Available online at: http://e-jurnal.lppmunsera.org/index.php/parahita
Wikrama Parahita: Jurnal Pengabdian Masyarakat
p-ISSN 2599-0020, e-ISSN 2599-0012

School Building's Thermal Comfort Analysis: A Community Service Implementation to Develop Comfortable Learning Environment

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Article Information

Article history

Received: June 13, 2025
Revised: September 23, 2025
Accepted: October 4, 2025

Keywords: Building Design; Community Service; School Building; Thermal Comfort

Abstract

The quality of teaching and learning activities is a key indicator of success in formal education, and the provision of comfortable classrooms plays a vital role in supporting optimal learning outcomes. This community service aimed to analyze and improve the thermal comfort of the proposed classroom design at MTs Ummu Aiman Malang, ensuring that the building meets thermal comfort standards and regulations. A 3D model of the school building was developed, and a Computational Fluid Dynamics (CFD) simulation was employed to assess indoor air distribution and airflow. Based on the theoretical analysis and simulations conducted, some alternative design optimizations suggested are choosing the color of the exterior wall paint with a light color gradation that has a good heat absorption value, using a type of double-glaze glass that has better thermal performance, adding heat insulation material to the exterior walls of the east and west sides, and modifying the opening of the window to maximize natural ventilation and improve air circulation in the classroom. By optimizing the design, the OTTV value of the MTS Ummu Aiman building was reduced from 97.07 W/m² to 33.49 W/m². In addition, the addition of openings in the window changes the temperature range in the classroom, which was previously 26.6 -29.3 °C, to a temperature range of 22.8-25.8 °C, with the air velocity falling above the occupants' heads not exceeding 0.25 m/s. The results demonstrate that design optimization and appropriate material selection significantly improve thermal comfort and energy efficiency, providing a practical reference for sustainable school building design.

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INTRODUCTION

MTs Ummu Aiman is one of the providers of formal education equivalent to junior high school located on Jl. Argopuro No. 24 Lawang, Malang Regency. MTs Ummu Aiman began operating in July 2024. This educational institution is part of the Bani Salim Ummu Aiman Foundation, which was founded in 1991 (Kemendikdasmen, 2024). Due to the high number of new students enrolling, the foundation decided to open a new educational institution equivalent to the junior high school level. For this reason, the need for a new building is inevitable, as educational facilities are one of the key factors that determine the success of education. The completeness and availability of educational facilities in schools greatly affect the effectiveness of schools and the smoothness of learning in the classroom (Saputri et al., 2023). Currently, the Bani Salim Ummu Aiman Foundation is in the process of planning the construction of a new school building dedicated to supporting learning activities at MTs Ummu Aiman.

According to data from the Ministry of Energy and Mineral Resources, buildings account for approximately 50% of Indonesia's total energy expenditure. It is further stated that more than 70% of Indonesia's total electrical energy consumption is used for building purposes. The electrical energy consumption in buildings is used to create an artificial indoor climate through cooling, ventilation and lighting (Mulyadi, 2023). Therefore, the design of this new building must prioritise the efficient use of electricity in current building operations. Therefore, the design of the new school building faces the

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DOI: https://dx.doi.org/10.30656/jpmwp.v9i2.10781

challenge of creating a building that provides comfort for students while minimising energy use to support sustainable development.

Building comfort assessment encompasses two specific concepts, namely building comfort and physical environment comfort (Xue & Zhao, 2021). The comfort of a building is influenced by thermal, acoustic, and lighting conditions (Peraturan Menteri Pekerjaan Umum, 2006). At the design stage, ventilation, acoustic, and lighting systems must be considered to maintain optimal indoor conditions in accordance with applicable standards. Another important aspect is the application of green building principles to ensure environmental friendliness and energy efficiency.

Thermal comfort requires attention to air circulation, indoor cooling, and solar heat gain, which in Indonesia is regulated through SNI 6389:2020. Since thermal conditions directly affect both the well-being of occupants and their health and learning performance (Romero et al., 2023), it is crucial to evaluate the air conditioning and ventilation systems in the new MTs Ummu Aiman building. Responding to this need, the Department of Civil and Planning at Universitas Negeri Malang conducted a community service program to analyze the building's ventilation system and propose alternative designs. The main objective of this activity is to provide design recommendations that improve classroom thermal comfort while reducing energy consumption, thereby supporting the development of sustainable and energy-efficient school buildings.

MATERIALS AND METHODS

Materials

The materials used in this community service activity consist of data sources and software that support thermal comfort analysis through simulation. Outdoor temperature and relative humidity data were obtained from historical records provided by the Meteorological, Climatological, and Geophysical Agency (BMKG) to represent the microclimate conditions at the school site. Additionally, building characteristics such as classroom dimensions, building orientation, wall and roof materials, and opening configurations (including windows and vents) were accurately identified during this activity. All these inputs were used in Computational Fluid Dynamics (CFD) simulations, which utilised numerical modelling software to simulate the temperature distribution and airflow inside the classroom. This approach allows for objective analysis of air circulation patterns and air temperature within the classroom. The simulation results and analyses were used to provide design and material recommendations that improve the physical environment of the school, aiming for a more comfortable and energy-efficient classroom.

Methods

This community service activity employed the Research and Development (R&D) method to develop an optimized school building design that fulfills both energy efficiency and thermal comfort standards. This method was selected to ensure that the proposed solutions are grounded in comprehensive technical analysis and applicable. There are three stages in implementing this community service activity, namely (1) preparation, (2) implementation, and (3) evaluation and reporting (Fig. 1).

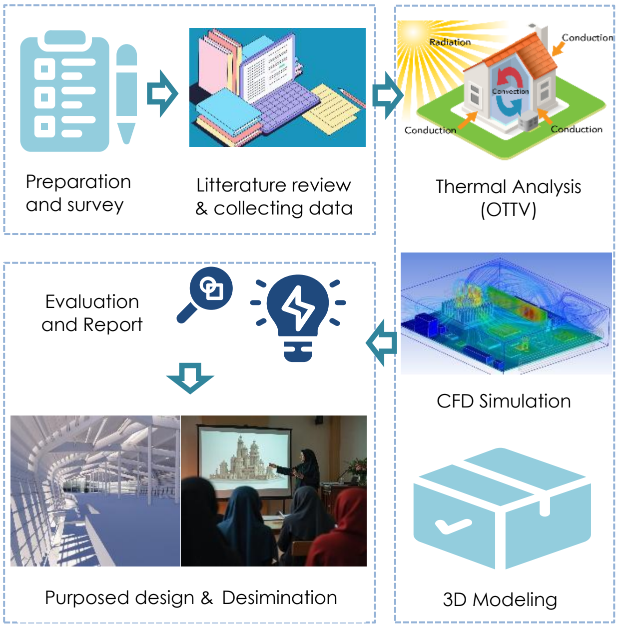

Fig. 1. Stages of community service activities

The preparation stage is to conduct a literature study of the applicable standards for several building comfort criteria to be analyzed. At this stage, a survey was also conducted at the partner location and the planned location for the new building's construction. The survey activity was conducted to assess and measure the land for the construction of the new building, as well as to collect data on environmental conditions. The average daily temperature and wind speed data for the location were obtained based on data provided by BMKG (BMKG, 2024).

The implementation stage, the community service team created a 3D model of the MTs Ummu Aiman school building, calculated the Overall Thermal Transfer Value (OTTV) of the building envelope, and conducted temperature distribution and airflow simulations using CFD software.

Heat transfer values are obtained through the difference between heat gain and heat loss through the building envelope. These values are obtained by performing simulations considering the building envelope, construction materials, geographical and

DOI: https://dx.doi.org/10.30656/jpmwp.v9i2.10781

meteorological data, orientation, and built-up area (Fig. 2). The building envelope, which includes the floor, walls, windows, and doors, is the external heat source considered in the analysis (Kirme & Kapse, 2023). Calculating OTTV values based on data and surveys, the analysis results are then compared with the standard values provided by the Indonesian Standard for OTTV, which is 35 W/m², a temperature range of 22.8°C – 25.8°C, and an air velocity falling over the occupants' heads not exceeding 0.25 m/s. If the analysis results show higher results than the standards, modifications to the building envelope design are required.

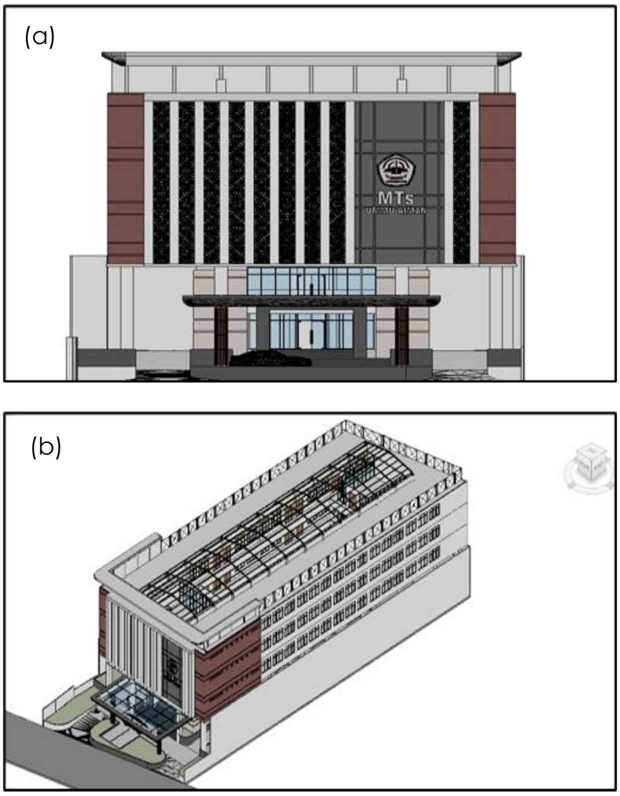

Fig. 2. Building design (a) Front view 1, (b) 3D view

The analysis of fluid flow behaviour and temperature distribution in the classroom was conducted using Computational Fluid Dynamics (CFD) software. There are three main stages in the CFD simulation process, namely pre-processing, solver, and post-processing (Choudhari et al., 2021). In the pre-processing stage, a geometric model was created, and meshing was performed on the simulation domain. Geometric modelling of classrooms is created in a simplified form that closely resembles the actual design without changing the actual dimensions. The geometric model represents an empty classroom, excluding consideration of furniture, such as desks and chairs, and occupants. The inlet and outlet were determined based on the direction of outdoor air velocities, as observed from objects. This study focuses on the variations in classroom inlet arrangements (Fig. 3).

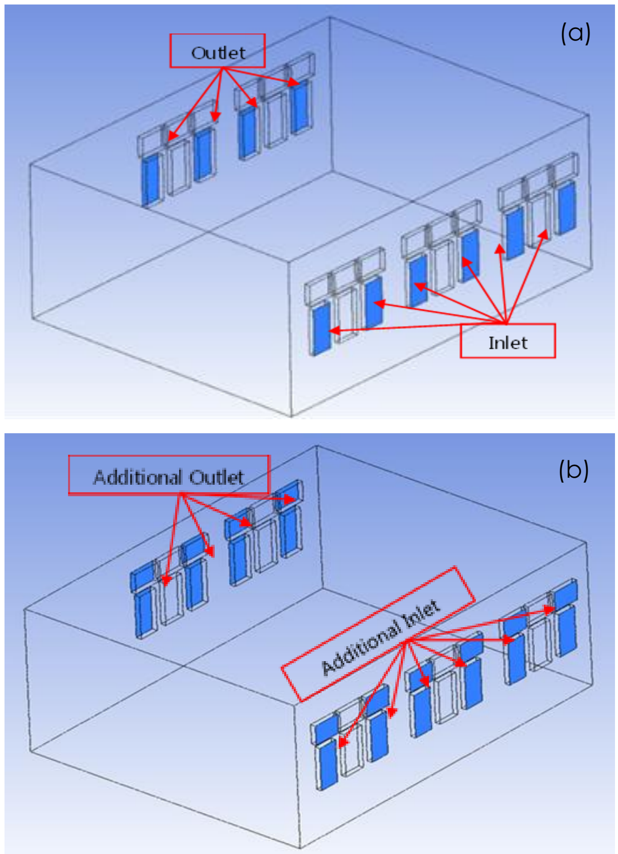

Fig. 3. Object Study (a) Natural ventilation model 1 (b) Natural ventilation model 2

In model 2, six of the nine clerestory windows on the inlet side were used as additional inlets, while on the opposite side, four of the six clerestory windows were arranged as additional outlets. Next, for the processing stage, settings are made for the solver model, viscous model, materials, boundary conditions, solution methods, and the iteration process (Sofialidis, 2013). The inputs for temperature and air velocity in the boundary condition were set based on Lawang town's daily weather report from the BMKG official website. The thermal properties input for the boundary condition of the wall is the heat flux, which is the rate of heat energy transfer through a given surface per unit area. Lastly, in the post-processing stage, data were collected and presented in the form of temperature contours and airflow streamlines. The temperature contours were taken with a horizontal plane at heights of 1.5 m from the floor, which reflects the head-high hardness of the human body in a sitting or standing position (Liu et al., 2024), and at a height of 2 m from the floor to help visualise the temperature distribution.

At the evaluation and report stage, the results of thermal load calculations, CFD simulations, and ventilation design models are analyzed and compared with relevant thermal comfort standards to assess their feasibility. The findings are compiled into a comprehensive report, which includes technical recommendations and alternative design options to enhance comfort and reduce energy consumption. The report and proposals are then presented to the partner institution through a formal discussion, enabling them to understand, review, and consider the solutions for implementation.

RESULTS AND DISCUSSION

Survey and Preparation

A preparation activity was carried out on May 16, 2024. During this activity, an initial discussion was held with the construction team of MTs Ummu Aiman. The survey at the construction site was carried out jointly by the State University of Malang team and its partners. In this session, the community service team and construction team held discussions regarding the initial building design. Construction work has entered the site preparation stage, and the foundation has started. At this stage, the team studied the initial building design, conducted a literature review, and collected supporting data from reliable sources, including daily temperature and average wind speed for the Lawang sub-district area (Fig. 4). This was done to produce accurate data analysis and approach the actual field conditions. In addition, a 3D model of the building was created based on the proposed design to visualise improvements in comfort and energy efficiency.

Fig. 4. Survey and initial meeting with construction teams

OTTV Analysis

In the first stage of implementation, an OTTV (Overall Thermal Transfer Value) analysis was conducted to determine the amount of heat transferred into the building. The existing building design was evaluated based on the standards set by SNI. The existing facade design is a brick wall painted in dark grey. The windows use clear glass with a thickness of 5 mm, resulting in an OTTV value of 97.07 W/m², which exceeds the SNI requirement of 35W/m². This elevated OTTV indicates excessive heat gain through the envelope, resulting in higher cooling loads and increased energy consumption. This result aligns with findings by Latifah et al. (2022), who demonstrated that suboptimal façades can be substantially improved through glass curtain wall retrofit, achieving OTTV reductions through material upgrades and shading mechanisms.

Buildings with optimised heat transfer can reduce energy consumption for heating and cooling, thereby decreasing electricity consumption and emissions by up to 50% (Deshmukh & Yadav, 2025). Heat transfer analysis showed that conduction through the four exterior walls reached 77.13 W/m², accounting for 79.46% of the total heat gain due to the high absorption value (0.88) of the wall paint. It aligns with scientific studies indicating that dark-colored walls retain significantly higher surface temperatures than lighter ones under solar exposure (Abdullah & Faraj, 2022).

Optimization was carried out by changing the colour of the outer wall paint to white with an absorption value of 0.25. With this change, the conduction through the walls decreased from 77.13 W/m² to 21.91 W/m². Wall color plays a critical role in influencing solar heat gain. A white-painted surface reflects most of the incoming solar radiation, reducing the heat absorbed by the wall (Shen et al., 2011). In addition, using insulation material on both sides of the exterior wall (east and west) exposed to sunlight so that the amount of heat conduction through the wall can be reduced to 16.24 W/m². Adding thermal insulation further reduces the rate of heat transfer by increasing the wall's thermal resistance (R-value). This is particularly effective for east and west orientations, which receive the most intense solar radiation. The combination of reflective paint and insulation yields synergistic thermal performance (Deshmukh & Yadav, 2025).

Table 1. Design optimization of MTs Ummu Aiman

Building element	Original design	Purposed design
Eksterior Wall paint	Dark grey	Glossy white
Insulation	No	Glasswool insulation thk. 30 mm on the east and west sides.
Natural Ventilation	Fixed window	Additional inlet on both sides
Glass	Sunergy Clear SNGN	Double glaze

Further, optimization that can be considered is to replace the type of glass that was previously used, 5mm thick clear glass, with double-glazed glass, then

DOI: https://dx.doi.org/10.30656/jpmwp.v9i2.10781

the heat transfer value passing through the glass can be reduced by 32% from 8.17 W/m² to 5.48 W/m². Replacing clear single glazing with double-glazed units featuring low U-values and shading coefficients (SC). Studies show double glazing can reduce OTTV to 25.60 W/m² and yield a 6 % reduction in cooling loads (Albab & Adi, 2019). Based on the OTTV analysis that has been conducted, to reduce heat transfers from 97.07 W/m² to 16.24 W/m², some design recommendations are presented in Table 1.

CFD Simulation – Temperature

Following the OTTV analysis, the next stage of implementation involved conducting Computational Fluid Dynamics (CFD) simulations. This step was crucial for evaluating the indoor air distribution, airflow patterns, and thermal conditions within the proposed classroom design. Through CFD simulation, a more detailed understanding of the building's ventilation performance and its impact on thermal comfort could be obtained, providing a stronger basis for design optimization. The temperature contour is created by placing the ZX plane at heights of 1.5 m and 2 m from the floor, considering that secondary school children, generally aged 13-16 years old, have heights between 1.5 m and 1.7 m. It is important to evaluate the airflow based on the height of the students' breathing lines (Son & Jang, 2021).

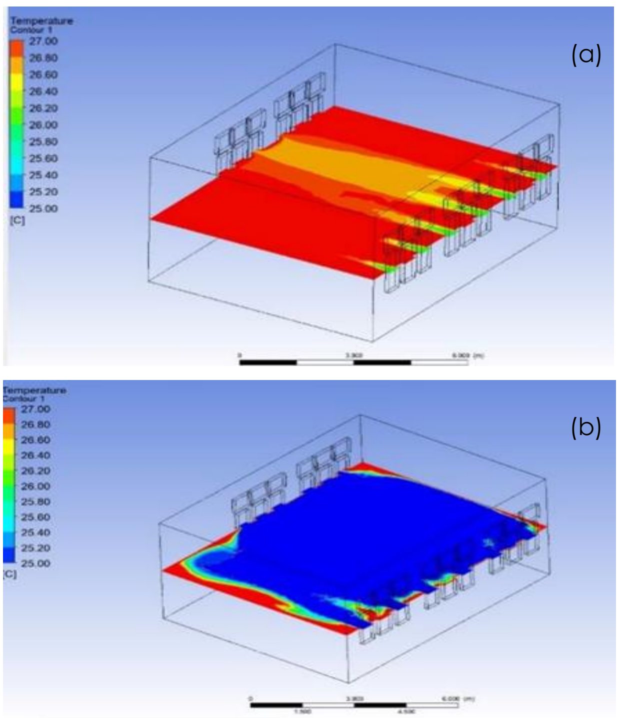

Fig. 5. Temperature distribution contour at a height of 1,5m from the floor, (a) Ventilation model 1 (b) Ventilation model 2

The simulation results show that the temperature distribution in the classroom at a height of 1.5 m, from the floor, shows the temperature contour of model ventilation 1 is dominated by a reddish-orange color Fig. 5 (a). The average temperature produced by Natural Ventilation Model 1 is 29.3°C, making the room feel hotter and less comfortable for occupants. Meanwhile, in Fig. 5(b), it is evident that ventilation model 2 produces a less reddish-orange area, resulting in an average temperature of 26.6 °C, which describes the temperature in the classroom as cooler and closer to the comfortable temperature range for learning activities. Designing symmetric or asymmetric window openings combined with louvres, CFD simulations demonstrate that the optimal configuration can expand the "comfort zone" on the psychrometric chart, especially when the outdoor air is hot (Kouhirostami, 2018).

The temperature distribution in the classroom at a height of 2 m from the floor is shown in Fig. 6. At a height of 2 m from the floor, the temperature contour of ventilation model 1 is still dominated by a reddish-orange colour, with an average of 30.7 °C. At the same height, ventilation model 2 produces a lower average temperature of 26 °C.

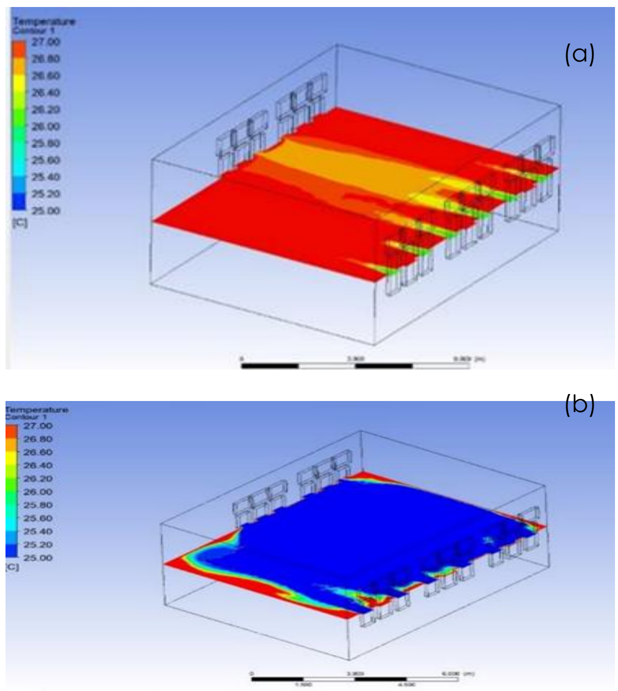

Fig. 6. Temperature distribution contour at a height of 2m from the floor, (a) ventilation model 1, (b) ventilation model 2

Based on SNI 03-6572, the optimal comfort level in tropical regions is within the temperature range of 22.8°C – 25.8°C, with the air velocity falling above the occupants' heads not exceeding 0.25 m/s. Therefore,

DOI: https://dx.doi.org/10.30656/jpmwp.v9i2.10781

the average temperatures at heights of 1.5 m and 2m from the floor, produced by ventilation model 1, do not meet the optimal comfort level requirements according to SNI, while the average temperature produced by ventilation model 2 does meet the requirements.

CFD Simulation – Air Velocity

After completing the OTTV analysis and temperature simulations, the next step was to evaluate air velocity based on the airflow results. According to SNI 03-6572, the acceptable indoor air velocity for naturally ventilated buildings should not exceed 0.25 m/s. The simulation results showed that both ventilation models 1 and 2 produced indoor air velocities of less than 0.25 m/s, indicating that both models comply with this standard. A similar study revealed that although achieving thermal comfort often requires air velocities above 0.75 m/s, air velocity levels below 0.25 m/s are still acceptable for "comfortably warm" conditions according to tropical climate standards (Nor Azli et al., 2023).

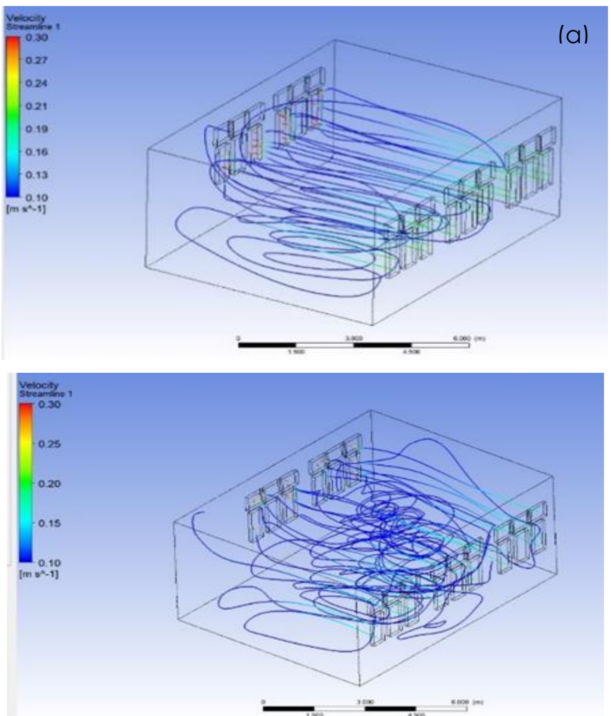

Fig. 7. Velocity streamline (a) ventilation model 1 (b) ventilation model 2

The CFD simulation shows differences in airflow patterns between the two models (Fig. 7). Model 1 produces a more directed airflow with fewer vortices, while Model 2 generates a more complex circulation that enhances air mixing. Although the airflow pattern in Model 1 is more stable, the temperature simulation results indicate that Model 2 is more effective in reducing the average indoor temperature. Therefore, Model 2 is recommended due to its combination of optimal air circulation and effectiveness in improving thermal comfort. The type of opening also directly affects the performance of cross ventilation, interfering either with the resistance offered to the airflow or with the direction and intensity (Widiastuti et al., 2020).

Design recommendations

Based on the OTTV analysis, the use of insulation materials on external walls and the application of reflective wall paint colors are recommended to reduce heat transfer into the classroom. The CFD temperature simulation indicates that utilizing six of the nine clerestory windows as air inlets significantly reduces the average indoor temperature, thereby enhancing thermal comfort. Furthermore, the CFD velocity analysis indicates that this opening configuration enhances airflow distribution and minimizes stagnant zones, thereby facilitating effective natural ventilation.

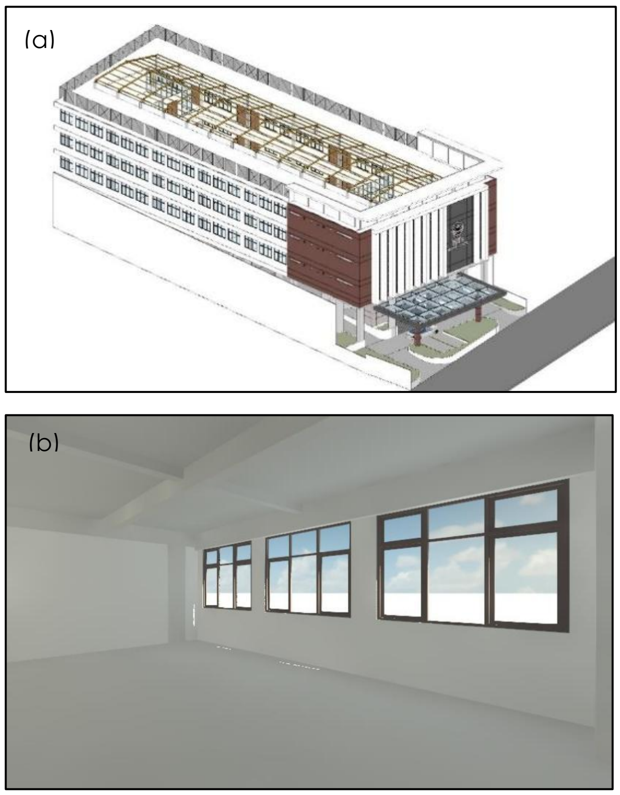

Fig. 8. 3D modeling optimisation design, (a) 3D view, (b) Ventilation model 2

In the long term, these strategies contribute to sustainability goals by reducing energy demand for mechanical cooling (SDG 7: Affordable and Clean Energy), promoting resilient and resource-efficient building designs (SDG 11: Sustainable Cities and Communities), and lowering carbon emissions

DOI: https://dx.doi.org/10.30656/jpmwp.v9i2.10781

associated with the built environment (SDG 13: Climate Action). Building upon the results of OTTV, temperature, and air velocity analyses, the final stage of implementation involved remodelling the building design to optimise thermal comfort, as illustrated in Fig. 8.

Evaluation and reporting

At this stage, the analysis of thermal comfort aspects in the modified building design was evaluated in accordance with SNI standards. Based on the theoretical results, design optimization and material selection were conducted to achieve maximum thermal performance, which then served as the basis for developing an optimal 3D blueprint design. The findings were compiled into a comprehensive report, presented, and discussed with the construction implementation team to ensure their applicability during the construction process. This activity was conducted on September 26, 2024, at the Bani Salim Ummu Aiman office (Fig. 9).

Fig. 9. Dissemination of optimization building designs to partners

Discussion

To achieve thermal comfort in the new building of MTs Ummu Aiman, several design optimizations were made to meet the Overall Thermal Transfer Value (OTTV) requirement of the Indonesian National Standard, which is no more than 35 W/m². In addition, to maintain optimal air circulation within the classrooms, modifications to the ventilation design were also recommended. Some optimization steps for the building envelope design, including changing the colour of the outer wall paint, applying insulation materials to the east and west exterior walls, and replacing clear single glazing with double glazing, resulted in an OTTV value of 33.49 W/m², which meets the SNI requirements.

The implementation of Windows Model 2, with six of the nine clerestory windows on the inlet side, was used as additional inlets. CFD simulation illustrates that the temperature inside the classroom is within the range of 22.8°C-25.8°C, with the air velocity over the occupants' heads not exceeding 0.25 m/s, in accordance with the requirements of SNI 03-6572. Thermal comfort is a crucial requirement in building design, ensuring optimal indoor air quality (Zuhri et al., 2024). Due to the increasing frequency of extreme weather and increasingly dense landscapes, buildings are becoming vulnerable to heat-related discomfort, especially buildings located in naturally ventilated environments in tropical climates. Therefore, indoor thermal comfort is critical for building sustainability and improving occupant health and well-being (Ramalingam Rethnam & Thomas, 2024). Additionally, ASHRAE guidelines indicate that indoor thermal comfort and acceptable ventilation rates are also influenced by building design characteristics (Reiniche et al., 2010). To ensure the practical application of these design strategies, a 3D model of the optimised building was also developed. This model serves as a visual and technical reference to guide construction implementation, ensuring alignment with energy-saving provisions while simplifying decision-making during the constuction process.

CONCLUSION

This community service activity was carried out over a period of 6 months, from May to October 2024. The purpose of this activity is to evaluate and analyse thermal comfort, as well as optimize the natural ventilation system in the new MTs Ummu Aiman building, an application of the concept of energy-efficient buildings. Based on the theoretical analysis and simulations conducted, some alternative design optimizations suggested to partners are choosing the color of the exterior wall paint with a light color gradation that has a good heat absorption value, using a type of double-glaze glass that has better thermal performance, adding heat insulation material to the exterior walls of the east and west sides, and modifying the opening of the window to maximize natural ventilation and improve air circulation in the classroom.

By optimizing the design, the OTTV value of the MTS Ummu Aiman building was reduced from 97.07 W/m² to 33.49 W/m². In addition, the incorporation of additional window openings reduced the classroom temperature range from 26.6 - 29.3 ° C to a temperature range of 22.8 -25.8 ° C, with air velocity falling on the head of the occupants no more than 0.25 m/s, which has met the SNI requirements for thermal comfort of school buildings.

Some limitations of this community service activity include: The daily average temperature and wind speed data used in the CFD simulation conducted in this activity were obtained based on data provided by the BMKG, which may result in slight differences from the actual conditions at the building location. To obtain more accurate analysis results in accordance with environmental conditions, it is recommended to measure the daily average temperature at the building location in the thermal comfort analysis. Additionally, the final outcome of this activity is a blueprint design for 3D modelling of the building, optimized in accordance with energy-efficient building requirements.

ACKNOWLEDGEMENTS

The author would like to thank the State University of Malang, through the Lembaga Penelitian dan Pengabdian Kepada Masyarakat (LPPM), for providing financial support for this community service activity. Gratitude is also extended to the MTs Ummu Aiman construction team, who collaborated and helped collect the data needed for this activity.

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