Journal of Environment Sciences (JOES) ISSN 1118-8936 (Print); 3043-6176 (Online), Vol. 23, No. 2, December 2024
Published by the Faculty of Environmental Sciences, University of Jos
https://journals.unijos.edu.ng/ojs/index.php/joes/
https://doi.org/10.5281/zenodo.14888173

An Assessment of the Influence of Passive Cooling Strategies on Level of Thermal Comfort in Selected Office Buildings in Abuja, Nigeria

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ABSTRACT

Buildings contribute significantly to global energy consumption, with cooling needs forming a substantial part of this demand. Passive cooling techniques present an energy-efficient alternative, promoting occupant comfort while reducing energy costs. This study analyzed the influence of passive cooling strategies on thermal comfort within office buildings in Abuja, Nigeria. Specifically, it evaluated current practices, analyzed implementation patterns, and provided recommendations for improved adoption. A quantitative research approach was employed, involving data collection through questionnaires distributed to 73 participants across three office buildings, with a response rate of 90%. The data, analyzed using both descriptive and inferential statistical techniques, revealed that most respondents (69.7%) reported discomfort. Regression analysis identified 15 significant factors affecting thermal comfort, including operable windows, courtyards, and window-to-wall area ratios, which had positive effects, while factors such as external insulation and vertical air shafts negatively impacted comfort. These findings offer insights into designing more sustainable and energy-efficient office environments, ultimately enhancing occupant well-being and productivity.

Keywords: Passive cooling, Thermal comfort, Office buildings, Sustainability, Building design.

1. INTRODUCTION

Buildings constitute a significant portion of global energy consumption, accounting for approximately 40% of total energy use, with cooling demands forming a considerable part of this energy expenditure (Cooper & Branch, 2015; IEA, 2020). This trend underscores the critical need for energy-efficient and sustainable design solutions to address growing environmental and economic concerns. Passive cooling, which relies on natural methods to regulate indoor temperatures, has emerged as a viable strategy to enhance thermal comfort while minimizing energy consumption.

Thermal comfort, as defined by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), reflects "the mental state that indicates satisfaction with the thermal environment" (American National Standards Institute, 2004). Achieving this state through passive means is particularly relevant in office buildings, where occupants spend substantial portions of their day. Office design significantly influences user satisfaction, health, and productivity, making thermal comfort a central aspect of sustainable building strategies (Antoniadou & Papadopoulos, 2017; Borghero, 2019).

Passive cooling techniques are classified into three main categories: heat protection, heat modulation, and heat dissipation (Givoni, 1998; Prieto et al., 2018). These strategies encompass the use of external shading devices, reflective finishes, thermal mass utilization, cross-ventilation, and evaporative cooling systems. When properly integrated into building designs, these approaches harness natural resources to create energy-efficient and comfortable environments (Taleb, 2014; Toe & Kubota, 2015).

Research across various building typologies has underscored the effectiveness of passive cooling in enhancing energy efficiency and occupant comfort. For instance, Yu et al. (2020) explored its implementation in residential buildings, while Díaz-López et al. (2022) examined Mediterranean schools. Firfiris et al. (2019) analyzed its relevance in livestock structures, further showcasing the adaptability of these strategies to diverse contexts. However, its specific influence on thermal comfort in office buildings, particularly in the hot and humid climate of Abuja, Nigeria, remains underexplored. While prior studies, such as those by Voss et al. (2007) and Baharun et al. (2019), have demonstrated the potential of passive cooling to improve occupant well-being and reduce energy demands, this study focuses on providing localized insights for Abuja's office buildings.

Office buildings are unique environments where thermal comfort directly impacts productivity, collaboration, and health outcomes. Decisions made during the design phase can significantly affect a building's performance over its lifecycle, making it essential to integrate energy and thermal considerations into early planning stages (De Oliveira et al., 2017; Robati et al., 2017). Additionally, environmental variables (e.g., air temperature, radiant temperature, and humidity) and personal factors (e.g., clothing and metabolic rate) must be balanced to achieve thermal comfort (Lin & Deng, 2008; Yao et al., 2009).

This study aims to bridge the existing research gap by analyzing the relationship between passive cooling strategies and thermal comfort in selected office buildings in Abuja. The objectives include evaluating current passive cooling practices, assessing their implementation patterns, and developing recommendations for improving their adoption. By focusing on the Abuja context, this research contributes to the broader discourse on sustainable building design while addressing practical challenges faced by policymakers, architects, and facility managers.

2. METHODOLOGY

This study employed a quantitative research approach to evaluate the influence of passive cooling strategies on thermal comfort in selected office buildings in Abuja, Nigeria. The quantitative methodology was deemed appropriate due to its capacity to provide high levels of accuracy in data collection and analysis, enabling the detection of trends and relationships that may be challenging to establish through other approaches.

2.1. Research Population and Sampling

The research population comprised office buildings located in Abuja, Nigeria, with over thirty (30) such buildings identified. From this population, three (3) office buildings were selected for detailed investigation using a purposive sampling technique. This non-probability sampling method was chosen due to its ability to select cases rich in information relevant to the area of interest—office buildings with diverse passive cooling features. The selection criteria included accessibility, architectural features, and location, ensuring the representativeness of the selected buildings within the broader context of Abuja.

2.2. Data Collection Instruments and Procedure

A structured questionnaire served as the primary data collection instrument, designed to capture both qualitative and quantitative data. The questionnaire was divided into three sections:

1. Section A: Socio-economic characteristics of the office users.
2. Section B: The presence and extent of implementation of passive cooling strategies.
3. Section C: The perceived thermal comfort of occupants.

The questionnaire utilized a 5-point Likert scale for responses, ranging from "Not Present at all" to "Present in all spaces" for Section B and "Not at all" to "To a large extent" for Section C.

Physical visits to the selected office buildings were conducted to administer the questionnaires and carry out on-site observations of the passive cooling strategies implemented. This allowed for direct documentation of features such as operable windows, shading devices, and courtyards. Sketches and photographs of the buildings were also taken to illustrate architectural features influencing thermal comfort, these were not included in this study.

2.3. Data Analysis Techniques

Quantitative data analysis was performed using the Statistical Product and Service Solutions (SPSS) software. Descriptive statistical techniques were used to summarize the demographic characteristics of respondents and the prevalence of passive cooling features in the buildings. In addition, inferential statistical techniques, including regression analysis and Analysis of Variance (ANOVA), were employed to identify significant factors influencing thermal comfort and to compare group differences.

The assumptions underlying the regression analysis, such as linearity, independence, and homoscedasticity, were verified to ensure the validity of results. For ANOVA, the descriptive statistics for each group were computed, and post hoc tests were performed to identify significant differences between variables. Effect sizes were also calculated to measure the strength of observed effects.

While the sample size of three buildings represents a relatively small subset of the total population, this limitation was offset by the depth of data collected and the rich contextual insights gained from the selected cases. The study acknowledges this constraint and considers it in the interpretation of findings.This study employed a quantitative research approach to evaluate the influence of passive cooling strategies on thermal comfort in selected office buildings. The quantitative methodology was deemed appropriate due to its capacity to provide high levels of accuracy in data collection and analysis, enabling the detection of trends and relationships that may be challenging to establish through other approaches. Additionally, the quantitative approach facilitated the investigation of a large sample size, enhancing the reliability and generalizability of the findings.

3. RESULTS AND DISCSSION

The study analyzed data collected from questionnaires distributed to occupants of three selected office buildings in Abuja, Nigeria. Out of 73 questionnaires distributed, 66 were returned, resulting in a response rate of 90%. The demographic characteristics of the respondents are summarized in Table 1.

Table 1: Demographic Characteristics of Respondents

Variables	Categories	Frequency (N= 66)	Percentage (%)
Gender	Male	39	59.1
	Female	27	40.9
Age	20-30 years	20	30.3
	31-40 years	12	18.2
	41-50 years	20	30.3
	Above 50 years	14	21.2
Office building	Office of the head of service	21	31.8
	Ministry of women affairs	22	33.3
	NYSC headquarters	23	34.8
Level of education	OND/HND	13	19.7
	B.Sc	38	57.6
	M.Sc	15	22.7

Thermal Comfort Analysis: The results on perceived thermal comfort indicated that 69.7% of respondents reported feeling uncomfortable, 19.7% reported being highly uncomfortable, and only 1.5% indicated comfort within their office spaces (Table 2).

Table 2: Level of thermal comfort

Level of thermal comfort	Frequency	Percent (%)	Valid Percent (%)
Highly uncomfortable	13	19.7	19.7
Uncomfortable	46	69.7	69.7
Undecided	6	9.1	9.1
Comfortable	1	1.5	1.5
Total	66	100.0	100.0

Regression analysis identified 15 significant factors influencing thermal comfort, such as operable windows, courtyards, and higher window-to-wall ratios, which had positive effects. Conversely, factors like external insulation and vertical air shafts negatively impacted comfort. Table 3 provides a summary of the regression model, Table 4 presents the ANOVA results, and Table 5 presents the regression coefficients for each variable.

Table 3: Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.942[a]	.887	.555	.39372

Table 4:ANOVA Results for Regression Model

ANOVA[a]						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	18.208	44	.414	2.669	.021[b]
	Residual	2.325	15	.155		
	Total	20.533	59			

Table 5: Regression Coefficients

Model	Standardized Coefficients	t	Sig.
	Beta		
(Constant)		1.622	.126
Use of bricks, concrete blocks etc	-.101	-.490	.632
Use of external insulation	-.852	-4.025	.001*
Use of light colours	.211	1.014	.327
Use of low mass construction to allow rapid heat-up or cooling of structure	-.016	-.079	.938
Bright interior surface colours and finishes to optimise daylighting	.332	2.264	.039*
Buffer zones are protected from direct solar radiation	.095	.486	.634
Specific spaces or functions are planned to coincide with solar orientation	.325	1.787	.094
Provision of light shelves to allow daylight to penetrate deep into the building	.559	3.148	.007*
Use of mud bricks for cooler interior	-.087	-.464	.649
Use of white/light colour external wall finishes	-.638	-3.138	.007*
Use of operable windows	.555	2.698	.017*
Presence of courtyard(s)	.853	2.298	.036*
Use central atriums, courtyards, and lobbies for optimum ventilation	-.440	-1.302	.213

Model	Standardized Coefficients	t	Sig.
	Beta		
Provision of vertical air shafts/stacks, and central exhaust paths to promote interior	-.619	-3.330	.005*
Link of the exterior and interior airflows by single-sided, cross or stack ventilation	-.089	-.624	.542
Use of roof elements for stack ventilation	.202	1.283	.219
Use of skylight, light tube and clerestory for natural illumination	-.278	-1.761	.099
Use of double roof and wall construction for ventilation within envelope	.379	2.434	.028*
Use of ventilated roof to lower heat gains through roof	-.228	-1.072	.301
Use of louvred wall for maximum ventilation control	-.377	-1.052	.309
Detailed openings to limit undesired air infiltration and ex-filtration as well as to reduce convective gains	-.337	-1.927	.073
Use of higher window to wall area ratios to maximise ventilation	.800	4.700	.000*
Use of vegetation or optimum lighting	-.755	-4.479	.000*
Use of hard landscape	-.015	-.094	.926
Use nearby landforms and structures for wind protection and summer shading	.392	1.684	.113
Use of exterior elements to direct summer wind flow into the interior	-.931	-3.396	.004*
Use of water bodies for evaporative cooling	.613	2.974	.009*
Sun Orientation (East – West)	-.288	-1.463	.164
Wind Orientation (South-West – North-West)	.482	2.940	.010*
Orientation of the building for optimum lighting, ventilation, and thermal comfort	-.326	-1.740	.102
Shading by overhangs, louvers, awnings, etc	.009	.032	.975
Shading of roof	.297	1.672	.115
Provision of shading strategies for wall exposed to sunlight sun to mitigate unwanted heat gain	.201	.869	.399
Foam, cellulose, fiberglass, and polystyrene	-.159	-.795	.439
Cavity wall	.266	1.050	.310
Phase change materials	-.079	-.270	.791
Use high mass construction with appropriate insulation to promote night ventilation	.188	1.032	.318
Location of thermal mass on the floor and wall to be exposed to direct sunlight if possible	-.702	-2.651	.018*
Large building surface area	-.122	-.581	.570
Compact building form for optimum ventilation	-.357	-2.057	.058
Shape the building to maximise exposure to wind	.094	.568	.579
Subdivision of interior to create separate heating and cooling zones	.142	.767	.455
Use of open plan interior airflow	.735	3.961	.001*
Organisation of rooms, corridors, stairwells to provide low resistance airflow path through the building	-.399	-1.954	.070

Dependent Variable: Level of Thermal comfort

3.1. Discussion

The findings of this study highlight the critical role of passive cooling strategies in enhancing thermal comfort in office buildings. Features such as operable windows, courtyards, and higher window-to-wall area ratios positively contributed to thermal comfort, aligning with previous studies (e.g., Grygierek & Sarna, 2020). These strategies enhance natural ventilation and daylighting, which are vital in a tropical climate like Abuja's.

The negative impact of external insulation and vertical air shafts underscores the need for context-specific design. Insulation materials may trap heat in tropical climates, exacerbating discomfort. This aligns with studies like Toe and Kubota (2015), which emphasize the importance of material choice in passive cooling strategies.

The Analysis of Variance (ANOVA) results further supported the regression findings, revealing statistically significant differences in thermal comfort levels across various design features ($p < 0.05$). Post hoc tests identified higher window-to-wall ratios and open-plan designs as key contributors to improved comfort. These findings validate the effectiveness of passive cooling strategies when carefully tailored to building typologies and climatic conditions.

Relevance of Demographic Characteristics: The demographic data indicated that younger occupants and those with higher educational levels reported greater sensitivity to thermal discomfort. This suggests the need for participatory design processes that consider diverse occupant preferences and thermal expectations.

3.2. Implications for Building Design

This study underscores the importance of integrating passive cooling strategies into the design and retrofitting of office buildings. Design considerations should prioritize natural ventilation, daylight optimization, and the careful selection of materials to mitigate thermal discomfort. Furthermore, architectural elements like courtyards and shading devices should be emphasized to enhance occupant well-being and energy efficiency.

4. CONCLUSION AND RECOMMENDATIONS

This study has provided valuable insights into the influence of passive cooling strategies on thermal comfort within office buildings in Abuja, Nigeria. The findings demonstrate that architectural features such as operable windows, courtyards, and higher window-to-wall area ratios significantly enhance thermal comfort by promoting natural ventilation and daylighting. Conversely, features like external insulation and vertical air shafts were found to negatively impact thermal comfort, highlighting the importance of context-specific design approaches in tropical climates.

The regression analysis identified 15 significant factors affecting thermal comfort, validating the efficacy of carefully implemented passive cooling strategies. The results emphasize the critical role of design elements in achieving sustainable, energy-efficient office environments that prioritize occupant well-being. By addressing the specific challenges of Abuja's climate, this study contributes to the broader discourse on sustainable architecture and offers practical guidance for building professionals and policymakers.

To enhance the adoption and effectiveness of passive cooling strategies in office buildings, the following recommendations are proposed:

1. Integration into Building Codes and Policies: Regulatory bodies should incorporate passive cooling strategies as mandatory design requirements in building codes. This ensures that new constructions and renovations prioritize thermal comfort and energy efficiency.
2. Awareness and Capacity Building: Educational initiatives for architects, engineers, and facility managers are essential to promote the benefits and practical implementation of passive cooling techniques. Workshops and training sessions can improve the skill set of professionals in this area.
3. Material Selection and Design Optimization: Building designers should consider materials and configurations that align with the local climate. For instance, avoiding insulation materials that trap heat in tropical settings while prioritizing features like operable windows and reflective finishes.

4. Post-Occupancy Evaluation: Regular post-occupancy evaluations should be conducted to assess the effectiveness of passive cooling strategies. Feedback from occupants can inform future design improvements and optimize building performance over time.
5. Incentives for Sustainable Design: Governments and private stakeholders should provide financial incentives, such as tax breaks or grants, to encourage the adoption of passive cooling strategies. These incentives can offset initial implementation costs and promote widespread adoption.
6. Promotion of Participatory Design: Engage building users in the design process to align passive cooling strategies with their preferences and thermal expectations. This approach ensures user satisfaction and maximizes the effectiveness of implemented features.

By adopting these recommendations, stakeholders in the built environment can significantly improve thermal comfort, energy efficiency, and overall occupant well-being in office buildings. This holistic approach aligns with global sustainability goals and promotes resilient, environmentally conscious architectural practices.

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