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# Heat gain reduction and cooling energy minimization through building envelope material

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ABSTRACT

*This study aims to reduce heat gain and minimise cooling energy through building envelope material as a passive design intervention strategy to achieve thermal comfort. Integrated Learning Building in the Faculty of Engineering, Universitas Indonesia, is used as a case study due to its air conditioning setting. First, the material characteristic of the building envelope is calculated using the Overall Thermal Transmission Value (OTTV) calculation to determine heat gain and the EDGE (Excellence in Design for Greater Efficiencies), a software to estimate cooling energy consumption. Then, a passive design intervention strategy is performed by adding insulation (polyester, bagasse, and recycled textile and paper) and substituting window glazing (reflective, PVB laminated, and Clear IGU Low-E). The results show that the combination of recycled textile and paper insulation and clear IGU Low-E window glazing has an OTTV value of 24.89 W/m2 which is lower than the standard in Indonesia (35 W/m2). Meanwhile, the cooling energy usage shows an energy consumption of 1.14% lower, but it did not achieve the 5% reduction target. Therefore, further intervention on other parts of the building envelope, such as the roof and floor, should be observed to achieve higher energy-saving potential.*

## Introduction

In providing thermal comfort, air conditioning uses 40% of the energy consumption of buildings in tropical climates (United National Environment Program 2021). Indonesia has a hot-humid climate with average air temperature of 29.7°C followed the rising trend of 0.017-0.048°C/year (Prasetyo et al. 2021). Passive design strategies and resistant building envelope can increase energy efficiency and reduce $CO_2$ emissions (Kibert 2016; Notodipuro and Mandala 2022; Antaryama, Ekasiwi, and Erwindi 2022). As a physical barrier between the internal and external environments, building envelope properties needs to be responsive to the local weather and climate conditions (MeetMED 2020; Adeeb Fahmy Hanna 2020; Leccese et al. 2018; Lalu and Hariyadi 2022) . In Indonesia, specified temperature levels at 20.5°C-27.1°C and maximum humidity level at 60% defines thermal comfort condition (ASHRAE 55 2020).

This study prioritises heat gain avoidance as the first-tier design approach in optimising passive design intervention strategy and its possible significant effect (Lechner 2015). To reduce radiation received by building envelopes and minimise the cooling load, possible strategies include Window-to-wall Ratio (WWR), building orientation, glazing system, horizontal overhang depth, vertical fin depth, exterior wall coating, and roof coating (Bhamare, Rathod, and Banerjee 2019; Qiu et al. 2021). Opaque and transparent surface transfers heat based on material conductivity and radiation (Kumar et al. 2022).

Building envelope materials with high thermal resistance is suitable for heating dominated region (Kumar et al. 2022). Overall Thermal Transfer Value (OTTV) as building envelope regulation specifies thermal transmission factors (SNI 6389:2020 2020). It is predicted that OTTV as a regulation can minimize electricity consumption (Sheng, Zhang, and Ridley 2020; Muhfizaturrahmah et al. 2021). OTTV value and energy savings are not calculated directly, thus building envelope form optimization is helped using simulation software as calculation input (Pramesti et al. 2021b; Pramesti et al. 2021a; Natephra, Yabuki, and Fukuda 2018) . Other passive design strategies use Phase Change Materials (PCMs), which act as thermal storage and uses heating-cooling processes to release and absorb heat (Putra et al. 2017; Kalbasi and Afrand 2022). However, it cannot be calculated in OTTV measurement.

OTTV as building envelope regulation can predict heat gain minimization. However, it has limitation such as no energy reduction prediction. This study focuses on building envelope material which has a high potential in affecting heat gain performance and energy reduction. This study aims to reduce heat gain and minimise cooling energy through building envelope material as a passive design intervention strategy to achieve thermal comfort in Integrated Learning Building.

Wall insulation material inventory for the hot-humid climate in Indonesia

Insulation material can minimise cooling load by reducing HVAC energy requirements (Bataineh and Al Rabee 2022). Thermal transmittance through conduction, convection and radiation is expressed as U-value (Abdul Nasir and Hassan 2020). Organic material from renewable resources has lower embodied energy, whereas inorganic materials have lower cost (Aditya et al. 2017). There are three types of materials: natural, converted, and artificial materials (Alfuraty 2020). These material's thermal conductivity and density are collected as listed in table 1.

**Table 1.** Amino acid composition of catfish skin gelatin (G), hydrolyzed catfish skin gelatin (GE) and dried skin sample (SKPD)

| Material | Thermal conductivity (W/mK) | Density (kg/m$^3$) |
|---|---|---|
| Recycled textile and paper | 0.034–0.039 | 433 |
| Bagasse | 0.046–0.055 | 70– 350 |
| Polyester insulation | 0.077 | 25 |

Source: (Asdrubali, D'Alessandro, and Schiavoni 2015; Hilon Insulation, n.d.)

From table 1, polyester, bagasse, recycled textile and paper are materials of different types, and a range of thermal conductivity values was chosen for the insulation material intervention.

Window glazing material inventory for the hot-humid climate in Indonesia

Concerning heat gain calculation, properties of glazing are shading coefficient (SC) and U-value (SNI 6389:2020 2020). The SC value measure window's ability to transmit solar heat; lower SC value combined with external shading is preferred for energy saving (Irvandi, Soebiyan, and Tomasowa 2021; Bhatia, Sangireddy, and Garg 2019). The U-value is defined as heat flow rate per area where window generally has higher values than wall (Aguilar-Santana, Velasco-Carrasco, and Riffat 2020). This study chooses several window glazing; reflective glass, PVB laminated glass, and clear IGU Low-E with an SC value range of 0.52 - 0.79 and U-value range of 3.1-5.8 (table 2).

**Table 2.** Window material inventory

| Window glazing type | Shading coefficient | U-value (W/m$^2$K) | Visible light transmission |
|---|---|---|---|
| Reflective glass grey 6 mm | 0.52 | 5.7 | 30 |
| Laminated glass - Translucent PVB 6 mm | 0.76 | 5.8 | 58 |
| Insulating Glass Unit (IGU) - Clear Low-E 10 mm | 0.79 | 2.1 | 74 |

Source: (Asahimas Flat Glass n.d.; National Glass n.d.)

To conclude, this study considered materials for additional insulation and window glazing substitution design strategies. A comparison of the calculation of passive design strategies is made to recommend heat gain and cooling energy reduction in achieving thermal comfort of the Integrated Learning Building.

## Method

A passive design intervention strategy is performed by adding insulation (polyester, bagasse, and recycled textile and paper) and substituting window glazing (reflective glass, PVB laminated, and clear IGU Low-E) from the existing condition (figure 1). Two calculations are done: namely, the calculation of heat gain through OTTV and energy efficiency through the EDGE software. The calculation from the existing Integrated Learning Building envelope is compared to passive design strategies through material interventions to provide recommendations.

Overall Thermal Transmission Value (OTTV)

OTTV is a measure of external heat gain transmitted through the unit area of the building envelope (W/m$^2$) (SNI 6389:2020 2020). OTTV measurement includes thermal conduction through opaque walls and glass, and transmission of solar radiation through glass.

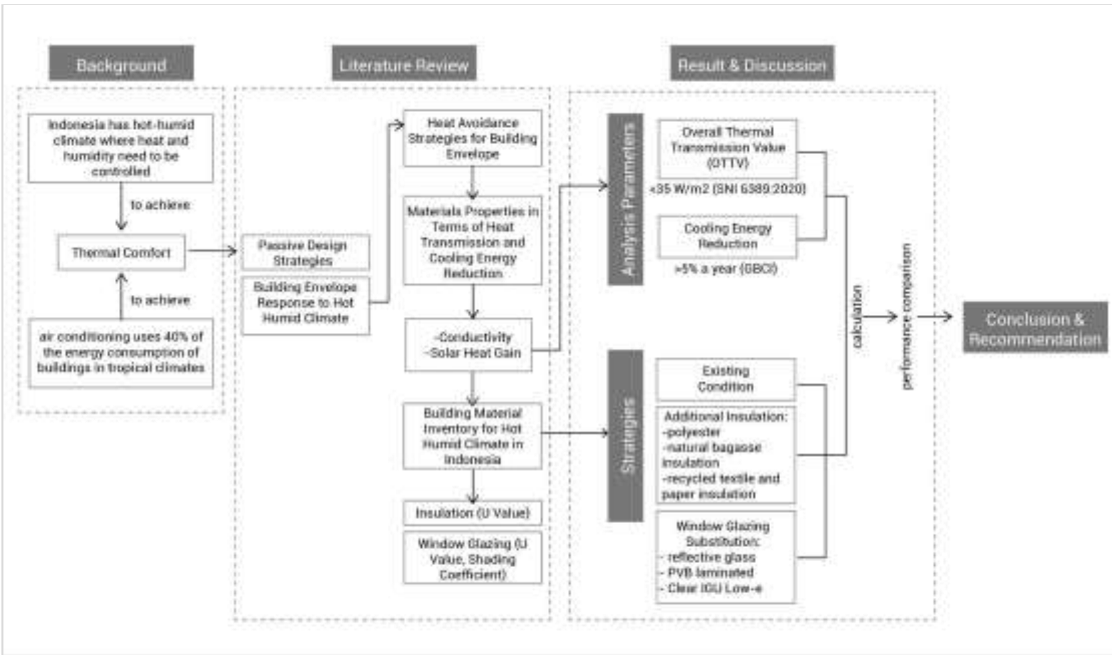


**Figure 1.** Research framework

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Therefore, OTTV of one orientation area of the wall can be calculated with:

$$OTTV = \alpha[U_W\, x(1 - WWR)xTD_{EQ}] + (U_f xWWRx\, \Delta T) + (SCxWWRxSF) \quad (1)$$

OTTV of the whole building is expressed as:

$$\frac{(Ao1xOTTV1)+(Ao2xOTTV2)+\ldots+(AoixOTTVi)}{Ao1+Ao2+\ldots+Aoi} \quad (2)$$

Where,

| | | |
|---|---|---|
| $\alpha$ | = | Solar absorption factor |
| Uw | = | Opaque wall thermal transmittance (W/m$^2$K) |
| WWR | = | Window-to-wall area |
| TDeq | = | Equivalent temperature difference (K) |
| Uf | = | Fenestration thermal transmittance (W/m$^2$K) |
| ΔT | = | Planning temperature difference between outside and inside (K) |
| SC | = | Shade coefficient of the fenestration system |
| SF | = | Sun radiation factor (W/m$^2$) |

Each passive design intervention strategy is calculated using the material inventory listed in the previous section compared with Integrated Learning Building's existing calculation.

EDGE building cooling energy efficiency measures

EDGE software provides region-specific database to predict building performance and environmental impact (International Finance

Corporation 2020). Material heat gain factors include insulation of exterior walls (U-value), glass efficiency (U-value), and SHGC (Solar Heat Gain Coefficient). Each passive design intervention strategy is input based on the material inventory in the previous section. The Green Building Council Indonesia (GBCI) points out a minimum of 5% energy saving target in a year (GBCI 2016).

Measurement and observation of integrated learning building

Measurement is done using a temperature logger hung in the chair to take temperature data and an anemometer in the outdoor area to take wind speed data. The class samples located on the north-sided classroom of 1st, 3rd, and 5th floor were chosen with different capacities, namely classes with 40 and 70 student capacities. The observation takes place on March 30, 2022, from 10.00-12.00 during the active hour of students attending class at the beginning of the COVID-19 offline learning schedule.

## Result and discussion

Integrated learning building – Faculty of Engineering, Universitas Indonesia

Integrated Learning Building was built in 2012 and located in Universitas Indonesia, Depok City, as one of the buildings used for teaching and learning activities. It has six floors with 26 classrooms that can facilitate up to 1,600 students at maximum capacity. Classrooms on 1st and 3rd floor with 70 people capacity uses 3 AC, and 40 people capacity uses 2 AC with 2 HP, while the 5th floor uses wall mounted AC with 5 HP (figure 2). The primary material of the building envelope is an Autoclaved Aerated Concrete (AAC) wall layered with terracotta tiles and light-yellow paint. It has most of its openings in the north and south facades, while minimum openings are in the west and east façade (figure 3). All the openings have overhang shadings 1-meter depth that minimises direct heat gain through windows. As an educational building in Universitas Indonesia, Integrated Learning Building uses air conditioning as its primary cooling system to cool all the classrooms and waiting rooms. However, this condition will potentially increase the energy consumption of the building if the facade cannot adapt to the temperature rise caused by climate change.

From table 4, measurements of sample rooms in existing Integrated Learning Building is done. Measurements of outdoor temperature show an average of 31.53°C, while the indoor temperature without air conditioning of 28.4°C resulted in a temperature difference of 3.13°C. The average temperature of the 1st, 3rd, and 5th floor is 28.19°C causing a temperature gap of 3.34°C with outdoor temperature. The measurement of wind outside the Integrated Learning Building also shows very minimum results, which is 0-0.12 m/s. This measurement is higher than ASHRAE 55 standard in warm comfort (25.8°C-27.1°C).

**Table 3.** Existing Integrated Learning Building Measurement

| No Air Conditioning | | | Air Conditioning | | |
|---|---|---|---|---|---|
| Location | Temperature °C | RH % | Location | Temperature °C | RH % |
| 1st Floor | 28.12 | 73.37 | 1st Floor | 27.43 | 45.71 |
| 3rd Floor | 28.57 | 58.27 | 3rd Floor | 29.79 | 54.34 |
| Outdoor | 31.53 | 72.21 | 5th Floor | 27.40 | 50.57 |

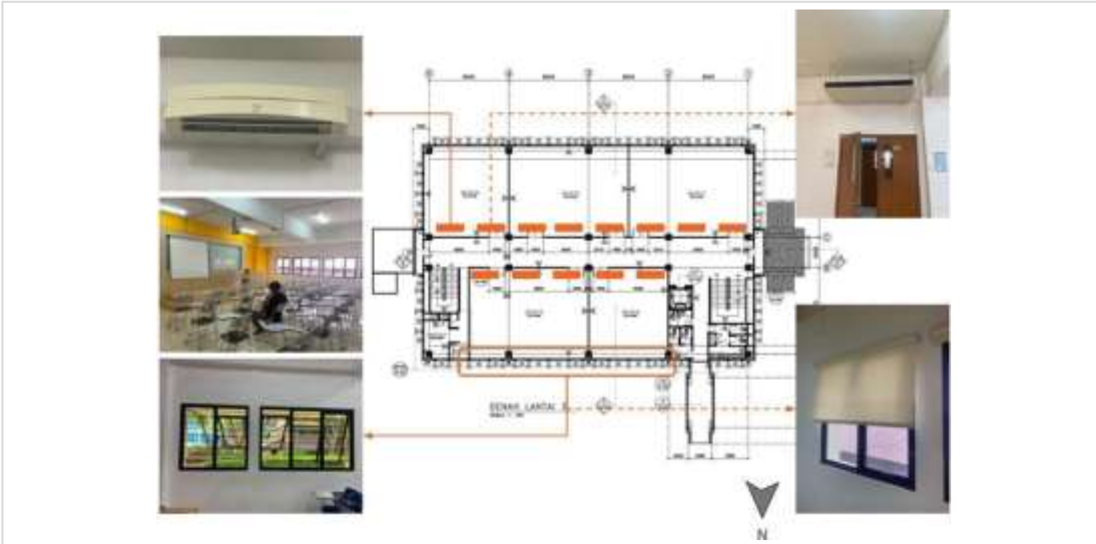


**Figure 2.** Existing integrated learning building air conditioning system

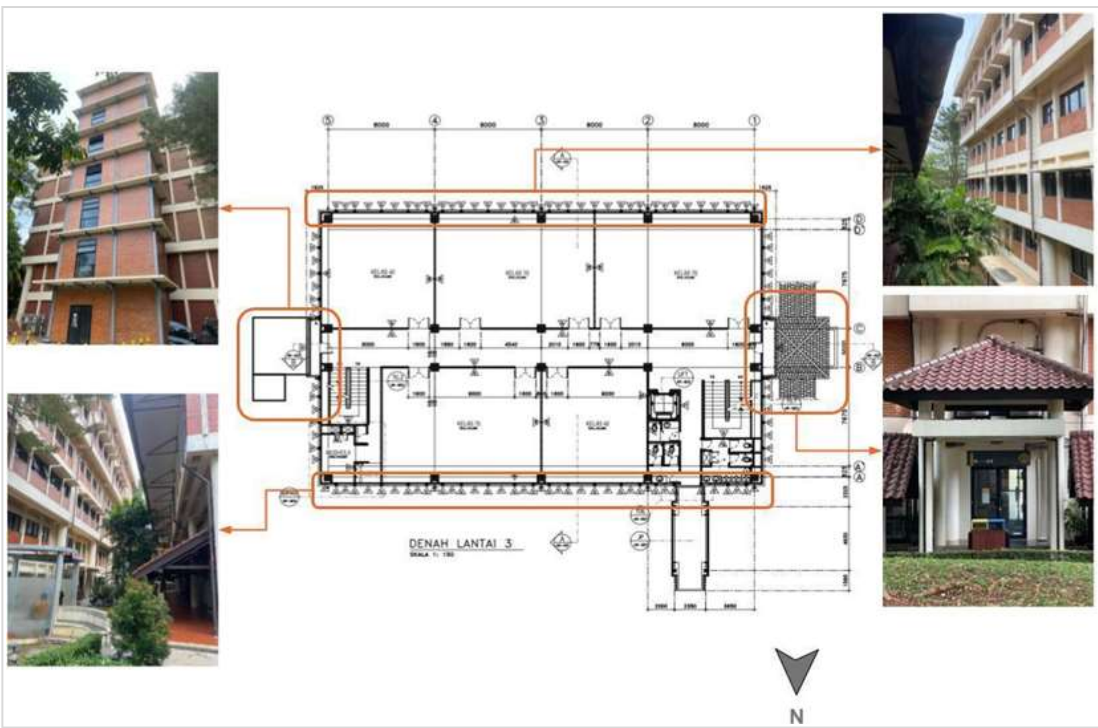


**Figure 3.** Existing integrated learning building heat avoidance system

The observation data shows that Integrated Learning Building in air-conditioned and non-air-conditioned state has minimal temperature difference with the outdoor temperature that is higher than the thermal comfort standard. Optimization of the current heat gain reduction system should be done to minimise cooling energy usage.

Existing OTTV calculation

The existing Integrated Learning Building OTTV calculation is 31.49 W/m$^2$ (table 4). The wall conduction OTTV value is affected by the material's solar absorption factor and U-value, where a layered terracotta wall is slightly higher than a yellow-painted wall. The window conduction calculated U-value of the glass material is 5.80. As a result, window radiation has the most significant value, with the WWR of the north and south façades calculated as smaller than the east and west façades.

**Table 4.** Existing OTTV calculation

| Orientation | Wall conduction ($W/m^2$) | Window conduction ($W/m^2$) | Window radiation ($W/m^2$) | A ($m^2$) | Total OTTV ($W/m^2$) |
|---|---|---|---|---|---|
| North | 12.64 | 4.78 | 13.84 | 821.89 | 31.49 |
| South | 12.40 | 6.06 | 13.09 | 813.55 | |
| East | 12.71 | 1.48 | 4.23 | 451.32 | |
| West | 13.82 | 0.22 | 1.39 | 451.32 | |

As calculated, the OTTV value of Integrated Learning Building's existing heat avoidance system differs slightly from the acceptable standard namely 35 $W/m^2$, which can be improved to minimise heat gain and cooling energy. Passive design intervention of the existing condition by adding insulation and window glazing material.

Insulation material OTTV calculation

OTTV calculation of the insulation materials shows that a lower thermal conductivity value results in lower heat gain (table 5). Therefore, additional insulation material has lower U-values than the existing building envelope, with a range of 0.99-1.01. recycled textile and paper, bagasse, and polyester as an additional interior insulation has total U-value of 0.15, 0.26, and 0.23 respectively.

**Table 5.** Insulation material calculation

| Material | Conductivity (W/mK) | Total U-value ($W/m^2K$) | OTTV ($W/m^2$) |
|---|---|---|---|
| Recycled Textile and Paper (0,2m) + Gypsum Board (0,12m) | 0.04 | 0.15 | 28.58 |
| Bagasse Insulation (0,12m) + Gypsum Board (0,12m) | 0.06 | 0.26 | 28.95 |
| Polyester insulation (0,2m) + Gypsum Board (0,12m) | 0.08 | 0.23 | 28.85 |

The insulation material is applied as additional layers on the interior part of all façade areas of the Integrated Learning Building. Recycled textile and paper insulation have the lowest conductivity and OTTV value (28.58 $W/m^2$), followed by polyester (28.85 $W/m^2$), and bagasse (28.95 $W/m^2$).

Window glazing material OTTV calculation

Existing window glazing has a shading coefficient and U-value of 0.05-0.21 and 5.8, respectively. Table 6 shows that the window glazing intervention of Clear IGU has the lowest OTTV value, 27.80 $W/m^2$ which is 3,69 $W/m^2$ lower than building's existing calculation. Reflective and PVB laminated glass has a similar result to OTTV due to similar U-Value, namely 29.54 $W/m^2$ and 29.76 $W/m^2$.

**Table 6.** Window glazing material calculation

| Window glazing type | Window shading coefficient | Total U-value ($W/m^2K$) | OTTV ($W/m^2$) |
|---|---|---|---|
| Reflective glass grey 6 mm | 0.51 | 5.6 | 29.54 |
| Laminated glass - Translucent PVB 6 mm | 0.76 | 5.8 | 29.76 |
| Insulating Glass Unit (IGU) - Clear Low-E 10 mm | 0.79 | 2.1 | 27.80 |

Clear IGU/Double Glass is a manufactured glass made of two or more glass panels with air voids between the glass layers, resulting in the lowest U-value (Lestari and Alhamdani 2014). The radiation that enters the building becomes smaller than single glass due to the presence of a vacuum that acts as an insulator (Halida Ibrahim and Candra Dewi 2020). However, it has the thickest glass compared to reflective and PVB laminated glass.

Energy usage estimation

Table 7 compares the energy usage percentage of existing conditions with additional insulation and window glazing intervention. The comparison of additional insulation materials shows that the lowest energy used in the cooling system is obtained from recycled textile and paper insulation (table 6). The total energy consists of cooling, cooling fan, cooling pump, equipment, lighting, hot water, and cooking where minimizing cooling energy affects total energy. However, the cooling energy percentages are insignificant from the existing material, with only a 0.09% difference. Calculation of window glazing intervention shows that reflective glass has the lowest energy use among other glass materials, with a 0.49% difference from the existing glass material.

Comparison of existing and intervention performance

From the comparison of passive intervention strategies across the materials, recycled textile, and paper insulation and clear IGU Low-E glass has the lowest OTTV result, which is 28.58 W/m$^2$ and 27.8 W/m$^2$, respectively (table 7). The energy usage percentage shows that recycled textile, paper insulation, and reflective glass have the lowest energy percentages, namely 24.08% and 24.52% (table 7). The low energy percentage is because clear IGU Low-E glass and recycled textile and paper insulation have the lowest U-value, 2.1 and 0.15, compared to the other materials. However, the window shading coefficient of clear IGU Low-E is the highest among reflective and PVB laminated, thus resulting in only 24.52% energy usage, which is higher than reflective glass.

**Table 7.** Comparison of existing intervention performance

| Design strategies | U-value (W/m$^2$K) | Window shading coefficient | OTTV (W/m$^2$) | Cooling energy (kWh/m$^2$/Year) | Total energy (kWh/m$^2$/Year) | Cooling energy usage Percentage | Energy saving percentage |
|---|---|---|---|---|---|---|---|
| Existing | Wall (0.99 & 1.02), Window (5.80) | 0.85 | 31.49 | 23.50 | 94.48 | 24.87% | - |
| Recycled textile and paper Insulation | 0.15 | - | 28.58 | 22.40 | 93.00 | 24.08% | 0.79% |
| Bagasse insulation | 0.26 | - | 28.95 | 22.50 | 93.13 | 24.16% | 0.71% |
| Polyester insulation | 0.23 | - | 28.86 | 22.50 | 93.12 | 24.16% | 0.71% |
| Reflective glass grey 6 mm | 5.6 | 0.51 | 29.5 | 22.79 | 93.47 | 24.38% | 0.49% |
| Laminated glass - Translucent PVB 6 mm | 5.8 | 0.76 | 29.7 | 23.20 | 94.06 | 24.66% | 0.21% |
| Insulating Glass Unit (IGU) - Clear Low-E 10 mm | 2.1 | 0.79 | 27.8 | 23.01 | 93.84 | 24.52% | 0.35% |

The comparison of energy saving of additional insulation material and window glazing intervention shows slight differences from the existing cooling energy usage. To raise the possibility of energy saving, combination of both material intervention is done. Recycled textile and paper insulation material and clear IGU Low-E glass reduce most OTTV and provide the highest energy saving. The materials are applied and calculated compared to Integrated Learning Building's existing calculation.

Passive intervention strategies through material recommendation

Passive intervention strategy through the material in Integrated Learning Building using recycled textile and paper as insulation and clear IGU Low-E as window glazing show high OTTV value reduction of 6.6 W/m$^2$. However, the energy savings only account for 1.14% lower than the existing calculation (table 8).

**Table 8.** Passive intervention strategies through material recommendation

| Design strategies | U-value (W/m$^2$K) | Window shading coefficient | OTTV (W/m$^2$) | Energy saving percentage |
|---|---|---|---|---|
| Existing | Wall (0.99 & 1.02), Window (5.80) | 0.85 | 31.49 | - |
| Recycled textile and paper Insulation + (IGU) - Clear Low-E 10 mm | Wall (0.15) Window (2.1) | 0.79 | 24.89 | 1.14% |

The OTTV result shows heat gain from facade walls; however, factors such as roofs that also receive heat are not calculated. Therefore, a lower OTTV value does not always imply lower cooling energy consumption. From the EDGE energy usage estimation, significant energy savings can be achieved through natural ventilation and cooling system technology, while this study only changes the façade's materials. However, in terms of a passive cooling system, the observation of wind velocity in integrated learning building shows that it cannot depend on wind ventilation to minimise energy, which leads to high use of air conditioning. Thus, a possible improvement for the building's passive strategies is through façade material that can maximise the air conditioning cooling load.

## Conclusion

Following the literature review and EDGE software simulation, insulation and glazing materials are compared from U-value and Shading Coefficient values. Polyester, Bagasse, and Recycled textile and paper are the materials with the lowest conductivity and density values. Reflective glass, PVB laminated glass, and Clear IGU Low-E are the materials with the lowest U-value and Shading Coefficient.

This study shows that the combination of recycled textile and paper insulation and clear IGU Low-E window glazing has an OTTV value of 24.89 $W/m^2$. Based on Indonesian National Standard (SNI 6389:2020 2020) this number should be lower than 35 $W/m^2$. The cooling energy usage shows 1.14% energy consumption lower, which has not achieved the 5% reduction target. On the theoretical basis of heat gain and cooling energy estimation calculation, this study recommends combining additional insulation material and window glazing strategies, namely recycled textile and paper insulation and clear IGU Low-E glass in Integrated Learning Building, to reduce heat gain and minimise cooling energy. According to OTTV and EDGE energy estimation, such a combination significantly reduces OTTV and energy savings. However, the total energy percentage is not significantly different from the existing material. Practical consideration of these materials needs to be studied further, such as the durability of recycled materials, humidity factor, structural load, and flammability. Further studies can also be done on other building envelope parts, such as roof insulation, external shadings, and reflective exterior walls. Another calculation method that includes continuous heat exchange using PCMs as a building envelope can be explored as a comparison.

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**Muthiah Hakim Hadini** contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

**Ova Candra Dewi** contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

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