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Analysis of Building Orientation and Window-to-Wall Ratio (WWR) Influence on Indoor Air Temperature

Case Study: FMNS and FIS Buildings*, Universitas Islam Indonesia*

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Abstract

Building orientation and the window-to-wall ratio (WWR) are two key factors impacting thermal comfort in educational buildings in tropical climates. However, previous studies often examine these variables separately, without exploring how their combination influences indoor air temperature in real building settings. This research addresses that gap by studying the combined effect of building orientation and WWR on indoor thermal performance in educational facilities. The study investigates how orientation and changes in WWR affect indoor air temperature through case studies of the Faculty of Mathematics and Natural Sciences (FMNS) and the Faculty of Islamic Studies (FIS) buildings at Universitas Islam Indonesia. Simulations using Computational Fluid Dynamics (CFD) were conducted to evaluate airflow and temperature distribution across different orientations and WWR scenarios. The results show that a north–south orientation provides a more stable temperature distribution, while a 40% WWR is optimal for balancing daylight and heat gain. These findings highlight the importance of passive design strategies in improving energy efficiency and thermal comfort in tropical educational facilities.

Keywords: *building orientation; educational buildings; indoor air temperature; thermal comfort; Window-to-Wall Ratio (WWR)*

Introduction

Global climate change has caused a steady increase in ambient temperatures, which, in turn, affects building design, especially in tropical regions. Key elements of sustainable architecture include building orientation and Window-to-Wall Ratio (WWR). Orientation determines how much solar radiation the building receives, while WWR controls the amount of natural light and heat entering interior spaces. This research was chosen because educational buildings in tropical countries, including Indonesia, often experience excessive heat gain due to poor orientation and unbalanced façade openings. Although many studies address thermal comfort, few compare the effects of orientation and WWR using real case studies and CFD simulations for similar building types. Therefore, this study aims to provide a contextual understanding of how orientation and WWR together influence indoor temperatures in educational facilities.

Previous studies have demonstrated that north–south orientation typically offers better thermal performance than east–west orientation (Putra & Yuliastuti, 2020). Additionally, a WWR exceeding 60% on west-facing facades significantly increases indoor temperature (Wijayanti & Hidayat, 2021).

(1)

(2)

Figure 1. Building Elevations of FIS (1) and FMNS (2)
Source: Author

The FMNS and FIS buildings at Universitas Islam Indonesia, which vary in orientation and facade openings, serve as ideal case studies for examining how orientation and WWR affect indoor air temperature. This research aims to develop passive design guidelines for energy-efficient and thermally comfortable educational buildings in tropical climates.

Literature Review

Building Orientation Theory

a. Definition of Building Orientation

Building orientation refers to the positioning of a structure relative to the cardinal directions and significantly affects the amount of solar radiation received by building surfaces. This, in turn, influences the thermal conditions of indoor spaces (Hashem et al., 2021). The orientation of façades and openings determines how much sunlight penetrates the building, impacting interior temperatures (Syafii et al., 2022). In the context of tropical architecture, orientation serves as a passive strategy to reduce the cooling energy demand (Putri & Santosa, 2020). Moreover, proper alignment with the sun's daily path can optimize natural lighting without causing excessive heat gain (Nuraini & Hidayat, 2023). Therefore, building orientation is not only a geometric or technical consideration but also a crucial design approach for enhancing energy efficiency and thermal comfort.

b. Impact of Building Orientation on Indoor Temperature

Building orientation greatly affects indoor thermal conditions, especially in tropical climates where solar intensity is consistently high year-round (Wahyudi & Harimurti, 2020). East- or west-facing buildings tend to receive direct sunlight during the morning and afternoon, resulting in significant indoor temperature increases (Sari et al., 2021). Conversely, a north–south orientation can help moderate solar exposure and maintain cooler indoor conditions (Kurniawan & Maulana, 2022). In addition to thermal comfort, appropriate orientation can reduce the reliance on artificial cooling systems (Lestari et al., 2023). Thus, orientation selection is a strategic factor in the design of energy-efficient, climate-responsive buildings.

Air Temperature Theory

a. Definition of Indoor Air Temperature

Indoor air temperature refers to the level of heat or coolness experienced within enclosed spaces. It is influenced by various factors such as outdoor climate conditions, airflow, natural lighting, and building materials (Prasetyo & Suryani, 2020). This parameter is a primary indicator of thermal comfort as it directly impacts the human body's perception of warmth (Wulandari et al., 2021). Maintaining an appropriate indoor temperature is essential for preserving thermal equilibrium and comfort (Fauziah et al., 2022). According to Yusuf and Hasanah (2023), uncontrolled indoor temperatures can lead to discomfort and reduced occupant productivity. Therefore, understanding indoor air temperature dynamics is fundamental in designing user-centered, comfortable buildings.

b. Impact of Indoor Air Temperature

Indoor temperature significantly influences thermal comfort, energy efficiency, and occupant productivity. Santoso and Lestari (2021) assert that deviations from comfortable temperature ranges can result in notable discomfort. Ariyani et al. (2022) support this by noting that high indoor temperatures often lead to increased use of artificial cooling, thus elevating energy consumption. Suryana and Rahman (2023) observed that fluctuating indoor temperatures can negatively impact performance and health. Herlambang and Setiawan (2021) found that unstable temperatures in classrooms reduced student concentration. Therefore, effective temperature management is a vital component of building design to ensure optimal functionality and comfort.

c. Indoor Temperature Standards

Establishing indoor temperature benchmarks is vital for designing thermally comfortable environments. According to SNI 6390:2011, the ideal indoor temperature for workspaces in Indonesia ranges from 23°C to 26°C, depending on humidity and air movement (Badan Standardisasi Nasional, 2011). Research by Ramadhani et al. (2020) suggests a tropical comfort range of 24°C to 27°C for passive strategies. Wicaksono and Dewi (2021) indicate that deviations from this range can disrupt occupant activities. Additionally, Putra and Widodo (2022) emphasize that standards must consider local climatic adaptation. Hence, temperature benchmarks should be contextually applied for long-term energy efficiency and user well-being.

Window-to-Wall Ratio (WWR) Theory

a. Definition of Window-to-Wall Ratio (WWR)

The Window-to-Wall Ratio (WWR) is defined as the proportion between the total area of windows and the total wall surface area on a building façade. It plays a vital role in managing natural daylight and ventilation (Sari & Prasetya, 2021). WWR is a critical design parameter that influences both thermal and visual performance (Ramadhan & Wulandari, 2020). A well-calculated WWR can optimize natural lighting while minimizing dependence on artificial illumination (Nasution & Fadillah, 2023). It must be considered in conjunction with building orientation, as direct solar radiation can increase indoor heat gain (Nugroho et al., 2022). Therefore, WWR should be applied contextually, taking into account local climate conditions and passive design strategies (Yuliana & Rachmawati, 2023).

b. Impact of WWR on Indoor Air Temperature

The size of the WWR directly affects indoor air temperature, mainly through the intensity of solar radiation entering through window openings (Lestari & Putra, 2020). Without proper control, a higher WWR may result in overheating, particularly on façades exposed to direct sunlight (Suryani & Akbar, 2021). On the other hand, a well-designed WWR that aligns with proper building orientation can enhance cross-ventilation and help reduce indoor temperature (Hidayat et al., 2022). Therefore, achieving a balance between window area and solar protection is essential for maintaining thermal comfort. This strategy can be further supported by external shading devices or canopies to reduce heat gain (Yuliana & Rachmawati, 2023).

c. WWR Standards

The ideal WWR value depends on building function, local climate, and façade orientation (Permana & Wahyuni, 2020). In tropical climates, a WWR between 20% and 40% is generally recommended to balance natural lighting and thermal loads (Fitriani & Nugraha, 2021). According to guidelines from the Indonesian Ministry of Public Works and Housing (PUPR), the maximum permissible WWR is 60%, provided that thermal protection features such as low-E glass or shading devices are included (Kementerian PUPR, 2022). However, these standards must be adapted to local conditions and integrated with other passive design elements such as orientation and natural ventilation (Sasmita & Dewi, 2023). Consequently, WWR guidelines should be applied flexibly to suit the specific climate and building characteristics.

Educational Building Theory

a. Definition of Educational Buildings

Educational buildings are physical facilities designed to support teaching, research, and other academic activities (Maulida & Ismail, 2021). These facilities typically include classrooms, laboratories, reading rooms, and other supporting spaces that must meet specific standards for safety and occupant comfort (Rizky & Fathurrahman, 2022). The quality of the physical environment in educational buildings significantly impacts learning outcomes and productivity, necessitating the consideration of natural lighting, ventilation, and air temperature in the design process (Putri & Susanto, 2023). In tropical contexts such as Indonesia, the design of educational buildings should adopt climate-responsive architectural principles, particularly through orientation and window design, to improve energy efficiency (Hakim et al., 2020). Therefore, educational buildings must be viewed not only in terms of their functional roles but also in terms of their ability to provide a comfortable and conducive learning environment (Fauziyah & Wijayanto, 2021).

b. Impact of Educational Buildings on Thermal Comfort

Thermal comfort is a key indicator of the environmental quality in educational buildings and directly affects students' and lecturers' focus and productivity (Kusumawardhani & Darmawan, 2020). Indoor temperatures that fall outside of comfort standards can reduce concentration and increase fatigue (Salsabila & Haryanto, 2021). Research by Safitri and Widodo (2022) found that educational buildings that neglect orientation and WWR considerations tend to experience significant temperature increases during the day. Consequently, architects must incorporate passive strategies such as WWR optimization and proper building orientation to control indoor thermal conditions (Azizah & Rahmat, 2023). Moreover, Pramudya et al. (2023) emphasized that improved thermal comfort correlates positively with academic performance and student attendance in classrooms.

Methodology

This study employs a quantitative, numerical-simulation approach based on Computational Fluid Dynamics (CFD) to analyze the thermal performance of buildings as a function of orientation and Window-to-Wall Ratio (WWR) variation. The research focuses on two case study buildings: FMNS and FIS at Universitas Islam Indonesia, to assess how architectural configurations affect indoor air temperature.

The primary tools used include Autodesk CFD 2026 software for airflow and temperature distribution analysis, along with 3D modeling software such as SketchUp and ArchiCAD 27 for creating digital building models.

Table 1. Types of Variables

Type of Variable	Variable Name	Description
Independent	Building Orientation	Primary directional facing of the building
Independent	WWR	Ratio of window area to wall area
Dependent	Indoor Temperature	Measured by air temperature levels
Controlled	Wall/Glass Materials	Fixed (based on field data)

Source: Author

The research process was conducted systematically, beginning with the collection of architectural and local climate data, followed by the development of digital 3D models of the buildings under study. Simulation parameters such as boundary conditions and material properties were then entered. CFD simulations were performed for each combination of orientation and WWR, and the results were analyzed to compare temperature distributions and airflow patterns. These findings served as the basis for conclusions and recommendations on passive design strategies for educational buildings in tropical climates.

Result and Discussion

Field Measurement Results

On-site temperature measurements were conducted at various points on the 1st and 2nd floors of both the FIS and FMNS buildings. The findings show that the average indoor temperature in the FIS building was approximately **27.5 °C**, while the FMNS building recorded a slightly higher average of **28.0 °C**. Despite similar functions and building masses, the two structures exhibited notable differences in indoor thermal conditions.

Table 2. Field Measurement Results

Location	FIS Building	FMNS Building
1st FL Pt 1	27,5 °C	29,3 °C
1st FL Pt 2	27,9 °C	27,7 °C
1st FL Pt 3	28,3 °C	28,3 °C
2nd FL Pt 1	26,9 °C	27,4 °C
2nd FL Pt 2	27,3 °C	27,4 °C
2nd FL Pt 3	27,1 °C	27,3 °C
3rd FL Pt 1	26,8 °C	27,5 °C
3rd FL Pt 2	26,9 °C	27,7 °C
3rd FL Pt 3	26,9 °C	27,8 °C
4th FL Pt 1	27,1 °C	28,5 °C
4th FL Pt 2	26,9 °C	28,3 °C
4th FL Pt 3	27,3 °C	28,0 °C
5th FL Pt 1	28,2 °C	-
5th FL Pt 2	28,5 °C	-
5th FL Pt 3	27,8 °C	-

Source: Author

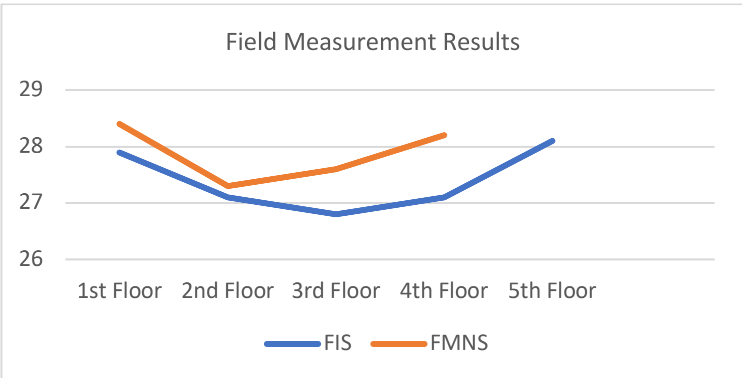
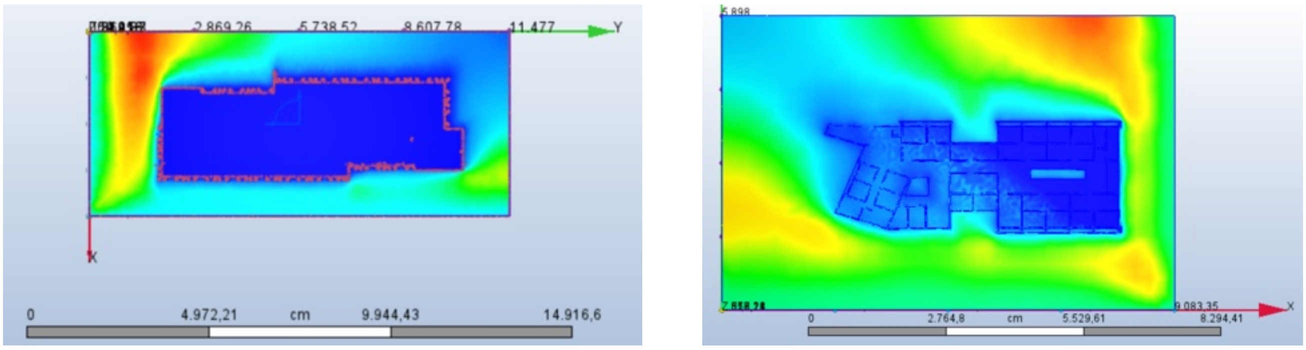


Figure 2. Field Measurement Temperature Diagram – FIS and FMNS
Source: Author

This temperature difference is strongly attributed to the building orientation. FMNS is oriented east–west, exposing it to direct sunlight during both morning and afternoon hours, which causes a gradual indoor temperature increase—especially on façades lacking natural shading. In contrast, FIS's north–south orientation is more suited to tropical climates, as it avoids direct solar exposure throughout the day, resulting in more stable and comfortable indoor temperatures. This finding is consistent with Lestari et al. (2023), who reported that east–west orientations expose façades to high solar intensity during morning and afternoon hours, increasing surface heat absorption. Similarly, Suryana and Rahman (2023) noted that such exposure leads to higher internal temperature fluctuations, which correspond with the FMNS's observed results.

CFD Simulation Results



(1) (2)

Figure 3. CFD Simulation Results – FIS (1) and FMNS (2)
Source: Author

To further analyze thermal performance, CFD simulations were performed on the digital models of both buildings using local climate data for Yogyakarta and detailed material and geometry inputs. Results indicated that the **average indoor temperature** was **27.0 °C** for the FIS building and **26.9 °C** for the FMNS building. The reliability of CFD as a simulation tool in predicting indoor thermal behavior has been confirmed in prior studies by Ramadhani et al. (2020) and Hidayat et al. (2022). Their findings emphasized that CFD-based models closely correlate with real measurement data, validating their use for passive design evaluations in tropical educational buildings. Although the numerical difference is slight, the FIS building exhibited **more stable airflow patterns and uniform temperature distribution**, particularly on the north- and south-facing areas.

Table 3. CFD Simulation Results

Location	FIS Building	FMNS Building
1st FL Pt 1	26,9 °C	26,9 °C
1st FL Pt 2	27,0 °C	26,9 °C
1st FL Pt 3	27,0 °C	27,0 °C
2nd FL Pt 1	26,9 °C	27,0 °C
2nd FL Pt 2	27,0 °C	26,9 °C
2nd FL Pt 3	27,0 °C	27,0 °C
3rd FL Pt 1	27,0 °C	27,0 °C
3rd FL Pt 2	27,0 °C	26,9 °C
3rd FL Pt 3	27,0 °C	27,0 °C
4th FL Pt 1	27,0 °C	27,0 °C
4th FL Pt 2	27,0 °C	26,9 °C
4th FL Pt 3	27,0 °C	27,0 °C
5th FL Pt 1	27,0 °C	-
5th FL Pt 2	27,0 °C	-
5th FL Pt 3	27,0 °C	-

Source: Author

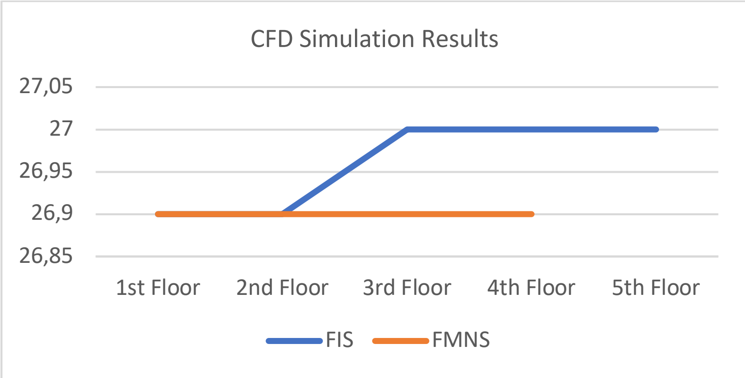


Figure 4. CFD Simulation Results
Source: Author

Although FMNS showed a slightly lower average temperature, it experienced higher temperature fluctuations across spaces and time due to its east–west orientation. In contrast, the north–south orientation of FIS provided more consistent thermal performance, even with a higher WWR. These findings align with Syafii et al. (2022) and Sari et al. (2021), who emphasized that north–south alignment minimizes solar heat gain in tropical zones. Similarly, Lestari et al. (2023) highlighted that east–west orientations tend to increase diurnal temperature variation, requiring higher cooling loads. The FIS building's performance further supports Putri and Santosa (2020), who found that integrating orientation control with optimal WWR ratios enhances passive cooling effectiveness. This indicates that façade configuration plays a synergistic role in determining indoor temperature stability, rather than functioning as an isolated parameter.

Comparison Between WWR and Orientation

Table 4. WWR Calculation Diagram – FIS (1) and FMNS (2)

Side	Total Opening Area	WWR (%)
North	253,60 m2	36,02%
East	1.038,40 m2	36,06%
South	259,60 m2	36,06%
West	1.038,40 m2	36,06%
TOTAL	***2.590,00 m2***	***36,05%***

(1)

Side	Total Opening Area	WWR (%)
North	125,04 m2	15,38%
East	188,80 m2	51,08%
South	202,56 m2	22,84%
Southwest	23,04 m2	8,08%
Northwest	12,96 m2	5,61%
TOTAL	***552,40 m2***	***21,56%***

(2)

Source: Author

Despite the FIS building having a significantly higher WWR (**36.05%**) compared to FMNS (**21.56%**), its indoor temperatures were generally lower and more stable. This highlights that **building orientation plays a more dominant role** than WWR in influencing indoor thermal performance.

Table 5. Window to Wall Ratio (WWR) Comparison

Building	WWR (%)
FIS	36.05%
FMNS	21.56%

Source: Author

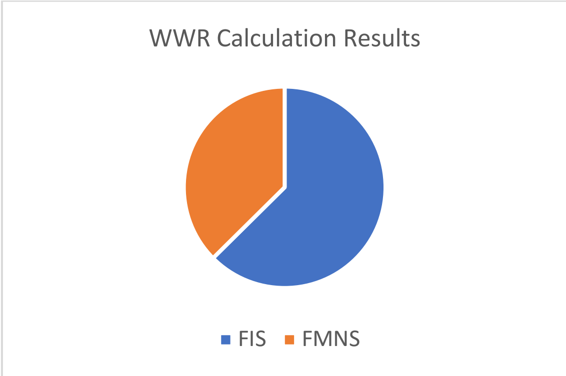


Figure 5. WWR Value Comparison Diagram
Source: Author

Although a large WWR is typically associated with increased heat gain, the FIS building's north–south orientation mitigated this effect. Conversely, the FMNS building—despite having smaller window openings—experienced higher temperatures due to east–west solar exposure. This emphasizes the need to evaluate WWR in conjunction with orientation and local climate context. Large openings can still support thermal comfort when paired with appropriate passive strategies. This interaction effect between WWR and orientation supports the conclusion by Nugroho et al. (2022) and Yuliana & Rachmawati (2023), who found that façade composition cannot be assessed independently of solar direction. Their research demonstrated that optimal thermal comfort occurs when large openings are paired with shading elements or favorable orientation, consistent with FIAI's design configuration.

Conclusion

This study demonstrates that building orientation is a dominant factor influencing indoor air temperature in educational buildings within tropical climates. A north–south orientation proved more effective in maintaining thermal stability, even when paired with a high window-to-wall ratio (WWR). While WWR also impacts thermal performance, its effect is highly dependent on the orientation of the façade and the building's exposure to the sun's path.

The CFD simulation accurately represented actual indoor thermal conditions, validating its use as a reliable performance-based design tool. The integration of orientation and WWR analysis provides essential insight into passive design strategies that can enhance both energy efficiency and occupant comfort in tropical educational buildings.

Future research may explore additional design variables such as building massing variations, application of thermal insulating materials, and integration of passive ventilation systems to evaluate their combined effects on indoor thermal performance. Moreover, extending CFD simulations to cover multi-zone models and longer time periods would increase predictive accuracy and offer deeper insights for sustainable design in tropical contexts.

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