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Research Article

RETROFITTING GLAZED BUILDING ENVELOPES FOR ENHANCED THERMAL COMFORT (A CASE OF NAIROBI CENTRAL BUSINESS DISTRICT)

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ABSTRACT

Nairobi's central business district features a growing skyline of high-rise buildings with glazed facades, creating modern, and light-filled spaces but with intensified solar heat gain. Indoor overheating and heavy energy use for cooling results, despite the prevailing tropical highland climate. This study, therefore, responds to arising urgent concerns about energy efficiency and occupant well-being. It investigates adaptive building strategies that are rooted in the shearing layers concept, adaptive thermal comfort, and the mediating role of building envelopes. Using a mixed-methods approach through case studies, field observations, surveys, focus group interviews, and digital sensor data, it explored passive cooling solutions. Such are external shading, thermal coatings, ventilation enhancements, and advanced glazed facades, as well as green retrofitting techniques. Comparative analysis identified climate-adaptive retrofit options that boost energy performance and occupant comfort, offering cost-effective, sustainable solutions that are tailored to the evolving urban context of Nairobi city.

Keywords: Thermal comfort, Retrofitting, Glazed facades.

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INTRODUCTION

The skyline of Central Business District (CBD) of the Nairobi City Country is rapidly transforming and is dominated by high-rise office buildings. Modern architectural styles often prioritize esthetics over climate-responsive design, leading to a growing challenge of thermal discomfort and high-energy consumption (Lechner, 2014). This trend is particularly concerning due to the extensive use of glazed facades, a design element popularized in the 1980s during the modernism era. This is a period that saw buildings such as the Anniversary Towers, Kenya Methodist University Towers, and View Park Towers being constructed within the CBD. The glazed facades that these buildings feature may not suit Nairobi's unique tropical highland climate.

Studies by Ngugi *et al*. (2023) interrogated the thermal performance of commercial buildings in Nairobi and found that extensively glazed facades significantly contributed to high-energy consumption for cooling. View Park Towers particularly have been heavily criticized by architects and scholars. Ralwala (2023) describes the building as a hazard to the environment due to the extensive use of glass on its facade that is not the double glazed version that enables air circulation. The use of extensive glazed building facades has not only resulted in glare to motorists but also led to overheating within the spaces because glass is opaque to long radiations and traps heat (Ibid). While glazed facades pose challenges, there is a growing interest in retrofitting existing buildings for improved environmental performance. Ndichu (2014), in his research on energy efficiency, building materials, and life-cycle costs, investigated the potential for retrofitting Nairobi office buildings with more sustainable glazed facades.

This study complemented Ndichu's (2014) work by shifting the focus to occupant thermal comfort and the impact of glazed facades on the user experience. The research explored various retrofitting strategies designed to address thermal discomfort and improve occupant well-being within these buildings. By analyzing various retrofit strategies for glazed facades, the research was able to develop evidence-based recommendations for effective climate-adaptive retrofits. These would be useful for enhancing occupant comfort, energy efficiency, and overall environmental sustainability for buildings within the CBD of Nairobi City County.

The Nairobi context: *A* clash of style and climate

The thermal inefficiency observed in many of Nairobi's glazed commercial buildings is not a recent phenomenon but rather a legacy of a historical and stylistic conflict. Post-independence architectural trends in the city often led to the importation of the glass-clad high-rise, an architectural symbol of corporate modernity prevalent in Western cities. This adoption of an international style, however, frequently prioritized a globalized esthetic over climate-responsive design (Lechner, 2014). As a result, a building typology designed for temperate, often overcast, climates was replicated in the unique tropical highland environment of Nairobi, without sufficient adaptation (Ralwala, 2023). This created a fundamental mismatch. Facades designed to maximize light and heat in colder regions were now causing significant overheating and glare under consistent equatorial sun of Nairobi. This contextual disconnect between architectural aspiration and climatic reality forms the core of the problem this research sought to address.

Problem statement

Climate change has long been a global source of dispute and concern. It refers to prolonged shifts in a region's weather patterns that deviate from historical norms (Sands, 1992; Cissé *et al*., 2022). These changes affect not only the well-studied northern and parts of the southern hemispheres but also developing countries like Kenya. As a worldwide challenge, climate change demands urgent resolution or adaptation strategies to prevent the loss of lives and resources. Abrupt and extreme climate shifts disrupt environments that were once stable, forcing communities to adjust to unfamiliar conditions. For example, warmer climates have led to rising mortality rates linked to heat stress and cardiovascular and chronic respiratory diseases in regions that previously enjoyed moderate weather (Singh & Dhiman, 2012; Huang *et al*., 2013; Alessandrini *et al*., 2011). To safeguard survival and minimize damage, humans and industries alike must proactively adapt to these evolving conditions.

Architects play a key role in developing innovative methods to retrofit existing buildings, enhancing sustainability, resilience, and climate adaptability. In rapidly developing nations such as Kenya and the United Arab Emirates, as well as developed countries such as Australia and the USA, many buildings are constructed from steel and stone. Given the enormous magnitude and cost of these structures, demolition is both economically and environmentally not viable. In Kenya, the construction sector surged by an estimated 7.7% at the end of 2023, with a market value reaching Kshs 973 billion (Research & Markets, 2024, January 09). The ongoing rapid construction underscores the importance of retrofitting rather than demolishing existing buildings. Retrofitting is a cost-effective way to conserve resources, reduce pollution from new construction, and protect human lives. For both public and private stakeholders, adapting buildings to withstand climate change is a far more sensible approach than costly demolition.

In Nairobi, an acute disconnect exists between modern architectural esthetics and the city's climate, presenting social and environmental challenges. The rapid urbanization of Nairobi's CBD has birthed numerous high-rise office buildings with sleek modern designs featuring extensive glazed facades. While these glass-heavy facades offer a sense of openness and visual connection to the outdoors, they clash with Nairobi's warm tropical highland climate, characterized by average temperatures ranging from 15°C to 25°C and intense solar radiation (United Nations Environmental Programme, 2021). Such glazed facades result in considerable solar heat gain, increasing cooling demands and energy consumption.

Large glass surfaces trap heat from solar radiation, elevating indoor temperatures and causing thermal discomfort for occupants. This, in turn, fuels dependence on energy-intensive cooling systems to maintain acceptable conditions (Lechner, 2014). The resulting discomfort diminishes occupant well-being and productivity, compromising the quality of experience of the built environment. Furthermore, reliance on constant mechanical cooling escalates energy use, often powered by fossil fuels. This occasions an increase in greenhouse gas emissions while deepening environmental harm (International Energy Agency - IEA, 2022). A heightened environmental footprint results, worsening Nairobi's climate challenges amid a globally warming planet.

Addressing climate change in Kenya, and similar contexts, requires prioritizing building retrofits and design adaptations that respect local climates. Meeting this need preserves resources, safeguards human health, and reduces environmental impact, ensuring that architectural progress aligns with sustainable urban futures.

Study objectives

General objective

To develop a practical design toolkit of retrofitting strategies for enhancing the thermal comfort of occupants within office buildings that have extensive glass facades within the CBD of Nairobi.

Specific objectives

1. To establish the thermal comfort status for occupants in glazed office buildings
2. To determine the best applications for the different retrofitting strategies and methods
3. To develop suitable design options that integrate these retrofitting strategies for user thermal comfort in buildings that are extensively glazed.

Primary investigative research questions (RQs)

RQ1: How do existing glazed facades in Nairobi's CBD buildings contribute to heat gain and thermal discomfort for occupants?

Affiliated secondary investigative RQs:

1. What is the measurable impact of different glazed facade types (single-reflective vs. double-tinted) on indoor temperatures?
2. How do building orientation and high window-to-wall ratios contribute to solar heat gain throughout the day?
3. What is the relationship between construction materials (high thermal mass vs. lightweight curtain walls) and the building's ability to regulate internal heat?
4. How do occupants perceive their thermal environment, and what is the level of dissatisfaction in relation to specific building designs?

RQ2: To what extent do different retrofit strategies for glazed facades improve occupant satisfaction, work productivity, and overall user experience within buildings?

Affiliated secondary investigative RQs

1. In what way do the complementary strategies (façade treatment, building orientation and construction materials) of retrofitting influence user perception of thermal comfort (temperature fluctuations, lighting and exposure, air movement, and ventilation)?
2. How does thermal comfort affect user productivity in the building spaces?
3. What form and level of control over thermal comfort can users access and how effective are these controls in promoting user comfort?

RQ3: How can climate-adaptive retrofits for glazed facades be integrated seamlessly with the existing architectural design of buildings in Nairobi's CBD?

Affiliated secondary investigative RQs

1. How can biomimicry inform the redesign of building facades and ventilation systems for passive cooling?
2. What is the potential performance of an integrated double-skin facade system in creating a thermal buffer and promoting natural airflow?
3. Which specific interventions, such as external shading devices, high-performance glazed facades, or green retrofitting solutions, offer the most significant gains in comfort and energy efficiency?
4. To what extent can redesigning internal spaces, such as atriums and circulation corridors, improve cross-ventilation and reduce cooling loads on occupied areas?

Theoretical framework

This research explored the retrofitting of glazed building envelopes in Nairobi's CBD to enhance thermal comfort and advance sustainability. Anchored in an integrated theoretical framework, the study weaved together principles of building adaptability, adaptive thermal comfort, and the critical role of the building envelope as a climate mediator. Through this lens, the study critically examined the shortcomings of existing glazed facades and evaluated the potential of climate-responsive retrofitting strategies. Performance benchmarks were set using American National Standards Institute (ANSI)/American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 55, guiding the assessment of expected outcomes. The key theoretical foundations are outlined below to demonstrate their relevance and application to this investigation.

Building adaptability: From shearing layers to circular lifecycles

Stewart Brand's influential model of the "Shearing Layers of Change" (Brand, 2022) provides a foundational filter for understanding the rationale and value of retrofitting. Brand challenges the notion of a building as a single, unchanging entity, instead portraying it as a composite of multiple layers, each characterized by distinct lifespans and rates of change. While Brand's framework remains seminal, contemporary research has expanded its scope, especially within the contexts of the circular economy and whole-life building performance (Table 1).

Today's sustainable design paradigm embraces the "decoupling" of these layers, a principle central to Design for Disassembly. This approach recognizes building components as individual assets with unique lifecycles that can be independently maintained, replaced, or repurposed (Durmisevic, 2006; Schmidt, 2010). This progression of Brand's concept underscores that a building's adaptability and ease of

Table 1: Building layers and their implications for retrofitting

Layer	Description	Timescale	Implication for retrofitting
Site	Geographic setting of building	Eternal	The fixed context which any retrofit must respond to.
Structure	The load-bearing frame and foundations. This layer represents the highest embodied carbon and is the most critical to preserve in an adaptive reuse model.	30–300 years	The primary asset to be preserved. Its capacity dictates the feasibility of vertical extensions or major facade changes.
Skin	The exterior surfaces that provide a weather protecting layer, technological advances, or changing esthetics. This is the primary target of the proposed retrofitting interventions	20 years	The most effective point of intervention for enhancing thermal performance and modernizing the building's aesthetic and function.
Services	The working guts of a building: HVAC, electrical, plumbing, sprinklers *et al*. These have short lifecycles due to rapid technological evolutions.	7–15 years	Often upgraded with the skin. Retrofitting provides an opportunity to replace inefficient systems with passive or low-energy alternatives
Space Plan	The interior layout – internal partitions, doors, ceilings, etc., depend on occupant needs.	3–30 years	The flexibility of the structure allows this layer to be reconfigured to accommodate new uses (such as commercial to residential).
Stuff	Furniture, equipment, personal belongings of occupants	Daily or monthly	Changes with the occupants and has minimal impact on the building's core performance but is influenced by the comfort provided.

Source: Ego[1], 2025, adapted from Brand (2022) and informed by principles of Design for Disassembly (Durmisevic, 2006)

modification serve as critical indicators of sustainability. As Geraedts (2016) emphasizes, embedding "in-built flexibility" into design is vital for future-proofing buildings, enabling them to respond effectively to evolving needs and environmental challenges.

The layers, adapted for the context of retrofitting and circularity, can be conceptualized as follows:

This research embraced a layered perspective to assert that the widespread glazed "skins" on many Nairobi CBD buildings are not only esthetically outdated but have also reached the end of their functional lifespan within a circular economy framework. For this circumstance, retrofitting, therefore, transcends mere repair. It becomes a strategic "re-cladding" that embodies principles of the circular economy. This approach preserves the high-value, high-carbon structure while revitalizing the underperforming skin to meet modern demands for thermal comfort and energy efficiency. Consequently, retrofitting emerges as a pivotal strategy to shift from a linear "demolish-and-rebuild" cycle toward a circular, sustainable model of urban development.

The adaptive model of thermal comfort

Traditional building design often depends on fixed, universal standards for thermal comfort, such as the Predicted Mean Vote model. In contrast, this research embraced the adaptive model of thermal comfort, pioneered by de Dear and Brager (1998), which views human comfort as fluid and shaped by climatic and cultural factors. It acknowledges that occupants of naturally ventilated buildings, who remain closely connected to the outdoors, develop broader thermal tolerance and favor more variable conditions (Table 2).

This perspective shifted the research focus from simply maintaining a prescribed indoor temperature to addressing the failure of building design to facilitate adaptation. Existing glazed facades create static, often uncomfortable environments that sever occupants from their surrounding climate. The proposed retrofits, emphasizing natural ventilation and adjustable shading, aimed not merely to cool the building but to restore adaptability, foster occupant agency, and cultivate a more resilient, satisfying indoor experience.

The Building envelope as a climate mediator

The building envelope, often described as the structure's "skin," serves as the vital interface between indoor and outdoor environments. It's essential function is to regulate and moderate climatic influences, such as solar radiation, wind, and temperature, to ensure a comfortable interior climate. This research framed the glazed facade as an active "climate mediator," evaluating its effectiveness in fulfilling this role. Specifically, in the context of Nairobi, an optimal building envelope must be finely tuned to local climatic demands (Table 3).

Table 2: Principles of the adaptive model of thermal comfort

Principle	Interpretation
Context matters	Thermal comfort standards should not be universally applied but should be specific to the local climate. The model challenges the importation of sealed, air-conditioned building typologies into a temperate climate like Nairobi's.
Occupant control	The ability of occupants to make adjustments, such as opening a window, adjusting a blind, or moving to a different space, is a critical factor in their comfort and satisfaction.
Psychological adaptation	Past thermal experiences shape future expectations. Occupants adapt to the conditions they are used to, developing a tolerance that static models fail to capture.

Table 2: Source: Ego[1], 2025, de Dear & Brager (1998)

At present, the widespread use of extensive single-glazed facades in Nairobi's CBD undermines this goal. Rather than moderating the climate, these facades act such as greenhouses, trapping solar heat, and generating excessive indoor temperatures, thereby directly opposing the climate needs of the region.

Building on this insight, the study investigated retrofitting strategies that can transform the building envelope from a source of inefficiency into a high-performance system. Approaches such as double-skin facades, low-emissivity coatings, and external shading devices such as fins and overhangs were examined for their ability to enhance the climate mediation function of the envelop. By leveraging these technologies, buildings can achieve greater thermal comfort through passive, energy-efficient means.

Synthesis of the preceding theoretical premise into a framework of reference for inquiry

By integrating these three theoretical pillars, this research establishes the following comprehensive tri-polar understanding and framework for its investigation (Figs. 1 and 2):

1. Shearing layers that provide the rationale for retrofitting directly addressing the primary investigative RQ three – RQ3, by framing it as a logical phase in a building's life.

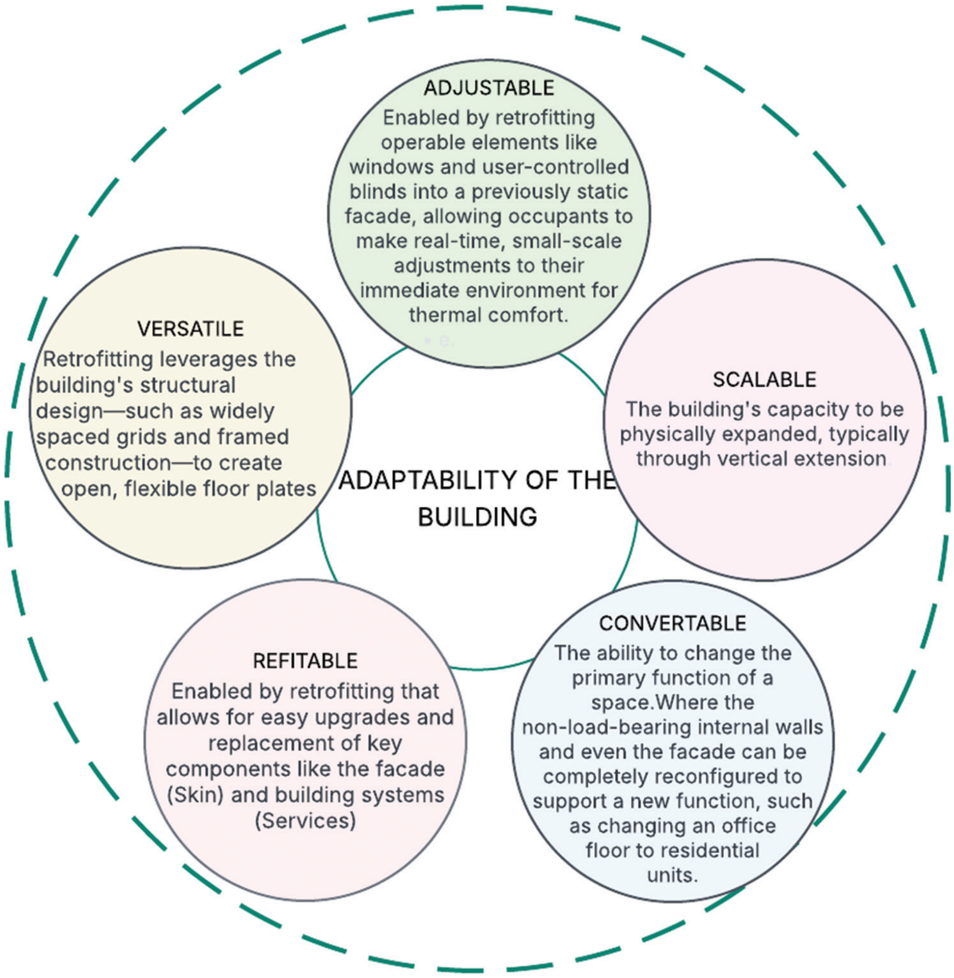

Fig. 1: Conceptual framework – aspects of building adaptability and their attributes
Source Ego[1], 2025

Table 3: Building envelope as a climate mediator

Mediation aspect	Interpretation
Admit daylight, but block excess heat	Maximize the use of natural light to reduce energy consumption for lighting.
Control solar gain	Effectively block or reflect direct solar radiation, especially from the east and west facades, to prevent overheating.
Provide thermal insulation	Minimize heat transfer to maintain stable indoor temperatures.
Enable natural ventilation	Allow for the controlled passage of air to cool the interior and improve air quality.

Source: Ego[1], 2025

2. The adaptive model of thermal comfort that defines the goal of the retrofit that helps to evaluate occupant satisfaction (primary investigative RQ two – RQ2). It does so focusing on creating a comfortable, resilient, and occupant-responsive indoor environment suited to the Nairobi context
3. The concept of the building envelope as a climate mediator. This provides the method for analyzing the sources of thermal discomfort (primary investigative RQ one – RQ1) and identifying the specific technologies that can be applied to achieve the goal (RQ three – RQ3).

This framework moves beyond a purely technical assessment of building performance to incorporate principles of sustainability, adaptability, and human-centric design (Figs. 1 and 2). It allows the research to analyze the problem holistically. Further, it enables the development of solutions that are not only technologically sound but also contextually appropriate. Such solutions would be aligned with the long-term vision of a sustainable Nairobi City County.

METHODS

Research design

This was crafted to deploy a research methodology capable of investigating the thermal comfort levels of occupants in office buildings with extensive glazed facades within Nairobi's CBD. It responded to the need to understand the real-world performance of these buildings and to propose effective, climate-responsive retrofitting strategies. This research design was put together to provide a comprehensive and in-depth understanding of the research problem by combining quantitative and qualitative measurements of building performance and occupant experiences. It was articulated by requisite appropriate research approach, sampling design, data collection field techniques, and tools. Affiliated procedures for data analysis were also assembled. On the whole, the research design ensured a systematic and credible research process.

Research approach

To adequately address the multifaceted nature of thermal comfort, which involves both physical environmental factors and subjective human perception, a mixed-methods research approach was adopted. This approach allows for the integration of both quantitative and qualitative data, providing a more robust and holistic understanding

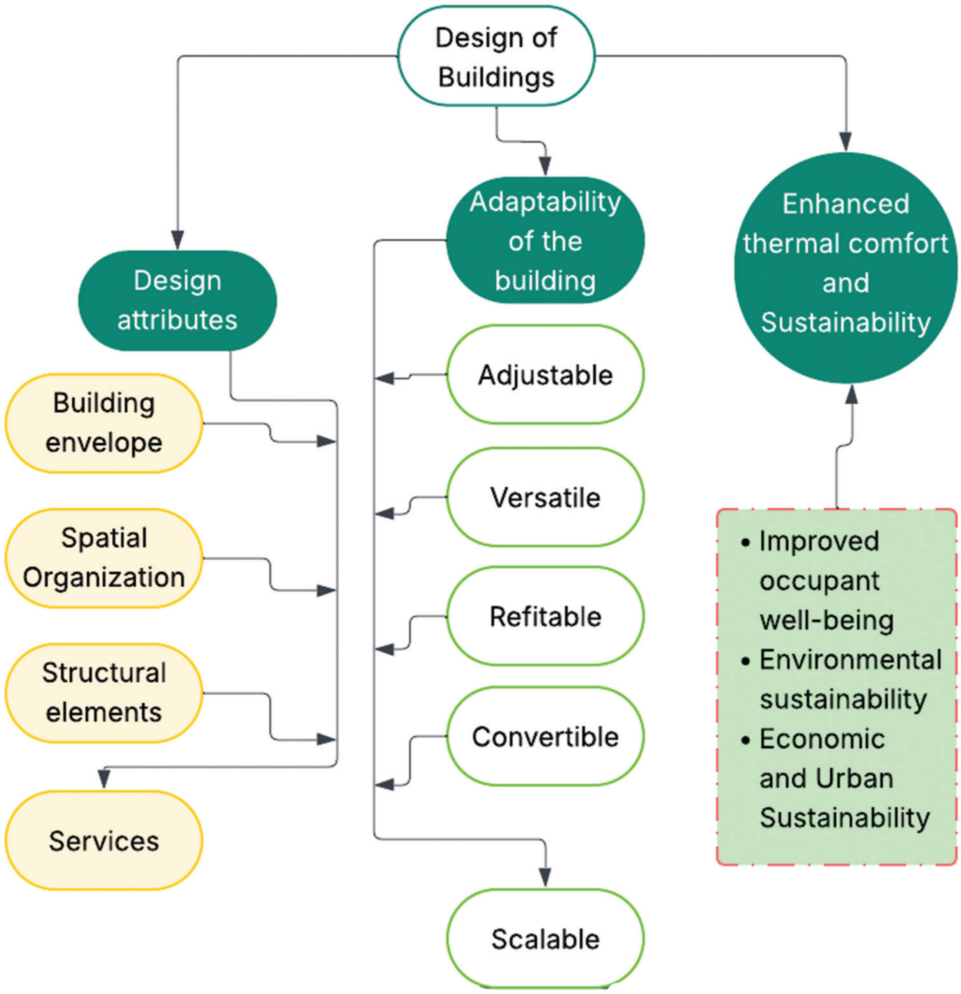

Fig. 2: Conceptual framework – designing for thermal comfort
Source: Ego[1], 2025

of the research problem than any single stand-alone method could achieve alone (Creswell, 2014).

The study was focused on finding practical solutions to the issue of thermal discomfort in glazed buildings of Nairobi City County. Accordingly, it was anchored on a pragmatic paradigm, which emphasizes a problem-centered, real-world approach to inquiry. This paradigm allows for the flexible use of different methods to best address the RQs. It employed its inherent resourcefulness of positivist and interpretivist elements to good measure as follows:

1. Positivist Elements (Quantitative inquiry):
   Quantitative approaches here aided in gathering objective, measurable data. This entailed measurement of onsite temperature and humidity readings taken with digital sensors and structured interview schedules using validated scales like the thermal sensation vote (TSV) to quantify thermal comfort perceptions (ANSI/ASHRAE Standard 55).
2. Interpretivist Elements (Qualitative inquiry):
   The living experiences of occupants measured through their, perceptions, and behavior were explored through qualitative approaches. This relied on open-ended survey questions, direct observation of occupant adaptations (e.g., use of personal fans and clothing adjustments), and photographic documentation of the building environments. This qualitative data provided a deeper, contextual understanding that quantitative numbers alone could not capture.

Research methods

A comparative case study research method was selected as the most appropriate framework for this research. This is particularly effective for an in-depth investigation of a complex, real-world phenomenon like thermal comfort within its specific context (Creswell, 2014). The method involved the careful selection of multiple office buildings within the CBD of Nairobi City County, allowing for a comparative analysis of buildings with different facade characteristics. It was complemented with observation and samples survey methods to anchor observations and interviews onsite.

This case study method was deemed suitable for the following reasons:

1. Contextual understanding:
   It allowed for a deep dive into the unique environmental and architectural context of CBD of Nairobi City County, enabling to obtaining of holistic, rich, and contextually pertinent data.
2. Comparative power:
   By comparing buildings with high levels of glazed facades against a control of buildings with low incidences of glazed facades, the method enabled the identification of specific architectural features that contributed to thermal discomfort.
3. Multiple sources of evidence:
   It facilitated the use of multiple data sources. These included physical measurements, occupant surveys, and architectural design analysis. The diversity of forms of data measurement helped triangulate findings and enhanced the validity of the conclusions.

Research situs

The research was conducted in the CBD of Nairobi City County. This area was purposively selected due to its high concentration of modern, high-rise office buildings constructed with extensive glazed facades, particularly from the 1980s onwards. The dense urban environment of the CBD also creates a unique microclimate that influences building performance.

Following a pilot study and building on previous research (Ndichu, 2014), a purposive sampling method was used to select three high-rise office buildings as case studies. The buildings were divided into two categories to facilitate a comparative analysis:

1. Group A: High levels of glazed facades/low thermal mass (>50% Window-to-Wall Ratio):
    - View Park Towers, constructed in 1990 (Fig. 3): Characterized by a single-glazed reflective curtain wall system and being 20 storeys in height fitted this bill well
    - Anniversary Towers, constructed in 1992 (Fig. 4): Features a double-glazed tinted glass curtain wall system and comprising 22 storeys also qualified to be in this category.
2. Group B (Control Group): Low levels of glazed facades:
    - Teleposta Towers, constructed in 1999 (Fig. 5): Built with a high thermal mass concrete structure and prominent concrete fins for sun shading, resulting in a lower window-to-wall ratio, with 27 storeys was selected here.

Sampling design

Target population

The target population for this study comprised full-time office workers who regularly occupied the selected buildings. This group was chosen because their daily, long-term experience provides the most valuable insights into the thermal performance of the buildings and its impact on comfort and productivity.

Sampling size and technique

Purposive sampling was employed to identify the three case studies for inquiry and to select respondents for interview in each of the three buildings. This form of sampling is favored for its efficiency, cost effectiveness, and ability to collect in-depth, high-quality data by focusing on buildings and users with specific characteristics relevant to the RQs. They were chosen on the premises of their relevance to context and affording the inquiry rich and holistic information on the three

Fig. 4: Anniversary Towers
Source: Ego[1], 2025, field data

Fig. 3: View park towers
Source: Ego[1], 2025, field data

Fig. 5: Teleposta Towers
Source: Ego[1], 2025, field data

building types chosen (McLeod, 2023). Respondents for interview in each of the three buildings were also chosen purposively. The occupants (the population) within each building were clustered by floor levels to ensure a representative cross-section of experiences from different heights within the towers. Data were collected from occupants on every fifth floor. A total of 45 occupants participated in the study, with 15 participants from each of the three case study buildings. Within each building, five participants were interviewed in each of a lower, middle, and upper floors, to register opinions at different heights of the buildings.

Data collection and recording techniques and tools

A multi-faceted approach was used for data collection, combining the diverse techniques of direct participant observation, guided individual respondent, guided focus group interview and digital instruments for measuring temperature. These were complemented with their respective, appropriate tools to draw out data from primary sources as outlined here below.

Data collection tools for onsite observation

1. Digital temperature sensors:
   These were used to collect quantitative data on indoor air temperatures at different times of the day (mid-morning and afternoon) and in various locations within the buildings.
2. Observation checklists:
   A pre-coded checklist was used to systematically record observations, including building materials, facade conditions, shading devices, occupant behavior (e.g., clothing), and evidence of any recent retrofits.
3. Photographs and sketches:
   Extensive photographic documentation and hand sketches were used to record the physical characteristics of the building envelopes, interior spaces, and specific design details.

Data collection tools for occupant experience

Structured interview schedules:

A questionnaire was administered to the sampled occupants. It included both closed-ended and open-ended questions to gather quantitative and qualitative data on:

1. Overall thermal comfort: Using a 7-point Likert scale based on the ANSI/ASHRAE TSV
2. Perceptions of temperature fluctuations, air movement, and natural light
3. Occupant control: Assessing the ability of occupants to adjust their thermal environment
4. Impact on productivity**.**

Data analysis and interpretation

The quantitative and qualitative data and collected data were analyzed using appropriate descriptive and inferential statistics as illustrated here below.

1. Analysis of quantitative data:
   The numerical data from temperature sensors were entered into spreadsheets. Descriptive statistics (such as means and frequencies) were used to map out the resulting patterns. This data were then visualized using bar graphs and charts to profile thermal performance across the three buildings.
2. Analysis of qualitative data:
   The qualitative data from open-ended survey questions and observational notes were analyzed using thematic analysis (Braun & Clarke, 2006). This involved identifying, analyzing, and interpreting recurring patterns and themes related to occupant comfort, dissatisfaction, and adaptive behavior.

Further, qualitative ranked data obtained using the Likert-scale questions were also entered into spreadsheets and descriptive statistics (such as modes and frequencies) thereafter used to map out the resulting patterns. This data was then visualized using bar graphs and charts to infer thermal performance as seen through the perception and behavior of occupant across the three buildings. In addition, inferential statistics were brought to bear using tests of correlations for this ranked data on occupant perception and behavior. These were carried out using the Spearman's rank correlation coefficient tests and significance levels and directionality of the identified associations confirmed.

This research employed a mixed-methods approach, integrating both deductive and inductive reasoning in its data analysis to address the stated research objectives and questions. The quantitative analysis, involving temperature sensor data and structured Likert-scale responses (e.g., TSV based on ANSI/ASHRAE Standard 55), primarily utilized a deductive approach. This phase systematically examined whether measured thermal conditions and occupant perceptions aligned with established comfort standards and existing theoretical understanding, thereby providing empirical evidence to answer questions about heat gain and discomfort (e.g., "How do existing glazed facades contribute to heat gain and thermal discomfort?"). Conversely, the qualitative analysis of open-ended survey questions and observational notes adopted an inductive approach. Through thematic analysis (Braun & Clarke, 2006), this phase allowed patterns, themes, and categories related to occupant experiences, adaptive behavior, and perceptions of potential retrofit impacts to emerge directly from the data. This inductive process generated rich, context-specific insights crucial for informing practical design toolkits and understanding the seamless integration of retrofits (e.g., "How can climate-adaptive retrofits be integrated seamlessly?"). The final step in this analytical process involved a synthesis of these deductive quantitative and inductive qualitative findings. In so doing, it built a comprehensive and nuanced understanding of the research problem by triangulating evidence and effectively addressing the RQs and overall objective.

Validity and reliability of data

To ensure the credibility of the research findings, the following measures were taken:

1. Validity:
   The use of standardized and internationally recognized tools, such as the ANSI/ASHRAE thermal sensation scale, enhanced the validity of the comfort assessment. This ensured that the concepts of inquiry were correctly and accurately captured in the data collection instruments and communicated in the field without error. Triangulation of data from multiple sources (temperature readings, surveys, and observations) further strengthened validity of the information obtained in the field.
2. Reliability:
   A standardized procedure was used for data collection in all three buildings, including taking measurements at consistent times and using the same observational checklist and questionnaire to ensure the reliability and comparability of the data. Control questions were built into the data collection instruments. Repeat measurements were also carried out to root out possible errors in understanding information requested for in interviews and instrumentation measurements. In this way, reliability was ensured.

Sources of error and mitigation

1. Sampling Bias:
   The use of purposeful sampling introduces a potential bias. This was mitigated for by clustering the sample by floor level to increase homogeneity of the target population sets and, therefore, ensure representativeness of occupants.
2. Measurement Error:
   Potential minor inaccuracies in digital thermometers were a considered limitation. This was mitigated using the same device for all readings to ensure consistency.

Research ethical considerations

The study was conducted in strict alignment with essential ethical principles that protect participant rights. It embraced the five core elements of informed consent, voluntary participation, confidentiality and anonymity, transparency, and accountability.

At the outset, participants were fully informed about the aims and procedures of the study, to ensure their clear understanding and comfort with the research process. It was explicitly communicated that the study was self-funded and purely academic, with no personal gain expected beyond contributing to scholarly knowledge. Participation was entirely voluntary, allowing individuals the freedom to engage or withdraw at any moment without pressure or consequence. This respect for autonomy preserved the dignity of participants and shielded them from any potential stigma.

To safeguard privacy, the research deliberately avoided collecting identifiable information, instead assigning codes to maintain anonymity. A robust data management system was implemented, securing all information with access limited strictly to the researcher, supervisors, and Egoized personnel. The study upheld a neutral and respectful tone throughout, consciously avoiding any coercion. It honored the autonomy of each participant and fostered an equitable dynamic between researcher and respondent, effectively reducing bias and power imbalances during interviews and observations.

RESULTS AND DISCUSSION

Profiles of thermal comfort at View Park Towers, Anniversary Towers, and Teleposta Towers

Strategy for onsite data measurement using digital temperature sensors

Thermal comfort is a state that is affected by the occurrence in temperature fluctuations (the rise and dropping of temperature). Therefore, to have a better grasp on the implications thermal comfort has on those who inhabit a building, it is vital to conduct an onsite study. This was done through observation and data recording. Data were collected through the use of smart thermometers that have temperature sensors. These were distributed across the different buildings which aided in collecting temperatures of different rooms, offices, and hallways across the case study sites to attain an average thermal data set. The data were collected from View Park Towers, Anniversary Towers and Teleposta Towers all of which are buildings that were selected for this study with the intent of determining how building envelopes can be optimized for thermal comfort.

The data collected were compared with optimal temperatures that have been experienced across Nairobi City County. Such temperatures were considered as being the most effective/optimal thermal profiles, especially for working offices. The data were collected between the dates of July 01st and July 05th. The data were collected across all business days. Data for Monday, Wednesday, and Friday were collected simultaneously across all three buildings. From the data collected, Friday was identified as the date that experienced the highest temperatures during the mid-morning hours as well as the evenings whereas Mondays were the coldest/coolest. The general temperatures were placed against the newly collected temperatures. It emerged that despite the different forms of thermal regulation initiatives used in these three towers, they all experienced varying thermal conditions that differed in both morning and evening (Table 5).

During the mid-morning hours, the internal thermals of all three buildings appeared to be lower in comparison to the actual general temperatures (Table 5). These temperatures mean that the mid-morning thermal conditions of the buildings were not optimal especially for employees. According to a recent study, it has been identified that optimal thermal temperatures range from 23°C to 26° C for most high-rise buildings that have various office spaces (ANSI/ASHRAE 55).

The ability of diverse building facades and their thermal performances, to influence indoor climates, variously emerges here distinctively. View Park Towers had the highest thermal temperatures in all 3 days within the afternoon hours. In comparison with the other towers, the lowest afternoon temperatures were being experienced at the Teleposta Towers. View Park Towers had a higher temperature range in comparison to the Anniversary Towers. It was attributed to the fact that the Anniversary Tower building utilized double-glazed tinted glass whereas View Park Towers utilized single glazed reflective glass. The use of a single glazed window design is one that has a single layer of glass and provides minimal insulation to sunlight rays. As such then, the amount of heat that passed through the windows at the View Park Towers was higher compared to the situation at the Anniversary Towers. This latter building had double glazed windows which provided an added insulation layer to the sunrays.

On the other hand, when it came to Teleposta Towers, the temperatures appeared to be somewhat lower in comparison to the other two towers. This was mainly due to the fact that the tower was primarily constructed in reinforced concrete that has a higher thermal mass compared to glass. A resulting slow absorption and thereafter, release of heat gained by the concrete throughout the day was thereby experienced. The low temperatures throughout the day could also be attributed to a lower window to wall ratio and the use of sun shading devices from overhangs to fins in the Teleposta Towers. All of these reduced solar heat gain in the building, resulting in extensively lower interior temperatures when compared to those that applied in the exterior.

The observed variations in internal temperatures across the three case studies critically highlight the role of the building envelope in thermal comfort. View Park Towers, with its single-glazed reflective curtain wall and South-East orientation, consistently recorded the highest afternoon temperatures (up to 28.1°C). Accordingly, it demonstrated significant heat gain due to poor insulation and lack of effective external shading. Anniversary Towers, despite also being heavily glazed, showed slightly better performance. It's double-glazed tinted curtain walls and mosaic tile cladding provided improved insulation, though its East-West orientation. Despite this, temperatures of above optimal (around 27°C) still prevailed here. In stark contrast, Teleposta Towers maintained consistently cooler afternoon temperatures (22°C) due to its high thermal mass concrete structure, lower window-to-wall ratio, and integrated external shading devices such as concrete fins and overhangs, effectively mitigating solar heat gain. These findings unequivocally illustrate how specific choices of the design of building envelopes differentially moderate solar heat transfer. The range of design choices reflected here include, glazing façade types, wall materials and therefore thermal mass, external shading, and building orientation. These elements of the façade of buildings directly impact indoor thermal stability and occupant comfort.

User perception of thermal comfort at View Park, Anniversary, and Teleposta Towers

Profiles of building users in all three towers served to verify the thermal trends that emerged in the preceding section from data measured using digital temperature sensors. Profiling the experiences and perceptions of the users of these three buildings would make it possible to better learn and understand how the different thermal conditions affected user comfort and productivity. To attain this information, a close ended interview schedule was administered to a total of 45 participants spread evenly across all three towers. The survey responses came in the form of ordinal data from the Likert type scales used in this interview schedule. This approach focused on the sentiment levels, frequency and percentage of respondents selecting each category or aspect measured. This provided clear, direct measurement, and understanding of the perceptions of the building occupant interviewed.

To determine the comfort levels that workers in these buildings experience, participants across all towers were interviewed using the structured interview schedules. The interviews sought to assess how comfortable they felt about the thermal conditions (temperature) of their workplaces. The questions used were not limited to a singular day or timeline to better understand how the

Table 4: Case study comparative analysis

Building	View Park Towers	Anniversary Towers	Teleposta Towers
Orientation	The building is oriented having the longer facade facing the South East direction. The building is directly exposed to sunlight for a major part of the day which can lead to overheating issues inside the building.	The building was oriented having the longer facade facing the East-West East direction. The building was directly exposed to sunlight for a major part of the day which could lead to overheating issues inside the building.	The building was oriented along the Northeast and Southwest direction. This reduced the building facades exposed to direct sunlight.
Building form	View Park Towers design was heavily influenced by the International architectural style, in line with the minimalistic aesthetic of the International style. View Park Towers was designed using clean lines and geometric form evident in the cubical shape of the towers linked by a bridge. The building was 20 floors high	The building employed a twin tower concept. The towers rose to a height of approximately 79.86 m high and has 26 floors. The building form followed international architectural style evident in the simple geometric line and cubical shape of the building. The style had an emphasis on functionality and simplicity with extensive use of glass in facade construction.	It was a single high-rise office tower standing at 120m high the building has 27 floors. The building form followed a brutalist architectural style characterized by large and imposing structures with sharp angles and clean lines with extensive use of concrete
Material use, finishes and color (exterior)	The buildings most prominent feature was the curtain wall system. The system was constructed in custom made single glazed glass panels. The single glazed facades glass panels offered poor thermal insulation compared to double or triple glazed units. Reflective films were used in the glazed panels to reduce some of the heat gain. Lightweight aluminium framing provided support to the glazed panels offering structural support to the curtain wall system. Concrete walls were used in the construction of the building. Concrete has a high thermal mass; it absorbs and releases heat slowly during the day making it beneficial in thermal regulation. Some parts of the exterior walls had been painted white. White reflects some of the sunrays reducing heat absorption by the walls. The building entrance was covered by a suspended concrete slab that offers sun shading and protection from weather elements to the building users.	Anniversary Towers were constructed in masonry stones with steel reinforcement exterior for structural support. The walls, predominantly comprising of curtain walls were constructed in tinted glass cladding on aluminium frames. The glass cladding reduced solar heat gain and glare. The double-glazed windows contained an insulating layer that reduced the buildings heat gain. The exterior walls of the building were cladded in mosaic tiles. The tiles acted as an insulation layer that helped improve the thermal insulation of the building.	Construction materials used in the building mainly included reinforced concrete, glass and steel. Reinforced concrete had been used on most part of the building. Concrete had a high thermal mass and helped in thermal regulation of the building. The building featured tinted glass panels screwed onto vertical concrete fins. This allowed natural light into the building. The use of tinting regulated the overall heat gain. The vertical fins were used for sun shading. The building had overhangs on the podium level floors for sun shading.
Material use, finishes and color (interior)	Most parts of the building were painted bright colors and are fitted with large single glazed windows fitted with reflective film. The colors reflected more light within the building reducing reliance on artificial lighting. Large windows allow for deeper penetration of natural light in to the building. This despite creating a simulating work environment caused a glare effect on screens especially for those located next to windows. This could be attributed to lack of sun shading devices on windows especially along the East –west facade. The Office units were mostly separated by stone walls. Stone having a high thermal mass regulated the amount of heat and light reaching the corridors and walkways. As a result, the corridors had a heavy reliance on artificial lighting. Some of the windows were operable. This allowed for natural air ventilation. This was further substituted using ventilation systems fitted within the building. On most floors tiles had used cladding. Tiles had a relatively high thermal mass and could absorb and store heat for longer periods. This helped with indoor temperature regulation and reduced cooling loads. Some floors were fitted with false gypsum ceilings that helped in thermal regulation of the building by trapping heat, preventing it from entering the office space.	Mosaic tiles had been used to clad the interior of the building. The tiles had a high thermal mass which helped in thermal regulation. The primary material used in the construction of some of the office separation panels on some floors was aluminium, laminate panels and glass. Laminate panels had a low thermal mass and in turn do not provided significant thermal regulation within the office space. Some office separations were constructed in stone and glass. Aluminium framed glass doors had been used to allow light into other parts of the building. Stone walls had a high thermal mass which helped in the regulation of thermal temperature within the office by reducing heat transfer through the office partitions. Each cubical stations within the office had a general occupancy number of 4–6 people. The workstations were divided by temporary glass screens allowing for light within the building. Modular workstations were in use within the building. This allowed for easy rearrangement and reconfiguring to meet changing needs of an office. The flexibility allowed for adaptable workspaces and easy reconfiguring of departments. The building windows were designed operable in some instances and fixed windows in others. Most windows were fitted with sun shading devices such as vertical blinds for light control.	Office separation panels were masonry stone and glass. Large windows have been used to light the corridor spaces. Some of the office separation panels were in aluminium and glass. Aluminium was used for its lightweight nature and to offer structural strength. The glass was used to allow light into the corridors. Some of the floors (2^{nd}–5^{th}) were fitted with suspended building tiles below the actual floor slab. The plenum space allowed easy access to the services such as electrical and ventilation and for air flow into the office space. The building was fitted with a rectangular venting skylight. This allowed natural light to enter a building reducing reliance on artificial lighting. The skylight also helped in thermos-regulation by improving natural ventilation within the building. The building was fitted with operable and fixed windows. Most of the windows were fitted with either curtains or vertical blinds to prevent glare when working and for general thermal comfort.

Source, Ego[1], 2025, field data

employees experienced their work environs based on their past history. Their responses the implications of these perceptions are discussed here below (Table 6).

View Park Towers

Similar computations are carried out as in Table 6 for the other six dimensions of thermal comfort to issue forth aggregated derived rank value scores and the associated percentage distribution of responses (Table 7 and Fig. 6).

View Park Towers had the highest level of thermal discomfort among the three buildings (Table 6). A majority of occupants (6 out 15=40%) reported a "somewhat uncomfortable" feeling, while a lower number (4 out of 15=27%) felt "very uncomfortable." Overall, 67% inclined toward the feeling of discomfort (Table 6). Occupants felt that the temperatures were stable, with 6 out of 15 (40%) reporting that there "never" were any fluctuations in temperature, and another 8 out of 15 (53%) saying that they "rarely" experienced fluctuations (Table 6). All in all, 93% perceived temperatures to be generally stable. However, they also reported a distinct lack of control, with (3/15=20%) declaring no control at all while (5/15=33%) said that they had only little control. All together this comprised a considerable (8/15=53%) of respondents stating, they had "no" or "little" control over the temperature (Table 6). While most (10/15=67%) found the amount of natural light to be "about right," a majority also reported dissatisfaction with air circulation (6/15=40%) or took a neutral stance (7/15=47%). Crucially, a majority (8/15=53%) felt that this environment had a "Moderate impact" on their productivity (Table 6).

Despite the observed general discomfort of the building users, View Park Towers failed to embrace the inherent energy efficiency of spontaneous behavioral and physiological user adaptation to thermal comfort (Tables 6 and 7, Fig. 6). It did fail to empower users and did not provide users with instruments such as operable windows such as louvers and blinds, and possibly smart glazed facades to adapt the indoor climate to variations in the external environments.

Table 5: Measured thermal temperatures at the three towers

Case study	Day of the week	Mid-morning hours			Afternoon hours		
Building	Day	General temperature	Temperature in building	Temperature difference	General temperature	Temperature in building	Temperature difference
View Park Towers	Monday 1st	22	21	1	25	27	2
	Wednesday 3rd	22	21	1	26	27.3	1.3
	Friday 5th	23	22	1	25	28.1	3.1
Anniversary Towers	Monday 1st	22	22	0	25	26.8	1.8
	Wednesday 3rd	22	21	1	26	27	1
	Friday 5th	23	22	1	25	27	2
Teleposta Towers	Monday 1st	22	21	1	25	22	3
	Wednesday 3rd	22	21	1	26	23	3
	Friday 5th	23	22	1	25	22	3
Legend	Too cold						
	Optimal						
	Hot						

Source: Ego[1], 2025, field data

Table 6: Occupant perception of overall thermal comfort showing generally low levels of comfort

Query: In general, how comfortable do you feel in terms of temperature in your workspace during a typical workday?				
Sentiment level/rank	Numerical value/score	Responses	Total number of responses×ranked numerical value/score ascribed to a rank	Percentage response
Very uncomfortable	1	4	4	26.67
Somewhat uncomfortable	2	6	12	40.00
Neutral	3	4	12	26.67
Somewhat comfortable	4	1	4	6.67
Very comfortable	5	0	0	0.00
Add the total number of responses and divide by the total number of respondents 32/15=2.1 rounded off to 2.				

Source: Ego[1], 2025, field data

Table 7: Consolidated perceptions on the dimensions of thermal comfort displaying overall ambivalence

Thermal comfort of the View Park Towers	Number of responses for the respective sentiments levels/ranks					Derived mode value of rank scores rounded off to nearest integer
	1	2	3	4	5	
1. Overall thermal comfort.	4	6	4	1	0	3
2. Temperature fluctuations.	6	8	0	1	0	2
3. Control over temperature.	3	5	6	0	1	3
4. Perception of lighting and exposure	4	-	10	-	1	2
5. Perception of air movement and ventilation	1	5	7	1	1	3
6. Impact on productivity	0	5	8	1	1	3
Total						15
Total rank score divided by the total number of entries 15/6=2.5, rounded off to 3 on the Likert scale, corresponding to the second to maximum status						

Source: Ego[1], 2025, field data

Teleposta Towers

Similar computations are carried out as in Table 6 for the other six dimensions of thermal comfort to issue forth aggregated derived rank value scores and the associated percentage distribution of responses (Tables 8 and 9, Fig. 7).

The findings for Teleposta Towers indicate the highest level of thermal comfort among the three buildings (Table 8 and Fig. 7). A majority of occupants (6/15=40%) reported a "somewhat comfortable" feeling, while a lower number (4/15=27%) felt "very comfortable." Overall, 67% of respondents inclined toward the feeling of comfort (Table 8). Occupants felt that the temperatures were stable, with (6/15=40%) reporting that there "never" were any fluctuations in temperature, and another (4/15=27%) saying that they "rarely" experienced fluctuations. All in all, 67% perceived temperatures to be generally stable (Table 8).

However, they also reported distinct environmental challenges. A significant portion (5/15=33%) declared that there was "too much natural light," indicating an issue with glare (Table 8). The most prominent issue was dissatisfaction with air circulation, where a clear majority were "very dissatisfied" (6/15=40%) or "somewhat dissatisfied" (4/15=27%). Altogether, this comprised a considerable 67% of respondents who were dissatisfied with the building's ventilation (Table 8). Crucially, despite these issues, a majority (8/15=53%) felt that the environment had "no impact" on their productivity, although a notable (5/15=33%) felt that it had a "moderate impact" (Table 8). This suggests that while the high thermal mass of the building effectively controls temperature, its ventilation systems were a notable source of occupant dissatisfaction. This challenge could be assuaged by design driven and facilitated user adaptation of fenestrations, to regulate air flows as needed, depending on changes to external climate.

Anniversary Towers

Similar computations are carried out as in table 6 for the other six dimensions of thermal comfort to issue forth aggregated derived rank value scores that can translated to an associated percentage distribution

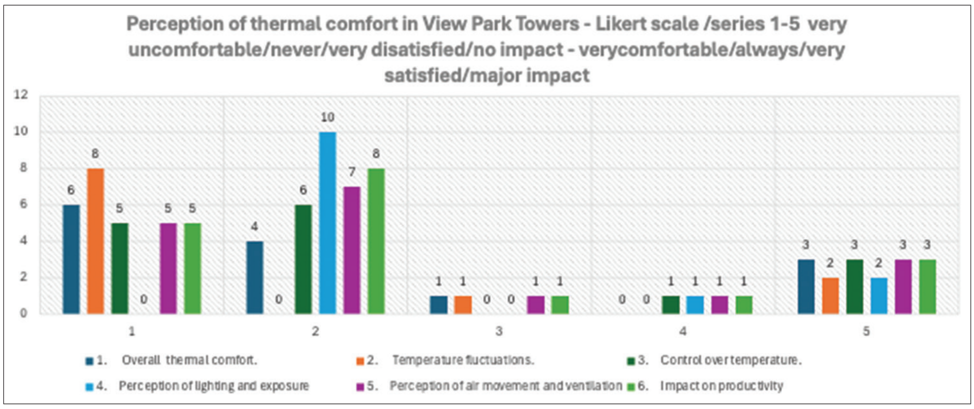

Fig. 6: Consolidated perceptions on the dimensions of thermal comfort reflecting considerable variation of patterns and trends
Source: Ego[1], 2025, field data

Table 8: Occupant perception of overall comfort that inclined toward high comfort levels

Query: In general, how comfortable do you feel in terms of temperature in your workspace during a typical workday?				
Sentiment level	**Numerical value**	**Responses**	**Total number of responses×ranked numerical value ascribed to a rank**	**Percentage response**
Very uncomfortable	1	1	1	6.67
Somewhat uncomfortable	2	2	4	13.33
Neutral	3	2	6	13.33
Somewhat comfortable	4	6	24	40.00
Very comfortable	5	4	20	26.67
Add the total number of responses and divide by the total number of respondents 55/15=3.67 that rounds off to 3				

Source: Ego[1], 2025

Table 9: Consolidated perceptions on the dimensions of thermal comfort that registered overall neutrality

Thermal comfort of the View Park Towers	**Percentage responses (%) for the respective sentiments levels/ranks**					**Derived mode value of rank scores rounded off to nearest integer**
	1	**2**	**3**	**4**	**5**	
1. Overall thermal comfort.	1	2	2	6	4	4
2. Temperature fluctuations.	6	4	4	0	1	2
3. Control over temperature.	1	4	4	6	0	3
4. Perception of lighting and exposure	0	-	10	-	5	2
5. Perception of air movement and ventilation	6	4	1	3	1	3
6. Impact on productivity	1	5	8	1	0	2
Total						16
Total rank score divided by the total number of entries 16/6=2.67, rounded off to 3 on the Likert scale, corresponding to the second to maximum status.						

Source: Ego[1], 2025, field data

of responses (Tables 10 and 11, Fig. 8).

The findings for Anniversary Towers indicate a predominantly neutral but problematic thermal environment (Table 10 and Fig. 8). A good number of respondents (6/15=40%) reported a "somewhat uncomfortable" feeling, while a smaller group (2/15=13%) felt "very uncomfortable." Overall, 53% of respondents inclined toward a feeling of discomfort, with a substantial (6/15=40%) remaining neutral (Table 10). Respondents felt that the temperatures were highly stable, with (7/15=47%) reporting that there "never" were any fluctuations in temperature, and another (5/15=33%) saying that they "rarely" experienced fluctuations. All in all, a notable 80% perceived temperatures to be generally stable (Table 10). Occupants also reported a high degree of control, with the majority (9/15=60%) feeling that they had "a lot of control," and a further respondent (1/15=7%) claiming "complete control"

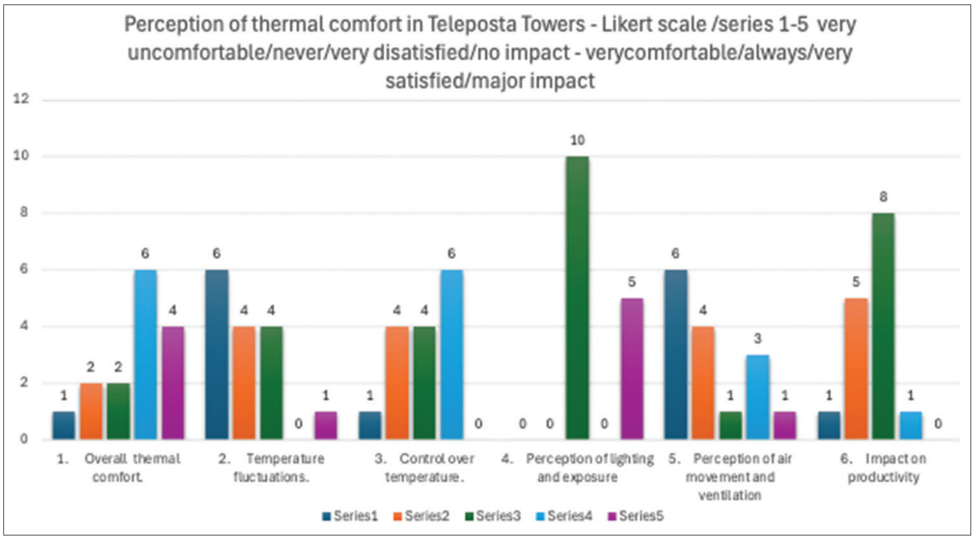

Fig. 7: Consolidated perceptions on the dimensions of thermal comfort, reflecting considerable variation of patterns and trends
Source: Ego[1], 2025, field data

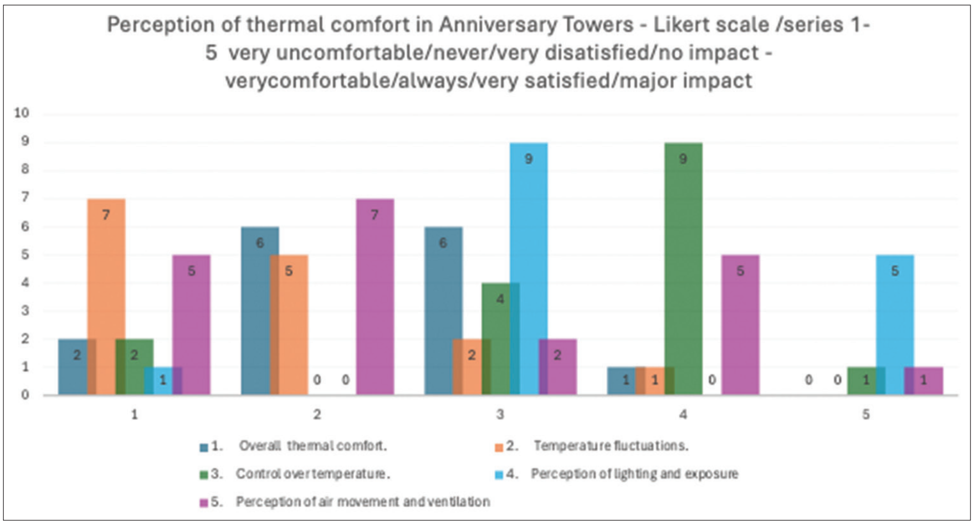

Fig. 8: Consolidated perceptions on the dimensions of thermal comfort, showing marked variation of patterns and trends
Source: Ego[1], 2025, field data

Table 10: Occupant perception of overall comfort that displayed general neutrality

Query: In general, how comfortable do you feel in terms of temperature in your workspace during a typical workday?				
Sentiment level	**Numerical value**	**Responses**	**Total number of responses×ranked numerical value ascribed to a rank**	**Percentage response**
Very uncomfortable	1	2	2	13.33
Somewhat uncomfortable	2	6	12	40.00
Neutral	3	6	18	40.00
Somewhat comfortable	4	1	4	6.67
Very comfortable	5	0	0	0.00
Add the total number of responses and divide by the total number of respondents 36/15=2.4 that rounds off to 2				

Source: Ego[1], 2025

(Table 10). Altogether, a considerable 67% of respondents stated that they had “a lot of” or “complete” control over the temperature (Table 10).

While most respondents (9/15=60%) found the amount of natural light to be “about right,” a credible minority (5/15=33%) reported “too much natural light,” hinting at a glare issue (Table 10). The most striking finding, however, was the overwhelming dissatisfaction with air circulation, where a majority reported being “somewhat dissatisfied” (7/15=47%) or “very dissatisfied” (5/15=33%), giving rise to an overwhelming negative sentiment by 80% of the respondents (Table 10). Crucially, this suggests that the available controls are insufficient to overcome the inherent thermal and air quality challenges of the building. The situation that prevailed in this building denied users the option to adapt to fluctuating thermal comfort levels seasonally and across the day.

In summary, the occupant feedback consistently revealed a clear comfort hierarchy (Table 12 and Fig. 9): Teleposta Towers was the most comfortable, Anniversary Towers the least, and View Park Towers in the middle. This hierarchy corresponds well with design principles. Teleposta Towers, which utilizes passive design features such as high thermal mass and solar shading, provided superior thermal comfort even with imperfect mechanical systems. Conversely, the extensive glazed facades and inadequate sun shading in View Park and Anniversary Towers created uncomfortable hot and stuffy environments that occupant controls could not fix, leading to dissatisfaction and reduced productivity. In general, user adaptation through operable windows such as louvers, and blinds, to changing comfort levels was not well provided for. A majority of the 45 participants confirmed that thermal comfort affected their work, highlighting the economic and personal imperative to address these design flaws through targeted retrofitting (Table 12 and Fig. 9).

The following specific patterns of thermal performance in the three buildings emerged (Table 12): Anniversary Towers (Least Comfortable), skewed heavily toward discomfort. This building had

Table 11: Consolidated perceptions on the dimensions of thermal comfort with an overall ambivalence

Thermal comfort of the View Park Towers	Percentage responses (%) for the respective sentiments levels/ranks					Derived mode value of rank scores rounded off to nearest integer
	1	2	3	4	5	
1. Overall thermal comfort.	2	6	6	1	0	2
2. Temperature fluctuations.	7	5	2	1	0	2
3. Control over temperature.	2	0	4	9	1	4
4. Perception of lighting and exposure	1	-	9	-	5	2
5. Perception of air movement and ventilation	5	7	2	5	1	2
6. Impact on productivity	1	6	6	1	1	3
Total						15
Total rank score divided by the total number of entries 16/6=2.5, rounded off to 3 on the Likert scale, corresponding to the second to maximum status						

Source: Ego[1], 2025, field data

Table 12: Comparative consolidated hierarchy of perception of thermal comfort for the three buildings

Consolidated thermal comfort (aggregate value for all 6 dimensions)	Percentage responses (%) for the respective sentiments levels/ranks					Derived mode value of rank scores rounded off to the nearest integer
	1	2	3	4	5	
1. View Park Towers	3	4	5	3	1	3
2. Teleposta Towers 3	3	3	5	3	2	3
3. Anniversary Towers	3	5	6	1	1	5
Total						11
Total rank score divided by the total number of entries 11/3=3.67, rounded off to 4 on the Likert scale, corresponding to the second to maximum status						

Source: Ego[1], 2025, field data

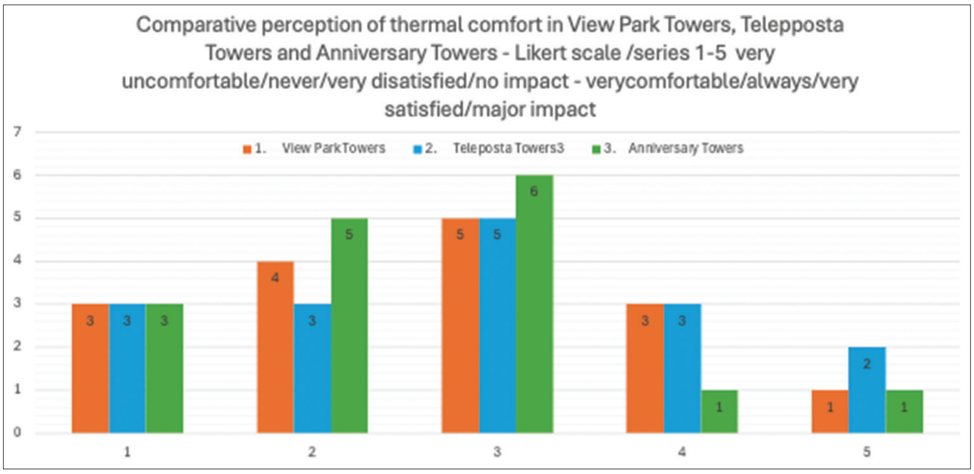

Fig. 9: Comparative consolidated perceptions on the dimensions of thermal comfort across the three buildings showing clear hierarchy
Source: Ego[1], 2025, field data

Fig. 10: Soft low E glass samples with varying light transmission and reflectivity properties
Source: Jinging

Fig. 11: Aerogels used in the creation of translucent material that is used for sun shading

the most "somewhat uncomfortable" (5/15) and neutral (6/15) responses and the fewest positive ratings, suggesting a generally poor thermal environment (Table 12). Teleposta Towers (Most Comfortable) displayed the most positive profile, with the highest number of "very comfortable" perceptions (2/15). Its more balanced distribution indicated a satisfactory environment for a larger proportion of occupants (Table 12). View Park Towers (Intermediate comfort rating) represented a middle ground. The occupant experience was mixed, being less problematic than Anniversary Towers but failing to achieve the comfort levels of Teleposta Towers.

The three case-study buildings were ranked based on their passive design features, from most effective (Teleposta Towers) to least effective (View Park Towers). These ranks were then correlated with the ranks of perceived occupant comfort derived from survey data.

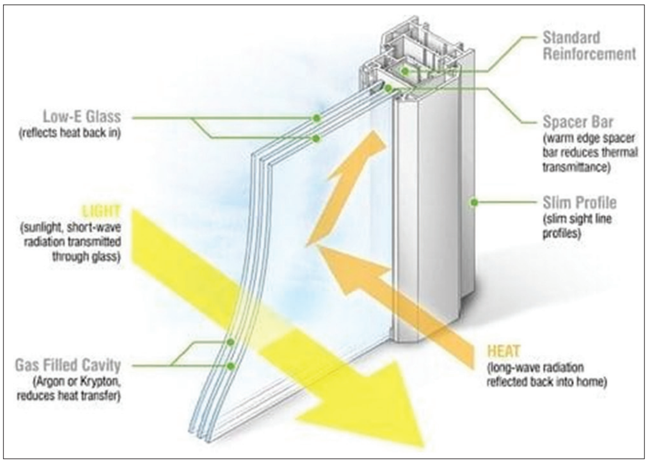

Fig. 12: Schematic view of a triple glazed facade unit with detailed heat and daylight

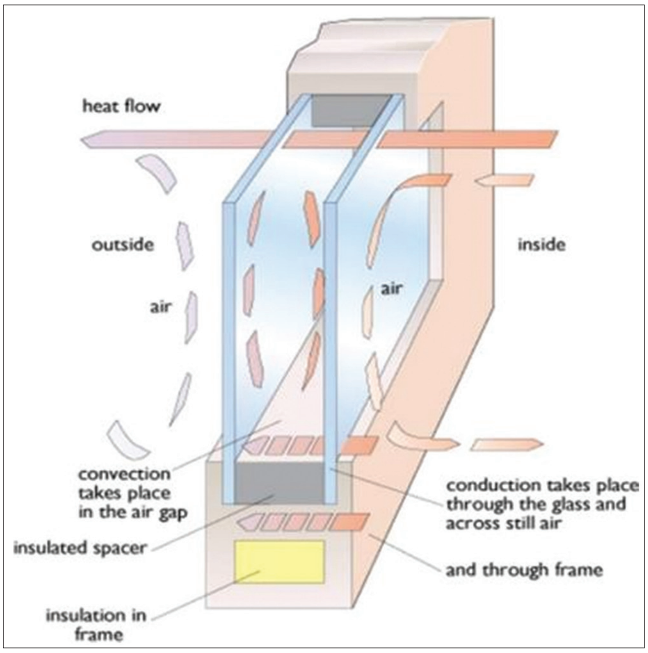

Fig. 13: Schematic view of a double-glazed facade unit with detailed heat and daylight

Promoting occupant comfort in buildings through the shearing layers concept, adaptive thermal comfort, and the mediating role of building envelopes

In Anniversary Towers (Table 13), occupant control over temperature is the most significant driver of overall thermal comfort, with a strong correlation coefficient of r=0.792 (p<0.01), emphatically supporting the adaptive thermal comfort model. The correlation tests also revealed a strong perceived synergy between sufficient natural lighting and exposure to sun, satisfaction with air circulation, and a positive impact on productivity. Specifically, "sufficiency of lighting and exposure to sun" showed perfect and strong significant correlations, respectively, with "satisfaction with air circulation" (r=1.000, p<0.01) and "impact of comfort on productivity" (r=0.747, p<0.01). The presence of "frequency of drafts and cold air" correlated positively though not significantly with productivity (r=0.323, p<0.05). This indicates that retrofitting extensively glazed facades should prioritize features that empower occupants with direct control over their thermal environment. Specifically, they should target to integrate user-operable solutions for natural ventilation and dynamic shading to optimize daylight. By so doing they would be able to enhance comfort and perceived productivity by allowing for active adaptation within the skin layer and services layers.

Table 13: Correlation coefficient matrix for aspects of thermal comfort in Anniversary Towers

Spearman's rho	Overall thermal comfort	Temperature fluctuation	Level of control over temperature	Sufficiency of lighting and exposure to sun	Frequency of drafts and cold air	Satisfaction with air circulation	Impact of comfort on productivity
Overall thermal comfort							
Correlation coefficient	1.000	0.148	0.792**	0.380	−0.470	0.380	0.154
Sig. (two-tailed)		0.598	0.000	0.162	0.077	0.162	0.583
Temperature fluctuation							
Correlation coefficient	0.148	1.000	0.135	0.006	−0.140	0.006	−0.294
Sig. (two-tailed)	0.598		0.630	0.982	0.619	0.982	0.288
Level of control over temperature							
Correlation coefficient	0.792**	0.135	1.000	0.528*	−0.318	0.528*	0.417
Sig. (two-tailed)	0.000	0.630		0.043	0.248	0.043	0.122
Sufficiency of lighting and exposure to sun							
Correlation coefficient	0.380	0.006	0.528*	1.000	−0.311	1.000**	0.747**
Sig. (two-tailed)	0.162	0.982	0.043		0.259		0.001
Frequency of drafts and cold air							
Correlation coefficient	−0.470	−0.140	−0.318	−0.311	1.000	−0.311	−0.274
Sig. (two-tailed)	0.077	0.619	0.248	0.259		0.259	0.323
Satisfaction with air circulation							
Correlation coefficient	0.380	0.006	0.528*	1.000**	−0.311	1.000	0.747**
Sig. (two-tailed)	0.162	0.982	0.043		0.259		0.001
Impact of comfort on productivity							
Correlation coefficient	0.154	−0.294	0.417	0.747**	−0.274	0.747**	1.000
Sig. (two-tailed)	0.583	0.288	0.122	0.001	0.323	0.001	

**Correlation is significant at the 0.01 level (two-tailed); *Correlation is significant at the 0.05 level (two-tailed)

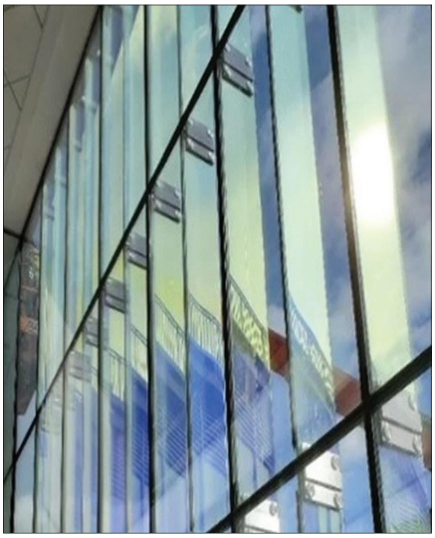

Fig. 14: Leveraging the use of vertical glass fins for sun shading

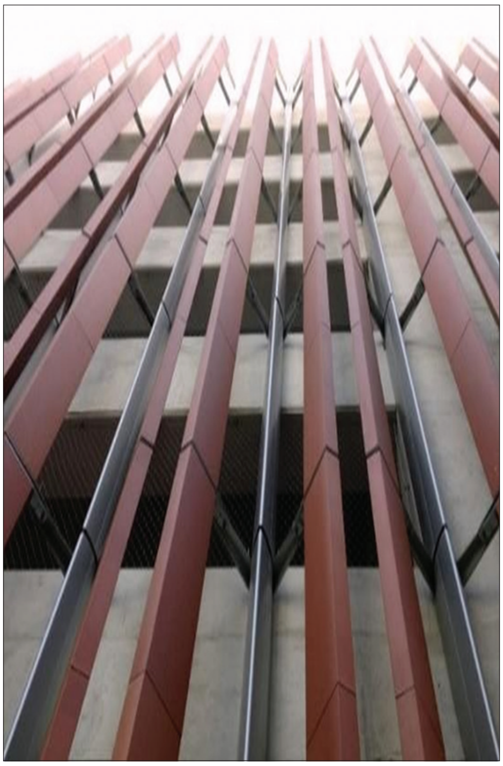

Fig. 15: Series of metal vertical fins that enhance thermal comfort

For View Park Towers (Table 14), the correlation test results highlighted an interconnected relationship where occupant control over temperature significantly though modestly influenced both the sufficiency of lighting and sun exposure (r=0.558, p<0.01) and satisfaction with air circulation (r=0.589, p<0.01). This suggests that occupants were utilizing adaptive strategies that simultaneously managed multiple environmental factors, likely through interaction with the building envelope. Therefore, glazed facade retrofits for View Park should focus on integrated solutions that enabled holistic occupant control, such as user-adjustable shading systems combined with operable window mechanisms. Such retrofits would enhance the skin layer's ability to facilitate occupant-led adjustments across light, air, and temperature. They would in this manner align with the adaptive thermal comfort model's principles and leverage on the inherent capacity of users to actively improve their thermal experience and overall well-being, even within existing architectural design constraints.

In View Park Towers, the level of control over temperature correlated significantly, modestly and positively with sufficiency of lighting and exposure to the sun (Table 14). This association registered a correlation coefficient r-value of 0.558*. The relationships were significant to an alpha (α) error value of 0.05 and therefore a confidence level of 95.5% likelihood of occurrence. This displayed complementarity of the adaptive thermal comfort model and the building envelope as a climate mediator. Here, the skin layer of the shearing layer concept and its rationale for retrofitting qualified the building envelope as a climate mediator. Users were satisfied with solar insolation and lighting levels when empowered to control their impact using instruments such as operable windows of the form of louvers, and blinds. Accordingly,

Table 14: Correlation coefficient matrix for aspects of thermal comfort in View Park Towers

Spearman's rho	Overall thermal comfort	Temperature fluctuation	Level of control over temperature	Sufficiency of lighting and exposure to sun	Frequency of drafts and cold air	Satisfaction with air circulation	Impact of comfort on productivity
Overall thermal comfort							
Correlation coefficient	1.000	0.323	0.333	0.403	−0.422	0.222	−0.297
Sig. (two-tailed)		0.240	0.225	0.137	0.117	0.425	0.282
Temperature fluctuation							
Correlation coefficient	0.323	1.000	0.335	0.440	0.207	0.190	0.155
Sig. (two-tailed)	0.240		0.222	0.100	0.459	0.497	0.581
Level of control over temperature							
Correlation coefficient	0.333	0.335	1.000	0.558*	−0.211	0.589*	0.205
Sig. (two-tailed)	0.225	0.222		0.031	0.451	0.021	0.464
Sufficiency of lighting and exposure to sun							
Correlation coefficient	0.403	0.440	0.558*	1.000	−0.263	0.211	0.050
Sig. (two-tailed)	0.137	0.100	0.031		0.344	0.451	0.859
Frequency of drafts and cold air							
Correlation coefficient	−0.422	0.207	−0.211	−0.263	1.000	0.263	0.110
Sig. (two-tailed)	0.117	0.459	0.451	0.344		0.344	0.695
Satisfaction with air circulation							
Correlation coefficient	0.222	0.190	0.589*	0.211	0.263	1.000	0.424
Sig. (two-tailed)	0.425	0.497	0.021	0.451	0.344		0.116
Impact of comfort on productivity							
Correlation coefficient	−0.297	0.155	0.205	0.050	0.110	0.424	1.000
Sig. (two-tailed)	0.282	0.581	0.464	0.859	0.695	0.116	

*Correlation is significant at the 0.05 level (two-tailed)

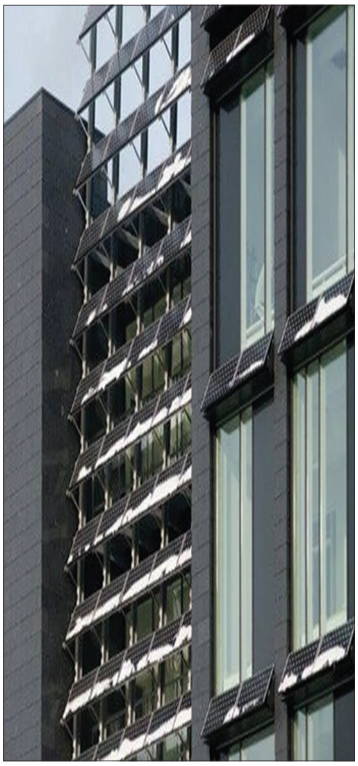

Fig. 16: The use of solar panels to reduce thermal heat gains
Source: Office in Aarhus Denmark

Fig. 17: Leveraging the use of smart green roofing to reduce heat island effects in a building
Source: Google images

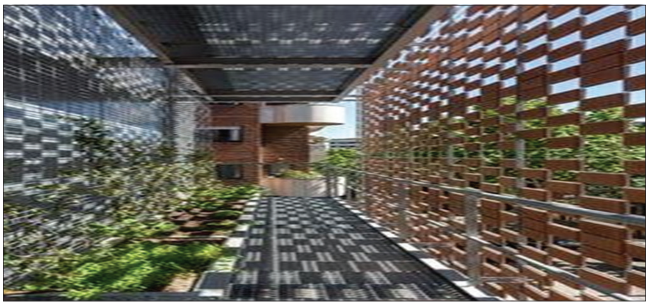

Fig. 18: Use of double skin facades to improve the thermal performance of a building
Source: Pich architects Desert House design

retrofitting initiatives to improve thermal comfort were ideally best introduced to accentuate performance of the envelope of glazed facades and also improvement user control.

Teleposta Towers (Table 15) provided compelling evidence that occupant control was central to comfort and productivity, with a moderate but significant link between "control over temperature" and "overall thermal comfort" (r=0.690, p<0.01), as well as "satisfaction with air circulation" (r=0.517, p<0.01). Crucially, the presence of "frequency of drafts and cold air" is not only highly correlated with "control over temperature" (r=0.833, p<0.01) but also modestly contributes to both "overall comfort" (r=0.555, p<0.01) and with a profound, significant "impact on productivity" (r=0.877, p<0.01). This suggests that air movements are actively sought and valued in

Table 15: Correlation coefficient matrix for aspects of thermal comfort in Teleposta Towers

Spearman's rho	Overall thermal comfort	Temperature fluctuation	Level of control over temperature	Sufficiency of lighting and exposure to sun	Frequency of drafts and cold air	Satisfaction with air circulation	Impact of comfort on productivity
Overall thermal comfort							
Correlation coefficient	1.000	0.115	0.690**	0.120	0.555*	0.337	0.405
Sig. (two-tailed)		0.683	0.004	0.671	0.032	0.219	0.134
Temperature fluctuation							
Correlation coefficient	0.115	1.000	−0.108	−0.465	−0.020	−0.674**	0.053
Sig. (two-tailed)	0.683		0.702	0.080	0.942	0.006	0.851
Level of control over temperature							
Correlation coefficient	0.690**	−0.108	1.000	0.603*	0.833**	0.517*	0.727**
Sig. (two-tailed)	0.004	0.702		0.017	0.000	0.049	0.002
Sufficiency of lighting and exposure to sun							
Correlation coefficient	0.120	−0.465	0.603*	1.000	0.642*	0.600*	0.617*
Sig. (two-tailed)	0.671	0.080	0.017		0.010	0.018	0.014
Frequency of drafts and cold air							
Correlation coefficient	0.555*	−0.020	0.833**	0.642**	1.000	0.434	0.877**
Sig. (two-tailed)	0.032	0.942	0.000	0.010		0.106	0.000
Satisfaction with air circulation							
Correlation coefficient	0.337	−0.674**	0.517*	0.600*	0.434	1.000	0.338
Sig. (two-tailed)	0.219	0.006	0.049	0.018	0.106		0.218
Impact of comfort on productivity							
Correlation coefficient	0.405	0.053	0.727**	0.617*	0.877**	0.338	1.000
Sig. (two-tailed)	0.134	0.851	0.002	0.014	0.000	0.218	

**Correlation is significant at the 0.01 level (two-tailed); *Correlation is significant at the 0.05 level (two-tailed)

Table 16: Recommendations for retrofitting of buildings for thermal comfort in the of Nairobi City County

Strategy	Model operation	Aim to improve buildings thermal performance	Material technology
Construction materials	Material use in the construction of the buildings	Incorporate high thermal mass in the construction of future building envelopes as they will absorb and release heat slowly in turn stabilizing indoor temperatures.	Materials such as reinforced concrete and masonry stone
Glazed facade material	Glaze envelopes used to wrap building with an aid of smart materials such as with low U value to help aid its performance	Reduce solar gains into the building, thus helps aiding in user comfort	Aerogels, vacuum glazed facades, electrochromic glazed facades, photovoltaic facades, materials with low E- films and spectrally selective films
Glazed façade glass type	Glass with more than one layer that helps prevent heat gain or loss in and outside the building	Helps in buildings thermal regulation	Double glazed and triple-Glazed glass
Sun shading materials	Using fins and overhangs to block sun radiations.	Helps in buildings thermal regulation Given Nairobi's equatorial location, a combined strategy is most effective. Horizontal overhangs are critical for north and south-facing facades to block the high midday sun, while vertical fins are essential for east and west-facing facades to control the low-angle morning and afternoon sun, which is a primary source of overheating and glare in the case study buildings.	Using concrete or spectrally selective glass fins. Use of Insulated Metal Panels, concrete or solar panels' overhangs
Smart roofing	Smart green roofing used to aid cooling in the building	Smart green roofs reduce heat island effects causing overall cooling within the building	
Intelligent facades/skins	Acting as a secondary building layer to filter direct sunlight	Ventilated facades, double skin facades are used to improve buildings air quality and overall thermal performance.	Facades using ethylene tetrafluoethylene (ETFE) skins, automotive duplex stainless steel.
Buffer spaces		They create a transition zone between the exterior and interior, minimizing heat transfer and improving overall thermal comfort.	Walkways, Stairways, waiting areas.
Occupant control system		Provide occupants with accessible individual controls over lighting and temperature settings within their workspaces	Automation Systems to monitor and regulate the indoor environmental conditions

Source: Ego[1], 2025

Nairobi's tropical climate. Glazed facade retrofits for Teleposta Towers must therefore prioritize highly responsive and user-friendly systems that allow for precise control over natural ventilation, turning. It is necessary to turn the façade or skin layer into a dynamic tool for managing air movement, while also optimizing daylight for enhanced productivity.

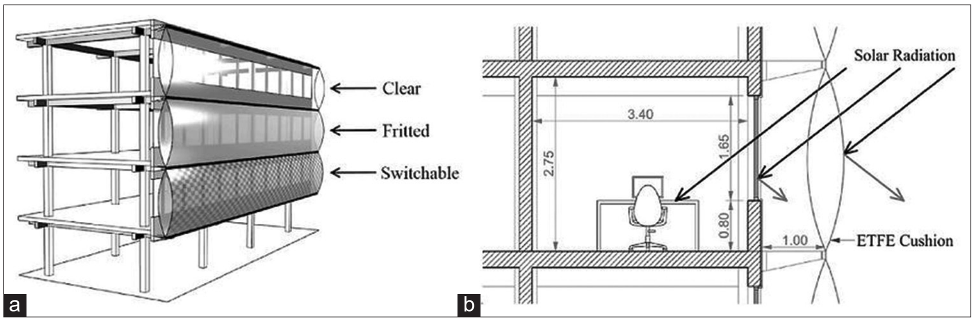

Fig. 19: (a and b) Leveraging the use of ethylene tetrafluoroethylene skins to improve thermal performance of a building
Source: Google

CONCLUSION

This study analyzed the thermal comfort in three of Nairobi's high-rise office buildings (View Park Towers, Anniversary Towers, and Teleposta Towers), linking occupant perceptions directly to architectural design. The findings from temperature measurements and occupant surveys were interpreted through a theoretical framework of building adaptability and climate-responsive design.

Perceptions on thermal comfort and indoor temperature

The study revealed a clear comfort hierarchy among the buildings that align directly with their facade design strategies and their suitability for Nairobi's tropical climate. Buildings prioritizing passive features such as high thermal mass and integrated shading consistently resulted in higher levels of occupant thermal comfort.

1. View Park Towers, with its single glazed facades, performed the poorest. Its occupants reported the lowest levels of comfort and control, and the highest perceived negative impact on productivity. The building's design offers insufficient protection from solar gain, leading to consistent overheating in the afternoons that is evidenced by internal temperatures reaching up to 28.1°C against an optimal range of 23–26°C (Table 5).
2. Anniversary Towers, despite its double-glazed facades, was rated as largely uncomfortable by a majority of its occupants. While it offered occupants a high degree of control, this was insufficient to mitigate the building's inherent thermal flaws, and it received the highest number of complaints regarding poor ventilation and consistent afternoon temperatures above 26°C (Table 5).
3. Teleposta Towers emerged as the most successful model. Its design, which incorporates high thermal mass, a lower window-to-wall ratio, and integrated concrete shading fins, resulted in the highest levels of occupant comfort. Correspondingly, it maintained stable afternoon temperatures at 22°C (Table 5), significantly cooler than its counterparts. This was achieved despite some dissatisfaction with its mechanical ventilation systems, highlighting the primacy of passive design strategies local climate context.

On the whole, the research provided clear evidence that the extensively glazed facades prevalent in the CBD of Nairobi City County were fundamentally ill-suited to the local tropical climate. This led to occupant discomfort and a negative impact on productivity. The superior performance of the Teleposta Towers that prioritized passive solar control validated the need to retrofit existing buildings with similar climate-responsive strategies.

Impact of the design strategies on thermal comfort in buildings

Construction and design choices wielded decisive influence on the thermal comfort of building occupants as outlined here below.

1. Orientation:
   While all three buildings faced challenges with solar heat gain, Teleposta Towers, with its north-east and south-west orientation, received less direct sunlight on its primary facades compared to the others demonstrating the critical role of facade orientation in mitigating heat gain in equatorial climates.
2. Building Form:
   The buildings, Anniversary Towers, View Park Towers, and Teleposta Towers all have a cubical shape. Teleposta Towers, however, differed from the other buildings in the use of sun shading devices. Fins constructed in concrete on the walls of Teleposta Towers played a crucial part in the thermos-regulation of the building by blocking direct sunlight. The use of overhangs on the lower floors of the building provided sun shading at the podium level. Both sun shading strategies greatly contributed to optimal thermal levels within the building.
3. Material Use:
   Buildings with extensively glazed facades were adjudged through literature review and site studies to generally have high internal temperatures. The use of large windows allowed for natural light into the building but also contributed to heat gain and glare. The single-glazed facades of View Park Towers, with their reflective film offered minimal insulation. The building also recorded the most negative response in the lighting and sun exposure with most participants confirming that windows allowed too much sunlight. This, in turn, caused glare and overheating within the building. The double-glazed tinted glass facades of Anniversary Towers provided better insulation compared to the single glazed facades options of Park Towers. On light and sun exposure, the building scored positively with most participants recording that the amount of natural light received was about right. The primary construction material of reinforced concrete, with its high thermal mass in Teleposta Towers, helped absorb and release heat slowly. In so doing, it regulated indoor temperatures. This building with a lower window to wall ratio compared to the other two case studies minimized heat gain and glare. It offered a clear material-based solution for thermal regulation in this climate.

In effect then, the study revealed that extensively glazed building facades may not suit Nairobi's unique tropical highland climate. The use of extensive glazed facades on buildings had also led to overheating within the spaces. There was therefore a need to re-think the approach of designing heavily glazed buildings in the CBD of Nairobi City County, to ensure that buildings remained thermally suited for the local unique tropical highland climate. Retrofitting of existing buildings to ensure they satisfy the occupant's thermal comfort was an attractive and imminent solution.

Recommendations

Based on the theory and findings of this study, strategies that, in essence, represent a design toolkit for retrofitting in tropical climates are recommended for adoption (Table 16 and Figs. 10-19). They offer architects, developers, and policymakers a clear, evidence-based guide for improving thermal performance and occupant well-being in new and existing buildings.

This inquiry examined retrofitting glazed building envelopes to enhance thermal comfort. The recommendations in Table 16 therefore emphasized adaptation of exterior surfaces that provide weather protection. Aligning with Brand's (2022) shearing layers theory, the recommended toolkit prioritized frequent, cost-effective upgrades to the Skin layer, including construction and glazed facade materials, sun shading, smart roofing, and intelligent facades/skins. Buffer spaces and occupant control systems such as operable windows, louvers, and blinds also added value, as they improved airflow and complemented the performance of glazed surfaces. Buffer spaces were important too as they related to internal layouts that influenced how fenestrations channeled air flows. Services represented high-energy options that operated contrary to concerns for passive energy and sustainability. Stuff was circumstantial to changing office users. It lacked easily generalizable permutations. Services and stuff were as a result left out of the recommended toolkit. While the permanent layer of site and the long lifespan layer of structure were important, they played a secondary role due to their relative permanence and arising inertia against change. They too were excluded from the recommended toolkit.

The intervention ranking of aspects of the recommended toolkit's varied with the particular condition of each building. For View Park Towers, double high-performance glazed facades were most urgent despite higher costs, with sun shading and operable windows as more accessible, less expensive initial measures. Anniversary Towers, with high dissatisfaction in air quality and user control, would benefit most from affordable options such as operable windows, louvers, and blinds. Both buildings could resort to the costly but highly effective option of replacing glazed facades with high thermal mass wall panels. These would be anchored to the existing structure. They would be considered only as a last resort. Teleposta Towers, with the best thermal comfort, required only the addition of operable windows to increase user control and airflow, representing the most cost-effective intervention for achieving desired comfort.

Areas for further research

This research provides a valuable starting point for understanding thermal comfort in glazed buildings. To complement this study, the following areas of further inquiry are suggested:

1. This study dealt with identifying the need for retrofitting extensively glazed buildings within the Nairobi CBD area. A related research can be undertaken to investigate the long-term impact of different retrofitting strategies on occupant productivity and energy consumption within the building
2. A further study can be conducted on the effectiveness of integrating renewable energy technologies like solar panels with building envelope design and the impact on energy consumption with the building as well as occupant comfort
3. An in-depth research on the development of user-centric design approaches to optimize thermal comfort preferences in office environments
4. Further research on the application of computerized modeling tools to predict and optimize thermal performance in glazed buildings.

ETHICAL CONSIDERATIONS

The research adhered to essential ethical standards regarding participant rights. It emphasized the four key principles of informed consent, voluntary participation, confidentiality and anonymity, and accountability. Informed consent was accorded priority, ensuring that all participants were fully aware of and that they agreed to the objectives and methods of the study before taking part in interviews and observations. For transparency, participants were informed that the research was funded independently and that it had the sole aim of academic inquiry. It was declared to them that the study had no personal interests for the researcher. Participation was completely voluntary. Participants had the freedom to join or leave the study at any time without any coercion, stigma, or loss of dignity. To safeguard the privacy of participants, the study refrained from collecting personally identifiable details. It instead used codes to anonymize identities as opposed to recording names. Data were handled securely, with access limited to the researcher, supervisors, and authorized individuals. Ultimately, the study was conducted with a strong sense of accountability and aimed at reducing power disparities. By employing non-coercive language throughout the research process, the study fostered an atmosphere of respect and consideration. This minimized bias and prejudice during interviews and observations. Fairness for both the research process and the individuals involved was in this way ensured.

AUTHORS' CONTRIBUTIONS

Rachel Jebet Ego carried out the primary research from which this paper was developed, with the guidance of Raphael Mirera. Thereafter, working with the guidance of Paul Mwangi Maringa, she abstracted this paper from the research. In this exercise, Maringa's guidance primarily contributed to giving acceptable form to the plausibility of theory and methods, consistency and flow of content, data presentation, analysis, and findings. He also carried out a comprehensive internal editorial work on the paper.

CONFLICTS OF INTEREST

The conduct of research and the ensuing research paper was kept free of financial, contracting, consultancy, employment, and personal conflicts. The authors owe no loyalty and have no affiliations whatsoever with the subjects of inquiry both at an individual and institutional level. Neither do they have any ideological or religious disposition that would cause bias with the target populations and premises in which the inquiry carried out.

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