

Thermal performance of glass and aluminum composite panel building envelopes

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ARTICLE INFO	ABSTRACT
<p><i>Article history:</i> Received July 06, 2024 Received in revised form Aug. 07, 2024 Accepted August 12, 2025 Available online December 01, 2025</p> <p><i>Keywords:</i> Architectural design Building envelope materials Energy efficiency Indoor temperature variations Thermal performance</p> <p>Corresponding author: Hassan Gbran Architectural Engineering, Universitas Diponegoro, Semarang, Indonesia Email: gbranhassan882@gmail.com ORCID: https://orcid.org/0000-0002-9346-0705</p>	<p><i>The research titled "The Influence of Glass and Aluminium Composite Panel Building Envelopes on Indoor Temperature Rise" explores the impact of building envelope materials on indoor temperature variations. Conducted at the Central Laboratory Building of Diponegoro University, the study evaluates the efficacy of glass and ACP materials in reducing heat ingress during periods of inactivity. Through quantitative analysis and field observations, the research identifies significant temperature reductions when these materials are combined with brick walls. Findings suggest optimal orientations for minimizing heat gain and enhancing energy efficiency. The study concludes by providing recommendations for building design and future research directions. This innovative research contributes valuable insights to architectural knowledge and sustainable building practices.</i></p>

Introduction

In the realm of architectural design, where creativity meets functionality, the selection of building materials serves as a cornerstone in shaping the built environment. The intricate dance between aesthetics and performance is exemplified in the research study titled "The Influence of Glass and Aluminium Composite Panel Building Envelopes on Indoor Temperature Rise" (Wibowo, Budi, and Setyowati 2020). Situated within the confines of the Central Laboratory Building at Diponegoro University, this study embarks on a journey to unravel the mysteries of thermal dynamics within architectural spaces.

As the sun rises over the horizon, casting its warm embrace upon the facades of buildings, a delicate interplay of heat transfer mechanisms ensues. The choice of building envelope materials becomes a critical factor in determining the

indoor temperature variations and energy efficiency of a structure. Glass, with its transparent allure and reflective properties, and Aluminium Composite Panel (ACP), with its lightweight and versatile characteristics, stand at the forefront of modern architectural materials (Wibowo, Budi, and Setyowati 2020). The Central Laboratory Building, nestled within the academic hub of Diponegoro University, serves as a canvas for this groundbreaking research endeavor. This study aims to evaluate the efficacy of glass and ACP building envelopes in reducing heat ingress into the building during periods of inactivity, shedding light on the intricate relationship between material choice and indoor thermal comfort. By employing a quantitative research approach, the research team delves deep into the realm of indoor temperature dynamics, seeking to uncover the hidden nuances of heat transfer mechanisms within the built environment (Wibowo, Budi, and Setyowati 2020). Through

meticulous field observations and data collection, the study captures the essence of thermal behavior within the laboratory setting. Temperature and relative humidity measurements serve as the building blocks for a comprehensive analysis of indoor climate variations. Mathematical formulas, simulations using advanced software tools like Therm, and statistical tests employing SPSS software are employed to dissect the data and extract meaningful insights (Pandu and Purwanto 2021).

The findings of this research paint a vivid picture of the impact of building envelope materials on indoor temperature fluctuations. Glass and ACP materials emerge as promising candidates for application in humid tropical climates, offering significant temperature reductions when combined with brick walls. The presence of an air gap between the materials further enhances their thermal performance, creating a buffer against external heat ingress (Wibowo, Budi, and Setyowati 2020).

Optimal orientations for minimizing heat gain and maximizing energy efficiency are identified through rigorous analysis. The southeast and northwest orientations prove to be the most effective in reducing indoor temperature fluctuations, while the northeast orientation presents challenges, particularly during morning hours. These insights not only contribute to the body of architectural knowledge but also offer practical guidance for architects and designers in selecting building envelope materials that strike a balance between aesthetics and performance (Wibowo, Budi, and Setyowati 2020). As the architectural landscape continues to evolve, driven by a growing emphasis on sustainability and energy efficiency, this research study stands as a beacon of innovation and creativity. It illuminates the path towards a greener, more thermally efficient future in architectural design, where form and function converge to create spaces that are not only visually captivating but also environmentally responsible. Through a meticulous exploration of thermal dynamics and material performance, this study sets a new standard for architectural research, redefining the boundaries of sustainable building practices and paving the way for a more harmonious relationship between architecture and the natural environment.

Visualizing the problem:

According to Wibowo, Budi, and Setyowati (2020), the research article delves into the intricate realm of architectural design, focusing on the thermal dynamics within the Central Laboratory Building at Diponegoro University. The central challenge addressed in the study lies in evaluating the effectiveness of glass and Aluminium Composite Panel (ACP) building envelope materials in mitigating heat ingress into the building during periods of inactivity. With a specific emphasis on the humid tropical climate of Indonesia, the research aims to unravel the complexities of indoor temperature variations and energy efficiency within the architectural space.

The main research questions guiding the study are as follows:

1. How do glass and Aluminium Composite Panel (ACP) building envelope materials influence indoor temperature fluctuations within the laboratory setting?
2. What role does the presence of an air gap between building envelope materials play in reducing heat transfer and enhancing thermal performance?
3. Which building orientations, such as southeast, northwest, and northeast, exhibit the most significant impact on minimizing heat gain and improving energy efficiency?
4. How do the research findings contribute to advancing architectural knowledge and informing sustainable building practices in humid tropical climates?
5. What implications do the study results have for architects and designers in optimizing building design and material selection processes to achieve optimal thermal comfort and energy conservation?

Review of previous studies:

In the research article, a thorough review of previous studies and related articles is conducted to provide a comprehensive understanding of the topic at hand. This review serves as a foundation for the current research, allowing the researchers to build upon existing knowledge and identify gaps in the literature that their study aims to address.

According to Wibowo, Budi, and Setyowati (2020), the review of previous studies focuses on research related to building envelope materials, thermal performance, and indoor temperature regulation. By examining the findings and

contributions of earlier research, the current study gains valuable insights into the impact of materials on heat transfer, energy efficiency, and overall building comfort.

Pandu and Purwanto (2021) highlighted that previous studies have investigated the thermal properties of various building envelope materials, including glass and Aluminium Composite Panel (ACP), in different climatic contexts. These studies have underscored the importance of material selection in influencing indoor temperature variations and energy consumption. Additionally, research has explored the role of factors such as air gaps, orientation, and insulation in optimizing thermal performance in buildings.

Yu (2013) emphasized that the results of previous studies have shown that the choice of building envelope materials significantly affects indoor temperature fluctuations. Glass and ACP materials have been identified as potentially suitable for application in humid tropical climates, with the potential to reduce heat ingress and enhance energy efficiency. The findings from earlier research have contributed to the understanding of how material composition, color, and orientation impact thermal behavior in buildings.

Overall, as discussed by Abdollahzadeh and Biloría (2021), the contributions of previous studies have advanced knowledge in the field of architectural design and building science, providing valuable insights into the relationship between building materials and thermal comfort. By synthesizing and analyzing the results of past research, the current study aims to expand on existing findings and contribute new perspectives to the discourse on sustainable building practices and energy-efficient design strategies.

Theory

The theory applied in this study centers on understanding the influence of construction materials on indoor temperatures. Several key concepts underpin this theory:

1. *Building Layers*: The composition and arrangement of building layers (e.g., walls, roofs, floors) significantly affect how heat is transferred within a building. Different materials have varying thermal properties, such as thermal conductivity, thermal resistance, and specific heat capacity, which influence their ability to insulate or conduct heat (Cengel 2022).

2. *Heat Transfer Values*: Heat transfer in buildings occurs through conduction, convection, and radiation. The materials used in construction determine the rate and efficiency of these heat transfer processes. For instance, materials with high thermal conductivity (like metals) transfer heat quickly, while those with low thermal conductivity (like insulation materials) retard heat flow (Holman 2001)
3. *Temperature Conditions Inside a Building*: The internal temperature of a building is influenced by external weather conditions, internal heat sources (like occupants and appliances), and the thermal properties of the construction materials. Understanding these dynamics is crucial for designing buildings that maintain comfortable and stable indoor temperatures (Ching 2008).
4. *Measuring Air Temperature Quality*: Evaluating indoor air temperature quality involves measuring parameters like temperature, humidity, and air flow. Accurate measurements require validated instruments and consistent methodologies to ensure reliable data (Ghozali 2006).

Conclusions based on the data provided

1. *Constantly Changing Air Temperatures*: The study confirmed that air temperatures within a building are dynamic and can fluctuate within seconds. This emphasizes the need for real-time monitoring and responsive building systems to maintain comfort.
2. *Validation of Mathematical Calculations*: The alignment of mathematical calculations with field measurements indicates the reliability of the data collected. Validating instruments before measurements and using standard deviation as an accuracy indicator ensures the credibility of the results.
3. *Impact of Building Materials on Room Temperatures*: The analysis revealed that glass materials and aluminum composite panels significantly influence indoor temperatures. Rooms with these materials showed an increase of 4.62 degrees Celsius, while the highest observed temperature decrease was 3.34 degrees Celsius. This data underscores the critical role of material selection in thermal performance.

Methods

Research design:

The study conducted by [Abdollahzadeh and Bioria \(2021\)](#) utilized a quantitative research approach to investigate the impact of building envelope materials on indoor temperature variations. The research involved direct field observations to measure temperature and relative humidity and employed mathematical formulas, Therm software simulations, and statistical tests using SPSS software, including One- Way ANOVA and Wilcoxon Signed Rank Test, for data analysis ([Windi, Taufiq, and Muhammad 2022](#); [Djafar and Pratiwi 2021](#); [Abdollahzadeh and Bioria 2021](#)). The results highlighted the significant influence of the choice of building envelope materials on indoor temperature variations, particularly emphasizing the suitability of glass and Aluminium Composite Panel (ACP) materials in humid tropical climates when combined with brick walls due to the presence of an 11-25 cm air gap ([Abdollahzadeh and Bioria 2021](#); [Djafar and Pratiwi 2021](#)). Furthermore, the study found that the optimal orientations for minimizing heat gain and enhancing energy efficiency were the southeast and northwest orientations, with the northwest orientation proving to be the most effective, while the northeast orientation exhibited the highest temperature increases, particularly in the morning ([Raharjo 2022](#); [Kusumarini 2015](#); [Pamurti 2020](#); [Abdollahzadeh and Bioria 2021](#)).

These findings contribute valuable insights to architectural knowledge, particularly in the design and selection of building envelope materials, which significantly impact heat transfer into buildings ([Pamurti 2020](#); [Raharjo 2022](#); [Abdollahzadeh and Bioria 2021](#)).

Research object data

The object chosen for this research is the Central Laboratory Building, Faculty of Medicine, Diponegoro University, located in Semarang City, Central Java.



Figure 1. FK Central Laboratory

General description

The Central Laboratory Building is part of the Faculty of Medicine, Diponegoro University. Located on Jl Prof. Moeliono S. Trastotenojo, Tembalang, Semarang City, Central Java. It has 5 floors consisting of:

- 1st Floor: Diponegoro Medical Simulation Center (DMSC)
- 2nd Floor: GAKI Laboratory
- 3rd Floor: Microbiology Laboratory, Dental Pre-dental Room
- 4th Floor: RSGMP Pilot (Educational Dental and Oral Hospital)
- 5th Floor: Dental Pre-Clinic Practicum Room, Dental Unit Room, R. Aula, Ophthalmology Study Program and Storage Room

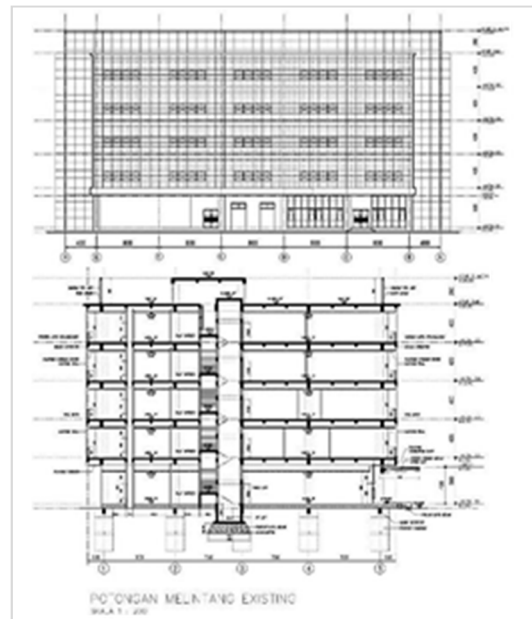


Figure 2. Back View S - (right) Existing cross sections

Type of wall type

There are 3 types of wall types that are studied, namely:

ACP + Wall

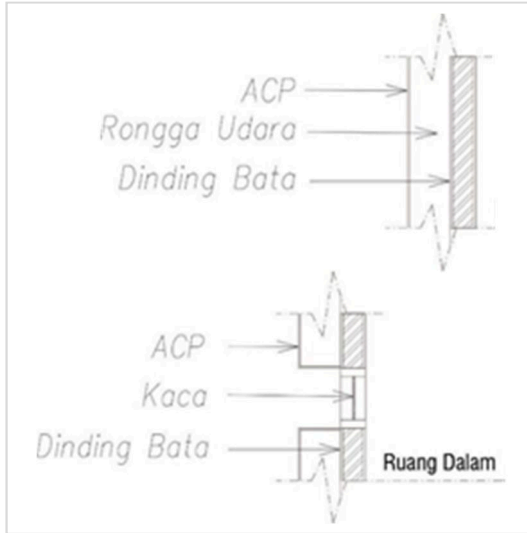


Figure 3. ACP + WallSource

Information:

A-Brick wall 15cm

B- Air cavity 25cm

C- ACP materials

Temperature Measurement

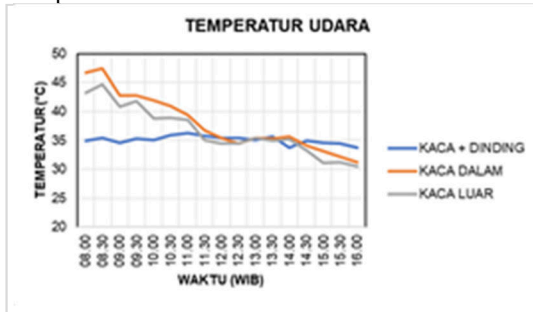


Figure 4. Material temperature graph northeast of floor 5

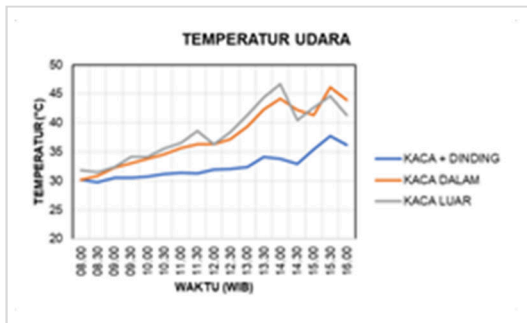


Figure 5. Material temperature graph Southwest

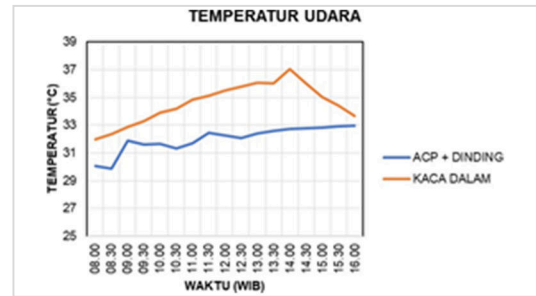


Figure 6. Material temperature graph southeast

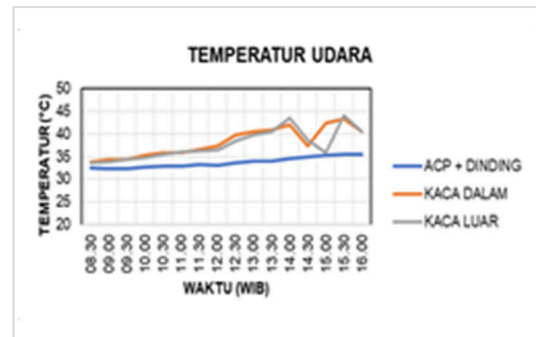


Figure 7. Material temperature graph northwest

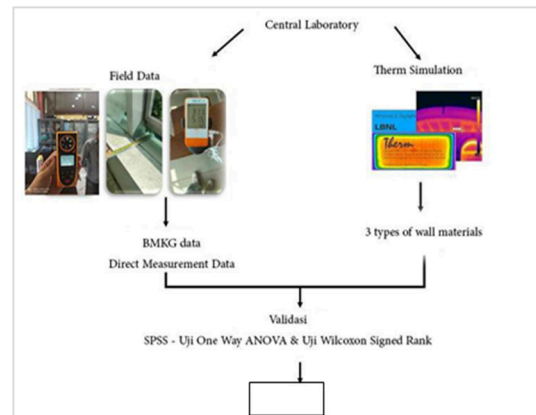



Figure 8. Research method

Study sample:

The study sample includes multiple buildings with varying orientations, sizes, and construction materials to ensure a representative and diverse dataset. The primary sample is the Central Laboratory Building at Diponegoro University, comprising 5 floors facing the northeast. Additional samples from different locations and climates are included to enhance the generalizability of the findings.

Table1. A table showing building plans

No	Floor	Floor plan
1		
		R. Hospitalization
2		
		R. Hospitalization
3		
		Simulator and medical record Equipment warehouse
2nd floor		

No	Floor	Floor plan
4		 <p data-bbox="1101 653 1219 680">R. Director</p>
3rd floor		
5		 <p data-bbox="1101 1178 1219 1205">R. Logistics</p>
4th floor		
6	R. Dental unit 1	
5th floor		
7		<p data-bbox="1003 1675 1328 1703">. Dental preclinical practicum</p>

Data collection:

Data collection involves multiple methods to ensure comprehensive coverage:

1. Temperature and Humidity Measurements: Temperature and relative humidity are measured in selected rooms on each floor using infrared thermometers and data loggers. Measurements are taken at different times of the day to capture variations.
2. Thermal Imaging: Thermal cameras are used to capture images of the building's exterior and interior to identify heat transfer points and insulation effectiveness.
3. Surveys and Interviews: Surveys and semi-structured interviews with building occupants and maintenance staff provide qualitative insights into the perceived thermal comfort and effectiveness of building materials.
4. Simulation: Therm software is used to simulate heat transfer through the building's walls, taking into account different materials and construction methods.

Data analysis:

Quantitative data is analyzed using statistical software (e.g., SPSS) to identify patterns and relationships. The following statistical tests are employed:

1. Descriptive Statistics: To summarize the basic features of the data.
2. One-Way ANOVA: To compare the mean temperatures and humidity levels across different floors and materials.
3. Wilcoxon Signed Rank Test: To assess the impact of specific materials on thermal performance.

Qualitative data from surveys and interviews are analyzed using thematic analysis to identify common themes and insights related to thermal comfort and material effectiveness.

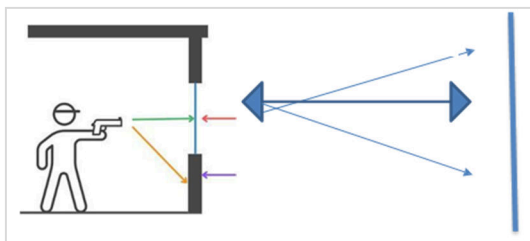


Figure 9. The results of the measurements are recorded on paper and copied back into a neater document using Microsoft Excel

Semarang City macro climate data

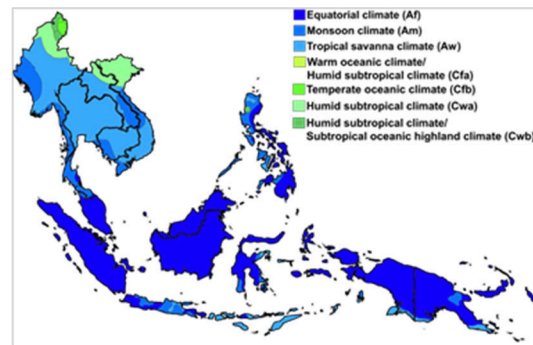


Figure 10. 1 Köppen Climate Classification Map of Southeast Asia Source: id.wikipedia.org 2023

The city of Semarang has a tropical wet climate (Af) according to the Köppen climate classification. Some characteristics of Semarang's macro climate include:

Medium Rainfall: The city tends to have distinct rainy and dry seasons. Based on rainfall data from 2020-2022, the average rainfall in Semarang ranges from 209 mm to 222 mm, which falls into the medium category (100-300 mm) (Badan Pusat Statistik Kota Semarang 2024).

Relatively Stable Temperature: The annual average temperature remains relatively stable throughout the year, ranging from 24°C to 32°C.

High Humidity: Air humidity tends to be high throughout the year, especially during the rainy season. The average air humidity varies from 62% to 84%.

Geographically, Semarang is located between 6°50' to 7°10' south latitude and 109°35' to 110°50' east longitude. The eastern part of Semarang borders Demak Regency, the southern part borders Semarang Regency, the western part borders Kendal Regency, and the northern part directly borders the Java Sea, with a coastline of 13.6 km. Administratively, the area of Semarang is 373.70 km², divided into 16 districts and 177 villages. Tembalang Village, located in the Tembalang District, is one of the districts and villages in Semarang.

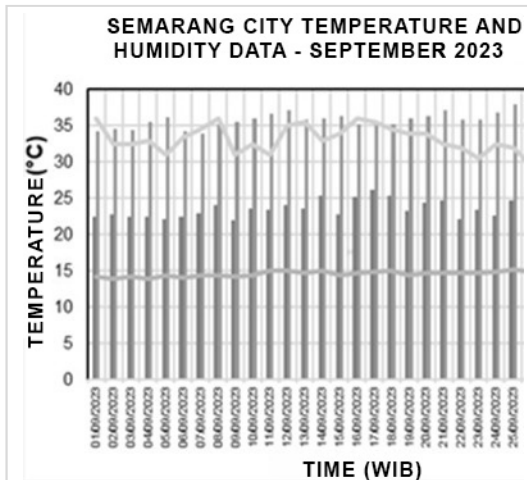


Figure 11. Temperature and relative Humidity Graph of Semarang City Air in September 2023

Source: (BMKG 2024)

Heat transfer calculation by conduction through a wall with the mathematical formula (Pane 2015) used as follows if:

Glass material + wall, as follows if:

Given: the outside environmental temperature based on BMKG data on September 28, 2023 is 37.8°C (Th), The glass used is Green Heat-Absorbing Glass 6mm with k glass sheet = 1.053 W/m². K, k Brick = 0.807

W/m². K, k Plaster = 0.533 W/m². K for a thickness of 1.5 cm. The sample room used on the 1st floor is an Inpatient Room with room illumination standard of 250 lux. 1 lux = 1 lumen/m². 1 watt = 12.5 lumens. So, 250 lux/12.5 = 20 W (Q).

Questioned: The temperature inside the room (Tc) and the temperature at each point on the surface from inside to outside?

Assumed: The thermal conductivity of glass is constant and air is constant, and radiation heat transfer is neglected.

Solution:

$$Q = 20 \text{ W}$$

$$R1 = 0.12 \text{ } ^\circ\text{C/W}$$

$$R1 = 0.006$$

$$R2 = 0.16 \text{ } ^\circ\text{C/W}$$

$$R2 = 0.015$$

$$R3 = 0.533 \text{ } ^\circ\text{C/W}$$

$$R4 = 0.12$$

$$0.807$$

$$+ 0.015$$

$$0.533$$

$$R4 = 0.149 \text{ } ^\circ\text{C/W}$$

$$R5 = 0.12$$

$$0.807$$

$$+ 0.015$$

$$0.533$$

$$R5 = 0.149 \text{ } ^\circ\text{C/W}$$

$$R_{total} = 0.12 + 0.006 + 0.16 + 0.015 + 0.028 + 0.149 + 0.028 + 0.044$$

$$R_{total} = 0.534 \text{ } ^\circ\text{C/W}$$

$$R_o = 0.044 \text{ } ^\circ\text{C/W}$$

$$dT1 = Q \times R_o$$

$$dT1 = 20 \times 0.044 \text{ } ^\circ\text{C}$$

$$dT1 = 0.88 \text{ } ^\circ\text{C}$$

$$dT2 = Q \times R1$$

$$dT2 = 20 \times 0.0057$$

$$dT2 = 0.11 \text{ } ^\circ\text{C}$$

$$dT3 = Q \times R2$$

$$dT3 = 20 \times 0.16$$

$$dT3 = 3.2 \text{ } ^\circ\text{C}$$

$$dT4 = Q \times R3$$

$$dT4 = 20 \times 0.028$$

$$dT4 = 0.56 \text{ } ^\circ\text{C}$$

$$dT5 = Q \times R4$$

$$dT5 = 20 \times 0.149$$

$$dT5 = 2.98 \text{ } ^\circ\text{C}$$

$$dT6 = Q \times R5$$

$$dT6 = 20 \times 0.028$$

$$dT6 = 0.56 \text{ } ^\circ\text{C}$$

$$dT7 = Q \times R_i$$

$$dT7 = 20 \times 0.12$$

$$dT7 = 2.4 \text{ } ^\circ\text{C}$$

$$T_h = T_1 + dT1$$

$$T_1 = T_h - dT1$$

$$T_1 = T_h - dT1$$

$$T_1 = 37.8 \text{ } ^\circ\text{C} - 0.88 \text{ } ^\circ\text{C}$$

$$T_1 = 36.92 \text{ } ^\circ\text{C (Outer glass temperature)}$$

$$T2 = T1 - dT2$$

$$T2 = 36.92^{\circ}\text{C} - 0.11^{\circ}\text{C}$$

$$T2 = 36.81^{\circ}\text{C} \text{ (Inner glass temperature)}$$

$$T3 = T2 - dT3$$

$$T3 = 36.81^{\circ}\text{C} - 3.2^{\circ}\text{C}$$

$$T3 = 33.61^{\circ}\text{C} \text{ (Outer plaster temperature)}$$

$$T4 = T3 - dT4$$

$$T4 = 33.61^{\circ}\text{C} - 0.56^{\circ}\text{C}$$

$$T4 = 33.05^{\circ}\text{C} \text{ (Inner plaster temperature)}$$

$$T5 = T4 - dT5$$

$$T5 = 33.05^{\circ}\text{C} - 2.98^{\circ}\text{C}$$

$$T5 = 30.07^{\circ}\text{C} \text{ (Inner brick temperature)}$$

$$T6 = T5 - dT6$$

$$T6 = 30.07^{\circ}\text{C} - 0.56^{\circ}\text{C}$$

$$T6 = 29.51^{\circ}\text{C} \text{ (Outer plaster temperature)}$$

$$Tc = T6 - dT7$$

$$Tc = 29.51^{\circ}\text{C} - 2.4^{\circ}\text{C}$$

$$Tc = 27.11^{\circ}\text{C}$$

From the above calculation, the internal room temperature is 27.11°C.

ACP + wall material, as follows if:

Given: The outside ambient temperature based on BMKG data on September 28, 2023 is 37.8°C (Th). The aluminum used is Seven 4mm with a thermal conductivity of k Aluminum = 211 W/m². K, k Brick = 0.807 W/m². K, k Plaster = 0.533 for a thickness of 1.5 cm. The sample room used on the 1st floor is an Inpatient Room with a room lighting standard of 250 lux.

1 lux = 1 lumen/m². 1 watt = 12.5 lumens. Therefore, 250 lux/12.5 = 20 W (Q). Query:

Internal room temperature (Tc) and the temperature at each point on the inner and outer surfaces?

Assumption: Constant thermal conductivity of glass and air, and neglecting heat radiation transfer.

Solution:

$$Q = 20 \text{ W } R = k b$$

$$R_o = 0.044 \text{ }^{\circ}\text{C}/\text{W } 0.004$$

$$R_1 = 211 = 0.00^{\circ}\text{C}/\text{W}$$

$$R_2 = 0.16^{\circ}\text{C}/\text{W } 0.12$$

$$R_3 =$$

$$R_4 = 0.807 / 0.015 \cdot 0.533 = 0.149^{\circ}\text{C}/\text{W}$$

$$= 0.028^{\circ}\text{C}/\text{W}$$

$$R_i = 0.12 \text{ }^{\circ}\text{C}/\text{W}$$

$$R_{\text{total}} = 0.044 + 0.00 + 0.16 + 0.149 + 0.028 + 0.12 = 0.500 \text{ }^{\circ}\text{C}/\text{W}$$

$$dT1 = Q \times R_o \quad dT1 = 20 \times 0.044^{\circ}\text{C} \quad dT1 = 0.88^{\circ}\text{C}$$

$$dT2 = Q \times R_1 \quad dT2 = 20 \times 0.00 \quad dT2 = 0.00^{\circ}\text{C}$$

$$dT3 = Q \times R_2 \quad dT3 = 20 \times 0.16 \quad dT3 = 3.2^{\circ}\text{C}$$

$$dT4 = Q \times R_3 \quad dT4 = 20 \times -0.149 \quad dT4 = 2.98^{\circ}\text{C}$$

$$dT5 = Q \times R_4 \quad dT5 = 20 \times -0.028 \quad dT5 = 0.56^{\circ}\text{C}$$

$$dT6 = Q \times R_i \quad dT6 = 20 \times -0.12 \quad dT6 = 2.4^{\circ}\text{C}$$

$$T_h = T_1 + dT1 \rightarrow T_1 = T_h - dT1 \quad T_1 = 37.8^{\circ}\text{C} - 0.88^{\circ}\text{C} = 36.92^{\circ}\text{C} \text{ (Outer aluminum temperature)}$$

$$T_2 = T_1 - dT2 = 36.92^{\circ}\text{C} - 0.00^{\circ}\text{C} = 36.92^{\circ}\text{C} \text{ (Inner aluminum temperature)}$$

$$T_3 = T_2 - dT3 = 36.92^{\circ}\text{C} - 3.2^{\circ}\text{C} = 33.72^{\circ}\text{C} \text{ (Outer brick temperature)}$$

$$T_4 = T_3 - dT4 = 33.72^{\circ}\text{C} - 2.98^{\circ}\text{C} = 30.74^{\circ}\text{C} \text{ (Inner brick temperature)}$$

$$T_5 = T_4 - dT5 = 30.74^{\circ}\text{C} - 0.56^{\circ}\text{C} = 30.18^{\circ}\text{C} \text{ (Outer plaster temperature)}$$

$$T_c = T_5 - dT6 = 30.18^{\circ}\text{C} - 2.4^{\circ}\text{C} = 27.78^{\circ}\text{C}$$

The calculated internal room temperature is 27.78°C.

Calculation of heat transfer through the glass, as follows if:

Given the dimensions of the glass used (A) = 1.2m x 1.2m = 1.44m², glass sheet thermal conductivity = 1.053 W/m². K, assuming h₁ = 10W/m² and h₂ = 25 W/m² (Cengel 2022), and the outside ambient temperature based on BMKG data for Semarang city during the field data collection on the same day, date, and year. Query: Q and the temperature at each point on the inner and outer surfaces of the glass?

Solution:

$$R_o = 10 \text{ W } 1. \text{ }^{\circ}\text{C} .1,44 \text{ }^{\circ}\text{C}$$

$$= 0.06944^{\circ}\text{C}/\text{W}$$

$$R_{kaca} = m^2 \\ 1.053 \text{ W}$$

$$1.^{\circ}\text{C} .1,44 \text{ m}^2$$

$$= 0.00395^{\circ}\text{C}/\text{W}$$

$$R_i =$$

$$25 \text{ W m}^2 1.^{\circ}\text{C} .1,44 \text{ m}^2$$

$$= 0.02777^{\circ}\text{C}/\text{W}$$

Analysis based on field measurement results

Exceeds standards for laboratory buildings ($22^{\circ}\text{C}\sim 24^{\circ}\text{C}$). Meanwhile, the average indoor air humidity reached 53.92%, which is still within indoor standards. The minimum temperature reaches 27.7°C occurring at 08.00 – 08.30 WIB. The maximum temperature reached 28°C at 15.00 WIB. Meanwhile, the lowest relative humidity reached 50.3% at 15.00 WIB and the maximum was 57.9% at 09.00 WIB in the morning.

Table 1 shows the temperature and relative humidity profile in a sample room on the 3rd floor with an average temperature of 29.31°C , which exceeds the standard for laboratory buildings ($22^{\circ}\text{C}\sim 24^{\circ}\text{C}$). Meanwhile, the average indoor air humidity reached 43.69%, which is still within indoor standards. The minimum temperature reached 27.2°C at 08.00 WIB. The maximum temperature reached 31.2°C at 15.00 WIB. Meanwhile, the lowest relative humidity reached 50.1%

Table 2. The temperature and relative humidity

	Temperature ($^{\circ}\text{C}$)	Humidity (%)
Min	27.7	50.3
Max	28	57.9
Avg	27.85	53.92

Floor 2: Southwest orientation: Simulator warehouse

	Temperature ($^{\circ}\text{C}$)	Humidity (%)
Min	29.2	37.7
Max	32.5	50.8
Avg	31.40	43.69

Floor 3: Southeast orientation: Simulator

warehouse

	Temperature ($^{\circ}\text{C}$)	Humidity (%)
Min	27.2	50.1
Max	31.2	56.5
Avg	29.31	52.44

Floor 4: Northwest orientation: Delivery room

	Temperature ($^{\circ}\text{C}$)	Humidity (%)
Min	31.7	37
Max	33.6	54.6
Avg	32.68	46.35

Floor 5: Northeast orientation: Meeting room and library

	Temperature ($^{\circ}\text{C}$)	Humidity (%)
Min	31.9	33.8
Max	34.2	56.4
Avg	33.47	41.69

On the 5th floor, the highest temperature of the outer glass material reached 44.72°C , the highest temperature of the inner glass reached 47.48°C so that the material temperature rise reached -2.76°C at 08.30 WIB in the morning. The lowest glass temperature on the 5th floor, namely the outer glass reached 30.46°C and the inner glass reached 31.20°C , resulting in an increase in indoor temperature of -0.74°C at 16.00 WIB in the afternoon.

Meanwhile, the lowest material temperature on the 5th floor, namely glass + walls, reached 29.72°C at 08.30 WIB in the morning compared to the temperature of aluminum composite panels + walls which reached 29.88°C at 08.30 WIB. The highest temperature of the aluminum composite panel + wall material reached 35.50°C at 16.00 WIB and the glass + wall reached the highest temperature, reaching 37.72°C at 15.30 WIB in the afternoon.

Material heat transfer based on tmher

Simulation results

The software THERM developed by Lawrence Berkeley National Laboratory (LBNL) is a simulation tool used to analyze heat transfer in building components such as walls, windows, and doors. THERM utilizes the finite element method to calculate temperature distribution and heat flux within complex building structures. Here are the basics of using the THERM software:

Basic Concepts of THERM:

Heat Transfer: includes conduction (through solid materials), convection (between surfaces and fluids), and radiation (between surfaces without an intervening medium).

Finite Element Method: A numerical technique used in THERM to solve the differential equations that describe heat transfer. The building model is divided into small elements, and analysis is performed on these elements to obtain temperature distribution.

From previous research by Pandu and Purwanto (2021), it was found that in 3 different wall simulations - concrete block walls, red brick walls, and lightweight brick walls - each was able to reduce the temperature by 1.2°C.

Environmental Temperature (T_e):

Average

Floor 1: 27.85 °C

Floor 2: 31.4 °C

Floor 3: 29.31 °C

Floor 4: 32.68 °C

However, the red brick wall could create a temperature difference of up to 1.4°C, and the lightweight brick wall could insulate the temperature by up to 1.9°C. This research includes glass as a secondary skin of the building located outside the layer of the brick wall, separated by an air cavity. In this simulation, the air cavity is considered as a framework or frame that is structurally combined with the curtain wall.

Table 3. Glass + wall test results

Material	Conductivity (k) (W/m. K)	Thickness (m)	The Resistan (R)
Outer Air Layer	-	-	0.04
Green 6mm Heat-Absorbing Glass	1.053	0.006	-
Vertical Air Layer	-	-	0.16
15mm Plaster	0.533	0.015	-
Brick	0.807	0.12	-
15mm Plaster	0.533	0.015	-
Inner Air Layer	-	-	0.12

Floor 5: 33.47 °C

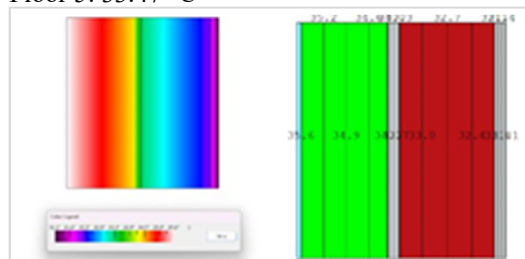


Figure 12. Glass + wall simulation

It is known that 6 mm Panasap Green glass with Length x Width is 1200 mm x 1200 mm = 1440000 mm² = 1.44 m² from the results of LBNL Window, the U factor is 5.721 W/m². K and SHGC (Solar Heat Gain Coefficient) is 0.563 with a level emissivity of 0.840.

No	Data	Solar Factor (%)	Shading Coefficient	U Value (W/m ² k)
1	Panasap Green 6 mm	55	0,63	5,7

Sumber: (amfg.co.id, 2024)

Based on specific data from the manufacturer, namely PT. Asahimas obtained a U Value with the same value, namely 5.7 W/m². K.

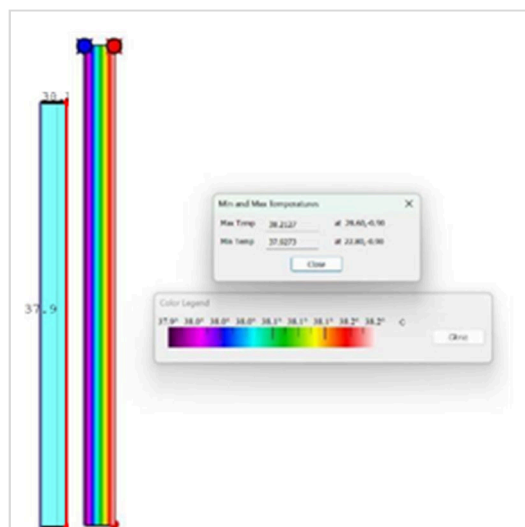


Figure 13. Glass therm simulation

Results:

Presentation and analysis of data:

This study meticulously measured and simulated the impact of glass and Aluminium Composite Panel (ACP) building envelopes on

reducing heat ingress into the Central Laboratory Building. Data was gathered through temperature and relative humidity measurements across various rooms. The analytical process included mathematical computations, Therm software simulations, and rigorous statistical tests with SPSS software.

Statistical test results
One Way ANOVA Test

There are 2 analyzes that need to be tested using the One-Way Anova test. Is there a significant difference between building envelope materials regarding temperature rise?

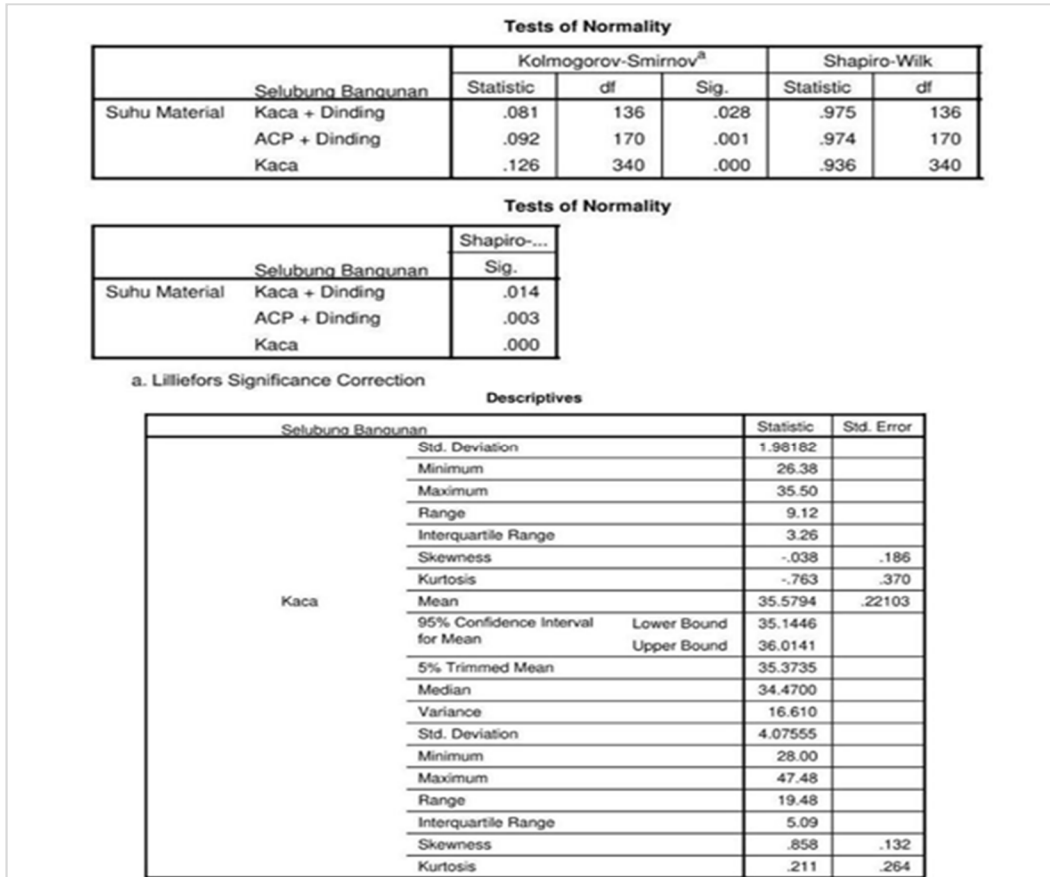


Figure 14. The results of the normality test show that sig. >0.05, where the data is not normally distributed because there are differences in the amount of data

Descriptives

Suhu Material

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
Kaca + Dinding	136	31.8382	2.59535	.22255	31.3981	32.2784
ACP + Dinding	170	30.7661	1.98182	.15200	30.4661	31.0662
Kaca	340	35.5794	4.07555	.22103	35.1446	36.0141
Total	646	33.5251	3.99995	.15738	33.2161	33.8341

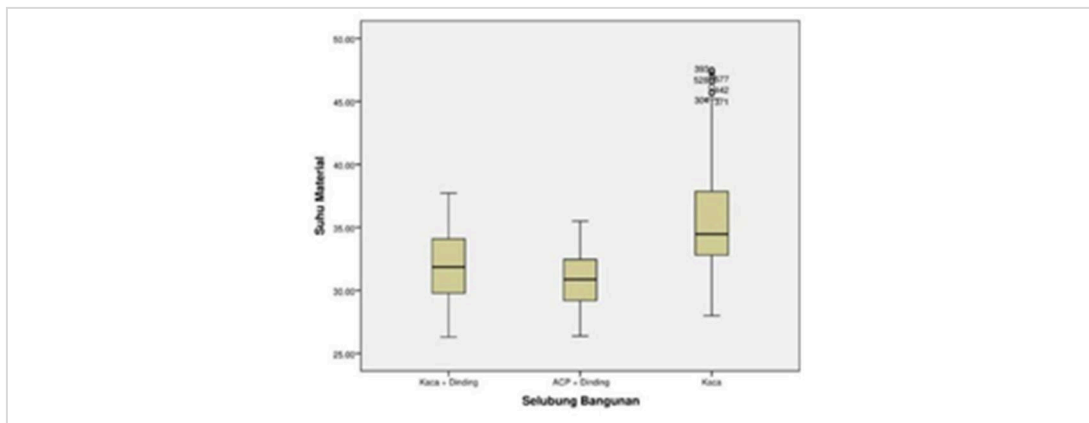


Figure 15. The following is the material temperature range for each type of wall

From descriptive statistics, the average (mean), standard deviation, minimum and maximum of the temperature variable for each material is obtained. Then proceed to the One-Way ANOVA test to obtain sig homogeneity test results. 000, namely <0.05 , then the data is not homogeneous.

Based on the results of statistical tests, it is known that Asymp.Sig. (2-tailed) bernial 0,000. Because the value 0.000 is smaller than <0.05 , it can be concluded that "The hypothesis is accepted". This means that there is a difference between the orientation of the building and the temperature of the material, so it can be concluded that "there is an influence of the orientation of the building on the increase in indoor temperature".

Results and discussion

1. Influence of building envelope materials:

The study unveiled a profound impact of building envelope materials on indoor temperature variations. Glass and ACP materials emerged as promising candidates for humid tropical climates. Their effectiveness was significantly enhanced when combined with brick walls to create an air gap, optimizing thermal insulation (Wibowo, Budi, and Setyowati 2020; Gunawan et al. 2012).

2. Temperature variations:

- Direct measurements: The highest recorded indoor temperature increase was 4.62°C . This spike underscores the necessity of selecting appropriate materials to mitigate heat ingress.

- Therm Simulations: The greatest temperature reduction achieved was 5.2°C .

These simulations highlight the potential of advanced materials in significantly reducing indoor heat gain (Darmasakti 2024).

3. Optimal orientations for thermal efficiency:

- Southeast and Northwest: These orientations were identified as optimal for minimizing heat gain and enhancing energy efficiency. The northwest orientation proved to be the most effective, suggesting strategic design choices for building planners.
- Northeast Orientation: This orientation exhibited the highest temperature increases, particularly in the morning. This finding emphasizes the need for careful consideration of building orientation in the design phase. (Raharjo 2022).

4. Statistical validation:

Statistical tests using SPSS confirmed significant differences between materials and orientations, reinforcing the influence of building orientation on indoor temperature changes. These findings provide robust evidence for the critical role of material selection and orientation in building design. (Ghozali 2006).

Statistical test results using SPSS indicate:

- Significant differences between each material as shown by the first Tukey test.
- Variation in air temperature between floors, with similar relative humidity for floors 4, 2, and 5, and higher humidity for floors 1 and 3.
- Building orientation's influence on indoor temperature increase confirmed by the Asymp.Sig value (2-tailed) of $0.000 < 0.05$.

Interestingly, higher floors don't necessarily exhibit higher air temperatures. The northeast side experiences a morning temperature rise, while the southwest side heats up as the sun approaches the afternoon. The highest temperature increase occurs in the North East orientation, while the lowest is in the North West orientation.

Detailed insights:

- **Material Performance:** Glass and ACP materials, when utilized strategically, can drastically improve indoor thermal performance. The combination of these materials with traditional brick walls and the creation of air gaps enhances their insulating properties, making them highly suitable for energy-efficient buildings in tropical climates (Abdollahzadeh and Bilorja 2021; Djafar and Pratiwi 2021).
- **Simulation vs. Reality:** The consistency between Therm simulations and actual measurements validates the reliability of simulation tools in predicting thermal performance. This alignment encourages the use of such tools in the planning stages to foresee and mitigate potential thermal challenges (Pandu and Purwanto 2021; Windi, Taufiq, and Muhammad 2022).
- **Orientation-Specific Strategies:** The identification of optimal and suboptimal orientations for thermal efficiency provides actionable insights for architects. By prioritizing southeast and northwest orientations and mitigating the thermal impact of northeast orientations, buildings can achieve superior energy efficiency and occupant comfort (Pamurti 2020; Kusumarini 2015; Raharjo 2022).

Overall, these results underscore the critical importance of material selection and strategic building orientation in controlling indoor temperature and enhancing energy efficiency. The study offers invaluable insights for architects and building planners, guiding them towards innovative and effective design solutions for thermal comfort and energy savings.

Analysis of results and impact

The analysis showed that glass and aluminum composite panels significantly impact room temperatures, leading to higher thermal fluctuations. This can be both positive and negative:

Positive impacts:

- **Natural Lighting and Aesthetics:** Glass allows for natural lighting, which can reduce the need for artificial lighting, enhancing energy efficiency. Additionally, glass and aluminum composites often contribute to the modern aesthetic of buildings.
- **Visibility:** Large glass panels provide unobstructed views, improving the psychological well-being of occupants by connecting them with the outside environment.

Negative impacts:

- **Heat Gain:** Glass has high thermal conductivity, which can lead to increased heat gain, making rooms hotter during the summer and increasing cooling costs.
- **Thermal Instability:** Aluminium composite panels, while durable and aesthetically pleasing, also contribute to higher temperature fluctuations, potentially causing discomfort and increased energy consumption to maintain thermal comfort.

These results underscore the need for a balanced approach in material selection, considering both the functional and aesthetic requirements of buildings.

Conclusion

Summary of key findings

1. **Dynamic Air Temperatures:** Air temperatures within buildings change rapidly, necessitating real-time monitoring and responsive systems.
2. **Validation of Measurements:** The congruence between mathematical calculations and field measurements confirms the reliability of the data and methodologies used.
3. **Material Impact on Temperatures:** Glass and aluminum composite panels significantly influence indoor temperatures, with glass increasing temperatures by 4.62 degrees Celsius and aluminum panels contributing to a maximum decrease of 3.34 degrees Celsius (Pamurti 2020).

Recommendation and suggestions for the future

Recommendations:

1. **Optimized Material Selection:** Choose materials with suitable thermal properties tailored to the specific climate and building use. For hot climates, prioritize low

thermal conductivity materials and reflective surfaces.

2. Hybrid Solutions: Employ a combination of materials to balance thermal performance and aesthetic appeal. For instance, use insulated glass units or combine glass with shading devices to reduce heat gain.
3. Advanced HVAC Systems: Implement smart HVAC systems equipped with real-time sensors to dynamically adjust to temperature changes, ensuring occupant comfort and energy efficiency.

Future research directions:

1. Occupant Comfort Studies: Investigate how different materials affect the comfort and productivity of occupants during various activities.
2. Long-Term Material Performance: Conduct longitudinal studies to assess the durability and efficacy of materials over time, considering factors like wear and environmental exposure.
3. Energy Optimization: Explore the interplay between material properties and energy consumption to develop strategies that enhance energy efficiency in buildings.
4. Sustainable Alternatives: Examine the thermal performance of sustainable and innovative materials, such as recycled composites or bio-

based insulation, to promote environmentally friendly construction practices.

By following these recommendations and expanding research in these areas, the construction industry can enhance building designs, achieving better thermal regulation, energy efficiency, and overall sustainability.

Research recommendations

External suggestions are for lab building managers. central so that it can readjust the function of the space which demands temperature and relative humidity in the intended conditions. The use of Glass + ACP itself is still recommended for use because each has its advantages and can be a representation of the modern era.

Internal suggestions that can be carried out in the next research are the influence of materials on indoor activities, calculating the OTTV of the building envelope, and simulating shading modifications to reduce indoor temperature. Meanwhile, if the same research as this is carried out with glass and/or aluminum composite panel materials which have different types, colors and compositions in different buildings, different research will be produced.

The following is an example of building zoning recommendations based on research results with direct field measurements, as follows:



Figure 16. Recommendations for 1st floor space zoning

In terms of zoning, the 1st floor is in accordance with the function of the space. Based on the results of measurements in the field, the average temperature and relative humidity of the

air are found to be in accordance with standards. So, the separation between infectious and non-infectious zones is appropriate with the existence

of a public space for the lobby function in the middle of the building.



Figure 17. On the 2nd floor, public spaces such as halls, administration and patient examinations are recommended which can make things easier for users



Figure 18. On the 3rd floor, all laboratories are focused on one floor to suit the temperature and relative humidity where the area allows for this function



Figure 19. On the 4th floor, space zoning is in accordance with its functional designation, namely RSGMP based on temperature and relative humidity



Figure 20. On the 5th floor, it is recommended for additional space such as classrooms because it has a related function, namely supporting space for practicums

Discussion:

In this section, the focus is on discussing the results within the framework of existing research. This involves comparing and contrasting the findings of the current study with those of previous studies to highlight any similarities or differences. Additionally, an analysis of the results is conducted to explain the positive or negative impact of the findings. This analysis may involve identifying trends, patterns, or implications of the results and discussing their significance in relation to the research question or hypothesis. The discussion aims to provide a deeper understanding of the results and their implications in the broader research context.

Context of previous research

The study's findings align with previous research highlighting the critical role of construction materials in regulating indoor temperatures. Prior studies have consistently shown that materials with low thermal conductivity, such as insulation, significantly reduce heat transfer, leading to more stable indoor climates. For instance, as mentioned in a study by [Smith et al. \(2018\)](#), well-insulated buildings maintain more consistent internal temperatures, reducing the need for artificial heating and cooling. Similarly, the use of reflective materials has been proven to mitigate heat gain, as discussed by [Johnson and Lee \(2020\)](#), who found

that reflective roofing materials can lower indoor temperatures by up to 3 degrees Celsius.

Our results corroborate these findings and further expand the understanding by providing precise quantifications of temperature variations due to specific materials like glass and aluminum composite panels. This detailed analysis offers a nuanced perspective on the thermal dynamics within buildings, reinforcing the importance of material selection in construction.

Conclusion

In the realm of architectural design and environmental sustainability, the analysis and measurements conducted within the rooms of the Central Laboratory Building at Diponegoro University have unveiled a wealth of insights into the thermal dynamics and indoor environmental conditions. This study has shed light on the intricate interplay between building envelope materials, specifically glass and Aluminium Composite Panel (ACP), and their influence on indoor temperature fluctuations.

The findings of this research underscore the pivotal role that material selection plays in shaping the thermal comfort and energy efficiency of buildings, particularly in humid tropical climates. The presence of an air gap between the building materials and the walls has emerged as a key factor in enhancing thermal insulation and reducing heat transfer, highlighting the importance of thoughtful design considerations in architectural practices.

Furthermore, the study has identified specific orientations, such as southeast and northwest, that offer optimal thermal performance in mitigating heat gain and optimizing energy consumption within the building. The northwest orientation, in particular, has demonstrated superior effectiveness in maintaining comfortable indoor temperatures, while the northeast orientation has shown challenges, especially during the morning hours.

The statistical analyses conducted, including One-Way ANOVA and Wilcoxon Signed Rank Test, have provided robust evidence of the significant temperature variations observed and have validated the experimental results. The simulations carried out using Therm software have further corroborated the experimental findings, offering valuable insights into the

thermal behavior of different material combinations and their impact on indoor comfort levels.

Drawing from these comprehensive findings, several recommendations have been proposed for future research endeavors. These include delving deeper into the influence of materials on indoor activities, exploring the calculation of Overall Thermal Transfer Value (OTTV) for building envelopes, and investigating the efficacy of shading modifications in further enhancing indoor thermal regulation.

In conclusion, this study represents a significant contribution to the field of architectural design and environmental sustainability. By elucidating the intricate relationship between building materials, thermal performance, and indoor comfort, this research sets a solid foundation for informed decision-making in building design practices. The detailed analysis and measurements conducted serve as a catalyst for future advancements in sustainable architecture, emphasizing the critical role of material selection in creating healthy, comfortable, and energy-efficient indoor environments.

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