



NATURAL LIGHTING AND NATURAL VENTILATION ON THERMAL COMFORT AND ENERGY EFFICIENCY IN COLONIAL HERITAGE BUILDINGS.

Andiyan^{1,2*}, Ikaputra³

¹Doctoral Student in Architecture, Department of Architecture and Planning, Gadjah Mada University

²Department of Architecture, Faletihan University

³Doctoral Programme in Architecture, Department of Architecture and Planning Engineering, Gadjah Mada University

*Email: andiyan@mail.ugm.ac.id

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Abstract: *Natural lighting and natural ventilation are very important in the architecture of cultural heritage buildings, especially concerning thermal comfort and energy efficiency. This study aims to explore the impact of these two elements on the design of cultural heritage buildings in tropical climates. The method used is a systematic literature review, highlighting the latest relevant scientific articles. The results of the study show that the optimal use of natural lighting and ventilation can improve occupant comfort. A reduction in indoor temperature of up to 5°C can also decrease the energy requirements for cooling and lighting. In addition, passive design strategies that consider building orientation and the use of local materials have proven effective in managing heat and humidity loads. These conclusions are expected to serve as a reference for practitioners and managers of heritage buildings. By applying sustainable design principles, they can maintain the historical integrity of buildings while achieving better energy performance.*

Keywords: *Natural lighting, Natural ventilation, Thermal comfort, Energy efficiency, Heritage buildings, Passive design.*

Abstract: Pencahayaan alami dan penghawaan alami sangat penting dalam arsitektur bangunan cagar budaya, terutama terkait dengan kenyamanan termal dan efisiensi energi. Penelitian ini bertujuan untuk mengeksplorasi dampak kedua elemen tersebut dalam desain bangunan cagar budaya di iklim tropis. Metode yang digunakan adalah tinjauan literatur sistematis, menyortir artikel-artikel ilmiah terbaru yang relevan. Hasil penelitian menunjukkan bahwa pemanfaatan optimal pencahayaan alami dan ventilasi dapat meningkatkan kenyamanan penghuni. Penurunan suhu dalam ruangan mencapai 5°C juga dapat mengurangi kebutuhan energi untuk pendinginan dan pencahayaan. Selain itu, strategi desain pasif yang memperhatikan orientasi bangunan dan penggunaan material lokal terbukti efektif dalam mengelola beban panas dan kelembapan. Kesimpulan ini diharapkan menjadi acuan bagi praktisi dan pengelola bangunan cagar budaya. Dengan menerapkan prinsip-prinsip desain berkelanjutan, mereka dapat mempertahankan integritas historis bangunan sambil mencapai kinerja energi yang lebih baik.

Kata Kunci: Pencahayaan alami, Penghawaan alami, Kenyamanan termal, Efisiensi energi, Bangunan cagar budaya, Desain pasif.

INTRODUCTION

Heritage buildings in Indonesia and other countries face challenges in maintaining thermal comfort and energy efficiency. According to UNESCO (Change, 2007), many historic buildings experience a decline in indoor environmental quality due to the lack of integration of natural lighting and ventilation systems. Climate change, which causes global temperature increases, adds pressure on energy for cooling (Masson-Delmotte et al., 2021). Therefore, natural lighting and natural ventilation are very important in maintaining thermal comfort and energy efficiency in heritage buildings. These buildings have specific characteristics that must be considered in the

application of these systems to preserve their historical value and ensure comfort for their occupants.

Optimising natural lighting reduces the need for artificial lighting, reduces internal heat load and energy consumption. Natural ventilation allows for air exchange that cools the building and improves the physiological comfort of occupants (Piraei et al., 2022). Proper integration of these two systems can lower indoor temperatures by up to 5°C, which is directly related to thermal comfort and reduced energy use for cooling (Alwetaishi, 2022). Passive design, such as planting shade trees around buildings, serves to block direct solar radiation and

reduce heat gain. Building materials with high thermal mass help stabilise internal temperatures (Aini, 2021). Adaptive comfort models, which consider non-thermal variables, are increasingly important in the context of tropical buildings as they can mediate users' thermal perceptions and reduce energy requirements (Srithongchai, 2019). Research in tropical climates shows that higher comfort temperatures can be achieved in buildings with good natural ventilation (Sadafi et al., 2011).

In the context of heritage buildings, the application of natural lighting and ventilation systems can reduce dependence on electrical energy for lighting and cooling. Research by Aini and Rani shows that making good use of natural lighting and ventilation can reduce electrical energy consumption, provided that valuable items are not directly exposed to sunlight (Aini & Rani, 2021). A study by Winandari et al. reveals that the application of passive design, such as skylights and optimal openings, can increase energy efficiency and create thermal comfort. Adequate natural lighting reduces dependence on artificial lighting and has a direct impact on energy savings (Iyati et al., 2020; Latifah et al., 2021). Effective natural ventilation is vital for maintaining indoor air quality, removing excess heat, and reducing humidity, all of which contribute to thermal comfort and reduced mechanical cooling loads (Aini, 2021; Sekartaji et al., 2023). For heritage buildings, adaptation to the tropical climate often requires passive design strategies such as proper building orientation and the use of weather-resistant materials to maximise the benefits of natural lighting and ventilation without compromising historical integrity (Saliim & Satwikasari, 2022).

Effective use of natural lighting and ventilation in heritage buildings can reduce the largest energy loads in tropical climates, namely for cooling and lighting (Acosta-Medina et al., 2025). Optimising openings and adding elements such as ceilings, fins, or sunshades further enhances energy performance and creates thermal comfort zones without compromising the historical integrity of the building (Fitriaty et al., 2021). High indoor air velocity also contributes to thermal comfort and reduces reliance on mechanical cooling (Wellun et al., 2023). A case study of traditional Malay houses shows that optimal natural ventilation can maintain comfortable indoor temperatures and reduce the need for artificial cooling, which accounts for more than a third of electricity consumption in the residential sector (Ramli & Hassan, 2010).

Local Knowledge in the Context of Natural Lighting and Natural Ventilation Regarding Thermal Comfort and Energy Efficiency in Colonial Heritage Buildings

Definition of Cultural Heritage Buildings

Based on **Law No. 11 of 2010** concerning Cultural Heritage, a cultural heritage building is defined as a structure made of natural or man-made objects to fulfil the need for walled and/or unwallled space, as well as a roof. Cultural heritage in general is a tangible cultural heritage that needs to be preserved

because it has important value for **history, science, education, religion, and/or culture** through the process of designation (disbud.kepriprov, 2023; Maulana, 1999).

The term cultural heritage itself comes from the Dutch word **monumenten**, which does not only mean buildings, but "heritage of historical value". This concept was first introduced into the Indonesian legal system in 1992 to replace the colonial law, namely the *Monumenten Ordonnatie* of 1931 (disbud.kepriprov, 2023).

To be designated as a cultural heritage building, a building must meet the following criteria: **be** at least **50 years old**, represent a style period of at least 50 years, have special significance for history and culture, and have cultural value for strengthening national identity (National Law Development Agency, 2010).

Definition of Colonial Cultural Heritage

Colonial heritage is architectural and cultural relics from the colonial era that reflect the cultural fusion between the colonising and colonised nations. According to **Laurence Smith** (in *critical heritage studies*), cultural heritage is not merely a collection of objects or sites with fixed meanings, but rather a **fluid** phenomenon formed through cultural and social processes (Cut Dewi, 2009).

Heritage is defined as **the history, memory, image, and identity** that describe a cultural community's past over time. Interpretations of cultural heritage are highly complex and change over time in line with changes in the social context, values, and communities that interpret them (Cut Dewi, 2009).

In a colonial context, colonial heritage buildings are the shared responsibility of both the colonising and colonised nations. If well preserved, colonial heritage can become a counter-monument that bears witness to the cultural assimilation of both sides and becomes an integral part of the architectural history of both countries (Cut Dewi, 2009).

Characteristics of Dutch Colonial Architecture in Indonesia

Helen Jessup divides the periodisation of the development of Dutch colonial architecture in Indonesia into four parts (Ambiya, 2005; Tamimi et al., 2020):

The First Period (16th century to 1800) was characterised by architecture that still carried pure European influences. During the VOC era, buildings prioritised functionality over architectural beauty (Tamimi et al., 2020; Wikipedia, 1997).

The Second Period (1800-1900), also known as **the Indische Empire Style**, was a time of adaptation of European architecture to Indonesia's tropical climate. Its distinctive features include a symmetrical floor plan, a single storey with a shield roof, an open front and rear porch with pillars, and towering Greek-style columns (Ambiya, 2005; Tamimi et al., 2020).

The Third Period (1900-1920) or Transitional Colonial marked the transition to more modern architecture with further adaptations to local conditions (Direktori.vokasi.unair, 2025; Tamimi et al., 2020).

The Fourth Period (1920-1940) or Modern Colonial introduced architectural styles such as *Nieuwe Zakelijkheid*, *De Stijl*, and *Amsterdamse School*. Architects such as **C.P.W. Schoemaker** and **H.M. Pont** sought to modernise indigenous Indonesian architecture by combining it with Western modernity, creating **the New Indies Style** (Wikipedia, 1997).

The characteristics of colonial architecture can be identified from elements such as: **gevel** (roof crown), **geveltoppen** (roof peak ornaments), **crepidoma** (podium stairs), entrance with double doors, symmetrical facade, wooden-framed windows, and the use of plastered brick wall materials (Rahmayana et al., 2023; Riskia et al., 2023).

Natural Lighting in Architecture

Natural lighting, or daylighting, utilises sunlight either directly or indirectly to illuminate the interior of a building. This is important for reducing electricity consumption and creating a comfortable visual environment (Tuck et al., 2020). Natural lighting can be divided into three main categories: direct light, indirect (diffused) light, and reflected light.

Direct light comes from unobstructed sunlight. It provides high intensity, but can cause glare and excessive heat if not managed properly. On the other hand, indirect light is obtained from reflections from the atmosphere or other objects. It provides more even and soft lighting, reducing glare and distributing light more efficiently. Reflected light, whether from interior or exterior surfaces, contributes to room illumination by using reflection to reach areas that are difficult to reach by direct or indirect light (Aini, 2021). The use of natural lighting is crucial in tropical architecture. It helps reduce dependence on artificial lighting and maintains stable internal temperatures (Aini, 2021; Saliim & Satwikasari, 2022). Using windows on the north and south sides can maximise natural light intake without adding excessive heat. Roof designs with appropriate overhangs or eaves are effective in blocking direct solar radiation while still allowing diffused light to enter the interior (Mohammad, 2016).

Additionally, the use of building materials with high reflectance values on the exterior can help reflect solar radiation. This not only reduces thermal load but also enhances natural lighting in the surrounding areas (Saliim & Satwikasari, 2022).

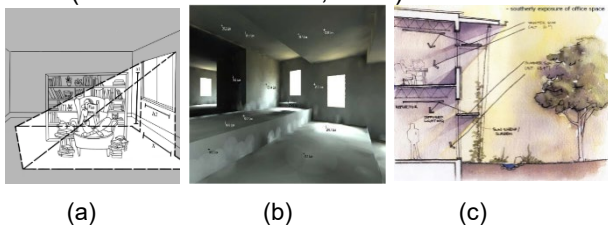


Figure 1 a) General Guidelines for Natural Lighting: Insights into Natural Lighting in Rooms; b) Strong light in the bengkilas room and the gegajah room; c) Natural lighting strategies (Source: (Amin, 2016; Berl, 1950; Culdesac, 2013)

In addition, there are ecological and conservation values, as natural lighting plays a role in maintaining thermal comfort while

preserving the historical character of colonial buildings, as seen in conceptual image 2.

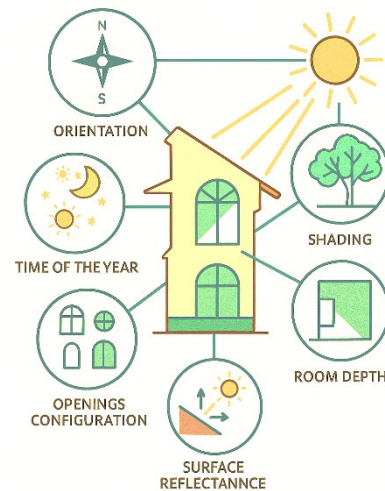


Figure 2 Conceptual diagram of the main principles influencing natural lighting in colonial heritage buildings (Source: Personal Analysis)

Ventilation in buildings

Concepts of natural and mechanical ventilation.

Natural ventilation is a passive design method that utilises differences in air pressure and temperature to circulate fresh air into and out of the building. In contrast, mechanical ventilation relies on devices such as fans to achieve the same goal (Ali et al., 2023). In tropical regions, natural ventilation is crucial as it can reduce energy consumption, particularly for cooling, and improve indoor air quality (Chung-Camargo et al., 2022; Falzon et al., 2023). These strategies include the optimal placement of openings for cross ventilation and the use of design elements such as solar chimneys, which utilise the thermal stack effect to create upward airflow (Bulbaai & Halman, 2021). On the other hand, although mechanical ventilation is effective in controlling airflow rates and filtration, its use tends to consume high energy. Therefore, mechanical ventilation is often seen as a less sustainable option in areas with limited resources (Dabe & Adane, 2020). However, the implementation of a hybrid system combining both types of ventilation can be an effective solution, especially for heritage buildings with structural limitations. This combination allows for more flexible climate control.

Natural ventilation strategies are essential in sustainable building design, each utilising the principles of fluid physics and thermodynamics to optimise air circulation without mechanical assistance. Wind-driven cross ventilation utilises pressure differences between sides of a building to create efficient horizontal airflow, ideal for spaces with openings on opposite sides. Buoyancy-driven single-sided ventilation utilises temperature differences between outdoor and indoor air to generate airflow through the same opening, suitable for confined spaces. Meanwhile, stack ventilation utilises the principle of rising hot air to create vertical airflow from low openings to high openings, highly effective for multi-storey buildings in passively

improving air quality and thermal comfort. These three approaches reflect the intelligent integration of architectural design and building physics for energy efficiency and occupant comfort.

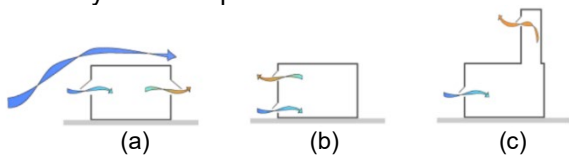


Figure 3 a) Wind ventilation/cross ventilation; **b)** Buoyancy ventilation/single-sided ventilation; **c)** Buoyancy ventilation/chimney ventilation (Source: (Gravitarchi, 2024))

Figure 3 above illustrates three different methods of natural building ventilation: wind ventilation (cross ventilation) and two types of buoyant ventilation (single-sided ventilation and stack ventilation).

Figure 3a **Wind ventilation/cross ventilation:** Relies on wind pressure differences to force air through the building via inlet and outlet openings on opposite sides.

Figure 3b **Buoyancy-powered ventilation/single-sided ventilation:** Driven by temperature differences, where warmer, less dense air rises and exits through an upper opening, drawing cooler air in through a lower opening on the same side.

Figure 3c **Flue-powered ventilation/chimney ventilation:** Also utilises temperature differences, but with a vertical duct (*chimney*) to reinforce the upward flow of warm air, effectively drawing fresh air in through the bottom inlet.

Circulation and spatial configuration in architecture, illustrating how direction of movement, spatial connectivity, and physical boundaries dynamically shape the experience of space. Each numbered scheme shows variations in movement patterns—linear, radial, or fragmented—reflecting design strategies to direct, constrain, or expand the user's perception of space. Elements such as walls, openings, and pathways are arranged in contrast to explore the interaction between enclosure and flow, making this image an effective pedagogical tool for understanding the basic principles of spatial organisation, both in the context of a single building and more complex spatial systems.

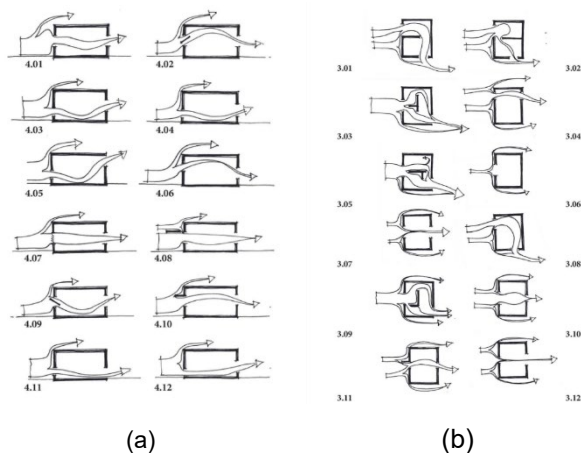


Figure 4 a) Cross ventilation/cross ventilation section; **b)** Cross ventilation/cross ventilation plan (Source: (Olgyay, 1963))

From Figure 4a above, each diagram shows variations in airflow configuration relative to the rectangular mass shape. The analysis of the flow diagrams above can be seen in Table 1.

Table 2. Analysis per Diagram (Source: (Olgyay, 1963))

Diagram	Flow Configuration	Technical Interpretation
4.01	Straight laminar flow	Ideal conditions, minimal turbulence. Suitable for streamlined shapes.
4.02	Spreading flow above	Indicates low pressure effects above the mass. Potential for lift.
4.03	Flow spreading downward	High pressure below, may increase drag.
4.04	Circular flow above	Indicates vortices, potential turbulence and high drag.
4.05	Side-sweeping flow	Suitable for cross ventilation. Effective for tropical buildings.
4.06	Downward sweeping flow	Can induce the Venturi effect, accelerating flow beneath the mass.
4.07	Upper and lower sweeping flow	Balanced pressure distribution. Suitable for symmetrical masses.
4.08	Diagonal sweeping flow	Shear force potential. Relevant for oblique wind studies.
4.09	Stagnant flow at the front	Maximum pressure point. Important for front façade design.
4.10	Full circular flow	Extreme turbulence. Aerodynamically inefficient.
4.11	Rear sweep flow	Indicates wake zone. Important for rear drag studies.
4.12	Flow spreading from below	Uplift potential. Relevant for roof and foundation design.

The impact of ventilation on air quality and comfort.

Adequate ventilation is essential for maintaining indoor air quality. It serves to remove contaminants and excess moisture, thereby creating thermal comfort for occupants by facilitating air movement and evaporative cooling (Kim et al., 2024). Poor air quality can cause serious health problems, such as irritation of the eyes, nose, and throat, and worsen

respiratory conditions (Xi et al., 2025) . Therefore, it is important to provide a constant flow of fresh air, to keep pollutant concentrations low and make the environment healthier for occupants (Falzon et al., 2023) .

By enhancing air movement through ventilation, the physiological cooling process of occupants can also operate more effectively. This allows for thermal comfort even at higher room temperatures, which is particularly beneficial in hot and humid climates (Ghiabaklou, 2010; Ragab et al., 2025) . In the context of heritage buildings, the implementation of an efficient cross-ventilation system can significantly reduce interior temperatures (Saliim & Satwikasari, 2022) .

Thermal Comfort

Definition of thermal comfort.

Thermal comfort is a mental state that reflects an individual's satisfaction with their thermal environment, where they do not feel too hot or too cold (Rana, 2021) . Research indicates that aspects such as air temperature, relative humidity, air velocity, and thermal radiation, as well as activity and clothing worn, all influence the perception of thermal comfort (Setyowati & Hardiman, 2018) . In the context of heritage buildings, a deep understanding of the interaction between these factors is crucial for designing adaptive solutions that can preserve historical value while improving thermal efficiency. Traditional architecture has implemented passive design principles that align with the local climate to achieve thermal comfort (Meutia et al., 2021) . Adaptive approaches to buildings, particularly those relying on natural ventilation, utilise airflow to create balance with the climate and reduce energy consumption (Sari & Andoni, 2019) .

(a) (b)
Figure 5 a) 3D illustration of thermal comfort; b) 3D

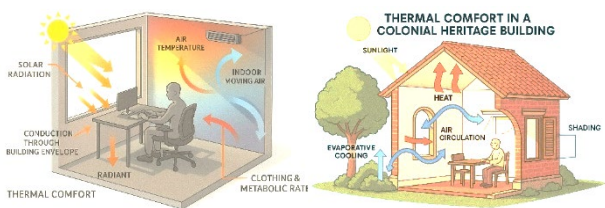


illustration of thermal comfort in colonial heritage buildings (Source: Personal Analysis)

Parameters influencing thermal comfort in colonial heritage buildings.

Parameters affecting thermal comfort in heritage buildings include material characteristics, building orientation towards the sun, and opening design to control light and airflow (Munir et al., 2021) . Local climatic conditions, such as wind speed, rainfall, and humidity, also play an important role in determining the thermal comfort threshold required for human activities. In lowland areas, for example, a minimum wind speed of 1.5 m/s is required to achieve thermal comfort (Bimantoro et al., 2018) .

Factors such as air temperature, relative humidity, and wind speed contribute to the perception of thermal comfort, which is also influenced by individual characteristics such as gender, age,

clothing, and activity level (Maknun, 2021; Nugraha, 2019) . In Indonesia, tropical architecture focuses on adaptation to the local climate, often through the application of traditional elements that support thermal comfort (Aini, 2021) .

However, adaptive models show that humans can adjust and interact with various thermal environments, often through behavioural changes or personal preferences (Pramesti et al., 2021) . Additionally, static thermal comfort, which assumes constant thermal conditions, is also important in the design of traditional Indonesian buildings, particularly through well-ventilated roof designs and house orientation that maximises air circulation (Pramesti et al., 2021) .

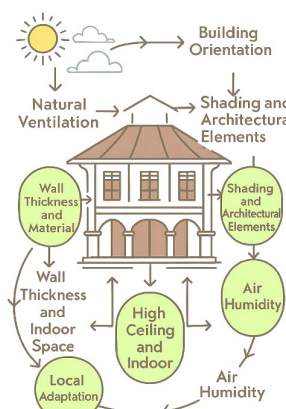


Figure 6 Conceptual Diagram of Thermal Comfort Principles in Colonial Heritage Buildings (Source: Personal Analysis)

From Figure 6 above, the Conceptual Diagram of thermal comfort principles in colonial heritage buildings shows the relationship between principles.

Energy Efficiency

The concept of energy efficiency in buildings.

Energy efficiency in the building sector means the optimal use of energy to achieve desired comfort levels, such as lighting, heating, and cooling, while minimising waste. The design strategies and technologies applied aim to reduce energy consumption without compromising the comfort or function of the building. This approach is particularly important for heritage buildings , where the preservation of historical value must go hand in hand with modernisation efforts to reduce carbon footprints and operational costs. The application of sustainable architecture principles is vital in achieving energy efficiency. This involves considering various factors, such as wind direction, indoor temperature, humidity, and solar radiation, all of which contribute to thermal comfort (Tawami & Mutaqin, 2018) .

The relationship between building design, natural lighting, and ventilation.

The relationship between design elements can synergistically influence energy consumption. Good design can reduce dependence on mechanical systems for lighting and cooling (Saliim & Satwikasari, 2022) . For example, a façade equipped with shading devices on the west and east sides of the building can help maintain stable indoor

temperatures, thereby reducing the need for artificial cooling (Saliim & Satwikasari, 2022). Passive design, often found in traditional architecture, naturally utilises natural lighting and cross ventilation to create a comfortable environment without high energy consumption (Johari & Said, 2021; Rahman & Wibowo, 2021). In tropical climates, the use of sustainable architecture is still underdeveloped, even though passive design has great potential to reduce energy use by utilising natural resources, such as sunlight and wind, to create a comfortable atmosphere (Bulbaai & Halman, 2021). In addition, optimal window design on building facades is crucial for controlling heat transfer and maximising natural lighting (Chen et al., 2020). However, existing literature still lacks evaluation of the influence of opening and window rhythms on airflow patterns, particularly in the context of low-rise buildings in tropical regions, as well as their impact on thermal comfort (Oforji et al., 2023). It is also important to conduct further research on various types of window openings and their impact on natural lighting quality and energy consumption (Wellun et al., 2023). More in-depth research is also needed to understand how building aspect ratios and material types affect thermal performance, especially at various building scales (Zune et al., 2021). The concept of sustainable colonial architecture emphasises that thermal comfort and natural lighting are not two separate principles, but are interrelated in a building's ecological system, as shown in Figure 7.

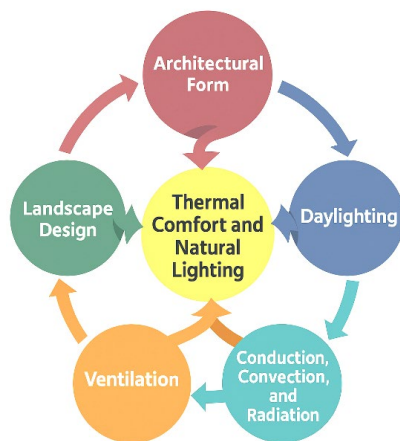


Figure 7 Conceptual map diagram of the relationship between thermal comfort and natural lighting principles in colonial heritage buildings (Source: Personal Analysis)

RESEARCH METHODOLOGY

This research focuses on literature published in the last five years to ensure the relevance and novelty of the information. Geographically, this study covers research on buildings in tropical and subtropical climates, especially those related to heritage buildings. This study will review articles related to the performance of various types of windows, including sliding windows, casement windows, and windows with double and multiple openings. The main focus is

on optimising window placement to facilitate natural ventilation in hot and humid climates (Wellun et al., 2023).

The study will also analyse the application of natural ventilation and mixed modes in building environments in warm climate zones, as well as their impact on thermal comfort and energy efficiency (Bienvenido-Huertas et al., 2023). This research prioritises publications issued between 2020 and 2025 in Figure 8 to ensure alignment with the latest practices and technologies in the field of sustainable buildings.

This restriction limits the focus to research highlighting cost-effective ventilation strategies as an adaptation to climate change (Bienvenido-Huertas et al., 2023). Older studies may be considered if they provide fundamental or historical insights relevant to contemporary issues in the context of heritage buildings and tropical climates. This research will integrate findings from recent publications with traditional design principles to provide comprehensive recommendations for the preservation and performance enhancement of heritage buildings (Manshour & Lehmann, 2025).

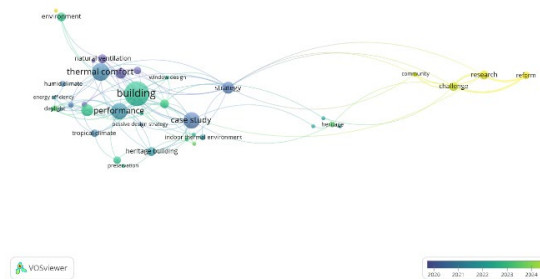
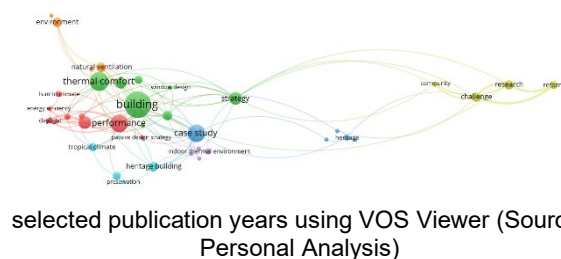


Figure 8 Visualisation of Keyword Overlay in the selected publication year using VOS Viewer (Source: Personal Analysis)

Explanation of the databases accessed: Scopus, Web of Science, and Google Scholar.

The search for sources was conducted using a systematic approach, utilising various scientific databases such as Google Scholar, Garuda, and Scopus (Beliyawati et al., 2025). The keywords used included "natural lighting," "natural ventilation," "thermal comfort," "energy efficiency," and "heritage buildings." The use of this combination of keywords aimed to narrow down the search results. In addition, the search was expanded to include terms in English such as "daylighting," "natural ventilation," "thermal comfort," "energy efficiency," and "heritage buildings." This step ensured that the literature reviewed included international insights, as shown in Figure 9.

Figure 9 Visualisation of the Keyword Network for the



selected publication years using VOS Viewer (Source: Personal Analysis)

Quality Control

Articles were selected through a rigorous screening process based on inclusion and exclusion criteria. These criteria included publication dates between January 2020 and mid-2025 and availability in Indonesian or English (Irwansyah & Ernungtyas, 2023). Each selected article is carefully evaluated for its methodological quality. This includes an assessment of the study design, research question formulation, and validity of results, all of which must meet high academic standards (Núñez, 2023).

The primary focus is also on the internal and external validation of findings. This evaluation ensures data consistency and the generalisation of research results within the context of cultural heritage buildings (Heston, 2024). This approach is in line with the PRISMA guidelines, which can be seen in the flowchart in Figure 10. PRISMA encourages the use of checklists to assess the quality and relevance of studies included in systematic reviews. This aims to reduce bias and increase transparency (Harianja et al., 2024; Mlote et al., 2024).

Inclusion criteria include articles in English or Indonesian published between 2020 and 2025, focusing on educational challenges in Indonesia (Samala et al., 2024). Selected articles must discuss the impact of natural lighting and ventilation on thermal comfort and energy efficiency in heritage buildings, with a focus on vernacular and tropical architecture (Hermansah et al., 2024). The selection process also considers the relevance of the findings to tropical climatic conditions and traditional building characteristics. This aims to ensure the practical application of the research results (Samala et al., 2024; Yani et al., 2024).

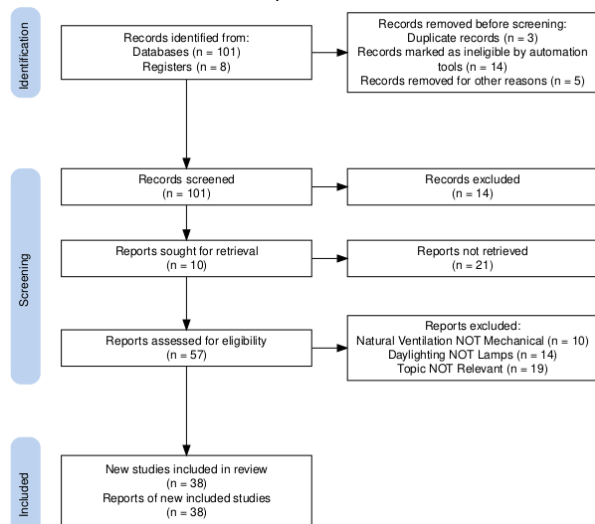


Figure 10 PRISMA Flow Diagram (Source: Personal Analysis)

RESEARCH FINDINGS AND DISCUSSION

This literature review critically evaluates 38 scientific articles on natural lighting and natural ventilation in relation to thermal comfort and energy efficiency in heritage buildings. The findings show that these articles were researched in various geographical regions globally. Among the publications studied,

Italy emerged as the country with the highest concentration of research locations in Figure 11.

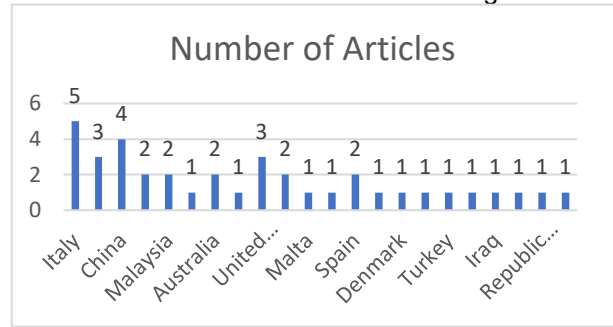


Figure 11 Distribution of the number of articles and countries of publication studied (Source: Personal Analysis)

The use of passive design in vernacular heritage buildings can significantly improve thermal comfort without compromising their historical characteristics. Case studies of traditional houses in Myanmar demonstrate this (Zune et al., 2020b). However, implementing sustainable energy efficiency strategies in these buildings requires a holistic approach. This approach must consider historical values and cultural context, while wisely integrating modern technology to achieve optimal thermal performance (Miran & Husein, 2023).

Achieving optimisation often depends on a deep understanding of the thermal performance of the building envelope, particularly the façade, which is the largest surface area. This aligns with research emphasising the importance of considering materials and thermal characteristics in historic buildings. For example, soft silica limestone walls need to be taken into account to balance preservation and improved energy performance (Gorączko et al., 2025). Further research is needed to find new ideas that can help address the challenges posed by climate change in the context of heritage buildings (Rashad et al., 2021).

Table 3. Summary of Research Cluster Grouping for the Performance of Cultural Heritage Buildings (Source: Personal Analysis)

No.	Factor	Sub-factor	Author
I.	Thermal Comfort, Natural Ventilation, and Passive Cooling Strategies	Focus on adaptive thermal comfort, the effectiveness of passive cooling strategies (free-running), natural ventilation patterns (NV), and case studies in hot/humid tropical climates. Includes a systematic review of passive cooling.	(Al-Tamimi, 2015; Bramiana et al., 2023; de Dear et al., 1991; De Brager, 2002; Fitriaty et al., 2021; Manshour & Lehmann, 2025; Pioppi et al., 2020; Rana, 2021; Rashad et

<p>II. Optimisation of Building Envelopes, Facades, and Solar Control (Shading)</p>	<p>Involves the role of <i>solar shading</i>, multi-objective optimisation (such as energy, lighting, and thermal comfort), the influence of window placement and size (WWR), and the efficiency of building envelope retrofiting.</p>	<p>al., 2021; Sekartaji et al., 2023; Zune et al., 2020b) (Bachrun et al., 2019; Bokel, 2007; Elnabawi et al., 2024; Hashemi & Khatami, 2017; Rubel & Joarder, 2024; Valladares-Rendón et al., 2017; Yan et al., 2021; Yi & Yeboah, 2025;</p>	<p>V. Methodology, Innovative Technologies, and Special Materials</p>	<p>on building performance. These factors often overlap with cooling needs. s new tools or methodologies, such as <i>wearable monitoring systems</i>, simulation validation procedures (ENVI-met), climate data development (IWEC2), and testing of functional materials such as <i>Phase Change Materials</i> (PCM) and kinetic materials.</p>	<p>(de Gracia et al., 2018; Gorączko et al., 2025; Joe et al., 2014; M. Soares & Bragança, 2013; Pigliautile & Pisello, 2018; Salata et al., 2016; W. E. Sari & Andoni, 2019; Taghavi Araghi, 2022)</p>
<p>III. Conservation, Thermal Performance, and Adaptation of Heritage Buildings</p>	<p>Focus on monitoring and improving the thermal performance of historic buildings, the impact of climate change/global warming on cultural heritage, seasonal thermal behaviour analysis, and the development of adaptation models and sustainability assessment tools.</p>	<p>Zhao & Du, 2020; Zune et al., 2018) (Al-Sakkaf et al., 2022; Mauri & Pracchi, 2021; Miran & Husein, 2023; Pioppi et al., 2020; Sáez-Pérez et al., 2023)</p>			
<p>IV. Impact of Climate Change, Overheating, and Urban Vulnerability</p>	<p>Researching residential vulnerability to overheating using measured data and simulations, the effects of summer heatwaves, and urban overheating</p>	<p>(Prozuments et al., 2023; Pyrgou et al., 2017; Zune et al., 2020a)</p>			

Table 3 shows the grouping of studies, indicating that the majority of studies (clusters I and II) focus on passive architectural design. The aim is to address tropical climate challenges and reduce energy demand. Clusters III and IV show a shift in focus towards resilience issues in the context of climate change and cultural asset preservation. Cluster V (Methodology/Materials) serves as a foundation, providing tools such as ENVI-met simulation and wearable monitoring, as well as solutions such as PCM for other research groups.

The thermal simulation approach helps to understand the behaviour of historic buildings over different periods, providing insights into effective adaptation strategies to extreme weather conditions (Sáez-Pérez et al., 2023). The use of materials with low U-values and high reflectivity for roofs, as well as the selection of appropriate wall and floor materials, significantly impacts the thermal performance of buildings in hot and humid climates (Zune et al., 2020a). The application of thermal mass and natural ventilation inspired by heritage buildings can reduce indoor temperatures by up to 5°C, improving thermal comfort and reducing energy consumption (Alwetaishi, 2022). Additionally, the use of appropriate insulation materials in building envelopes can optimise energy efficiency without compromising the aesthetic and historical value of buildings (Lotfabadi & Hançer, 2019). Passive cooling systems such as cross ventilation and solar chimneys, along with the use of thermal mass based on vernacular design principles, have been proven to significantly reduce the need for mechanical cooling (Al-Sakkaf et al., 2021). These strategies contribute to reducing greenhouse gas emissions while preserving the original architectural character of heritage buildings (Sáez-

Pérez et al., 2023). Improving the thermal performance of heritage building facades through the adaptation of modern materials and technologies can also support thermal comfort and sustainable energy efficiency (Mauri & Pracchi, 2021). The use of shading elements, such as trees around the building, blocks direct solar radiation and reduces excessive heat transfer into the room, while the thermal mass of the building slows down heat convection (Aini, 2021; Jørgensen & Flyckt-Nielsen, 2024).

Shading devices on the façade, especially on the west and east sides, are important for maintaining indoor temperature stability (Saliim & Satwikasari, 2022). Shading strategies integrated with design, such as the use of vegetation, also help mitigate direct solar radiation and reduce unwanted heat transfer (Aini, 2021). Natural ventilation through windows and air vents is vital for maintaining stable indoor temperatures (Saliim & Satwikasari, 2022). Building designs with good cross ventilation that allow fresh air to enter during cold weather support natural cooling and reduce dependence on mechanical cooling systems (Prozuments et al., 2023). This approach also includes optimising building orientation, window placement, and the use of building materials suitable for tropical climates, which significantly contribute to reducing energy consumption (Saliim & Satwikasari, 2022).

Architectural optimisation by planting shade trees around buildings is an effective strategy to block direct solar radiation and reduce heat transfer into the building (Aini, 2021). The use of longer roofs and shading devices on the facade, especially on the west and east sides, is an important design component to minimise excessive heat exposure and maintain a comfortable internal temperature (Saliim & Satwikasari, 2022).

Comparison between buildings with and without natural lighting and proper ventilation.

Case studies show that buildings with well-designed natural lighting and ventilation systems achieve higher energy efficiency and optimal thermal comfort compared to buildings lacking these features (Acosta-Medina et al., 2025). The placement, size, and type of openings must be considered in accordance with the building layout and structure to optimise airflow and natural lighting (Fitriaty et al., 2021). The application of this strategy can significantly reduce cooling loads, especially in tropical climates with minimal daily temperature fluctuations, thereby supporting occupant thermal comfort (Fitriaty et al., 2021). Passive designs such as natural ventilation and solar shading have proven effective in lowering interior temperatures and reducing cooling loads, particularly in buildings in hot and humid regions (Chen et al., 2020).

The effectiveness of natural ventilation also improves thermal comfort and indoor air quality, reducing the risk of pollutant and moisture accumulation (Sekartaji et al., 2023). The use of these passive design strategies can significantly improve thermal comfort and air quality while reducing energy consumption and greenhouse gas emissions in tropical regions

(Bramiana et al., 2023; Falzon et al., 2023). Research indicates that natural ventilation can improve internal environmental performance by up to 80% during the day and 50% at night compared to unventilated conditions (Al-Tamimi, 2015). Shading design is also important for protection from excessive heat, both under normal and extreme conditions, with effectiveness varying depending on building parameters, climate elements, and occupant behaviour (Hashemi & Khatami, 2017; Zune et al., 2021). Therefore, optimising building orientation, particularly by placing large windows on the north and south sides, is crucial to maximise natural lighting without increasing excessive heat gain (Rubel & Joarder, 2024; Saliim & Satwikasari, 2022). Additionally, placing service spaces on the side of the building exposed to direct sunlight can minimise heat gain in the main spaces. Ventilation in the space between the roof and ceiling also helps prevent unwanted heat accumulation (Aini, 2021). The integration of passive cooling principles such as natural ventilation has been shown to reduce energy consumption by 30-40% compared to buildings with mechanical ventilation, while ensuring a healthy and comfortable internal environment for occupants (Rana, 2021). An in-depth analysis of the ventilation and energy performance of vertical shading reveals that the optimal design of the orientation and depth of the shading significantly influences the thermal efficiency of the building (Yi & Yeboah, 2025).

Findings based on existing literature.

Research findings indicate that passive design, including natural ventilation and shading, significantly enhances thermal comfort and energy efficiency in buildings. These findings are consistent with previous studies (Xi et al., 2025). Natural ventilation, especially through optimal openings on the north and south sides, has been shown to reduce excessive exposure to sunlight and provide sufficient natural lighting (Saliim & Satwikasari, 2022). The selection of building materials suitable for a humid tropical climate, as well as the application of appropriate roof overhangs and shading devices on the west and east facades, are also crucial in maintaining a comfortable internal temperature (Saliim & Satwikasari, 2022). It is recommended that buildings be oriented lengthwise towards the north and south to minimise heat exposure. The application of shading on south-facing windows can reduce the need for cooling energy (Alajmi et al., 2021; Saliim & Satwikasari, 2022). This indicates that passive design strategies, which rely on natural ventilation and solar radiation control, form the basis of sustainable tropical architecture to achieve optimal thermal comfort and energy efficiency (Aini, 2021). The study also found that passive cooling strategies, including natural ventilation, are effective in improving the thermal environment indoors, consistent with findings showing the efficiency of heat release from buildings (Tuck et al., 2019). This approach is in line with the principles of humid tropical architecture, which utilises wind for ventilation while protecting against solar radiation

and preventing moisture accumulation (Aini, 2021). Protection against moisture and rainwater is an important factor. Architectural design must allow for cross ventilation to reduce heat (Aini, 2021). The use of thermal walls and thermal mass, combined with shading devices and a well-designed building envelope, can significantly reduce annual overheating hours and reduce extreme temperature variations (Zune et al., 2021). The synergy between shading strategies and building envelope design makes the implementation of sustainable building standards more feasible. Building envelope costs can be lower compared to conventional versions (Zune et al., 2021).

Optimising building envelope design involves selecting materials with appropriate thermal properties and using well-designed shading elements to reduce overall cooling loads (Zune et al., 2021). Passive design also emphasises the thermal performance of envelope elements such as walls, roofs, insulation materials, windows, and shading devices to reduce energy demand and improve thermal comfort for occupants (Rana, 2021). Therefore, adaptive design responsive to local climate, such as the use of kinetic louver openings, can optimise airflow and solar radiation to achieve more dynamic thermal comfort (Sari & Andoni, 2019). This strategy supports sustainable architecture efforts by focusing on reducing heat gain from solar radiation, thereby significantly reducing the building's energy load (Bachrun et al., 2019). The use of natural ventilation systems, such as the chimney effect or cross ventilation, can significantly remove internal heat and pollutants from buildings. This maintains indoor air quality (Kim et al., 2024).

Implications of research findings for the design and management of heritage buildings.

The application of adaptive design strategies that respond to local climatic conditions, such as the use of kinetic louver openings, can improve airflow and manage solar radiation. This supports the achievement of dynamic thermal comfort (Zune et al., 2021). By integrating proven passive design principles, such as solar control and natural ventilation, heritage buildings can maintain their architectural integrity while meeting modern thermal comfort standards and better energy efficiency (Manshour & Lehmann, 2025). Further research indicates that combining multiple mitigation strategies simultaneously yields better performance than using a single method, as evidenced by a significant reduction in average air temperature (Pioppi et al., 2020). This indicates that the combination of shading, building orientation, and cross ventilation is an important holistic approach to improving the thermal performance of historic buildings (Aini, 2021).

Limitations encountered during the study.

This study has several limitations. First, there is no in-depth analysis of the impact of relative humidity on thermal comfort and the degradation of cultural heritage building materials. Additionally, the long-term performance evaluation of adaptive ventilation

solutions under extreme climatic conditions has not been conducted. Another limitation is the use of simulation models that do not fully reflect the complexity of the interaction between local microclimate factors and heritage building materials (Mohammadi et al., 2022). For future research, it is important to expand the scope of the study. Research should examine the effects of humidity on thermal comfort and the integrity of cultural heritage building materials comprehensively. Integration of broader field data is also needed to validate the simulation models used.

Recommendations for further research in the same field.

Subsequent research could evaluate the impact of moist and porous media on building entrances. This study should also examine the extent to which occupants can adapt to the thermal variations allowed in buildings (Kamari et al., 2019). Future research needs to focus on optimising natural ventilation. The design of window openings on the north and south sides should be studied to maximise lighting and airflow without direct sunlight exposure. Additionally, the use of building materials resistant to hot weather and rain should be considered, especially for residential units (Saliim & Satwikasari, 2022).

CONCLUSION

Natural lighting and ventilation play a crucial role in the thermal comfort and energy efficiency of heritage buildings. Optimising natural lighting can reduce the need for artificial lighting and support the health and productivity of occupants. Meanwhile, natural ventilation serves to maintain indoor air quality, reduce humidity, and help remove excess heat. Passive design, including building orientation and the use of local materials, is crucial to maximise the benefits. Careful management of sunlight intensity and humidity is also necessary to avoid glare and increased heat loads.

Practitioners and managers of heritage buildings are advised to apply sustainable design principles that make optimal use of natural lighting and ventilation. This includes determining the appropriate building orientation and using suitable shading devices. In addition, a balance between traditional strategies and modern technology must be considered to ensure thermal comfort without damaging the historical value of the building. Further research is needed to assess the impact of various shading configurations and material types on the thermal performance of buildings in humid tropical climates.

REFERENCES

- Acosta-Medina, D., Quintana-Gallardo, A., Guillén-Guillamón, I., & Mediguchia, F. A. (2025). Evaluation of Passive Strategies for Achieving Hygrothermal Comfort in Social Housing Buildings in the Dominican Republic. *Sustainability* (2071-1050), 17(8).
- Aini, Q. (2021). Shifts in Building Design During the Development of Architecture in Indonesia. *Arsitekno*,

- 8(2), 45–55.
- Aini, Q., & Rani, I. A. (2021). Evaluation of the Effects of Ventilation and Lighting on the Tsunami Museum in Banda Aceh. *Rumoh Journal of Architecture*, 9 (17), 24–26. <https://doi.org/10.37598/rumoh.v9i17.70>
- Al-Sakkaf, A., Mohammed Abdelkader, E., Mahmoud, S., & Bagchi, A. (2021). Studying energy performance and thermal comfort conditions in heritage buildings: A case study of Murabba Palace. *Sustainability*, 13(21), 12250.
- Al-Sakkaf, A., Zayed, T., Bagchi, A., Mahmoud, S., & Pickup, D. (2022). Development of a sustainability rating tool for heritage buildings: future implications. *Smart and Sustainable Built Environment*, 11(1), 93–109.
- Al-Tamimi, N. A. (2015). Toward sustainable building design: Improving thermal performance by applying natural ventilation in hot-humid climate. *Indian Journal of Science and Technology*, 8(28), 1–8.
- Alajmi, A., Aba-Alkhalil, F., & ALAnzi, A. (2021). Determining the optimum fixed solar-shading device for minimising the energy consumption of a side-lit office building in a scorching climate. *Journal of Engineering Research*, 9(2).
- Ali, R. A., Megahed, N. A., Shahda, M. M., & Hassan, A. M. (2023). Natural ventilation as a passive cooling strategy for multi-storey buildings: analytic vertical sky court formations. *City, Territory and Architecture*, 10(1), 28.
- Alwetaishi, M. (2022). Can we learn from heritage buildings to achieve nearly zero energy building and thermal comfort? A case study in a hot climate. *Advances in Building Energy Research*, 16(2), 214–230.
- Ambiya, R. (2005). *Characteristics of Colonial Architecture*. Scribd. <https://www.scribd.com/doc/312121875/Karakteristik-Arsitektur-Kolonial>
- Amin, A. R. Z. (2016). Study of Natural Lighting in Palembang Stage Pyramid Houses (Simulation with Ecotect 5.0 Program). *Teknoin*, 22(9), 629–641.
- Bachrun, A. S., Ming, T. Z., & Cinthya, A. (2019). Building envelope components to control the thermal indoor environment in sustainable buildings: a review. *Sinergi*, 23(2), 79–98.
- National Law Development Agency. (2010). *Law of the Republic of Indonesia Number 11 of 2010 concerning Cultural Heritage*. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://bphn.go.id/data/documents/10uu011.pdf
- Berl, M. (1950). *Rule of Thumb for Daylight: An Insight into Natural Lighting in Rooms*. Mcdberl.Com. <https://mcdberl.com/rule-of-thumb-for-daylight-an-insight-into-natural-lighting-in-rooms/>
- Bienvenido-Huertas, D., De La Hoz-Torres, M. L., Aguilar, A. J., Tejedor, B., & Sánchez-García, D. (2023). Holistic overview of natural ventilation and mixed mode in built environment of warm climate zones and hot seasons. *Building and Environment*, 245, 110942.
- Bimantoro, A. A., Ekasiwi, S. N. N., Samodra, F., & Damayanti, D. P. (2018). *The Modification Effect of Spatial Configuration and Openings on Natural Ventilation Performance Case Study: Betang House at Central Borneo*.
- Bokel, R. M. J. (2007). *The effect of window position and window size on the energy demand for heating, cooling and electric lighting*.
- Bramiana, C. N., Aminuddin, A. M. R., Ismail, M. A., Widiastuti, R., & Pramesti, P. U. (2023). The Effect of Window Placement on Natural Ventilation Capability in a Jakarta High-Rise Building Unit. *Buildings*, 13(5), 1141.
- Bulbaai, R., & Halman, J. I. M. (2021). Energy-efficient building design for a tropical climate: A field study on the Caribbean island of Curaçao. *Sustainability*, 13(23), 13274.
- Change, O. C. (2007). Intergovernmental Panel on Climate Change. *World Meteorological Organisation*, 52(1–43), 1.
- Chen, Z., Hammad, A. W. A., Kamardeen, I., & Haddad, A. (2020). Optimising window design on residential building facades by considering heat transfer and natural lighting in non-tropical regions of Australia. *Buildings*, 10(11), 206.
- Chung-Camargo, K., Bencid, M., Mora, D., & Chen-Austin, M. A. (2022). Low-consumption techniques in tropical climates for energy and water savings in buildings: A review on experimental studies. *I+ d Tecnológico*, 18(1), 5–18.
- Culdesac. (2013). *Application of Natural Lighting (Daylight) in Buildings*. Culdesachdmks.Wordpress.Com. <https://culdesachdmks.wordpress.com/category/article/building-science/>
- Cut Dewi, S. T. (2009). *Colonial Heritage: History, Architecture, and Interpretation*.
- Dabe, T. J., & Adane, V. S. (2020). Evaluation of daylight parameters on the basis of a simulation model for the tropical climate. *Journal of Architectural Environment & Structural Engineering Research*, 3(2).
- De Dear, R. J., & Brager, G. S. (2002). Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. *Energy and Buildings*, 34(6), 549–561.
- de Dear, R. J., Leow, K. G., & Foo, S. C. (1991). Thermal comfort in the humid tropics: Field experiments in air-conditioned and naturally ventilated buildings in Singapore. *International Journal of Biometeorology*, 34(4), 259–265.
- de Gracia, A., Navarro, L., Coma, J., Serrano, S., Romani, J., Perez, G., & Cabeza, L. F. (2018). Experimental set-up for testing active and passive systems for energy savings in buildings—Lessons learnt. *Renewable and Sustainable Energy Reviews*, 82, 1014–1026.
- Vocational Directory.unair. (2025). *Cultural Heritage Buildings*. Vocational Directory.Unair.Ac.Id. <https://direktori.vokasi.unair.ac.id/bangunan-cagar-budaya/>
- disbud.kepriprov. (2023). *Definition of Cultural Heritage According to the Law*. Disbud.Kepriprov.Go.Id. <https://disbud.kepriprov.go.id/pengertian-cagar-budaya-menurut-undang-undang/>
- Elnabawi, M. H., Saber, E., & Bande, L. (2024). Passive building energy saving: building envelope retrofitting measures to reduce cooling requirements for a residential building in an arid climate. *Sustainability*, 16(2), 626.
- Falzon, J., Dalli Gonzi, R., Loganathan, T., & Grima, S. (2023). *High performance high-rise buildings (HRB): a case in tropical climate construction*.
- Fitriaty, P., Bassaleng, A. J. R., Burhany, N. R., Mardin, R., Setiawan, A., & Alam, S. (2021). Visualisation of Naturally Ventilated House in Tropical Hilly Area of Indonesia, Case Study: Vatutela Village, Tondo Hills, Palu. *IOP Conference Series: Earth and Environmental Science*, 926(1), 12056.
- Ghiabaklou, Z. (2010). Natural ventilation as a design strategy for energy saving. *World Academy of Science, Engineering and Technology*, 71, 315–319.
- Gorączko, A., Szczepaniak, P., & Gorączko, M. (2025). Analysis of the Thermal Properties of Soft Silica

- Limestone Walls of Traditional Buildings in Central Poland. *Materials*, 18(10), 2399.
- Gravitarchi. (2024). *Understanding Cross Ventilation and Its Benefits*. Gravitarchi.Com. <https://gravitarchi.com/pengertian-ventilasi-silang-cross-ventilation-dan-manfaatnya/>
- Harianja, S. H., Antika, S., & Dewi, O. O. (2024). Melukat as a Ritual of Self-Purification in Balinese Culture: A Literature Review on Its Therapeutic Potential in Mental Health. *Healthy: Journal of Health Science Research Innovation*, 3(4), 171–176.
- Hashemi, A., & Khatami, N. (2017). Effects of solar shading on thermal comfort in low-income tropical housing. *Energy Procedia*, 111, 235–244.
- Hermansah, I., Nasrulloh, I., & Kartini, A. (2024). The Technological Pedagogical Content Knowledge Model in Learning: A Literature Review. *Science: Journal of Mathematics and Science Education Innovation*, 4(2), 105–116.
- Heston, T. F. (2024). *Foundations of Scholarly Writing*. BP International.
- Irwansyah, I., & Ernungtyas, N. F. (2023). Age-Friendly environment: A systematic literature review. *E3S Web of Conferences*, 452, 7009.
- Iyati, W., Riski, A. P., & Thojib, J. (2020). Strategies to Improve Natural Lighting in Deep-Plan Cultural Heritage Buildings in the Tropics. *International International Conference of Heritage & Culture in Integrated Rural-Urban Context (HUNIAN 2019)*, 86–91.
- Joe, Y., Fenxian, H., & Seo, D. (2014). Development of 3012 IWECC2 weather files for international locations (RP-1477). *Ashrae Transactions*, 120(1).
- Johari, M. N., & Said, S. Y. (2021). A comparative analysis between traditional Malay houses and terraced houses in energy conservation. *IOP Conference Series: Earth and Environmental Science*, 685(1), 12012.
- Jørgensen, M. B., & Flyckt-Nielsen, J. (2024). Heritage vs. Architecture: A Long-running Battle on the Future of Nyborg Castle. *Amps: Heritages: Past and Present-Built and Social*, 360–367.
- Kamari, A., Schultz, C. P. L., & Kirkegaard, P. H. (2019). Unleashing the diversity of conceptual building renovation design: Integrating high-fidelity simulation with rapid constraint-based scenario generation. *Proceedings of the Symposium on Simulation for Architecture and Urban Design*, 1–8.
- Kim, J., Naganathan, H., Moon, S., & Jang, D. (2024). Optimising Comfort and Sustainability: The Impact of Passive Cooling and Eco-Friendly Materials on Indoor Temperature Reduction—A Case Study. *Buildings*, 14(10), 3218.
- Latifah, N. L., Wigna, R. P. D., Darmawan, T., & Mundika, S. K. (2021). Colonial Building Design Related to Visual Comfort with Natural Lighting—*Terracotta Architecture Journal*, 2(2).
- Lofabadi, P., & Hançer, P. (2019). A comparative study of traditional and contemporary building envelope construction techniques in terms of thermal comfort and energy efficiency in hot and humid climates. *Sustainability*, 11(13), 3582.
- M. Soares, V., & Bragança, H. & T. (2013). *Thermal control in buildings by phase change materials (PCM): A review*.
- Maknun, J. (2021). Adaptive thermal comfort in colonial building classrooms. *IOP Conference Series: Materials Science and Engineering*, 1098(2), 22043.
- Manshour, S., & Lehmann, S. (2025). A Systematic Review of Passive Cooling Strategies Integrating Traditional Wisdom and Modern Innovations for Sustainable Development in Arid Urban Environments. *ArXiv Preprint ArXiv:2507.09365*.
- Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., & Gomis, M. I. (2021). Climate change 2021: the physical science basis. *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2(1), 2391.
- Maulana, I. (1999). *Understanding Cultural Heritage Sites, from Types to Conservation Efforts*. Negeri Rempah.Org. <https://negerirempah.org/id/publikasi/artikel/213-mengenal-cagar-budaya,-dari-jenis-hingga-upaya-pelestariannya.html>
- Mauri, S., & Pracchi, V. (2021). High-performance materials and technological solutions to improve the thermal performance of historic buildings. *IOP Conference Series: Earth and Environmental Science*, 863(1), 12044.
- Meutia, E., Rauzi, E. N., Sahputra, Z., & Maryana, D. (2021). The assessment of thermal comfort of sustainable modifying Rumoh Aceh in hot humid climate. *IOP Conference Series: Earth and Environmental Science*, 881(1), 12052.
- Miran, F. D., & Husein, H. A. (2023). Introducing a conceptual model for assessing the present state of preservation in heritage buildings: Utilising building adaptation as an approach. *Buildings*, 13(4), 859.
- Mlote, D. S., Budig, M., & Cheah, L. (2024). Adaptability of buildings: a systematic review of current research. *Frontiers in Built Environment*, 10, 1376759.
- Mohammad, P. S. (2016). Heat Removal Using the Hollow Roof in the Javanese House. *MATEC Web of Conferences*, 58, 4003.
- Mohammadi, E., Jarkeh, M., Zolfaghari, S. A., & Arbabi, V. (2022). Effect of resilient architecture in an ancient windmill in the Sistan region on natural ventilation enhancement. *Scientific Reports*, 12(1), 18240.
- Munir, A., Away, Y., Huda, K., & Salsabilah, M. (2021). Assessment of indoor thermal environment of Aceh house based on WBGT index. *IOP Conference Series: Earth and Environmental Science*, 881(1), 12023.
- Nugraha, D. (2019). Effectiveness of Ventilation in Houses in Densely Populated Areas in Perumnas Depok Timur. *Lakar: Journal of Architecture*, 1(1), 27–31.
- Núñez, L. A. H. (2023). Interculturality in the development of tutoring for school coexistence in secondary educational institutions, Cusco -2023. *Journal of Climatology*, 23 (2925). <https://doi.org/10.59427/rclii/2023/v23cs.2925-2929>
- Oforji, P. I., Mba, E. J., & Okeke, F. O. (2023). The effects of rhythm on building openings and fenestrations on airflow patterns in tropical low-rise residential buildings. *Civil Engineering Journal*, 9(8), 2062–2084.
- Olgay. (1963). Air Flow at Section. In *Australia's Forgotten Inland: How Can We Re-inhabit the 70% Again? The Working Guide*. dogspikedesign. <https://www.dogspikedesign.com/works/australias-vernacular>
- Pigliautile, I., & Pisello, A. L. (2018). A new wearable monitoring system for investigating pedestrians' environmental conditions: Development of the experimental tool and start-up findings. *Science of the Total Environment*, 630, 690–706.
- Pioppi, B., Pigliautile, I., Piselli, C., & Pisello, A. L. (2020). Cultural heritage microclimate change: Human-

- centric approach to experimentally investigate intra-urban overheating and numerically assess foreseen future scenarios impact. *Science of the Total Environment*, 703, 134448.
- Piraei, F., Matusiak, B., & Lo Verso, V. R. M. (2022). Evaluation and optimisation of daylighting in heritage buildings: A case study at high latitudes. *Buildings*, 12(12), 2045.
- Pramesti, P. U., Hasan, M. I., & Ramandhika, M. (2021). Locality values in thermal comfort embodied in traditional Indonesian houses: a literature review. *IOP Conference Series: Earth and Environmental Science*, 894(1), 12009.
- Prozuments, A., Borodinecs, A., Lebedeva, K., & Palcikovskis, A. (2023). Examining the efficacy of cooling pad technology to address increasing building cooling demand in Latvia. *Frontiers in Built Environment*, 9, 1258625.
- Pyrgou, A., Castaldo, V. L., Pisello, A. L., Cotana, F., & Santamouris, M. (2017). On the effect of summer heatwaves and urban overheating on building thermal-energy performance in central Italy. *Sustainable Cities and Society*, 28, 187–200.
- Ragab, A., Hassieb, M. M., & Mohamed, A. F. (2025). Exploring the impact of window design and ventilation strategies on air quality and thermal comfort in arid educational buildings. *Scientific Reports*, 15(1), 19596.
- Rahman, V., & Wibowo, L. H. (2021). Study of thermal comfort in traditional house buildings (Case study: Simalungun traditional house). *International Journal of Architecture and Urbanism*, 5(1), 90–99.
- Rahmayana, O., Dafrina, A., & Novianti, Y. (2023). Analysis of Colonial Architectural Characteristics on the Facades of Dutch Heritage Buildings (Case Study: Satpol PP and WH Office in Takengon City). *PROCEEDINGS OF THE, 11 ICAL*
- Ramli, M., & Hassan, A. S. (2010). Natural ventilation of indoor air temperature: A case study of the traditional Malay house in Penang. *American Journal of Engineering and Applied Sciences*, 3(3), 521–528.
- Rana, K. (2021). Towards passive design strategies for improving thermal comfort performance in a naturally ventilated residence. *Journal of Sustainable Architecture and Civil Engineering*, 29(2), 150–174.
- Rashad, M., Khordehghah, N., Żabnieńska-Góra, A., Ahmad, L., & Jouhara, H. (2021). The utilisation of reInternational Journal of Thermofluids, 9, 100059.
- Riskia, R., Dafrina, A., & Olivia, S. (2023). Identification of Colonial Architecture in Dutch Heritage Buildings in Bireuen Regency (Pendopo Bireuen, Gandapura Subdistrict Village Hall and Peusangan Uleebalang House). *ETNIK: Journal of Economics and Engineering*, 2(10), 925–936.
- Rubel, A., & Joarder, M. A. R. (2024). Performance of Shading Against West Glass Facades to Optimise Daylight, Thermal Comfort and Energy Efficiency of Office Buildings. *Journal of Daylighting*, 11(1), 131–148.
- Sadafi, N., Salleh, E., Haw, L. C., & Jaafar, Z. (2011). Evaluating thermal effects of internal courtyards in a tropical terrace house by computational simulation. *Energy and Buildings*, 43(4), 887–893.
- Sáez-Pérez, M. P., García Ruiz, L. M., Durán-Suárez, J. A., Castro-Gomes, J., Martínez-Ramírez, A., & Villegas-Broncano, M. Á. (2023). Comparative Analysis of Thermal Behaviour in Different Seasons in Building Heritage: Case Study of the Royal Hospital of Granada. *Buildings*, 13(12), 3048.
- Salata, F., Golasi, I., de Lieto Vollaro, R., & de Lieto Vollaro, A. (2016). Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data. *Sustainable Cities and Society*, 26, 318–343.
- Saliim, A. M., & Satwikasari, A. F. (2022). *Study of Modern Tropical Architectural Design Concepts in Rusunawa II Buildings in Madiun City*.
- Samala, A. D., Rawas, S., Criollo-C, S., Bondarenko, O., Samala, A. G., & Novaliendry, D. (2024). Harmony in Education: An In-Depth Exploration of the Indonesian Academic Landscape, Challenges, and Prospects Towards the Golden Generation 2045 Vision. *TEM Journal*, 13(3).
- Sari, W. E., & Andoni, H. (2019). Self-Kinetic Jalousie as an Application of Climate Responsive-Adaptable Architecture Technology. *Module*, 19(2), 119–126.
- Sekartaji, D., Ryu, Y., & Novianto, D. (2023). Effect of ventilation patterns on indoor thermal comfort and air-conditioning cooling and heating load using simulation. *City and Built Environment*, 1(1), 14.
- Setyowati, E., & Hardiman, G. (2018). The contribution of air vents and ventilation in the Sobokartti building in Semarang to achieving thermal comfort. *Module*, 18(2), 90–96.
- Srithongchai, T. (2019). *Human adaptive thermal comfort inside naturally ventilated buildings for religious practice in Thailand*. University of Nottingham.
- Taghavi Araghi, S. M. (2022). *The relationship between preference utilising VR and synoptic thermal evaluation: the case of Amirkabir public square, Arak*.
- Tamimi, N., Fatimah, I. S., & Hadi, A. A. (2020). Typology of Colonial Architecture in Indonesia. *Vitruvian Journal of Architecture, Building and Environment*, 10(1), 45.
- Tawami, T., & Mutaqin, A. F. (2018). Building Healthy and Comfortable Houses in Equatorial, Tropical Climate Indonesia. *IOP Conference Series: Materials Science and Engineering*, 407(1), 12019.
- Tuck, N. W., Zaki, S. A., Hagishima, A., Rijal, H. B., & Yakub, F. (2020). Affordable retrofitting methods to achieve thermal comfort for a terrace house in Malaysia with a hot-humid climate. *Energy and Buildings*, 223, 110072.
- Tuck, N. W., Zaki, S. A., Hagishima, A., Rijal, H. B., Zakaria, M. A., & Yakub, F. (2019). Effectiveness of free running passive cooling strategies for indoor thermal environments: Example from a two-storey corner terrace house in Malaysia. *Building and Environment*, 160, 106214.
- Valladares-Rendón, L. G., Schmid, G., & Lo, S.-L. (2017). Review on energy savings by solar control techniques and optimal building orientation for the strategic placement of façade shading systems. *Energy and Buildings*, 140, 458–479.
- Wellun, Z., Mohammad Yusoff, W. F., Mohamed, M. F., Mat Sulaiman, M. K. A., & Mohammad Rasani, M. R. (2023). Review of Window Performance in a Hot and Humid Climate. *Pertanika Journal of Science & Technology*, 31(1).
- Wikipedia, W. (1997). *Colonial architecture in Indonesia*. Wikipedia. https://id.wikipedia.org/wiki/Arsitektur_kolonial_di_Indonesia
- Xi, T., Sa'ad, S. U., Liu, X., Sun, H., Wang, M., & Guo, F. (2025). Optimisation of Residential Indoor Thermal Environment by Passive Design and Mechanical Ventilation in Tropical Savanna Climate Zone in Nigeria, Africa. *Energies*, 18(3), 450.
- Yan, H., Zhang, Y., Liu, S., Cheung, K. M., & Ji, G. (2021).

- Optimisation of daylight and thermal performance of building façades: a case study of office buildings in Nanjing. *The International Conference on Computational Design and Robotic Fabrication*, 168–178.
- Yani, A., Henjilito, R., Noviardila, I., Hasan, B., Setyawan, H., Shidiq, A. A. P., Gerdijan, N., Latino, F., Eken, Ö., & Zulbahri, Z. (2024). The Role of School Supervisors in the Quality Assurance of Physical Education Learning: A Systematic Review. *Challenges: New Trends in Physical Education, Sport and Recreation*, 57, 589–597.
- Yi, X., & Yeboah, S. (2025). Comprehensive ventilation and energy performance analysis of vertical shading devices in cooling-dominant climates. *CIB Conferences*, 1(1), 291.
- Zhao, J., & Du, Y. (2020). Multi-objective optimisation design for windows and shading configuration considering energy consumption and thermal comfort: A case study for office buildings in different climatic regions of China. *Solar Energy*, 206, 997–1017.
- Zune, M., Rodrigues, L., & Gillott, M. (2020a). The vulnerability of homes to overheating in Myanmar today and in the future: A heat index analysis of measured and simulated data. *Energy and Buildings*, 223, 110201.
- Zune, M., Rodrigues, L., & Gillott, M. (2020b). Vernacular passive design in Myanmar housing for thermal comfort. *Sustainable Cities and Society*, 54, 101992.
- Zune, M., Rodrigues, L. T., & Gillott, M. (2018). The sensitivity of roof surface and envelope insulation in naturally ventilated tropical housing: Case study across three climate zones in Myanmar. *Proc. 17th International Conference on Sustainable Energy Technologies*, 264–273.
- Zune, M., Tubelo, R., Rodrigues, L., & Gillott, M. (2021). Improving building thermal performance through an integration of Passivhaus envelope and shading in a tropical climate. *Energy and Buildings*, 253, 111521.