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Research Article

ENHANCING ENERGY EFFICIENCY THROUGH NATURAL VENTILATION IN NAIROBI'S COMMERCIAL BUILDINGS

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ABSTRACT

Buildings consume over 38% of global energy, with office buildings contributing 18%. In Nairobi, rapid urbanization has increased reliance on mechanically ventilated high-rise offices, despite the city's tropical climate being suitable for passive solutions. Projections by the United Nations Environment Programme indicate that energy demand from commercial buildings will continue to rise by 1.8% annually, underscoring the need for passive design strategies such as natural ventilation. However, this remains poorly integrated into building design. This study addressed this gap through case studies of three representative high-rise office buildings in Nairobi's Central Business District, accounting for 20% of office stock. Using mixed methods, including site observations, surveys, and interviews, the research analyzed ventilation design elements and their impact on energy use. Results showed that naturally ventilated offices consumed significantly less energy (4.95 kWh/m^2/month) compared to mechanically ventilated ones (7.91 kWh/m^2/month). Key contributors included optimized window configurations, louvered openings, and ventilation shafts. The study concludes that integrating passive design strategies can enhance energy efficiency, reduce operational costs, and improve indoor comfort. It recommends policy interventions mandating passive ventilation in new developments and retrofitting strategies for existing buildings.

Keywords: Passive ventilation, Stack effect, Pressure differential.

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INTRODUCTION

Natural ventilation is a widely recognized passive strategy for reducing reliance on mechanical cooling, operating through wind and thermal pressure differentials (Mahjoub, 2018; Rotimi & Kiptala, 2014). Studies in tropical regions show that cross ventilation, optimized window configurations, and louvered openings can improve thermal comfort while cutting cooling loads by up to 60% (Rahman *et al.*, 2024). In humid climates, maintaining indoor air velocities of 0.3–0.7 m/s has been shown to enhance comfort without disrupting office activities (Alain, 2005). Night ventilation and thermal mass integration further improve performance, with energy savings reported between 8% and 20% in tropical case studies (Xiao *et al.*, 2021; Artmann & Menberg, 2022).

Global best-practice examples, such as Singapore's National Library Board and Amsterdam's The Edge, demonstrate how architectural elements, atriums, solar chimneys, and double-skin façades support both airflow and energy savings (Nirman, 2024). However, research highlights that effectiveness depends heavily on local climate conditions, building orientation, and enforcement of design standards (Kubota *et al.*, 2010; Siew *et al*. 2011; Aflaki *et al*. 2015).

In Nairobi, despite its favorable high-altitude tropical climate, with average wind speeds of 3.5 m/s and moderate diurnal temperature swings, office towers continue to mimic fully glazed façades common in temperate countries. These trap heat, leading to overheating and dependence on mechanical cooling (Ndichu, 2017). While natural ventilation has been well studied in hot-humid coastal cities, its application and energy impact in Nairobi's high-rise context remain underexplored. Existing literature does not adequately address how façade design, window-to-wall ratios, and ventilation shafts perform under Nairobi's specific conditions (Rotimi & Kiptala, 2014; Paul, 2016).

This study, therefore, seeks to fill this gap by examining the extent to which passive ventilation elements are integrated into Nairobi's high-rise office buildings, and their measurable impact on energy performance.

Problem statement

Kenya's rapid urbanization, especially in Nairobi, has spurred a surge in commercial building development, driving energy demand that now exceeds supply capacity. World Bank estimates indicate that buildings in Kenya consume over 30% of total national energy. Commercial properties have relatively larger sizes, extended operational hours, and reliance on energy-intensive systems. These buildings pose a discernible high energy consumption challenge (Kenyan Energy Act, 2019) that highlights an urgent need to identify and adopt energy-efficient strategies.

Despite the country's equatorial climate, which favors natural ventilation, 70–80% of commercial buildings rely on mechanical ventilation (UNEP, 2018). This is largely due to designs that imitate those from Western countries with colder climates. Such designs display highly glazed facades, which are ill-suited for Nairobi's tropical context. Their use leads to increased solar heat gain and higher cooling costs (Heidarinejad *et al.*, 2018).

The government, through the Energy and Petroleum Regulatory Authority, established under the Energy Act of 2006, has passed laws promoting energy efficiency and conservation (Energy Act, 2019). On their part, Physical and Land Use Planning require provisions for adequate natural cross-ventilation. However, enforcement remains inconsistent, and overreliance on mechanical ventilation persists. Operational costs and greenhouse gas emissions continue to rise. This is an acute concern given Kenya's pledge to cut emissions by 32% by 2030.

Nairobi has the largest concentration of commercial buildings in the country. The city accounts for 38% of the city's non-industrial electricity demand and houses half of the nation's large power users in its Central Business District (CBD) and industrial area (Daily Nation, 2018). The CBD faces exceptionally high cooling demand due to its urban heat island effect and the use of air conditioning systems in office buildings (Okemwa, 2017; Paul, 2016). Inadequate ventilation also undermines indoor air quality, health, comfort and productivity (Wachira & Ochanda, 2020; IEA, 2023). It also increases operational costs and environmental degradation on account of increased greenhouse gas emissions (Ghiaus & Allard, 2005). This situation is particularly concerning given Kenya's commitment to reducing greenhouse gas emissions by 32% by 2030, as outlined in its updated Nationally Determined Contributions. Moreover, the International Energy Agency (2023) emphasizes the urgent need for improved cooling strategies globally due to rapid growth in air conditioning demand, especially in emerging economies.

There is, therefore, a critical need to investigate and promote the adoption of natural ventilation strategies in commercial buildings in Nairobi. Such strategies can significantly reduce energy consumption, improve indoor air quality, and contribute to the country's sustainability goals (Nurul, 2019).

Study objectives

General objective

This study aims to provide valuable insights into the effectiveness of natural ventilation strategies in Nairobi's commercial buildings.

Specific objectives

1. To evaluate natural ventilation techniques suitable for commercial buildings in Nairobi's climate.
2. To examine the current energy consumption levels in Nairobi's commercial buildings.
3. To evaluate the effects of natural ventilation techniques on energy consumption in commercial buildings in Nairobi.

Primary research questions

1. What natural ventilation techniques are most effective in reducing energy consumption in commercial buildings in Nairobi?
2. What are the current energy consumption levels in Nairobi high-rise commercial buildings, and how are they influenced by existing ventilation systems?
3. How do different natural ventilation techniques impact the overall energy consumption of commercial buildings in Nairobi?

Secondary research questions

1. How do Nairobi's climatic conditions affect the performance of each natural ventilation technique?
2. What architectural features or facade configurations are currently best adapted to Nairobi's built environment?
3. How do variations in facade design affect energy consumption and thermal comfort?

Theoretical framework

Range of theories that constitute the theoretical framework and inform the conceptual framework (Figs. 1 and 2).

Passive design principles

This idea lays a strong emphasis on improving a building's environmental performance by utilizing natural components; sunlight, air, and vegetation (David, 2012).

Energy efficiency theory

This idea focuses on methods and tools that reduce building energy use while preserving or enhancing occupant comfort.

Sustainability theory

The integration of social, economic, and environmental factors in building design and construction is encouraged by sustainable architecture philosophy (Nobert, 2015).

The stack effect

A natural ventilation phenomenon where warm air rises and escapes through higher openings, drawing in cooler air from lower openings.

Building performance simulation

The process of simulating a building's energy performance under different conditions involves the use of computer models such as Design Builder software (Seyed, 2019).

Bioclimatic design

The goal of bioclimatic design theory is to create structures that adapt to the environment in their immediate surroundings.

METHODS

Research philosophy

This study adopted a positivist philosophy, enabling objective measurement and analysis of data related to energy consumption and natural ventilation strategies (Collis & Hussey, 2013). This approach ensured that findings are based on observable and quantifiable evidence.

Research approach

A deductive approach was employed, starting from a hypothesis that natural ventilation could serve as an effective passive design solution to reduce energy loads in high-rise office buildings in Nairobi's tropical climate. From this, the following hypothesis was formulated:

- H_0: High-rise office buildings in Nairobi that integrate natural ventilation strategies do not consume less energy per unit area than those relying primarily on mechanical ventilation.
- H_1: High-rise office buildings in Nairobi that integrate natural ventilation strategies consume less energy per unit area than those relying primarily on mechanical ventilation.

To test this, empirical data were collected and analyzed to establish significant correlations on perceptual observations of the building users on ventilation strategies, building design elements, and energy performance, using the Spearman's rank correlation tests.

Research design

A mixed-methods case study design was employed, combining quantitative and qualitative data for a comprehensive understanding. A cross-sectional time horizon was applied, with all data collected within the same research period (Saunders *et al*. 2012). Quantitative analysis: Measurements of building energy consumption (kWh/m^2/month) and coded design characteristics. Qualitative insights: Surveys, interviews, and observations that captured occupant comfort perceptions and contextual factors affecting ventilation performance.

Sampling design

This study adopted a purposive sampling for selecting case studies to be studied. Three high-rise office buildings in Nairobi's CBD, the ICEA Building, Lonrho House, and I&M Building were selected. They were selected for contextual relevance, as they represented distinct ventilation strategies (natural, mechanical, and hybrid) respectively. They were also iconic within edifices in the CBD and were also quite accessible for inquiry. In addition, these buildings were also chosen for their scale (15+ floors) and occupancy levels, considerations which made them suitable for investigating the energy implications of ventilation design and providing rich, holistic information.

The sample chosen here was not intended to be statistically generalizable to all high-rise buildings in Nairobi. Rather, it provided in-depth, comparative insights into how different ventilation strategies influenced energy use and occupant comfort. Within the three buildings, 30 tenants, including office users, building managers, facility operators, and maintenance staff, were purposively selected as key informants, on the basis of their ability to provide relevant experiential and operational information.

Data collection techniques and tools

Data collected included:

- Energy consumption data: Current energy use in buildings with natural, mechanical, and mixed ventilation systems, measured in kilowatt-hours (kWh).
- Ventilation strategy data: Types of ventilation implemented, coded as 1 = Natural, 2 = Mechanical, 3 = Mixed.
- Building characteristics: Size (m^2) and orientation (1 = North-South, 2 = East-West).
- Survey data: Occupant perceptions of indoor air quality and comfort measured using 5-point Likert scales (ordinal).

Surveys and questionnaires

Structured questionnaires captured the experiences and perceptions of occupants, enriching quantitative data with user perspectives.

Interviews

These gathered qualitative insights from office users, building managers, and maintenance staff, who all served as key informants in order to evaluate ventilation effectiveness and energy efficiency.

Direct measurements in the field

Physical spatial measurements of offices assessed suitability for natural or mechanical ventilation based on building design depths.

Observations

Visual documentation (sketches, photographs, measured drawings) recorded the physical environment for contextual understanding. Key indicators differentiated mechanically ventilated buildings (presence of fans, ducts, airtight windows) from naturally ventilated ones (large fenestrations facing north/south, narrow floor plans, shading elements, atria, and courtyards).

This comprehensive methodology, combining quantitative rigor with qualitative depth, facilitated a robust analysis of the role of natural ventilation in reducing energy loads in Nairobi's high-rise commercial buildings (Table 1).

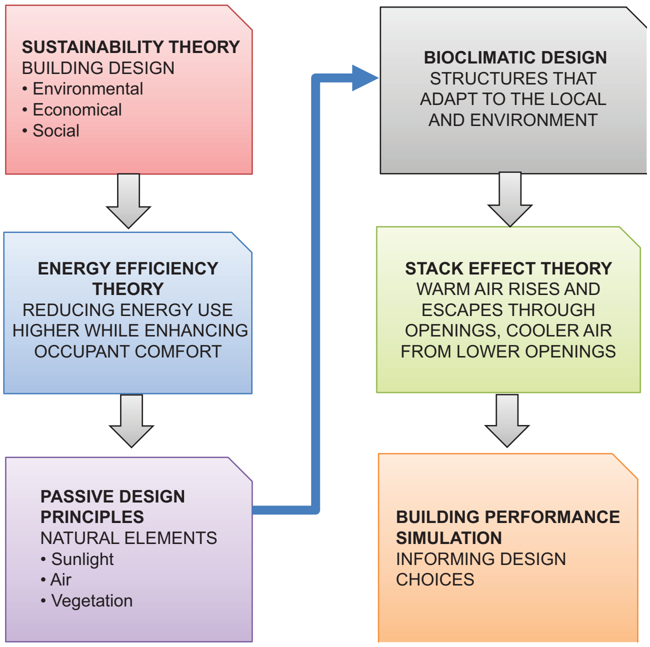


Fig. 1: Range of theories that constitute the Theoretical Framework
Source: Ranote, 2025

Data analysis

Data analysis combined the use of descriptive and inferential statistics to bring out patterns and relationships of the variables of interest in this inquiry. Energy consumption data (interval scale data, measured in kWh/m^2/month) was compared across the three ventilation strategies. Survey responses on indoor air quality and comfort were measured using adapted Likert scalogrames. These obtained ranked data in the ordinal scale. The data were analyzed using Spearman's rank correlation test. This is an appropriate non-parametric test suitable for data that is obtained in the ordinal scale (Bell & Waters, 2014). The approach to analysis adopted helped identify associations between occupant perceptions and building design features.

Data obtained through observation (such as window-to-wall ratios, presence of ventilation shafts, shading devices) was coded into categories of variables, allowing it to be associated with measured energy use. Photographs, sketches, and field notes provided qualitative depth to interpret the statistical findings.

The analysis or data on user perceptions revealed strong, significant correlations between specific architectural elements (such as louvered windows, ventilation shafts, and building orientation) and both occupant comfort and reduced energy loads. These results underscore the value of passive ventilation strategies in Nairobi's high-rise office context.

RESULTS

Quantitative energy consumption data

One building (ICEA building) out of the three that were studied relied solely on natural ventilation through building fenestrations. This is an efficient and sustainable strategy that saves a lot more on a building's energy consumption. Another relies on active ventilation (Lonrho House), while one the third one depends solely on hybrid ventilation (I&M building) (Table 2).

The observation checklist featured above in Table 3 was used to among other concerns establish if there was any vegetation around the buildings studied. Out of the three buildings studied, two buildings had planted vegetation consisting of planters and mature trees, and one building had no vegetation (Table 4). Vegetation improves the micro-climate of the buildings by providing shading, filtered fresh air and moisture, reducing use of HVAC, cutting costs and overheating in spaces.

The survey found out that one out of three (33%) building had its fenestrations on the south-facing and north-facing facades. Another one out of three (33 %) buildings had its fenestrations on three sides of the building. The last one out of three (33%) buildings had its fenestrations on all four sides of the building (Table 5). Orienting the longer elevations of the building facades to face the north and south directions and keeping the shorter sides with few or no windows mitigated the effects of solar radiation.

Further, it emerged that the three buildings that were studied had applied natural ventilation strategies (Table 6). Strategies identified were porous facade design, narrow plans, building orientation on

Table 1: Data collection methods, techniques and tools

Objectives	Variables	Methods	Tools	Output
To evaluate natural ventilation techniques suitable for commercial buildings in Nairobi's climate	Ventilation type Building size Building orientation Design features of the buildings Number of operable windows Perceived air quality	Literature Review, Case Studies, Observation	Pre-coded checklists, notes, sketches and photographs	Design guidelines Case studies Research Papers
To examine the current energy consumption levels in Nairobi's commercial buildings	Energy usage (current data on energy usage in commercial buildings with natural ventilation systems and those with mechanical ventilation systems)	Case study analysis, Comparative analysis	Survey interview schedules, utility bills	Energy performance Metrics Notes

Source: Ranote, 2025

the north-south axis, high ceiling, vegetation surrounding building, thermal mass, shading elements, atria, opening placement, operable windows, high-level vents and corridors.

Survey results

Respondent perceptual patterns are advanced here and consolidated practical and theoretical explanations for them on a building-by-building basis, advanced in the ensuing section on discussions. Thirty respondents were asked whether they found ventilation levels within the office premises sufficient. Here, 47% of them strongly agreed, 27% agreed, 17% of the respondents were neutral, 3% disagreed, while 6% strongly disagreed (Table 7). Thirty respondents were asked whether the office spaces sometimes had a mild odor. Here, 30% of them strongly agreed, 30% agreed, 20% of the respondents were neutral, 10% disagreed, while 10% strongly disagreed (Table 7). There was considerable consensus that the indoor environmental quality in all three buildings was sufficient, manifesting acceptable ventilation levels and only mild odors.

Thirty respondents were asked whether there was flexibility to open or close windows, to ease the regulation of air flow within the office. Of these, 30% strongly agreed, 23% agreed, 3% of the respondents were neutral, 4% disagreed, while 30% strongly disagreed (Table 8). Thirty respondents were asked whether air circulated adequately within the office. Of these, 23% strongly agreed, 43% agreed, 20% of the respondents were neutral, while 14% disagreed (Table 8). There was considerable consensus that the buildings were adequately ventilated and that this was possibly a result of the available flexibility or option of open windows.

Thirty respondents were asked whether the office spaces got too hot in the afternoons. Of these, 47% strongly agreed, 27% agreed, 17% of the respondents were neutral, while 9% disagreed (Table 9). Thirty respondents were asked whether keeping windows open on hot days kept the office spaces comfortable. Of these, 30% strongly agreed, 20% agreed, 10% of the respondents were neutral, 6% disagreed, while 24% strongly disagreed (Table 9). There was a marked consensus that there was a temperature build-up in the afternoons and that adequate thermal comfort in all three buildings could be achieved by opening windows.

Table 2: Measured intensity of monthly energy use (kWh/m^2) by building ventilation type

Building name	Ventilation type	Energy usage (kWh/M^2/Month)
I&M building	Hybrid ventilated	6.2
ICEA building	Naturally ventilated	4.95
Lonrho House	Mechanically ventilated	7.91

Source: Ranote, 2025

Table 3: Status of natural ventilation use in the buildings that were studied

Pertinent passive design attribute and building elements investigated	Observed status and disposition of the design attribute in each of the case studies		
	I&M building	ICEA building	Lonrho house
Building Information: Year of construction	• 2001	• 1982	• 1991
Architectural Features: Orientation of building	• East-West	• North-South	• North-South
Presence of atria or courtyards	• Atrium in the arcade	• Atrium in the arcade	• None
Type and size of windows	• Top hung windows • 2000 mm high fixed windows	• Sliding windows (3600 mm by 3600 mm) • High-level louvers display windows • Fixed glazing • Sliding windows (4000 mm by 3200 mm)	• Airtight sealed windows
Shading devices	• Vertical Shading	• Egg crate shading • Recessed windows • Louvered glazed slanting canopy	• None
• Natural Ventilation Strategies • Cross ventilation availability	• Operable top hung windows • Doors • Vents	• Operable windows. Thermal mass • Corridors	• Open parking levels • Mesh at the ramps • Main doors • High level vents
• Stack ventilation presence	• Atrium in arcade	• Atrium in arcade	• None
• Operable windows and their frequency	•Top hung windows from third level of tower	• Sliding windows on the tower	• None
• Use of ventilated facades	• Use of grills on the second level of tower	• None	• None
• Interior Design: Open plan vs. compartmentalized spaces	• Compartmentalized spaces.	• Compartmentalized spaces	• Compartmentalized spaces
• Mechanical Systems: Presence and type of mechanical ventilation	• 61 units Air Conditioners	• Some air-conditioned office spaces	• Air Conditioner main plant at the top floor
• Environmental Conditions: Perceived Air quality	• Good	• Excellent	• Fair
• Feedback on thermal comfort	• Good.	• Excellent	• Good
• Outdoor Environment: Surrounding vegetation	• Cleared	• Existing trees on the eastern side	• Planters around the building
• Proximity to other buildings (Possible obstructions)	• Pioneer House on the west façade	• -	• Pasava cafe and restaurant on the East side
• External noise sources	• Kenyatta Avenue • Muindi Mbingu Street	• Kenyatta Avenue • Wabera Street	• Standard street • Press lane
• Maintenance and upkeep: Observed barriers to natural ventilation	• Sealed off high level vents in some shops at ground floor level to prevent dust penetration	• Fixed glazing on the lift shaft due to mechanical room provision	• Airtight outer skin

Source: Ranote, 2025

Thirty respondents were asked whether they were aware of the benefits of natural ventilation for energy efficiency. 13% of them strongly agreed, 40% agreed, 20% of the respondents were neutral, 20% disagreed, while 7% strongly disagreed (Table 10). Thirty respondents were asked whether they believed that implementing natural ventilation strategies could reduce energy consumption in their building markedly. A paltry 7% of them strongly agreed, 20% agreed, 20% of the respondents were neutral, 30% disagreed, while 23% strongly disagreed (Table 10). There was a conspicuous consensus that, whereas natural ventilation favored energy efficiency, it could not reduce the energy consumption markedly.

Table 4: Vegetation around buildings

Surrounding vegetation	Number of buildings	Name of building
Existing vegetation	1	I & M building
Cleared vegetation	2	Lonrho house

Source: Ranote, 2025

Table 5: Orientation of windows in the buildings

Building windows orientation	Number of buildings	Name of building
North-South	1	I & M building
North-South/East	1	Lonrho house
North-South/East-West	1	Lonrho house

Source: Ranote, 2025

DISCUSSION

The study established that most high-rise buildings along Kenyatta Avenue incorporated some form of passive design strategy, particularly those constructed before the widespread adoption of fully glazed façades in the 1990s. This historical reliance on shading, narrow plans, and operable fenestration is consistent with tropical passive design principles. It explains why naturally ventilated buildings, such as the ICEA Building, performed better than their hybrid or fully mechanically ventilated counterparts.

ICEA building: Why natural ventilation worked

The ICEA building is a naturally ventilated 19-story general office building completed in 1982 by architect Richard Hughes and Partners. The superior energy performance of the ICEA Building can be explained through its north–south orientation, narrow elongated floor plan, operable windows, recessed shading, and high thermal mass (Figs. 3 and 4).

These features collectively optimized both cross-ventilation and the stack effect. By orienting the longer façades to the north and south, the building minimized east–west solar exposure, directly reducing cooling loads. The narrow plan ensured shallow spaces where wind-driven pressure differentials could effectively induce cross-ventilation (Figs. 5 and 6). Operable windows, especially louvers, increased the effective aperture ratio, enabling more air changes per hour (ACH) compared to sealed glazing.

Table 6: Natural ventilation strategies applied in the buildings

Response	Porous façade (PF)	Narrow plans (NP)	Building orientation (BO)	High ceiling (HC)	Vegetation (V)	Thermal mass (TM)	Shade (S)	Artria (A)	Oper Able Windows (OW)
Y	1	1	2	3	2	1	2	2	2
N	2	2	1	-	1	2	1	1	1

Source: Ranote, 2025. Y=Yes and N=No

Table 7: Indoor environmental air quality

Sentiment type and proportional measure of response	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I find the ventilation levels within the office premises sufficient.	14	8	5	1	2
Percentage distribution of response/sentiment	47%	27%	17%	3%	6%
The office space sometimes has a mild odor.	9	9	6	3	3
Percentage distribution of response/sentiment	30%	30%	20%	10%	10%

Source: Ranote, 2025

Table 8: Ventilation systems

Sentiment type and proportional measure of response	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
There is flexibility to open or close windows, easing the regulation of air flow within the office.	9	7	1	4	9
Percentage distribution of response/sentiment	30%	23%	3%	14%	30%
Air circulates adequately within the office.	7	13	6	4	0
Percentage distribution of response/sentiment	23%	43%	20%	14%	0%

Source: Ranote, 2025

Table 9: Thermal comfort

Sentiment type and proportional measure of response	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The office space gets too hot in the afternoons	14	8	5	3	0
Percentage distribution of response/sentiment	47%	27%	17%	9%	0%
On hot days, keeping windows open keeps the office space comfortable.	9	6	3	2	10
Percentage distribution of response/sentiment	30%	20%	10%	6%	24%

Source: Ranote, 2025

Table 10: Perception and awareness

Sentiment type and proportional measure of response	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I am aware of the benefits of natural ventilation for energy efficiency	4	12	6	6	2
Percentage distribution of response/sentiment	13%	40%	20%	20%	7%
I believe that implementing natural ventilation strategies can significantly reduce energy consumption in your building	2	6	6	9	7
Percentage distribution of response/sentiment	7%	20%	20%	30%	23%

Source: Ranote, 2025

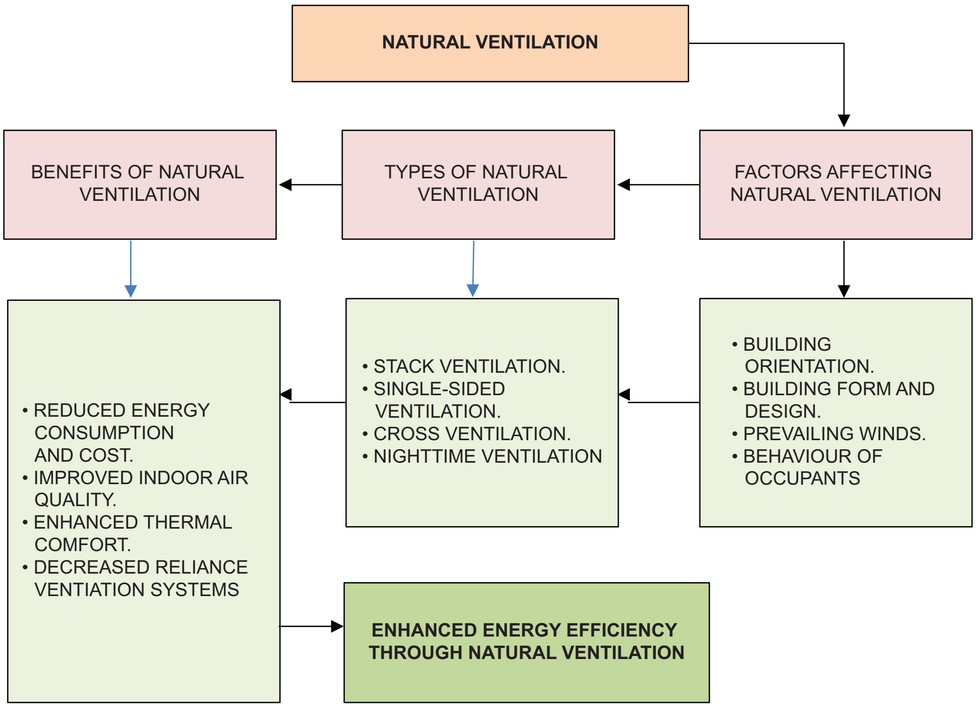


Fig. 2: Conceptual framework of the study
Source: Ranote, 2025

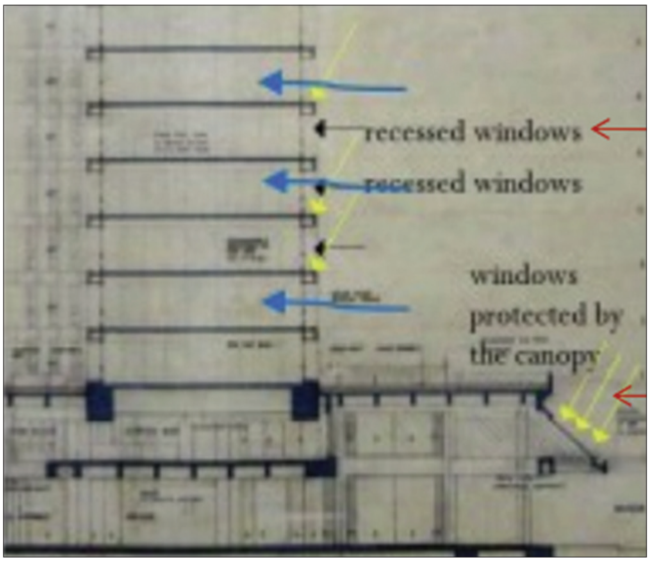


Fig. 3: Section and façade of the ICEA building showing operable windows, recessed shading, and high thermal mass
Source: Ranote, 2025

Shading devices, particularly egg-crate shading, reduced direct solar gains, lowering indoor air temperature and reinforcing buoyancy-driven air movement (stack effect). Complementarily, this stack effect

Fig. 4: Section and façade of the ICEA building showing operable windows, recessed shading, and high thermal mass
Source: Ranote, 2025

is enhanced by the atrium, whose glazed roof absorbs solar energy, raising air temperature differentials.

The strong positive or direct correlations observed between thermal comfort and perceived ventilation with r-values that ranges from $r = 0.52$ to 0.89 (Table 11) align well with theories of pressure differentials and

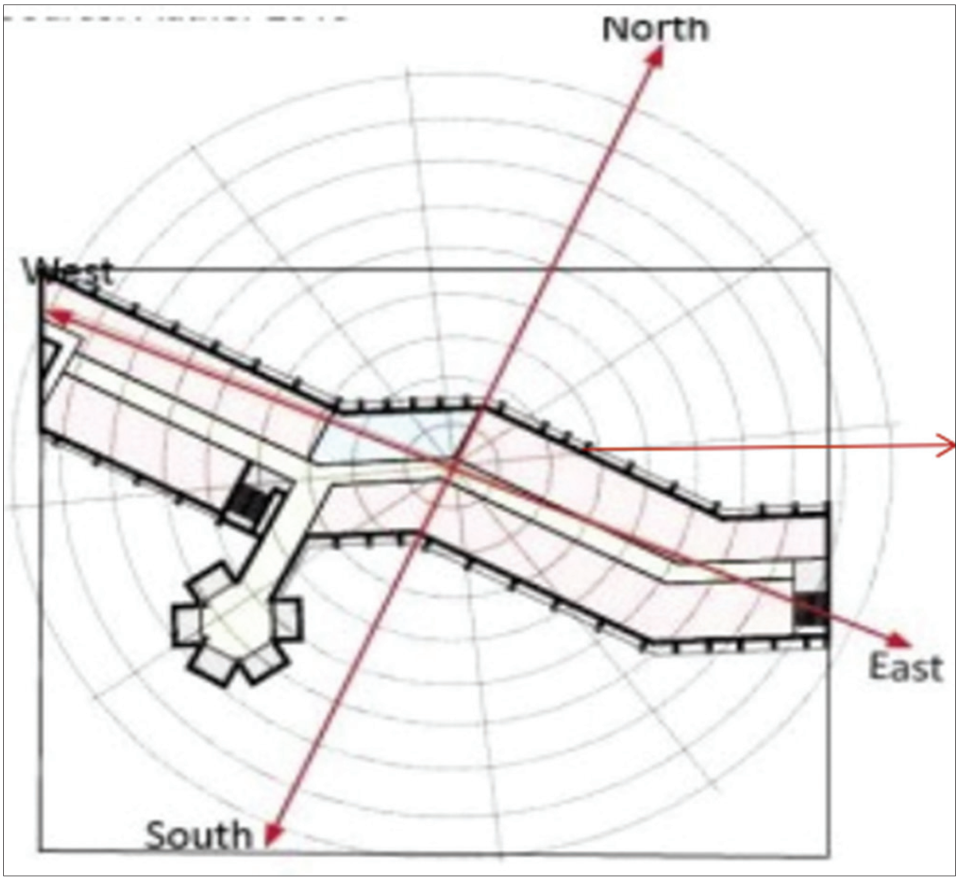


Fig. 5: ICEA building floor plan showing North-south facing longer elevations of the building facades in evidence
Source: Ranote, 2025

Fig. 6: Narrow elongated plan of the ICEA building that enhances easy passage of air for cross ventilation
Source: Ranote, 2025

buoyancy. When windows were operable and shading reduces radiant gains, occupants not only reported better comfort but also demonstrated lower reliance on mechanical cooling. This validates literature, which emphasizes that cross-ventilation in tropical cities is most effective in narrow appropriately oriented plans, with maximized operable window space, and high ceiling heights that permit stratification of hot air.

Table 11: Spearman rank correlation coefficient matrix on perception of thermal comfort and ventilation

Variable pair	p	S	Significance Level (n=30)
Ventilation Sufficient versus Office Gets Hot	−0.97	☑	Very Strong, P<0 .001
Ventilation Sufficient versus Air Circulation	+0.89	☑	Very Strong, P<0.001
Ventilation Sufficient versus Mild Odor	+0.85	☑	Very Strong, P<0.001
Ventilation Sufficient versus Ventilation Flex	+0.49	☑	Moderate, P≈0.005
Air Circulation versus Mild Odor	+0.75	☑	Strong, P<0.001
Office Gets Hot versus Windows Comfortable…	−0.67	☑	Strong, P<0.001
Ventilation Flexibility versus Air Circulation	+0.56	☑	Moderate, P≈0.001
Mild Odor versus Ventilation Flexibility	+0.52	☑	Moderate, P≈0.003
Awareness of Benefits versus Energy Savings	+0.29	×	Weak, non-significant
Ventilation Flexibility versus Awareness	+0.33	×	Weak, non-significant
Ventilation Sufficient versus Awareness	+0.22	×	Very weak
Energy Savings Belief versus Windows Comfortable	+0.12	×	Negligible

Source: Ranote, 2025. **Correlation is significant at the 0.01 alpha (α) error level (2-tailed). S= Significance (a tick for yes and cross for no).

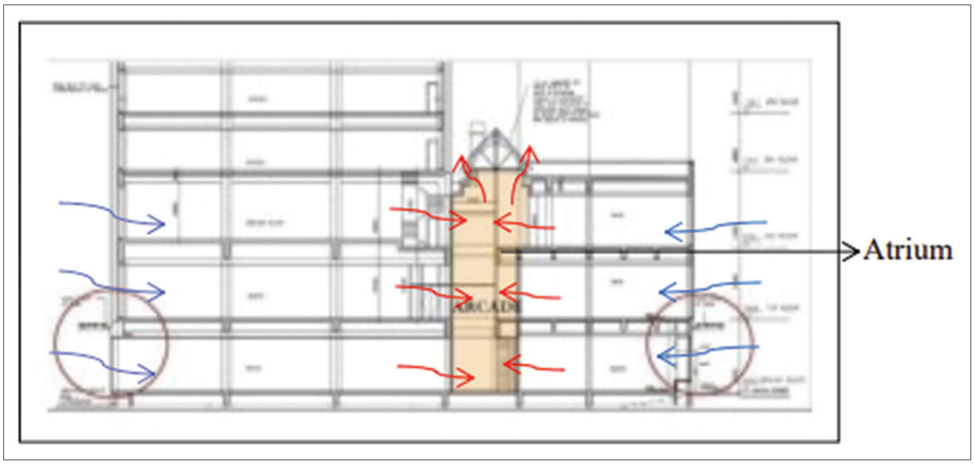


Fig. 7: Section through I&M building showing a central atrium used to promote stack-driven air movement
Source: Ranote, 2025

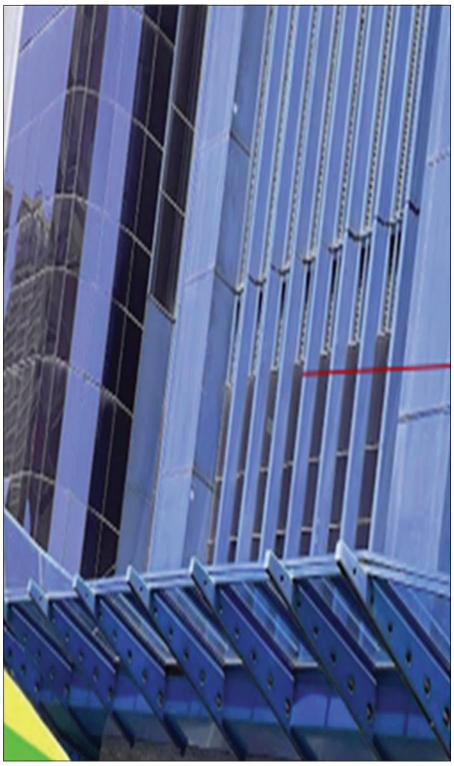


Fig. 8: Use of vertical sun shading elements on the tower to reduce solar heat gain
Source: Ranote, 2025

Fig. 9: Use of grilles on the second level of the tower to allow free movement of air in and out of the generator room
Source: Ranote, 2025

I&M building: Trade-offs in hybrid systems

In contrast, I&M Building, completed in 2001, illustrates both the potential and the limitations of hybrid ventilation. The building incorporated high ceilings, shading devices, and a central atrium to promote stack-driven air movement (Fig. 7). However, its deep floor plates (>15 m) limited cross-ventilation effectiveness, forcing reliance on 61 air-conditioning units. This confirms the passive design principle that natural ventilation becomes ineffective beyond a floor depth of 15 m without additional design interventions such as ventilation shafts.

The atrium acted as a partial stack chimney, stabilizing internal temperatures and reducing peak cooling demand. The building uses vertical sun shading elements on the tower to reduce solar heat gain (Fig. 8).

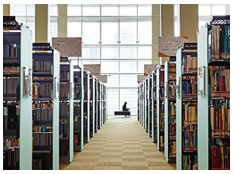
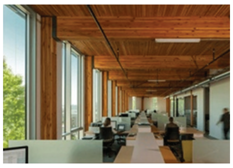
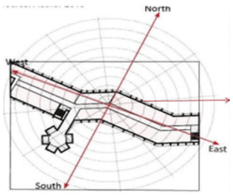
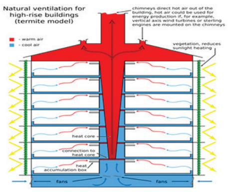
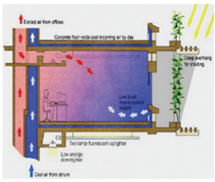
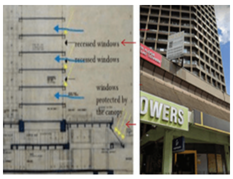
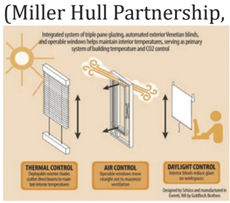
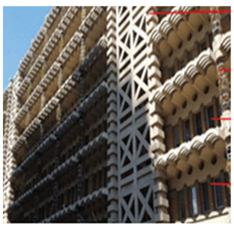
Use of grilles on the second level of the tower allowed free movement of air in and out of the generator room (Fig. 9). Yet, the glazed curtain walling increased solar heat gains considerably, negating much of the energy savings from natural ventilation. Thus, while hybrid systems theoretically offered flexibility, in practice the I&M Building demonstrated that without careful integration of façade design, the mechanical component would dominate as a necessary intervention.

Lonrho house: Lessons from mechanical dependence

Lonrho house is a fully actively ventilated 20-storey building completed in 1991 to be Lonrho Africa's Headquarters with a built-up area of 15,770.756 m^2.

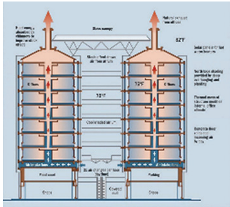
The building, with its fully glazed airtight façade, exemplified architectural mimicry detached from Nairobi's climate context

Table 12: Application of natural ventilation in tropical buildings

Design element	Eastgate building (central Harare, Zimbabwe)	National library board building (Victoria street, Singapore)	ICEA building (Nairobi, Kenya)	Bullitt center (Seattle, Washington)
Thermal mass	Heat is absorbed by the fabric of the building, which has a high heat capacity; the temperature inside increases but not greatly (Arup, 2021). 	The interior utilizes substantial concrete and masonry surfaces—walls, floors, and atrium surfaces—as thermal batteries (Singh, 2020). 	The building's material, solid concrete, can store the heat of the sun during the day to release it slowly during the night (Ranote, 2025). 	The use of concrete and heavy mass timber, which are high thermal mass materials, helps in controlling solar heat gains (Miller Hull Partnership, 2013). 
Building orientation	The building is oriented away from the east-west axis, and its southwestern side is constructed of solid wall (Arup, 2021). 	Deep overhangs provide shade over east and west façades (Singh, 2020). 	The longer elevations of the building facades are oriented to face the North and South directions (Ranote, 2025). 	Major glazing areas face south and north to improve daylighting and solar control (Miller Hull Partnership, 2013). 
Vegetation surrounding building	Vertical green walls reduce sunlight heating and purify air circulation within the building 	14 Landscaped gardens in the complex, with 120 species of tropical plants (Singh, 2020). 	The building has trees on the Eastern side, which improve the microclimate of the building (Ranote, 2025). 	Horsetails, and equisetum, are used for their hardiness and ability to thrive in Seattle's climate (Miller Hull Partnership, 2013). 
Shading	Windows have adjustable blinds. Deep overhangs keep direct sun off windows and walls. Massive protruding stone elements protect the small windows from the sun (Arup, 2021). 	Faces of the building are fitted with sunshade blades that prevent excessive heat and glare (Singh, 2020). 	Glazing shaded with metallic louvers protect the podium canopy from direct sun. The building also incorporates recessed 	Automated blinds integrated with operable windows minimize solar heat gain. Triple-pane glazing and deployable exterior shades (Miller Hull Partnership, 2013) 
Window-to-wall ratio/ Opening type	No direct sunlight ever hits the external walls, and the north window-to-wall ratio is capped at 25% (Arup, 2021). 	Employs a moderate window-to-wall ratio (44.4%) (Singh, 2020). 	Sliding windows (3600 X 3000 mm high). High level louvers. Ground floor (4000 mm wide by 3200 high) (Ranote, 2025). 	Two inches and three panes of glass keep the hot air out and cool air in (hot days), and the cold air out and warm air in (cold days) (Miller Hull Partnership, 2013). 

(*Contd...*)

Table 12: (*Continued*)

Design element	Eastgate building (central Harare, Zimbabwe)	National library board building (Victoria street, Singapore)	ICEA building (Nairobi, Kenya)	Bullitt center (Seattle, Washington)
Atrium	Comprises two buildings side by side linked together by a glass roof hence an atrium (Arup, 2021). 	Building consists of two adjoining blocks linked by bridges on the upper floors, creating an atrium in between that funnels air through (Singh, 2020). 	The presence of a glazed roof enables the atrium to absorb solar energy, raising air temperature differentials for stack effect (Ranote, 2025). 	The building has an open courtyard that aids in bringing in fresh air into the spaces enhancing cross ventilation (Miller Hull Partnership, 2013) 
High ceiling	Tall ceiling spaces naturally draw air upward into the 48 rooftop chimneys (Arup, 2021). 	High ceilings where heat can rise well above head height (Singh, 2020). 	Mezzanine floor 4400 mm high, Ground floor 4500 mm high (Ranote, 2025) 	The building has 13-foot-high ceilings and 10-foot-high windows (Miller Hull Partnership, 2013). 

Source: Ranote[1], 2025

Fig. 10: Fully glazed airtight façade of Lonrho House, which exemplifies architectural mimicry detached from Nairobi's climate context
Source: Ranote, 2025

(Fig. 10). Its reliance on mechanical ventilation underscored how global trends in curtain walling often overrode local passive strategies. The inefficiencies observed in air quality distribution, such as stuffy corridors, reinforced the theory that deep, sealed floor plates were inherently incompatible with passive airflow mechanisms, regardless of HVAC efficiency.

Occupant perceptions and awareness

One striking finding was the discrepancy in user awareness (Table 10). Even in the naturally ventilated ICEA Building, many occupants were unaware of the energy-saving benefits of operable windows or shading systems. This suggests a gap between architectural design intent and user behavior. Literature on adaptive comfort stresses that occupant engagement in adjusting windows, using shading, is central to the success of passive systems. If users remain unaware or disengaged, potential energy savings are undercut.

Limitations of natural ventilation in Nairobi's context and the tropics

While natural ventilation proved effective in reducing heating loads, the study also revealed its limitations. Several respondents cited dust infiltration and urban noise as deterrents to opening windows, leading to sealed vents in some shops at I&M. This reflected the trade-off between environmental quality and occupant comfort. Although pressure differentials and stack effects provide airflow, urban pollutants and noise can reduce the desirability of natural modes. These findings echo the caution that urban microclimates and externalities can undermine passive comfort strategies. Limitations of natural ventilation strategies across buildings in the tropics demonstrate how thermal mass, orientation, vegetation, and shading contribute to indoor thermal regulations (table 12). National, regional and international case studies that include the East gate building, the National Library Board building, the ICEA building and the Bullitt Center, employ context specific passive design measures to reduce reliance on mechanical cooling (table 12).

Explaining the strong correlations

The observed strong correlations between thermal comfort and perceived ventilation (r = 0.52–0.89) can be explained by the combined impact of shading and operable fenestrations on the stack effect (Table 11). For instance, egg-crate shading reduces solar-induced indoor temperature by an estimated 2–3°C in tropical climates. This in turn increases the indoor–outdoor thermal gradient and thus the buoyancy force driving upward airflow. Similarly, louvered windows, which allow nearly 100% opening efficiency, increase airflow rates by up to 50% compared to sliding windows. These quantitative effects translate directly into higher occupant comfort ratings and lower reliance on artificial cooling.

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

Where d_i = Difference in ranks of respondent i; n=30

Strong positive significant correlations with r-coefficient values ranging between 0.52 to 0.89, with a p-calculated values of less than 0.01 being significant at an (α) alpha error value of <0.01, and therefore a confidence level of 99.9% (Table 11). These were established between attributes that enhance or signify improved natural ventilation and air circulation, ventilation sufficiency, mild odors, comfort, and flexibility of ventilation. Inverse correlations, for instance, of improved natural circulation, comfortable provision and disposition of windows and offices getting hot, where observed to prevail with a correlation coefficient r = −0.97 and −0.67, and p-calculated values of <0.01.

CONCLUSION

This study set out to evaluate natural ventilation techniques suitable for Nairobi's climate, examine current energy consumption levels in high-rise commercial buildings, and assess the impact of natural ventilation on energy use. The findings demonstrate three clear outcomes that ally well with the specific objectives set out for the study here.

First, natural ventilation, when properly integrated into building design, leads to significant energy savings. The ICEA building showed that strategies such as north–south orientation, narrow floor plates, operable windows, and effective shading devices can reduce energy loads by approximately 37% per unit floor area compared to fully mechanically ventilated buildings. This confirms that passive strategies, when aligned with climatic principles, are both effective and viable in Nairobi's tropical urban context.

Second, current energy consumption patterns revealed sharp differences across ventilation modes. Fully mechanically ventilated buildings such as Lonrho House demanded the highest energy input, reflecting both the limitations of sealed glazed façades in this climate and the long-term operational costs of HVAC dependence. Hybrid systems, as observed in the I&M building, reduced energy consumption compared to mechanical-only solutions. They were nevertheless less effective than well-designed naturally ventilated options due to deep floor plates and heavy reliance on cooling systems.

Third, occupant behaviour significantly influences actual performance. Even in naturally ventilated buildings, the benefits of passive systems are reduced when windows remain closed due to dust, noise, or partitions blocking airflow. Conversely, active engagement with operable windows and shading devices directly improved thermal comfort and reduced reliance on artificial cooling. This underscores the importance of user awareness and adaptive comfort in realizing energy savings.

Taken together, the conclusions affirm that natural ventilation is not only suitable but highly effective for high-rise office buildings in Nairobi when design strategies are carefully applied. Hybrid systems provide flexibility but should not substitute for climate-responsive architectural design. Mechanically dependent buildings, though offering dust and noise control, are the least sustainable option, locking occupants into higher costs and potential health risks.

RECOMMENDATIONS

Recommendations for policy makers, design and construction professionals, and investors

Policy makers, investors, designers, and professionals in the built environment should be aware that Passive ventilation and hybrid ventilation emerge as the most favourable means of ventilation, especially in Nairobi, where climatic conditions are constructive. In cases where one wants to use mechanical ventilation for flexibility of design, hybrid ventilation strategies should be considered as a strategy instead, as it consumes less energy.

In general, passive design strategies recommended for office buildings in tropical climates fall into two classifications, namely, heat avoidance techniques and the provision for cooling (Badariah, 2012). Of the heat avoidance, external shading is the most significant. Shading blocks out solar radiation, which is the greatest source of heat gain in buildings (Richenel & Johannes, 2021). It is therefore highly recommended and frequently specified in energy efficiency regulations for tropical regions. It serves as one of the main structural controls applied to minimize energy consumption. It curbs poor thermal conditions in buildings.

Egg crate shading is recommended to be the most effective shading technique, irrespective of glazing orientation, as it helps to block solar radiation from varied sun angles. Horizontal shading is most effective when used to cut out high-angle sun, mainly in the northern and southern facing facades. Vertical shading is most effective when used to cut out low-angle sun, which is mainly experienced in the eastern and western facing facades.

Natural ventilation needs careful design so as to enable wind and stack-driven air movement to provide enough fresh air for a healthy internal environment (Marveh, 2018). It also enables the removal of excess heat gain in hot conditions. Operable openings in the facades can be windows or low-level or high-level vents, and these latter can be wind pressure-controlled to control the amount of wind-driven ventilation.

They must ascertain that the orientation of spaces should be such that one avoids the western sun in hot period. Where possible, architects could locate functions like wet areas and service areas in the west façade to act as buffer zones. The Glazed area of the window should be reduced to a functionally acceptable level. A maximum of 40% window-to-wall ratio, to reduce internal energy requirements, will serve well here. Buildings and their openings should be laid out to encourage the channeling of winds for ventilation (Yoon *et al.*, 2020). Close proximity of buildings can also enable them to mutually shade each other from solar radiation, thereby reducing heat gain. Narrow-plan buildings with the enable cross ventilation would be comfortable, given the enhanced natural ventilation, and this would provide the best energy efficiency where usable (Kiamba, 2016).

Recommendations for policymakers and regulators

It is necessary to update the Kenya national building code 2024 to establish maximum window-to-wall ratios (e.g., 40%) for commercial buildings, particularly limiting glazing in the east and west façades. This would directly reduce solar heat gain and cooling loads (Kamoru, 2010). The code should also require for the incorporation of external shading elements (louvers, egg-crate shading, or vertical fins) on east and west-facing elevations for all new high-rise office buildings (Ngaopier *et al.*, 2021). There is a need to additionally establish clear ventilation performance criteria in building regulations. These would include minimum operable window percentages and requirements for cross-ventilation in floor plans that are narrower than 12 m (Lee & Ramirez, 2023).

Further, hybrid systems should be permitted as an acceptable compliance option only where deep floor plates make natural ventilation insufficient. A critical proviso here should be that mechanical cooling demand is reduced by at least 30% compared to conventional designs

(Ismail & Abdul, 2010). Finally, vegetation buffers and reflective roofing materials in new developments to moderate urban heat island effects and improve air quality should be made mandatory feature of designs (Sen *et al.*, 2024).

As such, instead of simply encouraging global rating tools (BREEAM, LEED), establish a local energy performance certification benchmark tied to Nairobi's climate, using passive design metrics as minimum compliance thresholds.

Areas for further research

The overall review of studies presents a range of architectural elements and techniques within building facades and ventilation openings, which have been used to achieve natural ventilation inside buildings in tropical climates. A comparison of the results indicates that ventilation shafts, window-to-wall ratio, and building orientation are fundamental criteria for naturally ventilated buildings. This study identifies some further specific elements that are worth investigation. These include the shape of louvered windows, different forms of apertures, and vernacular elements. For instance, the design of louvered windows for night-time flushing as the best ventilation strategy in tropical climate, declared by Kubota *et al.* (2009), or different shapes of louver to maximize wind force ventilation are two effective strategies that are not explored in the above-mentioned studies.

According to the outcomes of the study by Nedhal and Fadzil (2012), further research should be conducted on the impact of vertical shadings on air velocity ratios inside buildings. Another architectural element worth looking into is the effect of different shapes and forms of apertures on differences in air pressure around the external surfaces of a building …laki *et al.*, 2015). Wall grooves, as used in vernacular architecture, could increase natural ventilation in buildings. Muqoffa *et al.*'s (2025) analysis of Javanese homes underscores how courtyard layouts, wing walls, and thermal chimneys effectively promote ventilation. This strategy is further emphasized in M'zab Valley dwellings using ventilated mask walls to channel airflow via neo-vernacular perforations (Arigue *et al.*, 2023). However, there is very little research on the application of these elements in modern architecture, and this would be something worth further inquiry (Abuhussain *et al.*, 2023).

ETHICAL CONSIDERATIONS

The study adhered to fundamental ethical principles concerning the rights of participant. Accordingly, it embraced the four core tenets of informed consent, voluntary participation, confidentiality and anonymity, and accountability. First, informed consent was prioritized by ensuring that all participants fully understood and agreed to the purposes and procedures of the study before engaging in interviews and observations. It was clearly communicated that the research was self-funded and conducted solely for academic purposes, with no personal gain for the researcher.

Participation was entirely voluntary, allowing individuals the freedom to join or withdraw from the study at any point without any pressure, stigma, or loss of dignity. To protect the privacy of participants, the study avoided collecting personally identifiable information by anonymizing identities through coding rather than recording names. Data were managed securely, and access was restricted solely to the researcher, supervisors, and authorized personnel. Finally, the study was conducted with a commitment to accountability and minimizing power imbalances. Neutral, non-coercive language was used throughout, respecting participant autonomy and fostering an environment of equality. This helped reduce bias and prejudice during interviews and observations. Fairness for both the research and those involved was thereby assured.

AUTHOR'S CONTRIBUTIONS

Rosebell Akinyi Ranote carried out the base inquiry of this paper under the guidance of Beatrice Kirongon. Rosebell proceeded on to develop the paper, guided by Paul Mwangi Maringa. Maringa's guidance focused most especially on the sequencing of reporting, data presentation, analysis, inferencing, and the overall formatting and editing of the paper.

CONFLICTS OF INTEREST

The research that informs this paper was kept free of personal and financial conflicts of interests. This was done in the sense of the authors having no financial, employment, or personal affiliation, or institutional loyalties, with respondents and proprietors of the situs where inquiry was conducted. Further, the authors carried no ideological or religious prejudice or bias that in any way impacted on the conduct of the inquiry, the premises visited for the inquiry of the people interviewed, and activities observed.

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