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Identifying Practical Material Retrofit Measures for Energy Efficiency in Existing High-Rise Buildings in the Malaysian Climate

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ABSTRACT

With the global focus on sustainable urban development, many cities are striving to formulate effective urban transformation strategies to transition from traditional urban structures to more sustainable ones. Enhancing the energy efficiency of buildings, particularly existing structures, is recognized as a crucial element in the fight against climate change. In the Malaysian context, improvements in energy consumption are predominantly propelled by retrofitting the country's existing building stock. However, targeted strategies are needed, especially for high-rise buildings, to address the unique challenges posed by the Malaysian climate. This study addresses this gap by focusing on retrofitting strategies specifically tailored for existing high-rise buildings in Malaysia. To evaluate energy efficiency accurately, a selected case study underwent modeling and simulation using Building Information Modeling (BIM) software for energy analysis. The simulation considered crucial aspects of window materials: U-factor, solar heat gain coefficient, visible transmittance, and emissivity. The study identified triple-glazed windows as the most energy-efficient choice, significantly outperforming single-glazed windows due to their lower U-factor and improved insulation properties. Light concrete bricks for walls demonstrated superior heat resistance owing to their lower density. Steel bar joists were found to enhance heat transfer efficiency in roofs. The recommended materials showed promising results, achieving a calculated energy consumption reduction to 266 kWh/m2/year. The study emphasizes that green consultants prioritize elements addressing excessive energy consumption during building upgrades, influencing their choice of retrofit options. Implementing energy-efficient retrofits can significantly reduce buildings' energy dependence, contributing to a substantial decrease in the country's overall energy consumption.

1. Introduction

In the quest for sustainable development, energy plays a pivotal role, particularly within existing buildings, which currently account for approximately 40% of global energy consumption, surpassing even the demands of the manufacturing and transportation sectors. According to Saadatian *et al.,*

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[1], Malaysia has been steadily increasing its efforts to promote sustainable development on a global scale. This endeavor includes not only incorporating green and sustainable practices into new infrastructure but also enhancing the performance of Malaysia's existing building stock, crucial for mitigating greenhouse gas (GHG) emissions and bolstering energy efficiency. High-rise buildings in Malaysia emerge as significant energy consumers due to their substantial size, density, and structural complexity. As noted by Hamad [2], these buildings currently consume 48% of the nation's total power production, a figure expected to escalate alongside the burgeoning demand for new residential and commercial construction projects. Retrofitting such buildings with energy-efficient measures holds promise for substantial reductions in energy consumption and greenhouse gas emissions, while also offering cost-saving benefits for both building owners and occupants.

Enhancing energy efficiency in buildings often requires upgrading critical components such as windows, walls, and roofs. Climate change, primarily caused by human activities like fossil fuel combustion and deforestation, has led to lasting shifts in the Earth's climate. Malaysia, highly vulnerable to these effects, faces numerous consequences that urgently require intervention, affecting ecosystems, public health, and the economy alike. Retrofitting high-rise buildings is particularly crucial due to their aging infrastructure and outdated systems. Despite recognizing the benefits, perceived high costs often deter building owners from pursuing retrofit measures [3-6]. This underscores the need to develop and implement strategies supporting energy-efficient design, construction, and operation within residential structures, addressing factors such as construction standards and building materials. Climate change presents a significant and ongoing challenge for humanity. To limit global temperature rises to 1.5°C, achieving net zero or negative carbon emissions globally is imperative. Weerasinghe *et al.,* [7] emphasizes that achieving this goal requires not only restricting cumulative carbon emissions but also achieving at least net zero carbon emissions, along with substantial reductions in other greenhouse gases. Buildings, responsible for over 40% of global carbon emissions, play a crucial role in this context. The large number of existing buildings significantly contributes to carbon emissions, underscoring the urgency to reduce their carbon intensity. Therefore, retrofitting existing buildings to achieve zero or negative carbon emissions (NZC retrofitting) is essential for effective climate change mitigation [7,8].

Despite significant progress in sustainable building practices, there remains a notable gap in research, particularly concerning high-rise buildings within Malaysia's unique climatic conditions. Existing studies predominantly focus on retrofit solutions for low-rise buildings such as single or multi-family homes, leaving a significant knowledge void regarding the distinct challenges and opportunities posed by high-rise structures. High-rise buildings exhibit different energy consumption patterns, architectural complexities, and environmental impacts that require tailored retrofitting strategies [3-10]. What sets this study apart from previous works is its explicit focus on high-rise buildings in Malaysia. While existing research provides valuable insights into low-rise building retrofitting, this paper uniquely addresses the specific needs and challenges of high-rise structures. To achieve this, the study analyzed current climatic trends and building characteristics influencing energy consumption in high-rise structures. This study proposed practical retrofit measures that consider local climate conditions, building materials, and energy demands. By emphasizing the importance of NZC retrofitting, this research contributes new insights into enhancing energy efficiency and promoting resilient urban development in Malaysia's high-rise settings. In summary, this paper addresses the unique challenges of high-rise buildings within Malaysia's climate context, offering practical solutions to reduce carbon footprints and advance sustainable urban development goals.

1.1 Retrofitting High-Rise Buildings in Tropical Climates

Retrofitting existing high-rise structures is integral to creating energy-efficient buildings while minimizing energy consumption. In practice, green consultants often propose retrofit solutions with the shortest construction period and payback period. Factors influencing energy consumption in high-rise buildings are significantly influenced by the condition and quality of the building, including its walls, roof, windows, and doors. A well-insulated and tightly sealed building envelope effectively prevents heat transmission, resulting in improved thermal efficiency and reduced energy consumption for heating and cooling purposes. According to Strzałkowski *et al.,* [11], in hot tropical climates like Malaysia, the design of a building's fenestration plays a crucial role in regulating heat transfer between indoor and outdoor environments. A well-designed building envelope is essential for maintaining a cool indoor environment while maximizing natural lighting and ventilation. The building envelope, which comprises walls, floors, roofs, fenestration (windows, skylights, etc.), and doors, serves as the physical barrier separating a building's interior from the external environment. To minimize heat transmission within the structure, a well-designed envelope must utilize suitable materials that are climate-appropriate [1,11-13]. Energy efficiency can be achieved through various envelope designs, including shading, window-to-wall ratio (WWR), selection of low shading coefficient glass, and maximizing the use of natural light for interior illumination [14]. Among these, shading design emerges as the most efficient option for façade retrofitting, as it effectively reduces cooling loads, limits solar insolation, and enhances daylight distribution.

In the Malaysian tropical climate, the impact of envelope design parameters on energy consumption and thermal performance of high-rise buildings (HRBs) has been examined. External wall and glazing enhancements contribute significantly to both energy use and thermal comfort compared to orientation, external shading, and roof alterations [9,15]. Malaysia's geographical location between latitudes 4°12' N and 101°58' E results in a climate characterized by ample sunlight, averaging 6 hours per day, with high solar radiation and abundant rainfall [16,17]. As temperatures rise due to climate change, heatwaves become more frequent. Consequently, buildings must be designed to accommodate both hot summers and chilly winters by incorporating insulation, efficient heating and cooling systems, and strategic placement of windows to reflect or block sunlight.

2. Methodology

This study employed a combination of approaches, comprising literature review, case study analysis of high-rise buildings, and energy analysis. The three-phase methodological framework utilized in this study is illustrated in Figure 1.

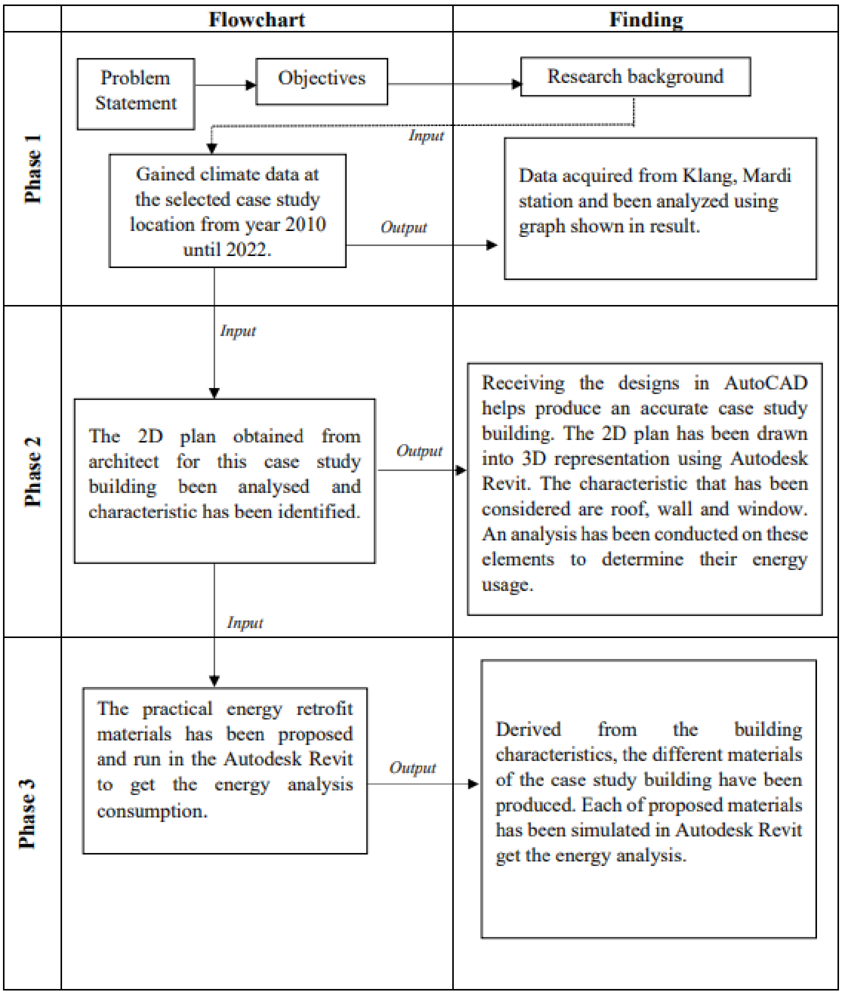

Fig. 1. Research framework

2.1 Location and Climate Data

Climate data relevant to the case study building was obtained from the Malaysia Meteorological (myMET) Department. Figure 2 displays the official website of myMET, from which temperature data was procured [18]. The collected climate data spans from 2010 to 2022 and is specific to Klang, Selangor. This data was gathered from the Mardi Klang Station.

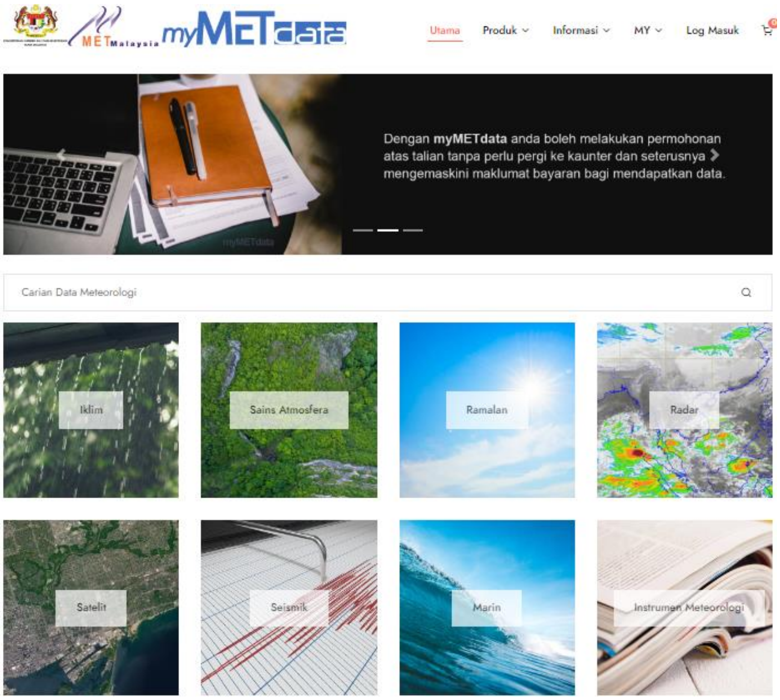

Fig. 2. Official website Malaysia Meteorology Department [18]

2.2 Description of the Case Study Building

To devise optimal retrofit measures aligned with energy efficiency, it is essential to assess both building characteristics and materials. The conducted case study revealed that common materials were used in the construction of this high-rise building, which is a public hospital located in Klang, Selangor. Positioned at 3.0202°N latitude and 101.4399°E longitude, the hospital comprises eight levels and serves as a suitable model for analyzing energy performance in tropical climates. Climatic data for this building, obtained from the Malaysia Meteorological Department, indicated an average temperature range of 26.3°C to 29.2°C. The analysis focused on the building's walls, windows, and roof, considering both their characteristics and energy performance based on material aspects. Consequently, the study aims to recommend material alternatives to optimize energy efficiency in the tropical humid climate of Malaysia. The architectural drawings and relevant information of the selected case study building were collected for analysis. In line with the research objectives, the selection of an older building, with an age exceeding 10 years, facilitates more effective energy retrofitting by allowing better adaptation to retrofit measures and offering stability in energy consumption. The hospital building in Klang Valley was chosen as a case study model. Figure 3 shows the layout plan in AutoCAD format and Table 1 summarizing the characteristics of the building components.

Fig. 3. Layout plan for case study building in AutoCAD

Table 1
Summary of characteristics component for case study building

Type of materials	Layer Name
Wall	Concrete with finishes (20 mm), Layer Brick wall (50 mm) and Air gap (18 mm)
Windows	Dark wood framed window
Door	Wood Dark Material with glass forted glazing
Roof	Roofing tile (38 mm), Sand/Cement Screed (50 mm), Concrete with Cast In situ (150 mm)

2.3 Modelling of the Case Study Building

After identifying the materials used in the existing case study building, several candidates were pinpointed for potential retrofitting, with careful consideration given to the building's energy consumption. The development of practical energy retrofit measures involves utilizing AutoCAD Software. The architectural drawings received will then be recreated in Revit Software. This plan in Autodesk Revit Software will incorporate the existing materials from the high-rise building. Figure 4 and Figure 5 display the plans plotted in Autodesk Revit.

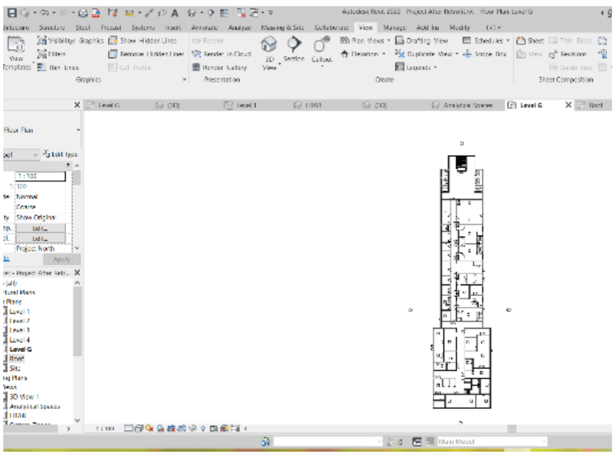

Fig. 4. One of the floor plans in Autodesk Revit

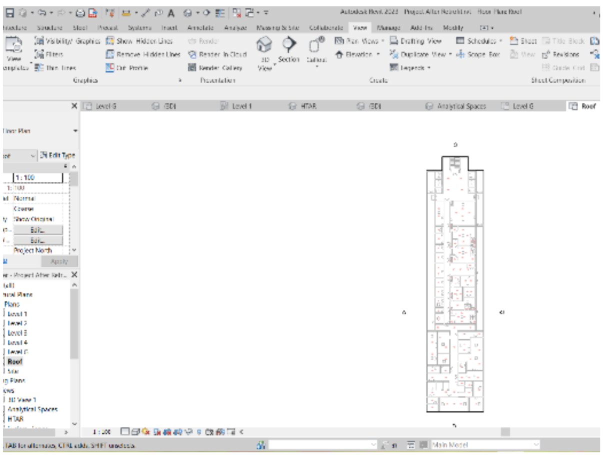

Fig. 5. Roof plan in Autodesk Revit

3. Results and Discussion

3.1 Climate Trend for Case Study Area

Climate conditions are crucial factors that need thorough analysis as they significantly impact the building's temperature, subsequently affecting its energy consumption. Climate data collected from the Mardi Station in Klang, the nearest station to the case study building, spans from 2010 to 2022 to observe climate trends. Figure 6 and Figure 7 display the climate data, with instances of missing observations due to defective values. Notably, peak temperatures occurred during specific months each year. For instance, in 2010, May recorded the highest temperature at 28.4°C, while in 2013 and 2014, June witnessed peak temperatures at 28.8°C and 29.2°C, respectively. Analysis of the data suggests that climatic temperatures are most frequent from May to July, with less frequency observed in the early and late months of the year.

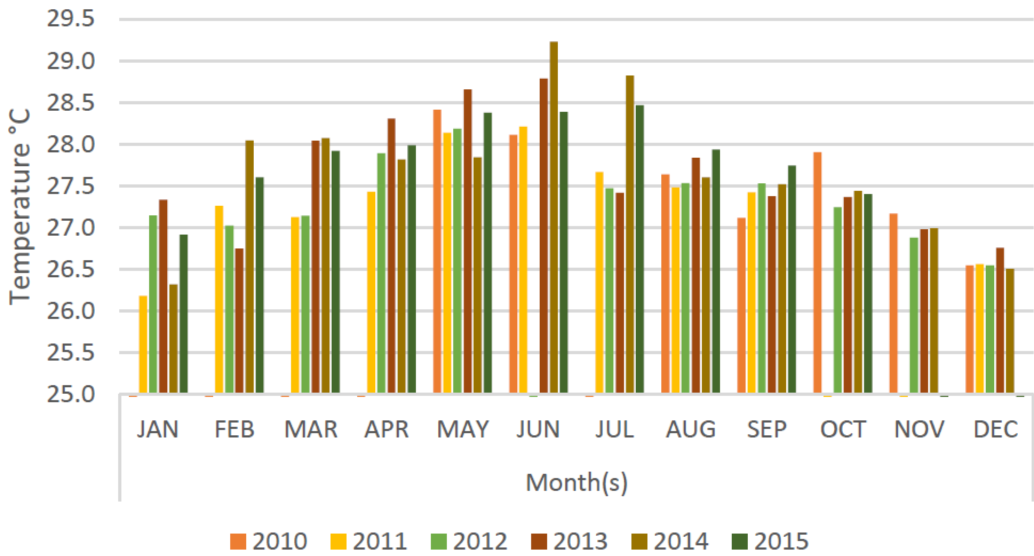

Fig. 6. Climate trend in Klang Valley from 2010 until 2015

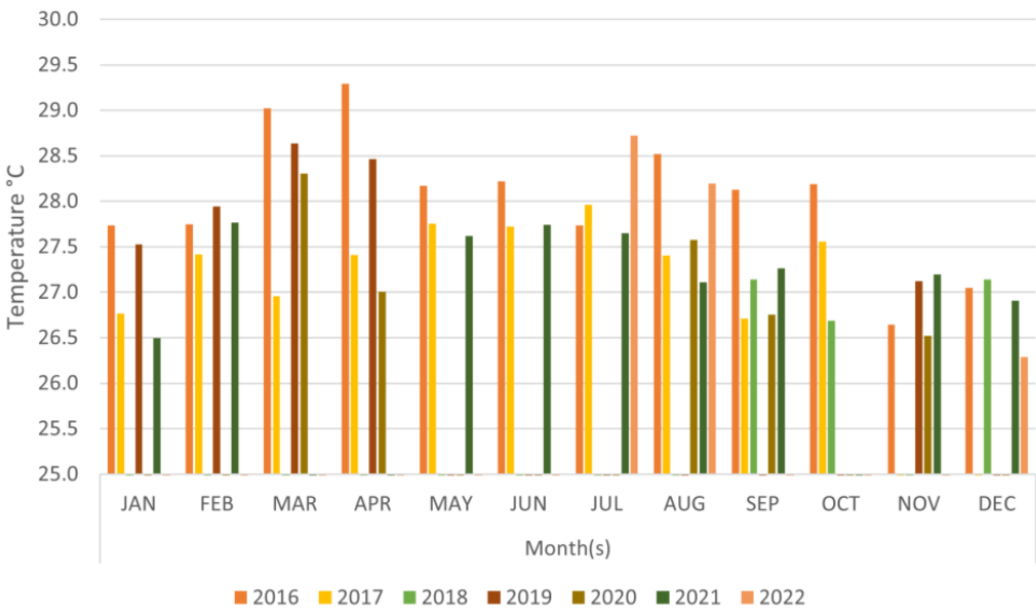

Fig. 7. Climate trend in Klang Valley from 2016 until 2022

3.2 Characteristics of the Case Study Building

The floor-by-floor construction of the case study building was accomplished by transferring the drawing from AutoCAD Software to Revit Software. Additionally, the existing materials within the case study building were identified. Figure 8 depict the 3D model of the case study building.

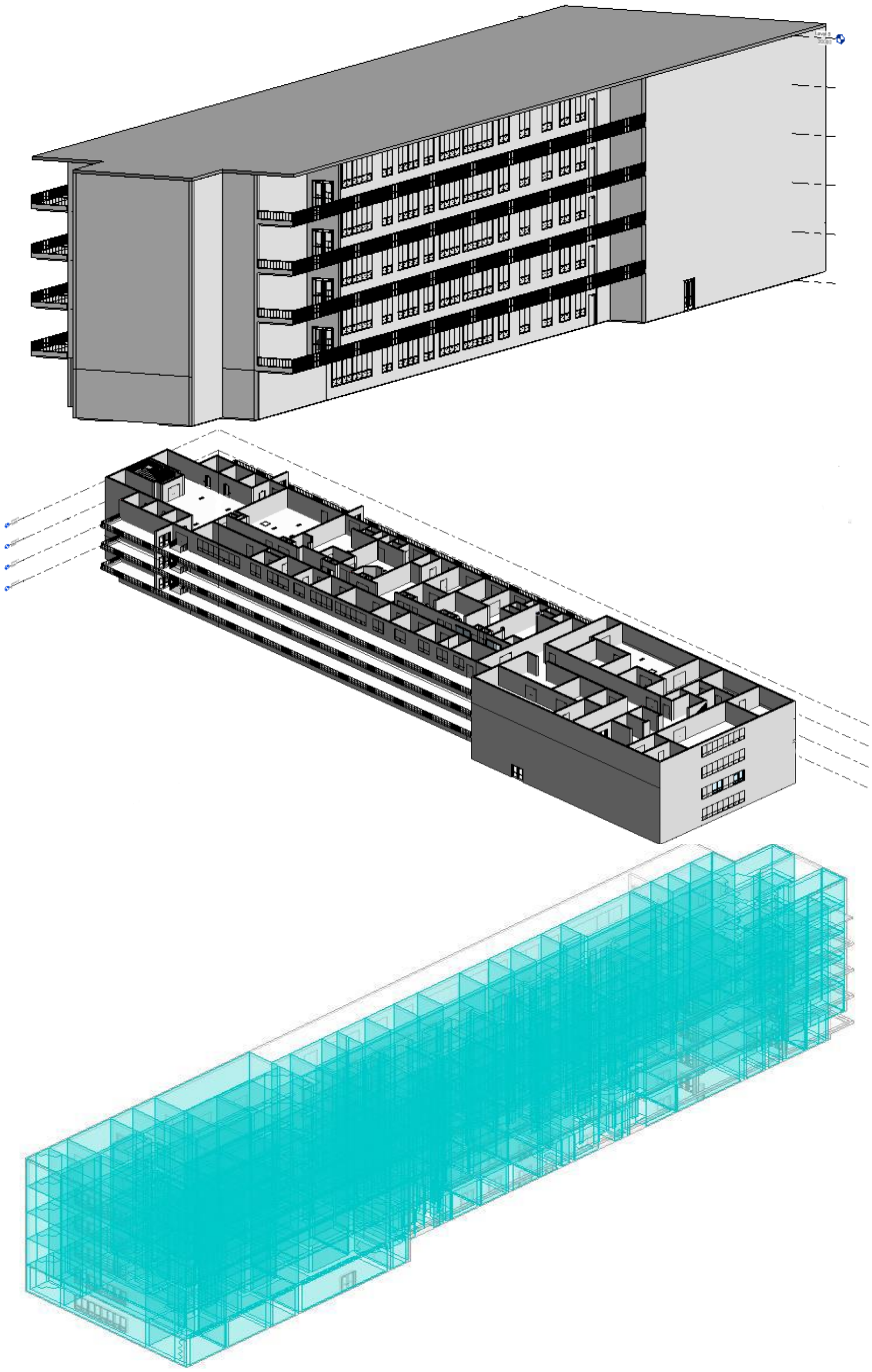

Fig. 8. 3D model of the case study building

The layers for the outer and inner wall materials of the case study building are depicted in Figure 9 and Figure 10, respectively. Meanwhile, Figure 11 and Figure 12 provide details about the windows

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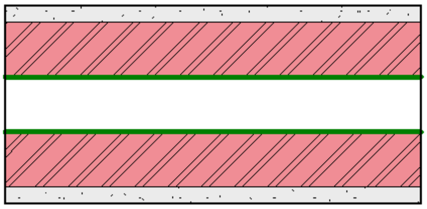
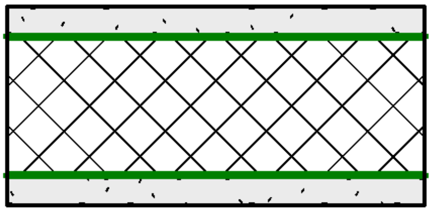
and roof of the building. Table 2 presents the thermal resistance and heat transfer coefficient for each type of existing material in the case study building.



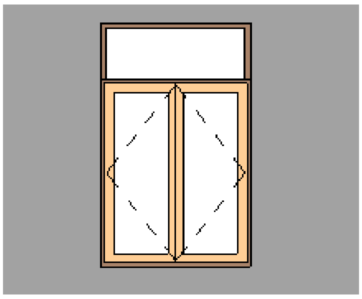
	Function	Material	Thickness
1	Finish 1 [4]	Concrete, Sand/Cement Screed	30.0
2	Structure [1]	Brick, Common	100.0
3	**Core Boundary**	**Layers Above Wrap**	**0.0**
4	Thermal/Air Layer [3]	Air	100.0
5	Membrane Layer	Air Infiltration Barrier	0.0
6	**Core Boundary**	**Layers Below Wrap**	**0.0**
7	Structure [1]	Brick, Common	100.0
8	Finish 1 [4]	Concrete, Sand/Cement Screed	30.0

Fig. 9. Outer wall material and preview



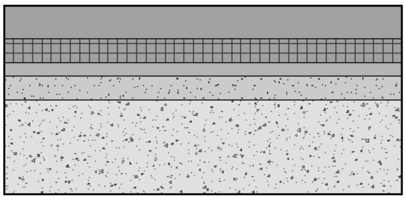
	Function	Material	Thickness
1	Structure [1]	Concrete, Sand/Cement Screed	30.0
2	**Core Boundary**	**Layers Above Wrap**	**0.0**
3	Structure [1]	Concrete Masonry Units	140.0
4	**Core Boundary**	**Layers Below Wrap**	**0.0**
5	Structure [1]	Concrete, Sand/Cement Screed	30.0

Fig. 10. Inner wall material and preview



Other	
Ventilator Height	450.0
Top Rail	60.0
Stile	60.0
Shutter	Light Wood
Panel	Glass 2
Frame Width	45.0
Frame Depth	60.0
Frame	Dark Wood
Default Sill Height	800.0
Bottom Rail	60.0

Fig. 11. Window material and preview



	Function	Material	Thickness
1	Finish 1 [4]	Roofing, Tile	70.0
2	Thermal/Air Layer [3]	Rigid insulation	50.0
3	Thermal/Air Layer [3]	Asphalt, Bitumen	30.0
4	Membrane Layer	Roofing Felt	0.0
5	**Core Boundary**	**Layers Above Wrap**	**0.0**
6	Structure [1]	Concrete, Sand/Cement Screed	50.0
7	Substrate [2]	Concrete, Cast In Situ	200.0
8	**Core Boundary**	**Layers Below Wrap**	**0.0**

Fig. 12. Roof material and preview

Table 2
The thermal resistance and heat transfer coefficient of the existing materials of the case study building

Type of materials	Thermal resistance ($m^2.K/W$)	Heat Transfer Coefficient ($W/m^2. K$)
Outer wall	4.4278	0.2258
Inner wall	0.1651	6.0586
Window	0.5032	1.9873
Floor	0.1434	6.9733
Roof	1.7770	0.5627

3.3 Alternative Materials for Energy Efficiency Retrofitting

Following the selection of alternative materials for walls, windows, and roofs in the design phase, it becomes crucial to recreate conditions analogous to the case study. This involves replicating the same construction with designated room sizes and matching the specifications of the case study's energy settings. The replication is carried out meticulously to ensure an accurate representation of the design. The analysis conducted with Insight360 subsequently presented the following charts and data. Figure 13 shows the analysis comparison and effects of different material on energy consumption of the building.

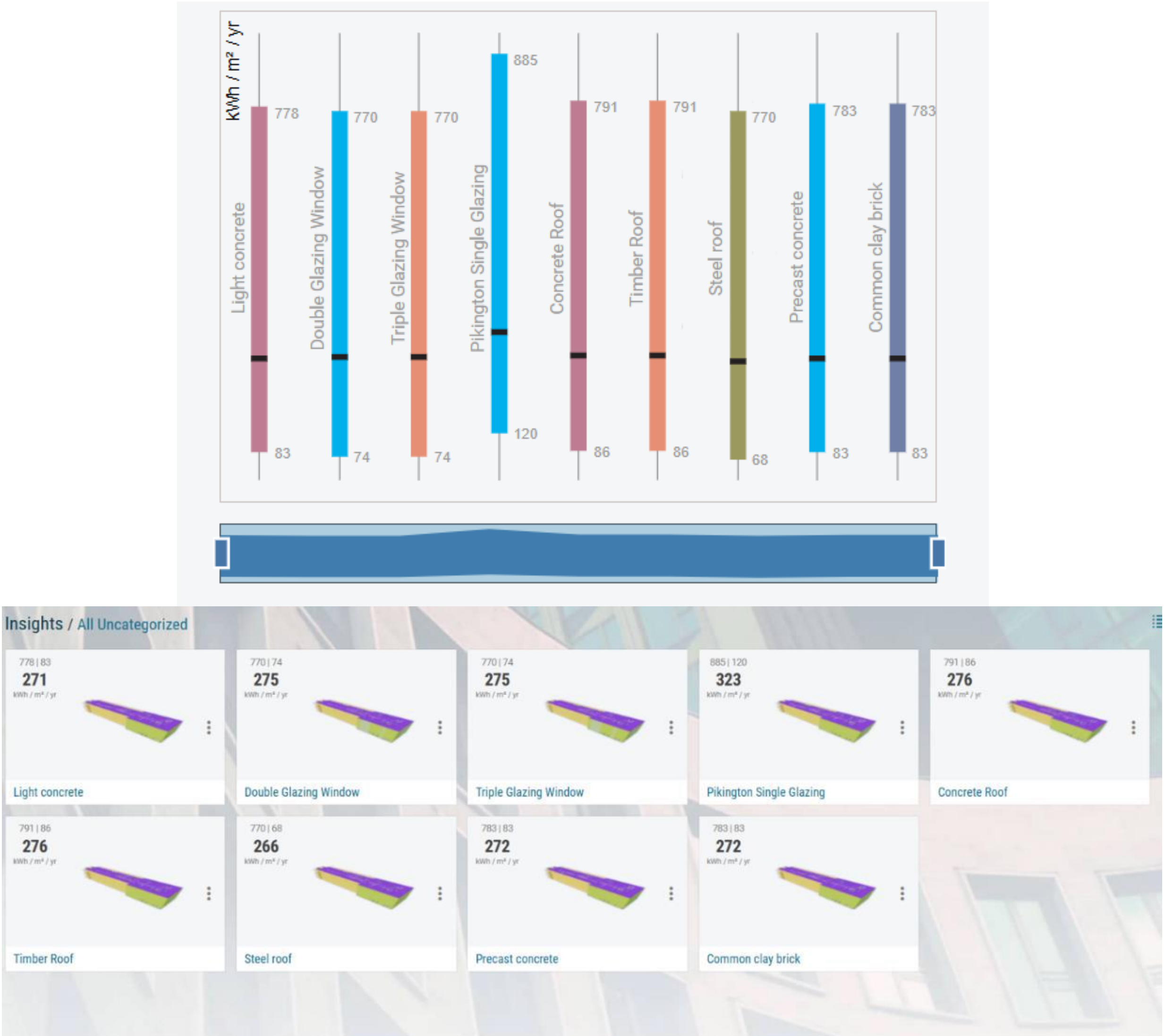


Fig. 13. Analysis comparison and effects of different material on energy consumption

Table 3 presents the selected materials based on their thermal resistance characteristics. Previous studies highlight that light concrete bricks offer superior thermal insulation compared to standard bricks, effectively enhancing energy efficiency and ensuring more stable indoor temperatures [19,20]. This property is crucial in reducing heat transfer through building envelopes, thereby lowering heating and cooling energy demands. Triple-glazed windows also demonstrate excellent thermal insulation properties. Moghaddam *et al.,* [21] indicates that upgrading to double or triple glazing significantly improves building envelope performance by minimizing heat loss and enhancing indoor comfort levels. Hence, the suggested material for the windows is similar with the past studies since double or triple glazing windows effective in reducing thermal conductivity and enhancing overall energy efficiency in buildings.

Table 3
The thermal resistance and heat transfer coefficient of the existing materials of the case study building

Comparison	Explanation
Walls	Light concrete bricks have the highest thermal resistance which is 1.7540 m2. k/W than other bricks. It heats transfer coefficient is 0.5943 W/m^2. K.
Windows	Triple glazing (e=0.05) has the highest thermal resistance which is 0.6523 m2. k/W than other windows. It heats transfer coefficient is 1.5330 W/m^2. K.
Roof	Steel bar joist – steel deck – EPDM membrane has the highest thermal resistance which is 17.4659 m2. k/W than other roofs. It heats transfer coefficient is 0.0573 W/m^2. K.

Regarding the steel bar joist with an EPDM membrane, its thermal resistance is primarily attributed to the insulation layer designed to reduce heat transfer. The EPDM membrane's reflective properties play a pivotal role in minimizing solar heat absorption, thereby maintaining a cooler roof surface and contributing to improved thermal performance. Past studies have shown that such roofing systems can effectively reduce cooling energy consumption in buildings located in hot climates [21-23]. These materials, chosen for their thermal properties, are critical components in retrofitting strategies aimed at enhancing the energy efficiency of existing high-rise buildings in Malaysia, aligning with sustainable building practices and climate resilience initiatives.

3.4 Recommended Materials for Energy Efficient Building

The chosen materials, selected after rigorous analysis and comparison using Autodesk Revit Software, were strategically implemented in the case study building to achieve an energy-efficient retrofit. Optimal selections such as light concrete bricks, triple-glazed windows, and steel bar joists with EPDM membranes were chosen based on their proven ability to enhance energy efficiency and thermal performance [21]. Past studies states that light concrete bricks offer superior thermal insulation compared to traditional clay bricks, effectively reducing heat loss through building walls and improving overall energy conservation [24]. Triple-glazed windows are recognized for their enhanced thermal resistance, minimizing heat transfer and enhancing indoor comfort levels, as supported by experimental data from laboratory and field studies. Additionally, steel bar joists with EPDM membranes contribute to improved thermal efficiency by minimizing heat absorption and reducing cooling demands, particularly in tropical climates [24-27].

Figure 14 illustrates the energy use intensity achieved with the recommended materials, highlighting their effectiveness in lowering operational energy costs to 266 kWh/m2/year. Materials with high thermal resistance play a critical role in reducing energy consumption by optimizing building envelope performance and reducing thermal bridging [28]. Their superior energy-efficient characteristics offer significant advantages over conventional materials, contributing to both environmental sustainability and economic savings [21,28-30]. The detailed analysis conducted in Autodesk Insight, as depicted in the figure above, further validates that these recommended materials are optimal choices for enhancing energy efficiency in the case study building. This approach not only aligns with sustainable building practices but also underscores the importance of selecting materials that promote long-term energy savings and environmental stewardship.

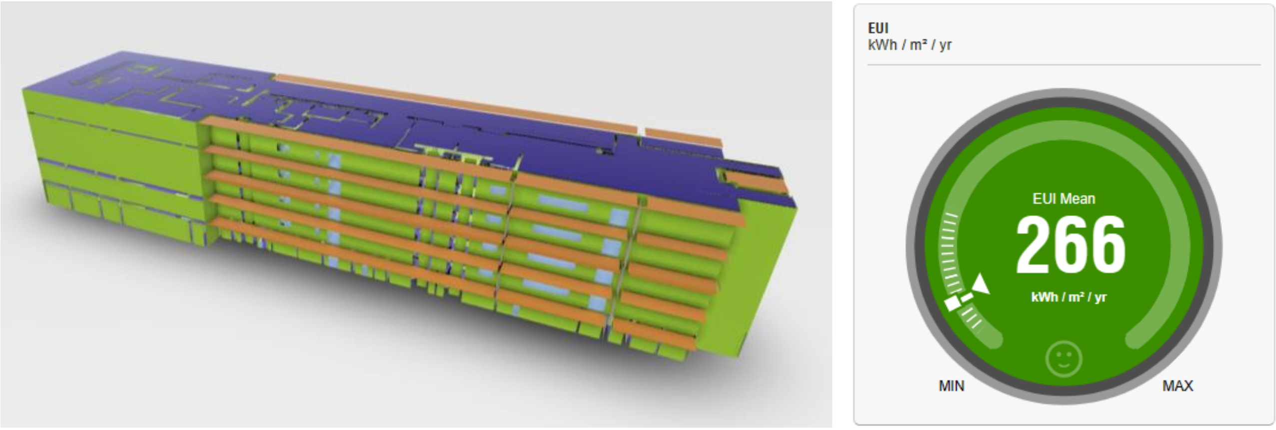


Fig. 14. Energy use intensity of the suggested material analysis comparison

4. Conclusions

Based on the findings of this research, retrofitting the proposed materials for the case study building is recommended to effectively address energy consumption, particularly in light of the specific climate conditions of the chosen location. A comparison of the hospital building's characteristics with other structures highlights the higher energy consumption associated with hospital equipment, indicating the need for targeted retrofit measures. Suggestions for adjustments in building materials were proposed and assessed using Revit Software to evaluate energy consumption. The analysis of materials, including common clay brick, triple glazing, and steel truss joists, demonstrates their potential in enhancing energy efficiency within the case study building. The calculated energy consumption for the recommended materials is 266 kWh/m2/year. For future recommendations, it would be beneficial to gather energy bill data from the case study building to establish correlations between energy consumption and climate data, offering further insights for sustainable retrofitting strategies.

Acknowledgement
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