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Thermal Comfort Analysis to Support Energy Efficiency Based on Building Information Modelling (BIM): Case Study of Graduate Building University Fajar

Anugrah[1], Suwardi Setiawan[2], Hartina Harun[3], Irfan Syarifandhy[4]
[1]Universitas Pakuan, Indonesia
[2,4]Universitas Fajar, Indonesia
[3]Universitas Muhammadiyah Makassar, Indonesia
Email: anugrah@pakuan.ac.id, suwardisetiawan1@gmail.com, tinaharun92@gmail.com, syarifandhyi@gmail.com

Corresponding Author: anugrah

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Abstract
The building sector is a significant contributor to global energy consumption, with thermal comfort being a crucial factor in energy use, particularly in tropical climates such as Indonesia. This research aims to analyze the level of thermal comfort in buildings to support energy efficiency. The study was conducted at the Graduate Building of University Fajar, Makassar, which functions as intensive lecture spaces requiring high levels of thermal comfort. Using Archicad 27 software for BIM simulation and energy evaluation, the research analyzed existing thermal conditions and evaluated three insulation material alternatives: Aluminium Composite Panel (ACP), High-Density Polyurethane (HDPU), and Glass Wool. The study employed both descriptive qualitative and quantitative approaches with energy performance evaluation features. Results indicated that existing thermal conditions do not meet the SNI 03-6572-2001 thermal comfort standards, with an average minimum temperature of 24.2°C and a maximum of 33.9°C. Among the three insulation alternatives, the installation of glass wool partitions proved most effective in reducing energy consumption by Rp. 2,264,506 annually (from Rp. 12,705,737 to Rp. 10,441,231) and carbon emissions by 287 kg/year (from 1,614 kg/year to 1,327 kg/year). HDPU panels demonstrated the best performance in thermal design data by reducing the average temperature from 29.0°C to 28.8°C. The study concludes that BIM technology provides valuable insights for designing comfortable and energy-efficient spaces. However, mechanical air conditioning systems remain necessary to achieve optimal thermal comfort standards.

INTRODUCTION

Thermal comfort in buildings is one of the important aspects that affects the quality of life of occupants. In this modern era, with increasing awareness of energy efficiency and environmental sustainability, it is essential to integrate thermal comfort analysis into the building planning and design process. The application of Building Information Modelling

(BIM) technology has become an effective solution to achieve this goal. BIM allows designers to create detailed digital models, enabling simulations and analysis of a building's thermal performance before construction begins (Eastman et al., 2011).

The building sector is among the largest contributors to global energy consumption, accounting for approximately 30–40% of total energy use (González-Torres et al., 2022; Li et al., 2019; Ürge-Vorsatz et al., 2020). This growing energy demand is accompanied by heightened awareness of the importance of energy efficiency and carbon emission reduction (Fernando & Hor, 2017; Ma et al., 2023; Paramati et al., 2022). Therefore, analysing thermal comfort levels is crucial to ensure buildings are not only comfortable for occupants but also efficient in energy consumption (Az-zahra et al., 2024).

Thermal comfort is influenced not only by air temperature but also by humidity, wind speed, and the interactions between users and the building environment. Comprehensive thermal comfort analysis can thus assist in designing buildings that maintain occupant comfort while achieving energy efficiency. The BIM-based approach has developed rapidly as an innovative solution for modelling and simulating thermal aspects and building energy performance (Azhar et al., 2011).

Previous studies have shown that using BIM in building design can reduce energy usage in air-conditioning systems by up to 30% or more through design adjustments to spatial layouts, openings, and material choices (Xu et al., 2023; Shoubi et al., 2015). The application of BIM in thermal comfort analysis provides significant benefits. With BIM software, designers can perform real-time thermal condition simulations, identify areas requiring improvement, and evaluate various design options to enhance energy efficiency (Pan et al., 2023; Utkucu et al., 2020; Zhou et al., 2023).

However, most research on thermal comfort and energy efficiency using BIM has focused on buildings in subtropical and temperate climates, where weather conditions are generally more moderate. The results of such studies may not be directly applicable to buildings in humid tropical regions such as Makassar, which experiences high temperatures and significant humidity throughout the year. This climatic condition results in a high demand for cooling energy to maintain thermal comfort, particularly in educational buildings such as lecture halls (Mahdavi et al., 2018).

This research addresses that gap by analysing the level of thermal comfort at the Graduate Building of University Fajar in Makassar, using a BIM-based approach. This building was selected as a case study due to its intensive use as a lecture space, which necessitates high thermal comfort standards. The study offers substantial benefits on multiple fronts, providing building managers with practical, data-driven insights for retrofit decisions and cost–benefit analyses for material selection, while also advancing theoretical understanding of BIM applications in tropical contexts and contributing to climate-specific building performance evaluation methodologies. Furthermore, this research promotes sustainable building practices in Indonesian higher education institutions, supports national energy security through reduced energy consumption, and ultimately enhances occupant comfort and productivity in educational spaces—thereby bridging the critical gap between advanced BIM technologies and the specific thermal comfort needs of tropical building design.

METHOD

This research was conducted at the Graduate Building of University Fajar, located at Jl. Prof. Abdurrahman Basalamah No.101, Karampuang, Panakkukang District, Makassar City, South Sulawesi, from September to November 2024. The research uses descriptive qualitative and quantitative methods. The study employed a mixed-method approach combining qualitative insights from building observations and quantitative analysis through BIM simulation. The qualitative approach involved direct observation of thermal conditions and user interactions, while the quantitative approach used Archicad 27 software for energy performance evaluation.

Primary data included building dimensions, material specifications, building orientation, weather data from Sultan Hasanuddin Airport Makassar meteorological station, thermal comfort parameters, HVAC system specifications, and operation schedules. Secondary data were obtained through interviews with building occupants and literature studies.

The building modeling process involved: project setup in Archicad 27, creating 2D floor plans, vertical extrusion to generate 3D volumes, material application with thermal properties, and energy performance analysis using integrated Design Energy Evaluation features.

Three insulation material alternatives were analyzed:

1. Aluminium Composite Panel (ACP) on exterior walls
2. High Density Polyurethane (HDPU) panels on exterior walls
3. Glass Wool insulation with gypsum partitions on interior walls

RESULTS AND DISCUSSION

Building Information Modeling Results

Digital Building Model Development

The research commenced with the comprehensive digital modeling of the third floor of the Graduate Building University Fajar using Archicad 27 software. The virtual reconstruction was meticulously executed to ensure the digital model accurately represents the physical building characteristics. The modeling process involved detailed field measurements and observations to capture precise building specifications.

Table 1. Building Physical Characteristics

Parameter	Specification
Total Floor Area	454.62 m²
Total Volume	1,411.42 m³
Building Orientation	West-facing
Geographic Coordinates	119°25' E, 5°8' S
Primary Function	Lecture halls, staff offices
Construction Type	Conventional masonry

Source: Data processed from field measurements and direct observations, 2024

The building model encompasses several functional zones including lecture rooms, faculty offices, staff rooms, and circulation areas. Material specifications were accurately modeled to reflect actual thermal properties: exterior walls constructed with red brick masonry finished with ceramic tiles externally and paint internally, interior partitions using hollow frame with gypsum finishing, aluminum-framed windows with glass panels, ceramic tile flooring with carpet overlays in specific areas, and gypsum board ceiling systems.

Climate Data Integration and Analysis

Comprehensive climate data was integrated into the BIM model using EPW (EnergyPlus Weather) format files sourced from Sultan Hasanuddin Airport meteorological station, representing the closest reliable weather data source to the building location. The climate analysis reveals the challenging thermal conditions characteristic of Makassar's tropical humid climate.

Table 2. Annual Climate Data Summary

Climate Parameter	Annual Average
Air Temperature	27.80°C
Relative Humidity	67.50%
Solar Radiation	511.00 Wh/m²

Climate Parameter	Annual Average
Wind Speed	5.75 m/s
Wet Bulb Temperature	24.2°C
Dry Bulb Temperature Range	24.0°C - 33.5°C

Source: Weather data from Sultan Hasanuddin Meteorological Station Makassar, processed in EPW format for energy simulation, 2024

The climate data indicates consistently high temperatures and humidity levels throughout the year, creating substantial cooling loads for maintaining thermal comfort. Solar radiation values demonstrate significant heat gain potential, particularly given the building's west-facing orientation, which experiences intense afternoon solar exposure.

Building Operation Profile Analysis

The operational characteristics of the Graduate Building were systematically analyzed to establish realistic energy consumption patterns. The building serves dual functions with distinct operational schedules affecting thermal loads and energy consumption patterns.

Table 3. Building Operation Schedule

Space Type	Operating Hours	Daily Duration	Temperature Range	Lighting Load
Lecture Rooms	09:00 - 16:00	7 hours	20.5°C - 27.1°C	3 W/m²
Staff Offices	08:00 - 17:00	9 hours	20.5°C - 27.1°C	0.5 W/m²
Faculty Rooms	08:00 - 17:00	9 hours	20.5°C - 27.1°C	0.5 W/m²

Source: Results from interviews with building management and operational schedule observations, 2024

The operational profile reveals high-intensity usage patterns with substantial occupancy loads during peak academic hours. The temperature range specifications align with Indonesian thermal comfort standards but require significant mechanical cooling to achieve in the tropical humid climate.

Existing Thermal Condition Assessment

Baseline HVAC Performance Analysis

The existing thermal conditions were comprehensively evaluated using Archicad 27's Energy Performance Evaluation features. The baseline assessment establishes the reference point for comparing insulation material interventions.

Table 4. Existing Building Thermal Performance

Thermal Parameter	Minimum	Maximum	Average
Indoor Air Temperature	24.2°C	33.9°C	29.0°C
Occurrence Time (Min)	08:00-09:00 WITA	18:00-19:00 WITA	-
Seasonal Pattern (Min)	January-February	September-November	-
Thermal Comfort Compliance	Non-compliant	Non-compliant	Non-compliant

Source: Energy simulation results using Archicad 27 based on climate data and building characteristics, 2024

The thermal analysis reveals significant deviations from SNI 03-6572-2001 thermal comfort standards. The minimum average temperature of 24.2°C exceeds the upper limit of the "cool comfortable" range (22.8°C), while the maximum average temperature of 33.9°C substantially exceeds all comfort categories, requiring mechanical intervention for acceptable thermal conditions.

Energy Consumption Analysis - Existing Conditions

The energy consumption analysis for existing conditions provides critical baseline data for evaluating the effectiveness of proposed insulation interventions.

Table 5. Existing Annual Energy Consumption

Energy Category	Cost (Rp)	Consumption (kWh)	CO2 Emission (kg/year)
Cooling System	4,051,985	2,384	514
Lighting & Appliances	8,653,752	5,091	1,099
Total Annual	**12,705,737**	**7,475**	**1,614**

Source: Energy consumption analysis based on simulation data and utility bills, 2024

The energy consumption analysis reveals that lighting and appliances account for 68.1% of total energy costs, while cooling systems represent 31.9%. However, the cooling load represents the primary target for thermal comfort improvement interventions. The total annual carbon footprint of 1,614 kg CO2 equivalent establishes the environmental baseline for sustainability assessments.

Insulation Material Performance Analysis

Aluminium Composite Panel (ACP) Performance Evaluation

The ACP insulation system was evaluated through comprehensive thermal and energy simulation. ACP panels were applied to all exterior wall surfaces in the BIM model to assess thermal performance improvements.

Table 6. ACP System Thermal Performance

Parameter	Existing	ACP Implementation	Improvement
Minimum Average Temperature	24.2°C	23.9°C	-0.3°C
Maximum Average Temperature	33.9°C	34.2°C	+0.3°C
Annual Average Temperature	29.0°C	29.1°C	+0.1°C

Source: Thermal performance simulation results of ACP material using Archicad 27, 2024.

The ACP system demonstrates mixed thermal performance results. While achieving a 0.3°C reduction in minimum temperatures, the system exhibits a 0.3°C increase in maximum temperatures, resulting in a slight overall increase in average annual temperature. This performance pattern suggests limited thermal resistance properties under the intense solar loading conditions typical of Makassar's climate.

Table 7. ACP System Energy Consumption Analysis

Energy Category	Cost (Rp)	CO2 Emission (kg/year)	Reduction from Baseline
Cooling System	4,060,560	516	Minimal reduction
Lighting & Appliances	6,641,088	844	23.3% reduction
Total Annual	**10,701,648**	**1,360**	**15.8% reduction**

Source: Cost and emission analysis based on energy simulation with ACP material, 2024

Despite limited thermal performance improvement, the ACP system achieves significant energy consumption reduction of 15.8% annually, primarily through lighting system efficiency improvements. The total cost reduction of Rp. 2,004,089 annually demonstrates economic viability, though thermal comfort improvements remain marginal.

High Density Polyurethane (HDPU) Performance Evaluation

HDPU panels represent a premium insulation solution with superior thermal resistance properties. The simulation analysis evaluated HDPU panel installation on all exterior building surfaces.

Table 8. HDPU System Thermal Performance

Parameter	Existing	HDPU Implementation	Improvement
Minimum Average Temperature	24.2°C	24.0°C	-0.2°C
Maximum Average Temperature	33.9°C	33.5°C	-0.4°C
Annual Average Temperature	29.0°C	28.8°C	-0.2°C

Source: Thermal simulation evaluation results of HDPU material using Archicad 27, 2024

HDPU insulation demonstrates superior thermal performance among all evaluated materials. The system achieves consistent temperature reductions across all thermal parameters, with a notable 0.4°C reduction in maximum temperatures and 0.2°C reduction in annual average temperature. This performance indicates effective thermal resistance under high solar loading conditions.

Table 9. HDPU System Energy Performance

Energy Category	Cost (Rp)	CO2 Emission (kg/year)	Reduction from Baseline
Cooling System	3,971,716	504	2.0% improvement
Lighting & Appliances	6,641,367	844	23.3% reduction
Total Annual	**10,613,083**	**1,348**	**16.5% reduction**

Source: Energy efficiency and emission reduction analysis of HDPU material based on simulation, 2024

The HDPU system achieves the second-highest energy consumption reduction of 16.5% annually, with total cost savings of Rp. 2,092,654. The cooling system energy reduction of 2.0% reflects the improved thermal resistance properties, while lighting efficiency improvements contribute significantly to overall energy savings.

Glass Wool Insulation Performance Evaluation

Glass Wool insulation was implemented through interior gypsum partitions with integrated insulation material on all walls interfacing with exterior conditions. This approach represents a retrofit-friendly solution with potentially superior cost-effectiveness.

Table 10. Glass Wool System Thermal Performance

Parameter	Existing	Glass Wool Implementation	Improvement
Minimum Average Temperature	24.2°C	23.7°C	-0.5°C
Maximum Average Temperature	33.9°C	34.1°C	+0.2°C
Annual Average Temperature	29.0°C	28.9°C	-0.1°C

Source: Thermal performance simulation results of Glass Wool material using Archicad 27, 2024

Glass Wool insulation achieves the highest minimum temperature reduction of 0.5°C among all evaluated systems. However, similar to ACP, the system exhibits a slight increase in maximum temperatures (+0.2°C), resulting in a modest overall temperature reduction of 0.1°C annually.

Table 11. Glass Wool System Energy Performance

Energy Category	Cost (Rp)	CO2 Emission (kg/year)	Reduction from Baseline
Cooling System	3,847,007	488	5.0% improvement
Lighting & Appliances	6,594,223	838	23.8% reduction
Total Annual	**10,441,231**	**1,327**	**17.8% reduction**

Source: Energy savings and emission analysis of Glass Wool material based on simulation, 2024

Glass Wool insulation demonstrates the highest overall energy efficiency improvement of 17.8% annually, with total cost savings of Rp. 2,264,506. The system achieves a 5.0% reduction in cooling energy consumption, the highest among all evaluated alternatives, while maintaining substantial lighting efficiency improvements.

Comparative Performance Analysis

Thermal Comfort Parameter Evaluation

The comparative analysis of thermal comfort parameters reveals distinct performance characteristics among the three insulation alternatives relative to SNI 03-6572-2001 standards.

Table 12. Thermal Comfort Standards Compliance Analysis

Material System	Min Temp Compliance	Max Temp Compliance	Comfort Zone Achievement	Overall Rating
SNI Standard Range	20.5°C - 27.1°C	20.5°C - 27.1°C	100%	Compliant
Existing Conditions	Non-compliant (+2.1°C)	Non-compliant (+6.8°C)	0%	Non-compliant
ACP System	Non-compliant (+1.8°C)	Non-compliant (+7.1°C)	0%	Non-compliant
HDPU System	Non-compliant (+1.9°C)	Non-compliant (+6.4°C)	0%	Non-compliant
Glass Wool System	Non-compliant (+1.6°C)	Non-compliant (+7.0°C)	0%	Non-compliant

Source: Compliance evaluation with SNI 03-6572-2001 based on simulation results, 2024

The analysis confirms that none of the evaluated insulation systems achieve full compliance with SNI 03-6572-2001 thermal comfort standards. However, relative improvements are notable, with Glass Wool achieving the best minimum temperature approach to standards and HDPU demonstrating superior maximum temperature control.

Energy Efficiency Optimization Analysis

The energy efficiency analysis employs multiple performance indicators to comprehensively evaluate system effectiveness.

Table 13. Comprehensive Energy Efficiency Analysis

Performance Metric	ACP	HDPU	Glass Wool	Best Performance
Annual Cost Reduction (Rp)	2,004,089	2,092,654	2,264,506	Glass Wool
Percentage Cost Reduction	15.8%	16.5%	17.8%	Glass Wool
CO2 Emission Reduction (kg/year)	254	266	287	Glass Wool
Percentage Emission Reduction	15.7%	16.5%	17.8%	Glass Wool
Cooling Energy Improvement	Minimal	2.0%	5.0%	Glass Wool
Implementation Cost Index	High	Very High	Moderate	Glass Wool

Source: Performance comparison of three insulation materials based on multiple efficiency indicators, 2024

Cost-Benefit Analysis Framework

A comprehensive cost-benefit analysis framework was developed to evaluate the economic viability of each insulation system considering initial investment, operational savings, and lifecycle performance.

Table 14. Economic Performance Indicators

Economic Parameter	ACP	HDPU	Glass Wool
Estimated Implementation Cost	High	Very High	Moderate
Annual Operating Cost Savings	Rp. 2,004,089	Rp. 2,092,654	Rp. 2,264,506
Payback Period Estimate	8-12 years	12-18 years	4-8 years
20-Year NPV Index	Moderate	Low	High
Maintenance Requirements	Low	Low	Moderate

Source: Economic feasibility analysis based on cost estimates and operational savings, 2024

Glass Wool insulation demonstrates superior economic performance with the shortest payback period and highest 20-year net present value, making it the most economically viable solution for thermal comfort improvement and energy efficiency optimization.

Building Information Modeling Technology Assessment

BIM Software Capabilities Evaluation

The research validates Archicad 27's capabilities for comprehensive thermal comfort analysis in tropical humid climates. The software's Energy Performance Evaluation features provide detailed simulation capabilities essential for evidence-based decision making.

Table 15. BIM Analysis Capabilities Assessment

Analysis Capability	Functionality Level	Accuracy Assessment	Decision Support Value
Thermal Load Calculation	Comprehensive	High	Excellent
Energy Consumption Modeling	Detailed	High	Excellent
Material Property Integration	Complete	High	Excellent
Climate Data Integration	Comprehensive	High	Excellent
Comparative Analysis	Advanced	High	Excellent
Visualization Capabilities	Superior	High	Excellent

Source: Evaluation of Archicad 27 software capabilities in thermal and energy simulation, 2024

Simulation Validation and Accuracy

The simulation accuracy was validated through multiple verification processes including material property validation, climate data verification, operational schedule confirmation, and energy consumption pattern analysis.

Table 16. Simulation Validation Results

Validation Parameter	Accuracy Level	Confidence Interval	Validation Method
Material Thermal Properties	±5%	95%	Manufacturer specifications
Climate Data Accuracy	±3%	98%	Meteorological station data
Energy Consumption Patterns	±8%	90%	Utility bill analysis
Temperature Predictions	±2°C	92%	Spot measurements

Source: Simulation validation results with field data and material specifications, 2024

Research Objectives Achievement Analysis

Objective 1: Thermal Comfort Condition Analysis

The first research objective focused on analyzing thermal comfort conditions at the Graduate Building University Fajar based on air temperature parameters. The comprehensive analysis reveals that existing conditions significantly deviate from SNI 03-6572-2001 standards, with temperatures ranging from 24.2°C to 33.9°C, substantially exceeding the comfort range of 20.5°C to 27.1°C.

The temperature analysis demonstrates clear diurnal and seasonal patterns, with minimum temperatures occurring during early morning hours (08:00-09:00 WITA) in January-February, while maximum temperatures occur during late afternoon hours (18:00-19:00 WITA) in September-November. This pattern reflects the building's west-facing orientation and the intense solar loading characteristic of tropical humid climates.

Objective 2: BIM-Based Simulation Development

The second objective involved creating BIM-based simulations for thermal comfort analysis and energy efficiency support. The research successfully developed comprehensive simulation models using Archicad 27, integrating detailed building geometry, material properties, climate data, and operational schedules.

The simulation framework enables systematic evaluation of multiple insulation alternatives, providing quantitative assessment of thermal performance, energy consumption, and carbon emission impacts. The BIM approach facilitates rapid iteration and comparison of design alternatives, supporting evidence-based decision making for building energy efficiency improvements.

Objective 3: Energy Consumption Impact Analysis and Optimization Recommendations

The third objective analyzed the influence of thermal comfort parameters on energy consumption and developed optimization recommendations. The research demonstrates clear relationships between insulation material selection and energy performance outcomes.

Table 17. Optimization Recommendations Matrix

Optimization Goal	Recommended Solution	Implementation Priority	Expected Outcome
Maximum Energy Savings	Glass Wool Insulation	High	17.8% cost reduction
Superior Thermal Performance	HDPU Panel System	Medium	0.2°C average improvement
Balanced Cost-Performance	Glass Wool Insulation	High	Optimal cost-benefit ratio
Rapid Implementation	Glass Wool Insulation	High	Retrofit-friendly installation

Source: Optimization recommendations based on thermal performance and economic analysis, 2024

Thermal Performance Interpretation

The thermal performance analysis reveals complex interactions between insulation material properties and tropical humid climate conditions. While all evaluated materials provide measurable improvements, none achieve full compliance with thermal comfort standards, indicating the necessity of mechanical air conditioning systems in tropical humid environments.

The superior performance of HDPU in temperature reduction reflects its high thermal resistance properties and closed-cell structure, providing effective barriers against heat transfer. However, the marginal improvements achieved even with premium materials highlight the challenges of passive thermal comfort strategies in extreme tropical climates.

Glass Wool's exceptional performance in minimum temperature reduction, achieving 0.5°C improvement, demonstrates effective thermal mass modification and heat transfer reduction during cooler periods. The slight increase in maximum temperatures across multiple materials suggests complex heat storage and release patterns requiring further investigation.

Energy Efficiency Optimization Analysis

The energy efficiency analysis reveals significant opportunities for building performance improvement through strategic insulation implementation. Glass Wool's superior energy performance, achieving 17.8% annual energy consumption reduction, reflects optimal balance between thermal resistance, cost-effectiveness, and implementation feasibility.

The 5.0% cooling energy reduction achieved by Glass Wool represents substantial improvement in the most energy-intensive building system component. This improvement translates to meaningful operational cost reductions and carbon emission reductions, supporting both economic and environmental sustainability objectives.

The lighting and appliances energy reductions of 23-24% across all materials reflect improved thermal stability reducing equipment cooling loads and improved operational efficiency. These secondary benefits contribute significantly to overall energy performance improvements.

BIM Technology Integration Assessment

The successful implementation of BIM technology for thermal comfort analysis validates its effectiveness for complex building performance evaluation in tropical climates. Archicad 27's integrated Energy Performance Evaluation features provide comprehensive analytical capabilities supporting detailed comparative assessment of design alternatives.

The BIM approach enables systematic consideration of multiple performance parameters including thermal comfort, energy consumption, carbon emissions, and economic viability. This integrated assessment capability supports holistic decision making considering both technical performance and economic feasibility.

The visualization capabilities inherent in BIM technology facilitate effective communication of complex thermal performance data to stakeholders, supporting informed decision making and implementation planning. The digital model serves as a comprehensive repository for building performance data supporting ongoing facility management and future optimization efforts.

Implementation Strategy Recommendations

Based on comprehensive performance analysis, Glass Wool insulation implemented through interior gypsum partitions emerges as the optimal solution for thermal comfort improvement and energy efficiency optimization. The recommendation considers multiple factors including thermal performance, energy efficiency, economic viability, implementation feasibility, and maintenance requirements.

The recommended implementation strategy involves phased installation beginning with highest-impact areas such as west-facing walls experiencing maximum solar loading. This approach enables validation of performance improvements and refinement of installation procedures before full building implementation.

Future research opportunities include investigation of hybrid insulation systems combining multiple materials, integration of natural ventilation strategies, and development of advanced building automation systems optimizing thermal comfort and energy efficiency in tropical humid climates.

CONCLUSION

This research demonstrates that BIM-based thermal comfort analysis provides valuable insights for designing energy-efficient buildings in tropical humid climates. The existing thermal conditions at the Graduate Building University Fajar do not meet SNI 03-6572-2001 thermal comfort standards, with average temperatures ranging from 24.2°C to 33.9°C. Among three insulation alternatives evaluated, Glass Wool partition installation proved most effective for energy efficiency, reducing annual energy costs by Rp. 2,264,506 (17.8%) and carbon emissions by 287 kg/year (17.8%), while HDPU panels showed superior thermal performance by reducing average temperature to 28.8°C. The study confirms that BIM technology, specifically Archicad 27, offers comprehensive capabilities for thermal analysis and energy performance evaluation, enabling evidence-based decision making for building energy efficiency improvements. However, mechanical air conditioning systems remain essential to achieve optimal thermal comfort in tropical humid environments. Future research should explore integration of natural ventilation strategies and renewable energy systems to further enhance building energy performance while maintaining occupant comfort.

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