the amount of radiant heat exposure of nearby surfaces and solar radiation (Johansson et al., 2018). Besides this, the direct exposure to the sun impacts on the mean radiant temperature felt by individuals in the outdoor areas and thus is a significant parameter in designing shaded areas like gazebos (Matzarakis et al., 2010). Such environmental parameters were determined by field measurements in order to determine the baseline microclimatic conditions of the sampled gazebo structures.

b) Derived Thermal Indices: Environmental variables are frequently grouped together into composite thermal indices to derive a more detailed analysis of thermal comfort. This paper works with two most commonly used indexes namely Physiological Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI). Physiological Equivalent Temperature (PET) is widely applied in the research of thermal comfort in the outdoor setting since it transforms the complex weather conditions into an equivalent temperature that illustrates the thermal sensation of humans (Matzarakis et al., 2010). It combines the values of air temperature, humidity, wind speed and radiation to give a standard measure of comfort. On the same note, Universal Thermal Climate Index (UTCI) has been implemented as a universal protocol to assess outdoor thermal stress and is especially suitable in comparing thermal conditions within various climatic scenarios (Potchter et al., 2018). UTCI is also popular in urban climate studies as it considers physiological interactions between temperature, wind, humidity, and radiation on the human body (Johansson et al., 2018). This study applied both of them to measure the thermal performance of gazebo environments and compare them with accepted thermal comfort limits.

c) *Subjective Perception Variables*: Although objective measurements are useful in capturing data regarding the environment, variables relating to the experience of the participants in relation to the gazebo were also necessary to examine. Such variables include: Perceived thermal comfort, intensity of heat, and air movement - all of these variables relate to the physical environment of the gazebo, but from the perspective of the individuals who entered and spent time within the gazebo. For example, the thermal comfort of the gazebo will correlate to the level of satisfaction of the individuals who entered the gazebo, the intensity of the heat will correlate to the feeling of the individuals within the gazebo of the thermal environment, and air movement will correlate to the feeling of individuals of the ventilation of the gazebo. Previous research has demonstrated that subjective perception factors are crucial for adaptive comfort behavior, especially in outdoor public areas where users modify their posture, activity level, or position in response to environmental factors (Nikolopoulou & Steemers, 2003; Lin et al., 2017).

The study provides a more thorough investigation of thermal comfort conditions in gazebo structure by fusing objective environmental data with subjective user opinion. The variables collectively guided the design of the questionnaire survey and the statistical analysis used to evaluate environmental performance and user experience.

Research Methods

The methodology explains the study area, the research design, data collection procedures, data analysis tools, and intervention techniques used to assess the outdoor thermal comfort and the performance of sustainable technologies in the chosen gazebos.

The case study was on Ndubuisi Kanu Park, Alausa, Lagos Mainland, because gazebos are frequently used there. Accessibility, representativeness, and user consent were also used to select the site. The park offers a controlled but realistic outdoor thermal comfort testing to imitate a common Lagos urban green space. The location was selected due to several criteria, such as user interest in the participation, accessibility by the population, and similarity to typical urban microclimates. Due to the tropical coastal climate that causes high temperatures, humidity, and irregular winds, the region is an appropriate location to investigate the outdoor thermal comfort solutions (Adekunle et al., 2018).

Environmental monitoring, simulation modelling, and qualitative feedback methods were employed as a mixed-methods approach. This experiment included user feedback, simulated microclimate, and environmental monitoring that made possible the overall study of the impact of thermal comfort and the efficiency of new technology. Mixed-method has been proposed in a variety of studies in the field of thermal comfort mainly because of its ability to triangulate data and enhance the reliability of results (Matzarakis et al., 2010). Data was collected to address the three research objectives.

User Feedback: Thermal comfort perception, level of satisfaction, and usage pattern: Ultimately, user attitudes of the gazebos were gathered using structured questionnaires and interviews carried out on the users of the gazebos. Likert-scale items and open-ended items were included in the question to assure both quantitative analysis and open-ended data. This follows the past literature that has emphasised the need to combine subjective and objective measurements to obtain a complete picture of outdoor thermal comfort (Huang et al., 2017).

Field Measurements: Microclimatic parameters such as temperature of air, humidity, wind speed, and temperature of globe were measured at various points inside and outside the gazebos. Data were recorded by using IoT-based gadgets and handheld sensors to capture data at all times. The videos were recorded at peak and off-peak times to record how much microclimatic variation was caused by solar radiation and human presence (Chung and Chun, 2021).

Simulation Modelling*:* The programmes of ENVI-met computer software were applied in order to simulate the microclimatic conditions both indoors and outdoors, inside and outside the gazebos. ENVI-met can simulate three-dimensional outdoor environments, including how vegetation, building materials, and urban geometry influence thermal comfort (Fröhlich et al., 2019).

Sensors and Monitoring Hardware*:* Hardware was assembled on Arduino with DHT22 sensors to measure the temperature and humidity and cup anemometers to measure the wind speed. In this case, the IoT was implemented to measure and provide real-time measurements and facilitate an appropriate, temporal analysis of the changes in the microclimate (Patil et al., 2019).

The thermal comfort indices: Physiologic Equivalent Temperature and the Universal Thermal Climate Index, were calculated on the basis of the obtained data, which were used as the criterion of the definition of the thermal comfort of various environmental conditions. Widely studied outdoor human comfort under urban tropical conditions has been using these indices (Havenith et al., 2016).

Three gazebos were assessed using some help from a combination of passive and smart technologies. Roofing materials that are reflective helped to reduce heat gain, planting of shrubs at strategic places to create shade, and automatic louvered vents with ventilation were introduced. Measurement before intervention and after intervention were compared to determine the effectiveness of the improvements in enhancing thermal comfort. Research has shown that this approach has the potential to substantially enhance outdoor thermal comfort in cities and towns via passive design with innovative technologies (Olajide et al., 2020).

Findings and Discussion

Demographic Information

Table 1 shows that there were 20 participants. 60% (n = 12) of the responders were men, and 40% (n = 8) were women, according to the sex distribution. Sixty percent of the respondents (n = 12) were between ages 25 and 34. Less representation was found for other age groups, with 5% (n = 1) older than 54, 20% (n = 4) between 35 and 344, 10% (n = 2) between 45 and 54, and 5% (n = 1) between 18 and 24. With frequency of use, 40% (n = 8) of the participants reported using the service occasionally, 25% (n = 5) reported using it somewhat, and the same amount of 25% (n = 5) reported using it extremely frequently. Just 10% (n = 2) reported using it frequently.

In order to capture the demographic properties, the perceptions of users in relation to thermal comfort, and their perception of the sustainability and technological improvements in the gazebo set-up, descriptive statistics were calculated on all the variables in the survey.

TABLE 1. Demographic Data (gender distribution of participants/frequency of use)

Variable	Category	Frequency	Percent (%)
Gender	Male	12	60.0
	Female	8	40.0
Age Group	18-24	1	5.0
	25–34	12	60.0
	35–44	4	20.0
	45–54	2	10.0
	54 and above	1	5.0
Frequency of Use of Ndubuisi Kanu Park	Rarely	5	25.0
	Occasionally	8	40.0
	Frequently	2	10.0
	Very Frequently	5	25.0

Comfort Level in Gazebo Structures

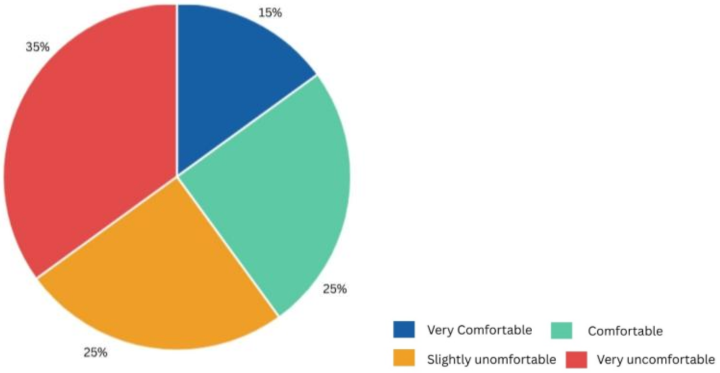

Figure 1: User’s Comfort Level in Gazebo Structures

Figure 1 shows a lean toward discomfort beacause 60% of the users fall in the uncomfortable range with very uncomfortable being 35%

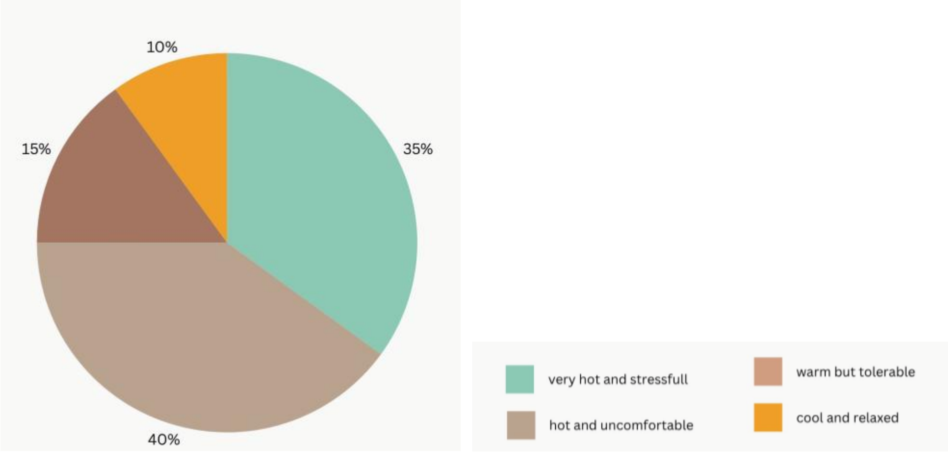

Figure 2: User’s Feeling During Hot Peak Hours in the Day

Figure 2 sheds light that majority of the respondents (65%) felt hot and very hot during peak hours, only 10% felt cool and relaxed, indicating that the temperature in the gazebo structure during peak hours was inadequate for comfort.

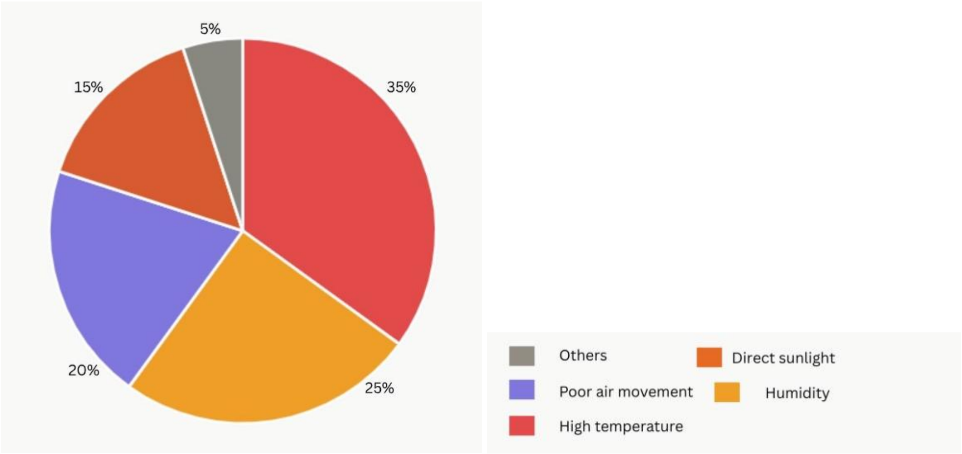

Figure 3: Main Source of Discomfort

Figure 3 shows that high temperature stands out as the primary source of discomfort factor at 35%, followed by humidity at 25%. Together, both thermal-related factors account for 60% of complaints, suggesting that moisture management should be the top design priority.

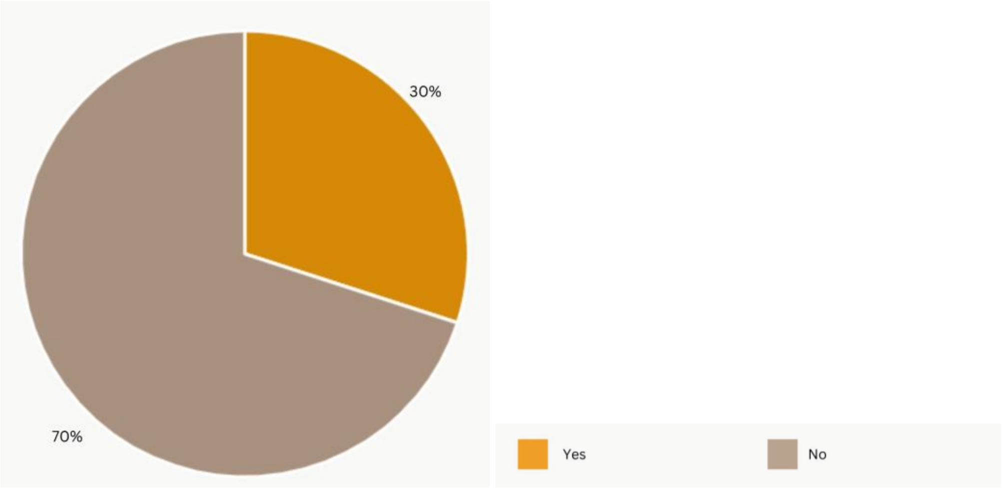

Figure 4: Adequacy of Shade Provision

Figure 4 reveals that majority (70%) of the respondents felt the gazebo does not provide adequate shade. This aligns with the results in Figures 1 and 2 where user's comfort level showed 35% very uncomfortable and 40% feeling hot and uncomfortable during the hot peak hours. Only 30% felt satisfied with the current shading. This points to a clear gap in gazebo’s shading performance and calls for structural improvement.

Additionally, Influence of Demographic Characteristics on Thermal Perception was also examined to further establish the comfortability of the gazebo structure. The crosstabs and Chi-square test was carried out between variables of age, feeling during hot periods, gender and comfort rating. In order to test whether the perception of heat in hot season among the various age groups are different, a cross tabulation was done between age and reported level of feeling. This will assist in establishing trends of thermal sensitivity amongst users of other age groups. Table 2 shows findings of test done with IBM SPSS Statistics.

TABLE 2: Crosstabulation of Age Group and Feeling during Hot Periods

Age Group	Feeling 1	Feeling 2	Feeling 3	Feeling 4	Total
18-24 (1)	1 (8.3%)	2 (16.7%)	7 (58.3%)	2 (16.7%)	12 (100%)
25–34 (2)	0 (0.0%)	0 (0.0%)	1 (100.0%)	0 (0.0%)	1 (100%)
35–44 (3)	0 (0.0%)	2 (50.0%)	1 (25.0%)	1 (25.0%)	4 (100%)
45–54 (4)	0 (0.0%)	1 (50.0%)	0 (0.0%)	1 (50.0%)	2 (100%)
54 and above (5)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (100.0%)	1 (100%)
Total	**1 (5.0%)**	**5 (25.0%)**	**9 (45.0%)**	**5 (25.0%)**	**20 (100%)**

Note: Feeling 1 to Feeling 4 indicates the degree of hotness in ascending order.

The findings from Table 4 indicates that most of the respondents (45%) experienced Feeling 3 in hot seasons, which is indicative of the moderate thermal discomfort. The largest category of young people (18-24 age group) chose Feeling 3 (58.3%), which means that there has been a relatively tolerable yet observable amount of heat stress. Conversely, the elderly age groups show the inclination of increased discomfort levels. As an example, 50% of the respondents with the age groups 45-54 years indicated Feeling 4 and the lone respondent with the age group 54 years and above indicated Feeling 4 as well thus indicating more sensitivity to higher temperatures as the age advances. Respondents within 35-44 years showed more diversified reactions which pointed to mixed thermal experiences. These results indicate the possibility of age as a factor of thermal perception in outdoor gazebos. Heat discomfort seems to be more of a problem to older users, which is why better shading performance, improved air movement, and passive cooling should be provided. To be inclusive in terms of thermal planning by designing structures of gazebos would therefore help in promoting comfort among different age brackets especially in warm tropical climates.

TABLE 3. Chi-square Test and Effect Size

Test	Value	df	p-value	Interpretation
Pearson Chi-Square	9.185	12	0.687	Not significant
Likelihood Ratio	10.150	12	0.603	Not significant
Linear-by-Linear Association	0.636	1	0.425	Not significant
Cramer's V	0.391	–	0.687	Moderate effect (ns)
Phi	0.678	–	0.687	Moderate effect (ns)
N of Valid Cases	20			

The Pearson Chi Square value χ^2 (12, N = 20) = 9.19, p = 0.687. demonstrates that the correlation between age category and reported thermal feeling during hot conditions does not have a statistically significant value at the 0.05 level of significance. This result is validated by Likelihood Ratio test (p = 0.603) and Linear by Linear Association test (p = 0.425), which also indicate non significance. Effect size measures (Cramer's V = 0.391, Phi = 0.678) indicates that the association between them is of moderate strength, the high p values lead to the conclusion that these effects, however, are not statistically sound in this sample. Likewise, there was not any statistically significant correlation between the gender and the rating of comfort, χ 2 (3, N = 20) = 1.11, p =.774.

Table 4 shows the self-reported comfort rating by gender. This analysis was done to respond to the following questions: (1) can perceived thermal comfort in the study environment differ significantly between the respondents of both sexes, and (2) to quantify the strength of an observed relationship.

TABLE 4. Crosstabulation of Gender and Comfort Rating (1-5)

Gender	Comfort Rating = 2	Comfort Rating = 3	Comfort Rating = 4	Comfort Rating = 5	Total
Male (1)	4 (33.3%)	4 (33.3%)	3 (25.0%)	1 (8.3%)	12 (100%)
Female (2)	2 (25.0%)	4 (50.0%)	2 (25.0%)	0 (0.0%)	8 (100%)
Total	**6 (30.0%)**	**8 (40.0%)**	**5 (25.0%)**	**1 (5.0%)**	**20 (100%)**

The findings indicate that the male and female respondents mostly rated their comfort at the level 3 and 4, with the most common rating of 3 being the most prevalent in general (40%). Male respondents were a bit more spread in the degrees of comfort, whereas female respondents were more concentrated on the 3 (50) and none on the highest level of comfort rating (5) category. However, the Pearson Chi-Square test (table 5a) has revealed that there is no statistically significant difference between the gender and comfort rating with χ^2 (3, N = 20) = 1.11 and p =.774. Seeing that the p-value is significantly higher than 0.05, it is impossible to reject the null hypothesis of the absence of a relationship between gender and perceived comfort.

TABLE 5. Chi-Square Test of Independence between Gender and Comfort Rating

Test	Value	df	p-value	Interpretation
Pearson Chi-Square	1.111	3	0.774	Not significant
Likelihood Ratio	1.462	3	0.691	Not significant
Linear-by-Linear Association	0.042	1	0.837	Not significant
Cramer's V	0.236	–	0.774	Small effect (ns)
Phi	0.236	–	0.774	Small effect (ns)
N of Valid Cases	20			

There was no significant correlation between gender and comfort rating, according to the Chi-square test of independence (Table 4a), with χ^2 (3, N = 20) = 1.11 and p =.774. Only a weak association is suggested by effect size measurements (Cramer's V = 0.236, Phi = 0.236), which are not statistically significant. The fact that both male and female participants showed comparable rating patterns suggests that respondents' comfort ratings were not significantly influenced by gender. Overall, the results suggest that there is a relative similarity in the experience of thermal comfort between genders in the study environment. It is possible that the small differences in percentage distribution can be attributed to sampling error as opposed to a systematic gender-based difference.

Field Measurement Results

The microclimatic measurements recorded inside the gazebo structures showed that the temperatures of the air measured at afternoons are between 34oC and 36oC, which means that thermal stress is high during the afternoons. The amount of wind noted in the gazebos was on the average less than 0.8 m/s indicating that there was little natural ventilation in the gazebos. These Conditions state that although the gazebos provided protection against the direct sunlight radiation, the current design does not allow the airflow enough or reduce the heat effectively.

Perception by the User about the Environmental Conditions.

User surveys also confirm of the environmental discomfort experienced in the gazebos. The average thermal comfort score was 3.05 on a five-point scale which showed that the comfort level of the respondent was moderate.

However, some environmental factors that contributes to discomfort were identified:

- 40% of the respondents found high temperature as the main factor of discomfort.
- 30% of the respondents complained of poor air movement.
- 30 percent of the respondents reported direct exposure to the sun.

These findings imply that the current gazebo structures have partial shade coverings but are inadequate in reducing the joint impacts of both the sun and high temperature ambient.

Effective Interventions for Thermal Comfort Solutions

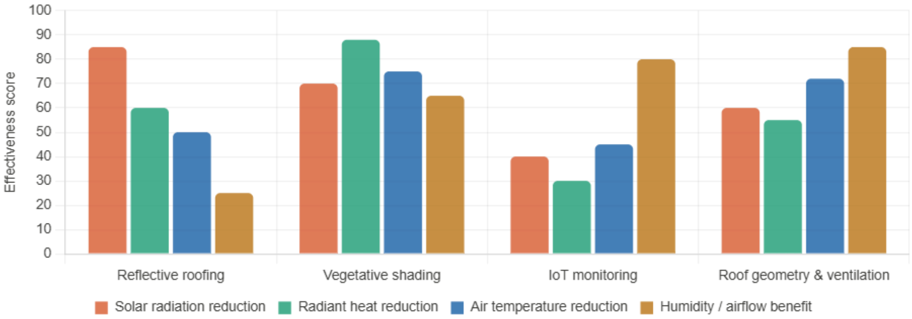

Figure 5: Statistical Relationships of Environmental Parameters

The statistical relationships point to the environmental parameters to be considered in order to enhance outdoor thermal comfort. On the findings, a number of new technologies and design solutions were established as effective interventions towards alleviating thermal comfort in gazebo structures. These include:

- Reflective roofing covers, which minimise the solar heat and surface temperature. Vegetative shading systems, e.g. green roof or vegetation surrounding the building, which cool down radiant heat by shading and evapotranspiration.
- Environmental monitoring systems based on IoT, enabling one to track the temperature, humidity, and wind in real-time.
- Efficient roof geometry and passive ventilation, which help to increase air circulation and minimise the heat retention.

These technologies are specifically focusing on the identified environmental stressors as a result of the statistical analysis and thus offer a scientific foundation upon which the enhancement of thermal comfort within which the exterior pavilion buildings can be based.

Sustainable Design Solutions Based on Simulations and Field Measurements.

The objective combined field measurement data with microclimatic simulations to develop sustainable design strategies that would enhance gazebo performance.

Simulation Results

The ENVI-met simulation modelling was done to determine the effectiveness of various technological and passive design interventions. The ENVI-met microclimate model evaluated the possibility of using design intervention to enhance the thermal conditions of gazebo structures in Lagos climatic conditions. The findings indicate that reflective roofing material has decreased the temperature of roof surface by about 3.2 o C because the material has high albedo thus reflecting more of the solar radiation rather than absorbing it. This is beneficial in minimising the amount of heat transfer into the shaded area underneath the gazebo and contributes to the production of a colder microclimate.

The simulation showed that vegetative shading (trees or landscaping) had a negative effect on the mean radiant temperature, direct sun rays were blocked and evaporative cooling was also facilitated. However, the Physiological Equivalent Temperature (PET) decrease of 45o C in hot afternoon hours when both reflective roofing and vegetation were used was called a significant positive change in perceived outdoor thermal comfort. These results indicate how reflective material and vegetation-based shading are effective to enhance thermal performance of gazebos in tropical areas.

TABLE 6: Simulation-Based Assessment of Design Interventions for Improving Thermal Comfort in Gazebo Structures

Design Intervention	Environmental Variable Affected	Observed Thermal Improvement	Implication for Gazebo Design
Reflective roofing materials	Surface temperature	Reduction of approximately **3.2°C**	Minimises solar heat absorption and lowers roof heat gain
Vegetation shading (trees/green elements)	Mean radiant temperature	Noticeable reduction in radiant heat exposure	Provides shading and evaporative cooling around the structure
Combined reflective roofing and vegetation	Physiological Equivalent Temperature (PET)	Reduction of **4–5°C** in peak thermal stress conditions	Significantly improves outdoor thermal comfort for users

These results support the fact that combining passive cooling methods with technology-oriented monitoring systems can help a great deal to enhance outdoor thermal comfort conditions.

Integrated Interpretation of Findings

On comparing the results of the simulation with the empirical data of the survey, three key patterns stand out:

1. Through his field measurements, it is established that there is a high thermal stress presence in the current gazebos.
2. The key discomfort drivers that are determined by statistical analysis are solar radiations and temperature.
3. It can be seen through simulation modelling that the targeted technological interventions can effectively alleviate these stressors.

Sustainable Design Solutions

Based on the combined findings, the sustainable design strategies recommended for gazebo structures in tropical urban areas are as follows:

- Use reflective roofing materials with high albedo in order to minimise heat intake.
- Include vegetation-based shading like climbing plants and shrubs.
- Enhance roof height and openings of ventilation to enhance air flow.
- Install IoT-based systems of environmental monitoring in order to manage microclimate in real time.

These interventions are a combination, which encompasses passive cooling techniques and emerging technologies which improve the thermal comfort in outdoor spaces.

Discussion of Findings

User’s comfort level in gazebo structures

The results Show participants who use it. The gazebo structures It usually causes discomfort. The heat. A large number of users (60%) They express they are restless, and 35% They declare they are very anxious. This is supported by answers peak hours, when 65% Users assert, they feel warm or very warm. It shows it the gazebo does not furnish enough thermal relief Under most important times of the day. The main environmental factors Caused by: High Temperature (35% - 40%), humidity (25% - 30%), Poor air movement (30%), Direct sunlight (30%).

In addition, 70% Users reported about Insufficient shading, which indicates that the structural design does not properly blocked sun rays. Field data supports this, showing low wind speed (< 0.8 m/ s) and high air temperatures (34– 36° C), which both indicate inadequate ventilation.

The consistency of discomfort in groups indicates that there is a problem in design related rather than user specific demographic analysis (age and gender).

Overall, the results indicates that the gazebo offer insufficient environmental protection to reduce heat stress in a tropical climate

Effective interventions for Thermal Comfort Solutions

The results of Objective 2 to demonstrate a robust correlation between focused design interventions and environmental stressors. Statistical correlations indicate that: High temperatures and direct sun exposure is a negative correlation with comfort, the main causes of discomfort are these factors. This led to the identification of numerous successful interventions:

Materials for reflective roofing: By reflecting radiation, they reduce surface and interior temperatures by lowering solar heat intake.

Systems for Vegetative Shading: Climbing plants and trees are examples of green features. They offer: Shadow, which lowers radiant heat and increase the microclimate throughout evaporative cooling.

Strategy for Passive Ventilation: The problem of low wind speed seen in the field is solved by improved airflow optimised roof geometry and apertures.

Environmental monitoring with IoT: Intelligent system allows real- time monitoring of: humidity, temperature wind conditions, this makes it possible to regulate the microclimate. These interventions are data- driven and contextual because they directly address the identified sources of discomfort. Their effectiveness is further supported by simulation results, which shows temperature decreases to 3.2°C (roof level) and 4 - 5°C (overall improvement in thermal comfort) when combined.

Integration of Empirical Findings with Simulation issues for Sustainable Design

The third objective focuses on developing sustainable design recommendations grounded on both field measurements and simulation modelling.

Field measures recorded peak afternoon temperatures between 34 °C and 36 °C under unmodified conditions, with low internal wind speed (below 0.8 m/ s), indicating limited natural ventilation effectiveness. These measurements corroborate user reports of high temperature discomfort. Simulation modelling further demonstrated that:

- Reflective roofing reduced surface temperatures by roughly 3.2 °C
- foliage reduced mean radiant temperature
- Combined interventions produced the topmost thermal enhancement

When interpreted alongside the survey findings, a clear pattern emerges:

- Empirical data confirm moderate comfort and heat- related stress.
- Correlation analysis identifies high temperature and solar exposure as primary discomfort motorists.
- Simulation results demonstrate that targeted technological strategies can reduce these stressors.

To encourage a sustainable design solution, the following design suggestions are thus offered in light of the analysis's findings:

- It is possible to use roofing materials with a high albedo.
- Shade from plants can be arranged both inside and outside the gazebo.
- It is possible to raise both the roof's height and ventilation.
- Smart monitoring systems that use little energy can be used.

The actual data gathered from the study demonstrates the demographic neutrality of the perception patterns, provides the baseline performance of existing gazebos, and highlights the key elements influencing environmental discomfort. The information gathered will be utilised in the development of sustainable design principles suitable for hot urban environments like Lagos Mainland and in the simulation-based assessment of innovative technologies.

Conclusion and Recommendation

Conclusion

The key Conclusions drawn from the findings of the objectives are as follows:

- The existing structure offers low to moderate thermal comfort due to high temperatures, inadequate shading making them ineffective during peak heat periods.

- Targeted interventions such as reflective roofing materials, and improved vegetations are effective in reducing heat stress and significantly improving outdoor thermal comfort in gazebo structures.

- The simulation data show that a passive and technological design solution has the most value for improving the gazebo's microclimate in a tropical region.

Recommendations

Three recommendations can be made based on the findings above:

1. Gazebo designs should be climatic-responsive, incorporating Enhanced shading systems and natural ventilation.

2. The design and planning of gazebo should adopt an integrated approach that combines passive cooling strategies, smart technologies to achieve sustainable and adaptive thermal comfort solutions.

3. In tropical cities, urban planning regulations should promote climate-responsive design strategies for outdoor public areas.

Contribution to Knowledge

The study contributes new insights to outdoor thermal comfort research by demonstrating that while passive methods are the essence, they can be made much more functional in tropical humid weather if supplemented with active monitoring systems. As believed by Lenzholzer et al. (2018), the study confirms the value of reflective surfaces, vegetation, and ventilation in alleviating heat stress. It also underpins Chatzidimitriou and Yannas' (2019) arguments, stressing the need for culturally and climatically sensitive design, in showing that Lagos's building occupants over a wide majority prefer natural ventilation and shading to mechanical cooling. At the same time, gendered difference in heat sensitivity is also backed up by earlier work by Nikolopoulou and Steemers (2003), extending the usefulness of their findings to a tropical African environment.

The following succinctly describes how this study adds to the body of knowledge already available on outdoor thermal comfort:

1) In order to address the geographic underrepresentation in outdoor thermal comfort studies, the paper presents empirical data from a tropical continent.
2) The study shows that combining affordable IoT technologies with passive cooling techniques works well.
3) The study provides a paradigm for designing outdoor public spaces with micro-architecture in gazebos.

Implications for Future Research

The research operated in one case study of the Lagos Mainland only but provided useful data. Future research must use case studies to cover greater number of cities, cultures and climatic areas to reflect variations in user perception and microclimatic performance. Multi-season longitudinal research would be more straightforward in verifying the consistency and longevity of identified benefits. Future research might look into building gazebos with bio-based materials such as bamboo or recycled composites and also how the Internet of Things (IoT) networks can be used to control things in real-time. The comparative studies of high and low technology solutions can possibly better the cost-benefit analysis and can influence the process of adopting policies that would be specific to a particular situation.

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