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Research Paper

Assessment of Current Thermal Comfort Level in Residential Buildings with Vertical Greenery Systems: A Study of Ikoyi, Nigeria

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Abstract
Urbanisation and climate change pose significant challenges to tropical cities such as Lagos, generating urban heat islands and increasing energy consumption. Vertical Greenery Systems (VGS) provide an eco-friendly option that enhances thermal comfort, mitigates heat, and promotes biodiversity in residential structures. This study assesses the current thermal comfort levels in residential buildings with VGS in Ikoyi. The study employed a mixed-method approach to select total sample frame of 15 VGS buildings using purposive sampling technique. Which 166 residents of these VGS buildings were selected for questionnaire administration. Descriptive statistical tool of percentage was used to identify types of VGS implemented and personal characteristics of respondents. The heat stress index was used to assess the current thermal comfort of the selected VGS buildings in Ikoyi, Lagos. The results indicate that the most residents were female (57.2%), majority of this resident are aged between 35-44 years (41.0%). Majority (38.0%) of residents engaged in moderate activity (1.0 met), while light clothing (0.3 clo) was prevalent (30.1%) among residents. In terms of thermal stress, majority of the VGS buildings (66.7%) were in 'caution state' which indicated mild heat stress. The study concludes that Vertical Greenery System in buildings reduce heat gain thereby enhancing the building thermal comfort.

Keywords: *Vertical Greening Systems, VGS, Thermal Comfort, Passive Cooling, Residential Building, Vertical Landscape, Ikoyi, Nigeria.*

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I. Introduction

Urbanisation and climate change pose significant challenge in tropical cities like Lagos, including amplifying heat and excessive rainfall, creating urban heat islands and increasing energy use in buildings (Ayinla and Adebisi, 2021). Rising temperatures and heat waves combined with sealed surfaces create urban heat islands, resulting in discomfort as well as causing fatalities in the urban population (Vicedo-Cabrera, 2021).

These challenges demand innovative and sustainable approaches to building design that enhance thermal comfort. Vertical Greenery Systems (VGS) tend to provide promising solutions to these challenges. VGS, also known as vertical landscaping, vertical gardens, or bio-walls, involves growing vegetation on vertical profiles (Morsi and Elian, 2021). VGS, as a sustainable building design feature, plays an important role in enhancing a building's environmental impact. (Reyes, Pérez, and Coma, 2024). VGS involves the use of vegetation on building facades, whereby vegetation is used in providing shading, especially evapotranspiration services that are crucial for cooling and decreasing surface and atmospheric temperatures (Čekić, Trkulja, and Došenović, 2020). VGS is a vital action toward creating liveable cities and mitigating climate change impacts (Irga, Torpy, Griffin, and Wilkinson 2023). This not only enhances the aesthetic appeal of buildings but also provides numerous environmental benefits. These systems can improve air quality, reduce the urban heat island effect, and provide insulation, thereby contributing to thermal comfort. These benefits underscore the importance of urban greening for maintaining sustainability. However, rapid urban development has led to a decrease in green open spaces, despite buildings being responsible for nearly 40% of emissions (Woon, Phuang, Taler, Varbanov, Chong, Klemeš, and Lee 2023).

In tropical regions, the cooling effects of VGS can be particularly beneficial, as they reduce the intense heat and improve thermal comfort. Thermal comfort' is the term used to describe a satisfactory, stress-free thermal environment in buildings and, therefore, is a socially determined notion defined by norms and expectations. (Meutia and Sari, 2021). The idea of what is comfortable has certainly changed from one time, place, and season to another. Thermal comfort is defined as “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation." ASHRAE 55 (2020). Mechanical heating or cooling use is the major behaviour of the residents for thermal comfort adjustments, which are, of course, the main reasons for indoor energy use (Liao 2023). These mechanical systems, such as air conditioning, are commonly used to maintain thermal comfort in residential buildings. However, these methods are energy-intensive and contribute to environmental degradation, particularly through increased greenhouse gas emissions and high energy consumption. As a result, there is a growing interest in passive cooling strategies that enhance thermal comfort while promoting sustainability.

In residential buildings, energy use is increasing due to the growing use of modern electric appliances. For sustainable energy use, effective energy management is crucial, especially in residential settings where energy consumption is particularly significant (Rajan, Bahadur, Masanori and Kazui 2019). The reliance on mechanical cooling systems to maintain thermal comfort results in high energy costs and significant environmental impacts in rapidly developing urban area of Lagos. This situation underscores the need for sustainable building practices that can effectively address these issues. While vertical greenery systems have been recognised for their potential benefits and their effectiveness in enhancing thermal comfort in condominiums.

While numerous studies have demonstrated the benefits of urban greening for thermal comfort in various global contexts, there remains a significant lack of localized data for rapidly urbanizing tropical environments such as Ikoyi. Previous research has primarily been investigated the impact of Vertical Greening Systems (VGS) on thermal comfort in Mediterranean, temperate, and some Asian climates similar to that of Lagos, Nigeria, there is a notable lack of research focused on tropical African cities.

Therefore, there is a pressing need for detailed localized research to evaluates the impact of VGS in enhancing thermal comfort in residential buildings in Ikoyi, with a focus on assessing the current thermal comfort levels in residential buildings with VGS.

II. Material and Method

Study Area

The study was carried out in Ikoyi, Nigeria. The study area has an estimated population of 342,000 people and a land size of 28 square kilometres which is located approximately between 6.6008° N latitude and 3.3515° E longitude. It is part of the Ikoyi-Obalende Local Council Development Area, which was carved out of the Eti-Osa Local Government Area. The district has evolved into one of the most desirable residential and commercial areas in Lagos, characterised by its luxury high-rise buildings, exclusive buildings, embassies, hotels, and corporate offices.

Ikoyi experiences a tropical climate typical of Lagos, with two main seasons: a wet season that spans from April to October, characterised by heavy rainfall and high humidity, and a dry season from November to March, featuring lower humidity levels and less rainfall. Average temperatures in the area range between 25°C to 32°C (77°F to 90°F), creating thermal comfort challenges in residential buildings, especially in a densely populated urban context.

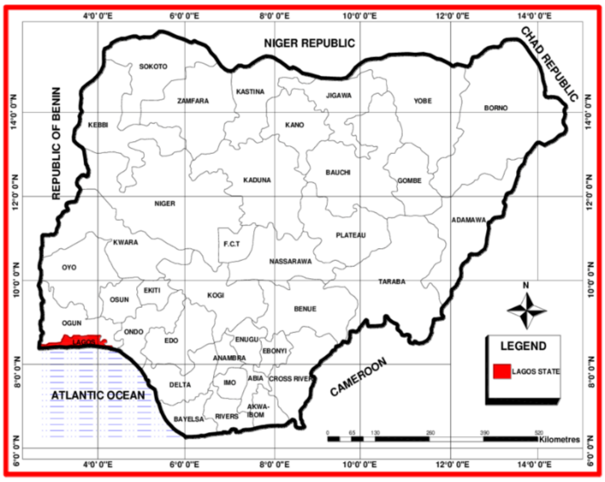


Figure 1: Lagos State within the Context of Nigeria
Source: Map Data, 2025

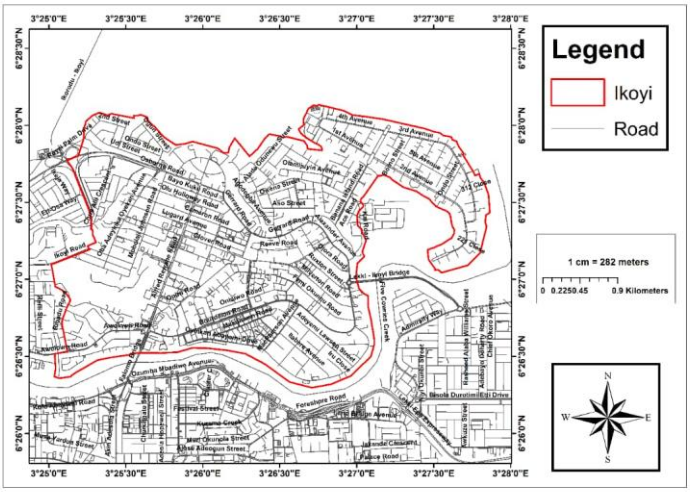


Figure 2: Map of Ikoyi/Obalende LCDA
Source: Map Data, 2025

III. Methodology

This study utilized primary data collection for this study. The primary data were obtained through questionnaires and physical measurements of buildings with VGS. The study adopted a mixed-method approach, combining qualitative and quantitative research designs; the quantitative data was gathered through structured questionnaires on personal variable of the resident, focusing on their thermal comfort experiences in relation to VGS. Qualitative data was obtained using a Kestrel 4400 to measure environmental variables such as air temperature and relative humidity in selected buildings with VGS.

A multi-stage sampling technique was used. First, Ikoyi was purposively selected for its urban characteristics. Second, buildings with VGS were selected and categorized by type. Third, adult residents (18+) in these buildings were surveyed. Finally, Reconnaissance Survey showed that the total number of residents of the residential building with VGS is 166 which served as the research population. A total enumeration technique was employed due to the small population size, ensuring all eligible residents were included.

Table 1: Residential Building with VGS

S/N	Name	Location (Ikoyi, Lagos)	Type of Residential Buildings	Type of VGS	No. of Floors	No. of Residents
1	House 45-BR	45, Bourdilion Rd.	Duplex	Green facade	2	7
2	House 8-OR	8, Oluwa Road.	Bungalow	Green facade	1	5
3	House 28-BR	28, Bourdilion Rd.	Duplex	Green facade	2	5
4	House 6-OR	6, Oluwa Road.	Bungalow	Green facade	1	5
5	House 31-AL	31, Adeyemi Lawson Street.	Duplex	Green facade	2	8
6	House 28-AL	28, Adeyemi Lawson Street.	Duplex	Green facade	2	5
7	House 24-LA	24, Lugard Avenue.	Bungalow	Green facade	1	3
8	House 44-CR	44, Cameron Road.	Duplex	Green facade	2	12
9	House 34-CR	34, Cameron Road.	Apartment	Green facade	3	18
10	House 3-RR	3, Reeve Road.	Bungalow	Green facade	1	6
11	House 7-LJA	7, Lateef Jakande Avenue.	Duplex	Green facade	2	8
12	House 7- RR	7, Ruxton Road.	Duplex	Green facade	2	7
13	House 30-CR	30, Cooper Road.	Apartment	Green facade	4	30
14	House 13-OR	13, Ojora Road.	Duplex	Green facade	2	12
15	House 10-AR	10, Adekunle Road.	Bungalow	Green facade	1	35
	Total					**166**

Source: Author's Compilation, 2025.

IV. Results and Discussion

This section presents the result and discussion on current thermal comfort level in residential buildings with VGS, which depends on both personal variables like age, clothing, and activity level and environmental variables such as temperature, humidity, and air movement. Understanding and assessing these variables is essential for identifying comfort challenges and developing strategies to enhance occupant well-being and improve energy efficiency.

Personal Variables

Gender

The analysis of residents from buildings with VGS (as shown in Table 2) shows that females made up 57.2%, while males accounted for 42.8%, indicating a slight gender disparity. This may result from demographic patterns in Ikoyi or greater female participation in surveys. The higher representation of women may influence how VGS is perceived, as thermal comfort preferences can differ by gender. Studies show that females are generally more sensitive to temperature changes and prefer warmer indoor conditions. These differences underscore the importance of designing adaptable thermal comfort strategies that cater to varying user needs.

Table 2: Residents Response to Gender

Study Area	Gender				Grand Total	
	Male		Female			
	Freq.	%	Freq.	%	Freq.	%
Selected Residential Buildings in Ikoyi	71	42.8	95	57.2	166	100

Source: Author's Field Survey, 2025

Age

The age distribution of residents in Ikoyi's residential buildings with VGS (as shown in Table 3) reveals that the majority fall within the economically active age group of 25–44 years (79.0%), with 35–44 years accounting for 41.0% and 25–34 years making up 38.0%. Smaller proportions include ages 45–54 (10.8%), 18–24 (7.2%), and 55+ (3.0%). This indicates that most residents are middle-aged adults likely to prioritize comfortable and healthy living environments, which may influence the acceptance and effectiveness of VGS in enhancing thermal comfort and air quality. Younger residents may be more adaptable to fluctuating conditions, while older adults may have specific thermal needs, reinforcing the importance of flexible and inclusive VGS design strategies.

Table 3: Age of the Respondent

Study Area	Age of the Respondent											
	18-24 years		25-34 years		35-44 years		45-54 years		55+ years			
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Selected Residential Buildings in Ikoyi	12	7.2	63	38.0	68	41.0	18	10.8	5	3.0	166	100

Source: Author's Field Survey, 2025

Current Activities Level at the Moment

Figure 3 shows that the majority of residents were engaged in sitting (38.0%) and walking (33.7%), indicating a dominance of sedentary to moderate activity levels. Fewer residents reported standing (12.0%), running (9.0%), and sleeping (7.2%), which involve varying metabolic rates. Since metabolic activity influences thermal comfort perception, those involved in low-intensity activities (e.g., sitting, sleeping) are more sensitive to cooler environments, while more active individuals tolerate slightly higher temperatures. In buildings with VGS, which enhance cooling and air quality, this variation means cooling effects may be more noticeable to sedentary residents. To maintain comfort for all, adaptive strategies such as natural ventilation control and well-placed greenery are essential, ensuring alignment with ASHRAE Standard 55-2020 for diverse activity needs.

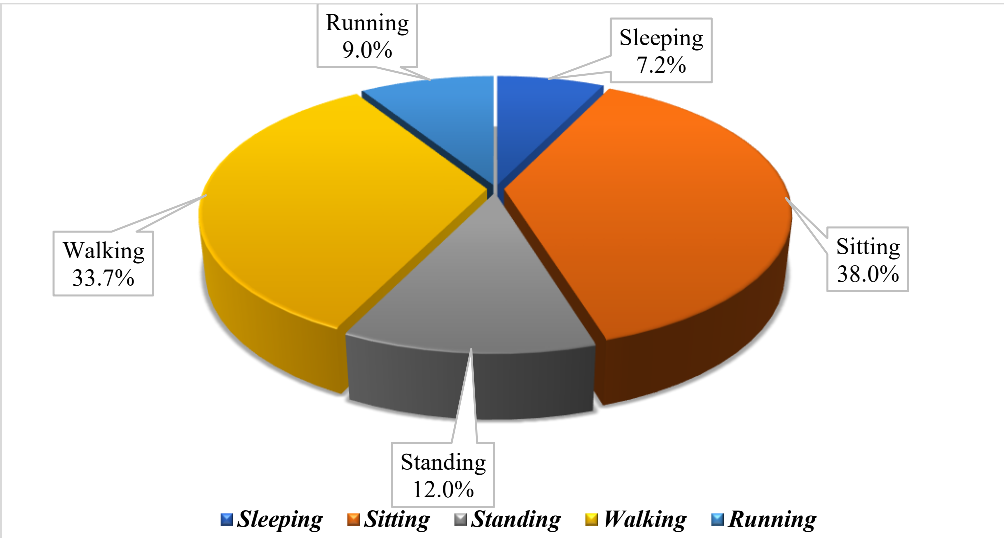


Figure 3: Respondent response to current activities level at the moment
Source: Author's Field Survey, 2025

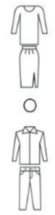
Current Clothing Type at Home

Table 4 shows that light clothing (0.3 clo) is the most common choice among residents (30.1%), suggesting that indoor temperatures are generally warm and within a comfortable range (26–30°C), in line with ASHRAE standards. Moderate clothing (0.5 clo) follows closely at 26.5%, reflecting a balance between warmth and ventilation, possibly indicating effective thermal regulation by VGS. Semi-nude clothing (0.1 clo), worn by 20.5%, implies that some homes remain warm, benefiting from natural ventilation and reduced heat gain. Meanwhile, heavy (12.7%) and very heavy clothing (10.2%) are least worn, suggesting that overcooling is not an issue, and indoor spaces generally remain warm enough without excessive insulation.

These patterns reveal that VGS may contribute to thermal stability, yet some residents still face heat retention, requiring enhanced shading, airflow, and material strategies. Overall, clothing preferences affirm that most residential buildings with VGS in Ikoyi support moderate thermal comfort, aligning with ASHRAE/ANSI Standard 55-2020, but point to the need for further optimization in passive cooling designs.

Table 4: Respondent response to current clothing type at home

Study Area	**Male**		**Female**		**Clothing Type**			
	Freq.	%	Freq.	%	Clothing Type	Freq.	%	**Symbology**
	11	15.5	23	24.2	Semi-Nude Cloth	34	20.5	
Selected Residential Buildings in Ikoyi	22	31.0	28	29.5	Light Cloth	50	30.1	
	20	28.2	24	25.3	Moderate Cloth	44	26.5	

	10	14.0	11	11.5	Heavy Cloth	21	12.7	
	8	11.3	9	9.5	Very Heavy Cloth	17	10.2	
Total	**71**	**100**	**95**	**100**		**166**	**100**	

Source: Author's Field Survey, 2025

Environmental Variables

Air Velocity (m/s) of the Residential Buildings with VGS in Ikoyi, Lagos

Figure 4 presents varying air velocity readings across residential buildings with VGS in Ikoyi, ranging from 0.13 m/s to 0.2 m/s. Peak air velocities of 0.2 m/s were recorded in House 28-BR, 6-OR, 24-LA, 44-CR, 34-CR, and 7-RR, suggesting optimal ventilation conditions likely due to favourable environmental features or VGS placement. In contrast, lower velocities in Houses 31-AL, 28-AL, 3-RR, 13-OR, and 13-AR indicate poor air circulation, potentially causing heat retention and discomfort.

According to ASHRAE 55 (2020), most of the observed velocities fall within the recommended comfort range of 0.15–0.25 m/s. Variations in air movement affect thermal comfort, indoor air quality, and energy efficiency. While high air velocity reduces the need for artificial cooling and improves comfort, low airflow areas may require design interventions such as strategic window placement, VGS positioning, or landscaping modifications to enhance ventilation. Proper airflow design is essential for minimizing health risks like respiratory issues and improving indoor comfort in VGS-equipped buildings.

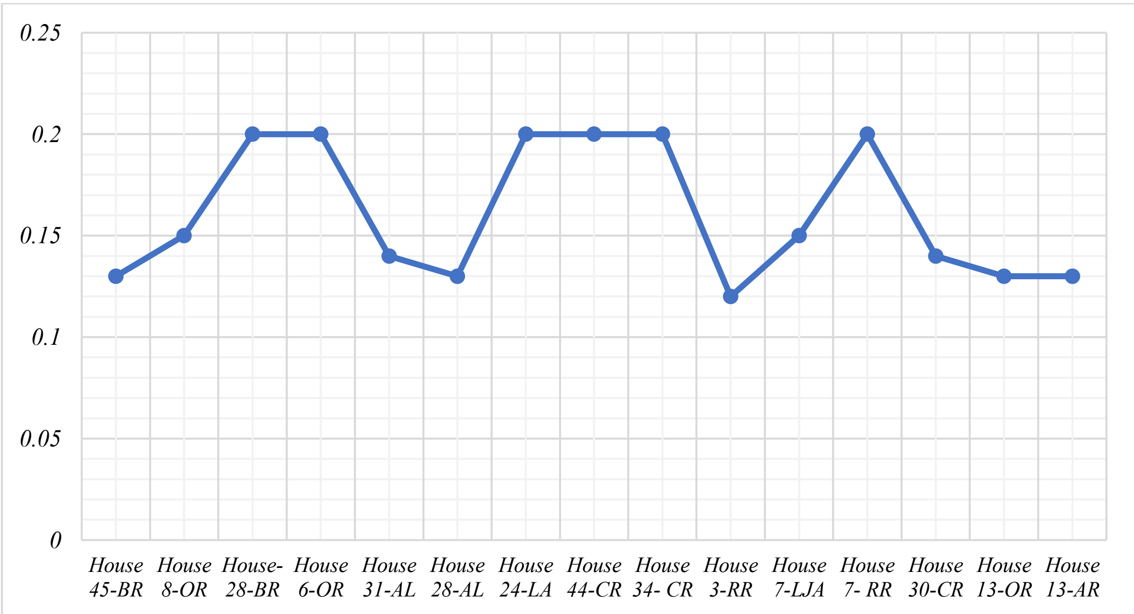
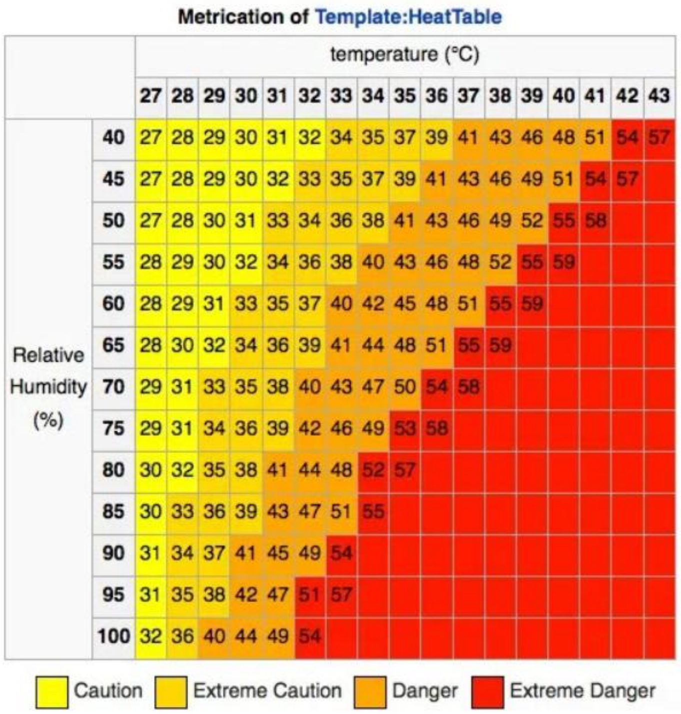


Figure 4: Air Velocity (m/s) of the Residential buildings with VGS in Ikoyi
Source*:* Author's Field Survey, 2025

Air Temperature and Relative Humidity of the Residential Building with VGS in Ikoyi

Table 5 presents air temperature and relative humidity data from residential buildings with VGS in Ikoyi, revealing notable variations in indoor environmental conditions. Air temperatures ranged from 27.7°C (House 31-AL) to 29.5°C (House 7-LJA), with higher values also recorded in House 6-OR (29.2°C) and House 24-LA

(29.4°C), indicating increased heat gain likely due to design, orientation, or limited shading. Cooler buildings, like House 44-CR (28.0°C) and House 34-CR (27.8°C), suggest better insulation and solar protection.
Relative humidity ranged from 70% to 81%, with House 28-AL (80%) showing signs of poor ventilation and moisture retention, while House 34-CR (71%) indicated effective air circulation. Most buildings-maintained humidity between 75% and 78%, reflecting the moderately humid conditions of the tropical climate. Elevated humidity levels in buildings like House 45-BR (75%) and House 13-AR (78%) may contribute to thermal discomfort, especially in warmer conditions. These findings underscore the need for improved ventilation, shading, and material strategies to enhance thermal comfort and humidity control in VGS-equipped residential buildings.



RH (%)	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
40	27	28	29	30	31	32	34	35	37	39	41	43	46	48	51	54	57
45	27	28	29	30	32	33	35	37	39	41	43	46	49	51	54	57	
50	27	28	30	31	33	34	36	38	41	43	46	49	52	55	58		
55	28	29	30	32	34	36	38	40	43	46	48	52	55	59			
60	28	29	31	33	35	37	40	42	45	48	51	55	59				
65	28	30	32	34	36	39	41	44	48	51	55	59					
70	29	31	33	35	38	40	43	47	50	54	58						
75	29	31	34	36	39	42	46	49	53	58							
80	30	32	35	38	41	44	48	52	57								
85	30	33	36	39	43	47	51	55									
90	31	34	37	41	45	49	54										
95	31	35	38	42	47	51	57										
100	32	36	40	44	49	54											

Figure 5: Heat Stress Index
Source: Author's Field Survey, 2025

Figure 5 illustrates the heat stress index values for residential buildings with VGS in Ikoyi. Most buildings such as House 45-BR, 28-BR, 31-AL, 44-CR, 34-CR, 7-LJA, 30-CR, 13-OR, 28-AL, and 7-RR fall under the "*Caution*" category (heat index: 30.10°C–32.66°C), indicating mild but tolerable heat stress. A smaller group such as House 8-OR, 6-OR, 24-LA, 3-RR, and 10-AR were classified under "*Extreme Caution*" (heat index: 33.79°C–36.42°C), suggesting increased discomfort and risk of heat-related stress, potentially due to limited VGS coverage, poor ventilation, or high sun exposure.

No buildings fell into "*Danger*" or "*Extreme Danger*" categories, showing that VGS helps prevent severe overheating. With 66.7% of buildings in the "*Caution*" category, the data confirms that VGS contributes positively to thermal comfort. However, the presence of "*Extreme Caution*" cases highlights the need for complementary passive cooling techniques, such as shading, ventilation, and water features, to optimize performance in hot-humid climates like Ikoyi, Nigeria.

Table 5: Air Temperature and Relative Humidity of Residential Building with VGS in Ikoyi

S/N	Name	Air Temp (°C)	Humidity (%)	Heat Index (°C)	Comfort Level
1	House 45-BR	28.2	75	31.80	Caution
2	House 8-OR	29.0	77	34.10	Extreme Caution
3	House 28-BR	28.1	74	31.43	Caution
4	House 6-OR	29.2	79	35.08	Extreme Caution
5	House 31-AL	27.9	73	30.87	Caution
6	House 28-AL	28.5	76	32.66	Caution
7	House 24-LA	29.4	80	35.88	Extreme Caution
8	House 44-CR	28.0	72	30.94	Caution
9	House 34-CR	27.8	71	30.41	Caution

S/N	Name	Air Temp (°C)	Humidity (%)	Heat Index (°C)	Comfort Level
10	House 3-RR	29.5	81	36.42	Extreme Caution
11	House 7-LJA	28.3	74	31.87	Caution
12	House 7-RR	28.4	75	32.26	Caution
13	House 30-CR	27.7	70	30.10	Caution
14	House 13-OR	28.2	76	31.96	Caution
15	House 10-AR	28.8	78	33.79	Extreme Caution

Source: Author's Field Survey, 2025

V. Conclusion

The study evaluated the current state of thermal comfort in residential buildings with Vertical Greenery Systems (VGS) in Ikoyi, Lagos. It revealed that both personal factors (such as gender, age, clothing, and activity level) and environmental factors (including temperature, humidity, air velocity, and heat index) significantly affect occupants' thermal comfort. A majority of residents were found to be middle-aged adults engaged in sedentary or low-intensity activities, with light or moderate clothing types, suggesting that indoor conditions are generally warm but tolerable.

Environmental assessments showed that air temperatures across buildings ranged from 27.7°C to 29.5°C, with relative humidity between 70% and 81%, consistent with a hot-humid climate. While most buildings recorded air velocity within ASHRAE's acceptable range, some still exhibited poor airflow and higher heat index values. Heat stress index analysis showed that 66.7% of buildings fell under the "Caution" category, and the rest under "Extreme Caution," indicating that VGS is effective in reducing heat stress, though not always sufficient on its own.

The study hence recommends that the placement of VGS should be optimized by extending its application to building façades and balconies, where it can provide more effective shading and cooling benefits. Passive cooling strategies such as cross-ventilation, deep overhangs, and open courtyards should be integrated into the building design to complement the thermal performance of VGS. Building orientation should be carefully considered; aligning structures along the east–west axis will minimize solar heat gain while maximizing the effect of prevailing wind directions. Natural ventilation should be encouraged through well-placed openings, particularly on the north and south walls at occupant height, to promote cross-breezes and improve indoor air quality.

Awareness programs should be developed to educate residents, architects, and developers on the environmental and thermal comfort benefits of VGS.

Government and planning authorities should incorporate VGS into building regulations and offer incentives to encourage its widespread adoption. Lastly, continuous monitoring of indoor climatic conditions is recommended to evaluate VGS effectiveness and inform necessary adjustments for long-term performance.

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