Research paper

Archimane, 2026, Vol. 4, No. 1, 49–62
DOI: 10.59810/archimane/v4i1.234
ISSN 2987-1131 (online); 2987-4033 (print)

Identification of Heat Spots and Thermal Insulation Deficiencies in Tropical Campus Buildings Using FLIR One

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Abstract

Campus buildings in tropical regions are highly vulnerable to elevated surface temperatures due to intense solar radiation and the limited performance of existing thermal insulation systems. These conditions reduce indoor thermal comfort and increase cooling energy demand, particularly in spaces used for academic and administrative activities. The Henricus Constant Campus, as the selected case study, shows indications of uneven heat distribution within several key rooms. This study aims to identify heat spots and thermal insulation weaknesses in the tropical campus building using the FLIR One infrared thermography device. The method involved capturing thermal and visual images in three primary rooms: Lecture Room A.5.1, the Administration Office, and the Faculty Office. Measurements were conducted during midday, when heat intensity typically reaches its peak. Each thermal image was analyzed to observe temperature distribution patterns, detect thermal anomalies, and locate areas potentially experiencing insulation failure, particularly along wall–roof junctions, ceilings, and window openings. The results indicate that Lecture Room A.5.1 exhibits the highest concentration of heat spots, especially on the ceiling and around window areas exposed to direct sunlight. The Administration Office shows several anomalies along wall joints, while the Faculty Office demonstrates a relatively stable temperature distribution. These findings highlight the need for improved thermal insulation to enhance indoor comfort and energy efficiency in the campus building.

Keywords: FLIR ONE, heat spot, thermal imaging, thermal insulation, tropical campus building

Article history:
Received December 30, 2025
Received in revised form February 06, 2026
Accepted March 16, 2026
Available online April 01, 2026

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Introduction

Buildings in tropical regions are inherently challenged in achieving a balance between thermal comfort and energy efficiency. In countries such as Indonesia, persistently high ambient temperatures and intense solar radiation throughout the year significantly increase cooling demands, particularly in campus buildings, lecture halls, and student activity facilities. In response to growing global concerns regarding sustainability and energy consumption, it becomes imperative to rigorously evaluate the performance of the building envelope including walls, roofs, glazing systems, and ventilation and to identify localized zones of excessive heat transfer (heat spots) that may signal critical deficiencies in thermal insulation.

Recent studies, such as Assessment of Thermal Comfort and Its Potential for Energy Efficiency in Low-Income Tropical Buildings: A Review (2025), indicate that cooling demand is a dominant contributor to both energy consumption and CO_2 emissions in tropical buildings. These works further underline the critical influence of parameters such as air circulation, thermal mass, and envelope material properties on thermal comfort and overall energy performance. In parallel, Thermal Performance and Properties Analysis of a Building Envelope Integrated with Phase Change Material for Energy Conservation in a Tropical Climate Region (2024) demonstrates that incorporating phase change materials (PCM) into wall assemblies can significantly mitigate heat transfer and reduce cooling loads. Taken together, this body of research reinforces the pivotal role of material selection and envelope design in optimizing thermal performance in tropical contexts.

However, most existing studies predominantly rely on numerical simulations such as EnergyPlus, TRNSYS, or Overall Thermal Transfer Value (OTTV) analysis to assess thermal performance. In contrast, the use of thermographic techniques, particularly infrared imaging, for the direct detection of heat spots and insulation weaknesses in tropical campus buildings remains underexplored in both local and global literature. This gap is significant, as thermographic approaches offer distinct practical advantages: they enable real-time, in-situ assessment, provide high-resolution spatial visualization of heat distribution, and allow for precise identification of building envelope components requiring targeted retrofit interventions.

A relevant contribution is presented in A New Method of Pixel-Level In-Situ U-Value Measurement for Building Envelopes Based on Infrared Thermography (2024), which proposes an infrared thermography-based method for spatially resolving wall U-values at the pixel level, as opposed to conventional point-based measurements. The study demonstrates that this approach enables the generation of two-dimensional U-value maps, offering a more accurate and representative assessment of actual insulation performance compared to traditional infrared thermography (IRT) methods. This advancement is particularly pertinent to the present research, as heat spots identified on building envelopes can be interpreted as localized zones of elevated U-values, reflecting intensified heat transfer and underlying insulation weaknesses.

Furthermore, within the context of tropical campus environments, Thermal Performance of Lecture Building Envelopes in Bandar Lampung (Itera) (2024) underscores the critical influence of glazing and ventilation systems on thermal performance. Although glazing enhances natural daylighting, it simultaneously increases solar heat gain, thereby intensifying reliance on mechanical cooling systems and elevating energy consumption. Similarly, Evaluation of Building Envelope Performance of Shophouses as an Energy-Saving Measure (Case Study: Coffee Shop in Lamgugop, Banda Aceh City) (2023) demonstrates that Overall Thermal Transfer Value (OTTV) in tropical commercial buildings often exceeds established standards, reflecting suboptimal thermal efficiency. These findings collectively point to persistent deficiencies in envelope design strategies within tropical contexts.

Addressing the identified research gap particularly the limited application of field-based infrared thermography using portable devices such as FLIR One for detecting heat spots and insulation deficiencies in tropical campus buildings this study aims to: (1) systematically identify heat spots and thermal insulation weaknesses within the building envelope of a tropical campus building using a portable infrared camera, and (2) assess the extent to which these deficiencies influence indoor thermal comfort and cooling energy demand. By adopting an empirical, in-situ thermographic approach, this study contributes to bridging the gap between simulation-based analyses and real-world thermal performance evaluation in tropical building contexts.

This study employs a mixed-method approach integrating quantitative and qualitative analyses, including the acquisition of thermal images from both exterior and interior surfaces of the building envelope using a portable infrared device (e.g., FLIR One), spatial analysis of heat spot distribution, and the estimation of U-values or heat loss derived from temperature gradients. Where applicable, environmental parameters such as indoor and outdoor air temperature, relative humidity, building orientation, and envelope material characteristics are also incorporated to enhance the robustness of the analysis. The methodological framework is grounded in recent developments in thermographic assessment and thermal performance evaluation, particularly the pixel-level infrared thermography (IRT) approach proposed by Wang, Hou, and Soibelman (2024).

The hypothesis of this study posits that tropical campus buildings contain specific zones within the building envelope characterized by inadequate thermal insulation, which can be identified as “heat spots” through infrared thermography. These zones are expected to significantly contribute to indoor thermal discomfort and elevated cooling energy demand. Accordingly, this study addresses the following research questions: (1) Where are the spatial distributions of heat spots within the building envelope? (2) Which envelope materials or components are most prone to insulation deficiencies? (3) To what extent can cooling loads be reduced through targeted insulation improvements or retrofit strategies in the identified areas?

The significance of this study lies in its provision of empirical, in-situ evidence on the thermal performance of tropical campus buildings, thereby advancing beyond predominantly simulation-based analyses. Such data are critical for informing evidence-based retrofit planning, optimizing the selection of building envelope materials, and enhancing energy efficiency strategies in educational environments. Moreover, the use of a portable thermographic device such as FLIR One offers a cost-effective and scalable solution, facilitating its widespread adoption across campuses in Indonesia and other tropical regions. This approach not only enables the development of comprehensive thermal mapping and energy auditing practices but also supports the formulation of more sustainable and data-driven building improvement policies.

This study contributes to the state of the art in tropical building research by bridging advanced thermographic methodologies with the underexplored context of tropical campus buildings in developing countries. By addressing this gap, it provides novel empirical insights that are currently limited in the international literature.

From a novelty perspective, existing studies have largely relied on simulation-based approaches such as PCM integration, ventilation modeling, or insulation optimization or on aggregated metrics such as Overall Thermal Transfer Value (OTTV), without capturing the actual spatial distribution of heat through real-time thermographic observation. By integrating portable thermographic techniques with pixel-level (or surface-level) spatial analysis in tropical campus buildings, this study constitutes one of the first empirical investigations in Indonesia and potentially beyond to systematically map heat spots and formulate targeted insulation strategies based on both visual evidence and quantitative thermal data.

Overall, this study integrates key dimensions of thermal comfort, energy efficiency, diagnostic technologies (thermography), tropical architectural design, and sustainability. By synthesizing these aspects, the study aligns with contemporary advancements in green building paradigms and responds to the growing global imperative for energy-efficient and environmentally responsible building practices.

Therefore, this study is expected to contribute significantly to both academic and practical domains. Academically, it advances the empirical body of knowledge on thermographic assessment of tropical campus buildings. Practically, it offers evidence-based recommendations for energy auditors, architects, campus facility managers, and policymakers, particularly within tropical contexts such as Indonesia, where improving building energy performance remains a critical challenge.

Methods

The research methodology is designed to ensure accurate and representative thermal identification of a tropical campus building, with a strong emphasis on the use of current data, the selection of relevant and representative samples, and the implementation of rigorous and reliable analytical procedures. All research stages are systematically structured to ensure that thermal measurement, data processing, and interpretation are conducted in a consistent and methodologically robust manner, enabling a comprehensive representation of the building’s actual thermal performance.

The dataset employed in this study is both current and empirically derived, as all measurements were conducted in situ under the existing conditions of the Henricus Constant tropical campus building, while accounting for diurnal climatic variations characteristic of tropical environments. Data acquisition was performed at multiple time intervals morning, midday, and afternoon to capture significant thermal fluctuations and provide a comprehensive representation of heat distribution patterns. This temporal sampling strategy ensures that the dataset is not fragmentary, but instead accurately reflects the dynamic thermal behavior of the building across its full daily operational cycle.

The selection of sample spaces and building elements was guided by criteria of structural and functional relevance. The sampled spaces represent high-intensity academic activities, including lecture rooms, administrative offices, and faculty offices. Each space was selected based on its distinct architectural characteristics, including differences in orientation, material composition, opening configurations, and levels of solar exposure. This sampling strategy ensures that the findings capture not only a single building condition but also reflect the variability inherent in tropical campus building typologies. Furthermore, key building envelope components such as walls, ceilings, windows, and structural joints were specifically targeted for analysis, as these elements are commonly identified as critical pathways for heat transfer and are particularly susceptible to insulation deficiencies.

Thermal measurements were performed using a calibrated FLIR One infrared camera with adequate resolution to capture fine-grained surface temperature variations. During data acquisition, the camera-to-object distance was carefully controlled within an optimal range to prevent distortion in both visual and thermal outputs. Concurrently, environmental parameters including ambient air temperature, relative humidity, and light intensity were recorded to ensure the reliability of thermographic interpretation and to minimize potential bias arising from environmental variability. Emissivity values were systematically adjusted based on the material properties of each building component, thereby enhancing the accuracy and consistency of surface temperature measurements.

Each thermal scan was processed using specialized thermal imaging software capable of quantitatively representing temperature distributions through annotated thermal maps. The analytical procedure involved systematic comparisons of temperature differentials across multiple points on the same surface, as well as among different building elements within a given space. This approach facilitates the identification of thermal anomalies, including heat spots associated with excessive heat gain and cold spots indicative of potential moisture accumulation or air infiltration. Crucially, the analysis is not limited to qualitative interpretation of thermal color gradients, but is based on consistent numerical temperature data, thereby enhancing analytical rigor and reducing interpretative bias.

To ensure methodological robustness, all measurements were repeated across different time intervals and systematically compared to assess the consistency of observed thermal patterns. Heat spots that appeared consistently at different times were classified as persistent thermal anomalies. In contrast, patterns that emerged only under specific conditions were further examined in relation to influencing factors such as solar orientation and occupancy-related activities. This internal validation approach strengthens the reliability of the methodology by minimizing the risk of drawing conclusions based on transient phenomena or non-representative environmental conditions.

Beyond thermal analysis, the interpretation of building conditions incorporates the interrelationship between visual observations, environmental parameters, and spatial functions. For example, significant vertical temperature gradients between floor and ceiling levels may indicate heat accumulation associated with structural design features or inadequate ventilation strategies. By integrating architectural analysis with thermographic data, this study offers a more comprehensive understanding of the underlying mechanisms of insulation deficiencies and their implications for indoor thermal comfort.

The final stage of the methodology involves synthesizing all findings into an evaluative framework that systematically maps areas of thermal deficiency and formulates technical recommendations based on comparative performance across building envelope components. The generated thermal maps function as a critical visual tool for prioritizing interventions, including insulation enhancement, joint refinement, glazing replacement, and ventilation optimization. Importantly, all procedures are conducted using non-destructive techniques, ensuring that the method remains efficient, practical, and broadly applicable to diverse tropical building contexts.

Results and discussion

This section presents an integrated analysis of infrared thermographic data acquired באמצעות the FLIR One device, combined with a critical review of relevant literature on building envelope performance in tropical climates. The analysis focuses on three key spaces within the Henricus Constant Campus Lecture Room A.5.1, the Administration Office, and the Faculty Office each representing distinct thermal exposure conditions and spatial characteristics. The discussion is structured to systematically address the core research questions, namely: (1) the spatial distribution of heat spots within the building envelope, (2) the identification of envelope materials and components exhibiting insulation deficiencies, and (3) the estimation of potential cooling load reductions achievable through targeted retrofit or insulation enhancement strategies.

Thermal observations reveal a non-uniform heat distribution across the building, with peak concentrations occurring in areas subjected to direct solar exposure and in envelope components with low thermal resistance. The spatial distribution of heat spots is clearly evidenced in the thermographic images presented in figures 1–3. In Lecture Room A.5.1 (igure 1), heat accumulation is predominantly observed at the central ceiling and along the wall–roof junction, indicating that the roof functions as the primary conduit for heat gain. The absence of effective insulation, combined with the high thermal conductivity of the roofing material, facilitates rapid heat transfer from solar radiation into the interior space. This observation aligns with Muri and Hariyadi (2024), who identify roofing materials with high conductivity as a critical factor influencing indoor temperature increases in tropical buildings. Moreover, the roof’s extensive surface area and direct solar orientation further amplify heat absorption, corroborating the findings of Ginting and Novrial (2024), who report that roofs may account for up to 60% of the total daily heat load in tropical building environments.

Figure 1
Thermal analysis in class A.5.1. with FLIR ONE camera and regular digital camera

Unlike the lecture room, the Administration Office demonstrates a distinct concentration of heat spots along wall junctions and window frames, as illustrated in figure 2. This pattern indicates façade-related insulation deficiencies, particularly in glazing areas utilizing clear glass and aluminum frames without thermal breaks. Solar radiation transmitted through the glazing contributes to localized heat gain, while the high thermal conductivity of aluminum frames facilitates rapid heat transfer into the interior environment. As highlighted by Evitasari, Defiana, and Badai Samodra (2023), unprotected glass façades lacking reflective coatings or phase change material (PCM) integration can significantly elevate indoor temperatures, especially in East–West oriented buildings such as the Administration Office. Furthermore, the observed thermal anomalies suggest the likelihood of hot air infiltration through micro-scale gaps at frame joints, which further degrades indoor thermal comfort.

Figure 2
Thermal analysis in the Administration Room with a FLIR ONE camera and a regular digital camera

In contrast, the Faculty Office demonstrates relatively stable thermal conditions, although localized heat spots are still observed on the upper wall areas adjacent to ventilation openings. As illustrated in figure 3, the overall heat intensity in this space is notably lower than that observed in the lecture room and the Administration Office. This thermal stability can be attributed to several factors, including the use of thicker wall materials, the presence of external shading elements, and a lower internal heat load due to fewer electronic devices. These observations support the findings of De Cristo et al. (2025), which highlight the effectiveness of external shading and enhanced wall insulation in mitigating indoor temperature fluctuations in hot climate environments.

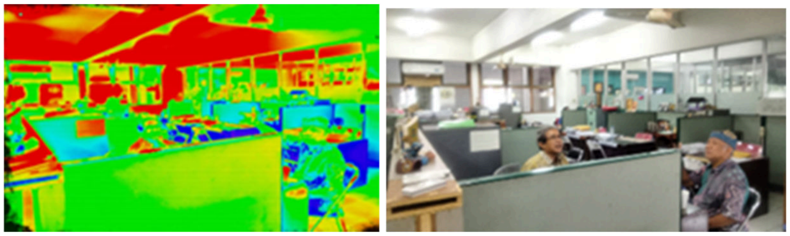

Figure 3
Thermal analysis in the Lecturer Room with a FLIR ONE camera and a regular digital camera

Based on the overall findings, the building envelope components most susceptible to insulation deficiencies include the roof, façade walls, window frames, and structural joints. The roof is identified as the dominant contributor to heat gain, particularly in Lecture Room A.5.1, primarily due to the lack of adequate insulation. This observation aligns with Sadafi, Jamshidi, and Zahedian (2021), who demonstrate that enhancing roof insulation in tropical buildings can reduce heat ingress by approximately 25–45%. Façade walls constitute another critical weakness, particularly at wall–frame junctions where pronounced thermal anomalies are observed. Thin, uninsulated brick walls commonly employed in tropical educational buildings exhibit low resistance to solar radiation and are highly susceptible to temperature elevation, as evidenced by Jhumka et al. (2023). In addition, aluminum frames without thermal breaks significantly accelerate conductive heat transfer into interior spaces, generating localized heat spots around openings. Micro-scale gaps at wall–roof and wall–frame interfaces further exacerbate heat ingress, acting as thermal bridges. Kharrufa and Makky (2024) report that such thermal bridging effects can increase localized temperatures by 15–30% relative to surrounding elements. This phenomenon is also evident in the Administration Office, where heat concentration is observed along wall junctions.

Beyond identifying insulation deficiencies, this study also examines the potential reduction in cooling loads by drawing on established literature on building envelope optimization in tropical climates. Conceptually, targeted improvements in envelope components such as roofs, walls, and openings exhibiting heat spots can lead to significant energy savings. In particular, enhancing roof insulation in Lecture Room A.5.1 is expected to substantially reduce heat ingress. Previous studies (Ginting and Novrial 2024; Sadafi, Jamshidi, and Zahedian 2021) indicate that improved roof insulation can decrease cooling loads by approximately 15–30%, depending on insulation material properties and thickness. Considering that the lecture room demonstrates the highest concentration of heat spots, roof retrofit interventions are likely to provide the greatest impact relative to other envelope components.

Enhancement of façade wall performance offers additional potential for energy savings. Österreicher and Seerig (2024) demonstrate that wall optimization in hot-climate buildings can reduce energy consumption by up to 20%, particularly when walls exposed to direct solar radiation are supplemented with insulation or integrated with external shading systems. In both the Administration Office and Faculty Office, such wall improvements can effectively reduce heat ingress and contribute to more stable indoor thermal conditions. Moreover, the application of reflective coatings or high-albedo exterior finishes can substantially decrease surface temperatures, further mitigating heat gain.

Glass façades constitute a significant source of heat gain, particularly in the Administration Office. Evitasari, Defiana, and Badai Samodra (2023) demonstrate that the implementation of low-emissivity (low-e) glazing or reflective film coatings can reduce indoor temperatures by approximately 2–6°C. In a campus context, such interventions may lead to a reduction in air-conditioning energy consumption of approximately 10–12%, thereby contributing to overall energy efficiency improvements. Furthermore, enhancing the performance of window frames either by employing materials with lower thermal conductivity or by applying additional sealing systems can effectively mitigate heat infiltration and reduce air leakage, further improving thermal performance.

Ventilation constitutes a critical component in reducing cooling loads. Although this study does not incorporate computational fluid dynamics (CFD) analysis, Nguyen et al. (2022) demonstrate that optimized ventilation strategies can passively reduce indoor temperatures by approximately 2–3°C. In Lecture Room A.5.1, enhancing ventilation is estimated to yield an additional heat reduction of approximately 5–8%, while simultaneously reducing dependence on mechanical cooling systems. When implemented in combination, retrofit strategies including roof insulation enhancement, façade wall improvement, optimization of glazing and window frames, and ventilation upgrades can achieve a cumulative reduction in cooling loads of approximately 30–40%. This projection aligns with the findings of Österreicher and Seerig (2024), who report that integrated envelope retrofit strategies can deliver energy savings of up to 35–50% in educational buildings situated in hot and humid climates.

The primary scientific contribution of this study lies in its provision of empirical thermographic evidence that enables detailed mapping of heat spots and insulation deficiencies in tropical campus buildings. The visual data presented in figures 1–3 substantiate the envelope optimization framework proposed by Yuliani et al. (2025), which identifies roofs, walls, and façades as the most critical components in regulating heat gain in tropical environments. In addition, the findings provide actionable insights for prioritizing retrofit interventions, offering practical value for campus facility planners and architectural practitioners engaged in energy-efficient building design.

Overall, the findings indicate that heat spots within the building envelope of the Henricus Constant Campus are primarily concentrated on the roof, thin façade walls, window-adjacent areas, and structural junctions. These components exhibit significant insulation deficiencies, leading to increased indoor temperatures. Targeted retrofit interventions addressing these critical areas have the potential to substantially reduce cooling loads while simultaneously enhancing indoor thermal comfort.

Conclusion

This study aims to identify heat spots and thermal insulation deficiencies in the Henricus Constant Campus building in a tropical climate using a FLIR One thermal camera. Based on thermographic data analysis and visual interpretation of surface temperature distribution, the findings indicate that the building envelope performance is not yet optimal in regulating heat transfer. The thermal scans reveal a concentration of heat spots in several façade elements, including wall roof junctions, wall surfaces exposed to direct solar radiation, and window areas exhibiting lower insulation performance compared to other components. These conditions indicate the presence of critical zones within the building that serve as dominant pathways for heat ingress.

These findings are consistent with the research problem, which underscores the importance of identifying critical weaknesses within the building envelope to improve thermal comfort and energy efficiency. The study objectives have been successfully achieved through a comprehensive empirical evaluation of the building’s thermal performance. Furthermore, the results confirm that thermographic analysis using the FLIR One device is a highly effective approach for detecting otherwise imperceptible thermal anomalies. This method provides a robust foundation for formulating targeted improvement strategies, including insulation enhancement, optimization of shading systems, and refinement of construction detailing.

Overall, this study underscores the importance of early heat spot identification as a key component of retrofit strategies for tropical campus buildings. By accurately identifying the location and characteristics of insulation deficiencies, building managers and decision-makers can implement targeted interventions that not only reduce cooling loads but also improve occupant thermal comfort and contribute to long-term energy efficiency and sustainability.

References

Anugrah A, Setiawan S, Harun H, and Syarifandhy I. 2025. "Thermal Comfort Analysis to Support Energy Efficiency Based on Building Information Modelling (BIM): Case Study of Graduate Building University Fajar." *International Journal of Engineering Business and Social Science (IJEBSS)*. 3 (7): https://doi.org/10.58451/ijebss.v3i7.281

Chung-Camargo K, González J, Chen Austin M, Carpino C, Mora D, and Arcuri N. 2024. "Advances in Retrofitting Strategies for Energy Efficiency in Tropical Climates: A Systematic Review and Analysis." *Buildings* 14(6), 1633. https://doi.org/10.3390/buildings14061633

Cristo, Edoardo De, Luca Evangelisti, Leone Barbaro, Roberto De Lieto Vollaro, and Francesco Asdrubali. 2025. "A Systematic Review of Green Roofs' Thermal and Energy Performance in the Mediterranean Region." *Energies* 18 (10): 2517. https://doi.org/10.3390/en18102517.

Degeorges M, Anand J, Varghese N. J., Mandal J. 2024. "Radiative Cooling and Thermoregulation of Vertical Facades with Micropatterned Directional Emitters." *Applied Physics* https://doi.org/10.48550/arXiv.2408.03512

Evitasari, Litani, Ima Defiana, and FX Teddy Badai Samodra. 2023. "PENGARUH FASAD KACA DENGAN MATERIAL PCM TERHADAP SUHU INDOOR PADA HIGH RISE APARTMENT." *Jurnal Arsitektur ARCADE 7* (1): 152. https://doi.org/10.31848/arcade.v7i1.1309.

Ginting, Sola Gratia, and Novrial. 2024. "The Effect of Material and Roof Shape on Thermal Comfort in Residential Buildings." *International Journal of Architecture and Urbanism* 8 (3): 497–503. https://doi.org/10.32734/ijau.v8i3.16321.

Hakim I. I., Edriawan R, and Putra N. 2024. "Thermal performance and properties analysis of a building envelope integrated with phase change material for energy conservation in a tropical climate region." *AIP Conference Proceedings*. https://doi.org/10.1063/5.0188417

Handri H, Pratiwi I. A., Ilmi M. R., Nurfadillah A. T., and Harimardika M. R. 2023. "Evaluation of Building Envelope Performance of Shophouses as an Energy-Saving Measure (Case Study: Coffee Shop in Lamgugop, Banda Aceh City)." *Lakar: Jurnal Arsitektur* 8(2): 167-178. https://doi.org/10.30998/rvydek03

Hariyanti A. D., Setyowati E., and Hardiman G. 2022. “Analisis Transfer Panas Menyeluruh Pada Selubung Bangunan Di Daerah Tropis.” *Jurnal Arsitektur ARCADE* 6(3): 305–313. https://doi.org/10.31848/arcade.v6i3.1112.

Hasan M.J., Elyan E., Yan Y., Ren J., Sarker M.M.K. 2024. “Segmentation Framework for Heat Loss Identification in Thermal Images: Empowering Scottish Retrofitting and Thermographic Survey Companies.” In: Ren, J., et al. Advances in Brain Inspired Cognitive Systems. BICS 2023. Lecture Notes in Computer Science, vol 14374. Springer, Singapore. https://doi.org/10.1007/978-981-97-1417-9_21

Jhumka, Hamza, Siliang Yang, Christopher Gorse, Sara Wilkinson, Rebecca Yang, Bao-Jie He, Deo Prasad, and Francesco Fiorito. 2023. “Assessing Heat Transfer Characteristics of Building Envelope Deployed BIPV and Resultant Building Energy Consumption in a Tropical Climate.” *Energy and Buildings* 298 (November):113540. https://doi.org/10.1016/j.enbuild.2023.113540.

Kajjoba D., Wesonga R., Lwanyaga J.D. et al. 2025. “Assessment of thermal comfort and its potential for energy efficiency in low-income tropical buildings: a review.” *Sustainable Energy res*. 12, 25. https://doi.org/10.1186/s40807-025-00169-9.

Kharrufa, Sahar Najeeb, and Sahar Makky. 2024. “Energy Efficient Design of Buildings in Hot Climates through Cooling of the Envelope.” *Energy and Buildings* 324 (December):114848. https://doi.org/10.1016/j.enbuild.2024.114848.

Muri, Ilham Sukarno Puji, and Agus Hariyadi. 2024. “Thermal Performance: Influence of Material and Inclination Angle on Vaulted Roofs in Tropical Climate.” *Jurnal Arsitektur ARCADE 8* (3): 240–44.

Nguyen, Y Quoc, Viet T. Nguyen, Long T. Tran, and John C. Wells. 2022. “CFD Analysis of Different Ventilation Strategies for a Room with a Heated Wall.” *Buildings* 12 (9): 1300. https://doi.org/10.3390/buildings12091300.

Österreicher, Doris, and Axel Seerig. 2024. “Buildings in Hot Climate Zones—Quantification of Energy and CO2 Reduction Potential for Different Architecture and Building Services Measures.” *Sustainability* 16 (22): 9812. https://doi.org/10.3390/su16229812.

Sadafi, N., N. Jamshidi, and M. Zahedian. 2021. “Energy Efficient Design Optimization of a Building Envelope in a Temperate and Humid Climate.” *Iranian Journal of Energy and Environment* 12 (3): 255–63. https://doi.org/10.5829/IJEE.2021.12.03.10.

Sani A. A., Matondang A. E., Kurniawan G. K., and Mardiyant, A. 2019. “Kinerja Termal Selubung Gedung Kuliah Kota Bandar Lampung Itera.” *Jurnal Arsitektur ARCADE* 3(3): 267–273. https://doi.org/10.31848/arcade.v3i3.303.

Taki Eddine Seghier, Abel Sepúlveda, Yaik-Wah Lim, Abdelhakim Mesloub, 2024. “Optimising thermal-daylight performance in tropical open-plan offices: A coupled OTTV and daylight prediction approach.” *Journal of Building Engineering* 98, (111369) https://doi.org/10.1016/j.jobe.2024.111369

Wang, Zihao, Yu Hou, and Lucio Soibelman. 2024. “A New Method of Pixel-Level in Situ U-Value Measurement for Building Envelopes Based on Infrared Thermography.” In *Computing in Civil Engineering* 2023, 697–704. Reston, VA: American Society of Civil Engineers. https://doi.org/10.1061/9780784485248.084.

Yuliani, Sri, Bambang Triratma, Dyah Susilowati Pradnya Paramita, and Kartika Tiffania Fairuza Firdaus. 2025. “Energy-Efficient Design of Building Envelopes for Multi-Story Buildings in Tropical Climates.” *International Journal of Civil Engineering* 12 (10). https://doi.org/10.14445/23488352/IJCE-V12I10P109.

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