https://doi.org/10.1051/bioconf/20236205001

Retrofit design strategies for educational building through shading and glazing modification

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Abstract. Passive design strategies play a significant part in improving the performance of retrofitting buildings. This especially applies to educational buildings that demand a high quantity of energy, not only due to various types of rooms and occupants but also operational needs of space regarding heating and cooling. Besides, the energy performance of the buildings will gradually decrease due to natural factors, such as aging and extreme weather conditions. Through retrofit design strategies, this study explores various scenarios on educational building facades by modifying shading and glazing properties. In this regard, several scenarios are proposed such as an addition of vertical fins, changing of glazing properties, and a combination of both. This study results in, *first*, the reduction of the Overall Thermal Transfer Value (OTTV) by 6,04 W/m^2 and *second*, the reduction of indoor temperature by 0,835°C from the existing to a proposed combination scenario. This study ultimately enables the architects in determining the optimum retrofitted facade strategy for educational buildings in the tropical climate.

1 Introduction

In Indonesia, the use of electricity in the commercial building sector dominates by 87.3% [1]. Rather than constructing new buildings that definitely consumes high cost and labor, there is an opportunity to improve existing building efficiency by retrofitting building components. However, as buildings ages, the energy performance of the building will gradually decrease. In order to prevent that happen, retrofitting becomes one alternative to increase building performance [2]. In this regard, retrofitting has less impact on the environment in terms of waste and materials. Public buildings such as educational buildings utilize the third-highest amount of energy [3] because of the various office, laboratory, and space cooling behaviours [4]. This is also a result of the growth of the economy and society, which has created greater demands in terms of a comfortable environment. Thermal comfort range for Indonesians is typically 25°C ± 1°C and 55% ± 10% relative humidity [5], and this makes air conditioning massively supplied in indoor spaces. In a tropical region, building facades facing East and West receive plenty of sunlight all year long. Solar exposure was also received by both North and South orientations for a period of the year [6]. Therefore, it is necessary to have a passive design study that can reduce the heat gain from solar radiation to lower the room temperature. However, studies that specifically discuss the application of passive design to lower the room temperature are still small. This paper aims to explore the optimal scenarios in a retrofitted educational building. The result

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is expected to improve occupant comfort and assist the architects in determining appropriate building retrofit. This study is formulated into several sections. Section 2 explains energy efficiency by retrofitting the facade, Section 3 introduces the framework for the passive design. Section 4 discusses the optimum facade strategy for several scenarios. Scenario 1 the addition of vertical fins, scenario 2 the change of glazing properties, and scenario 3 the combination of the addition of vertical fins and the change of glazing properties, and Section 5 draws the conclusions and future research.

2 Literature review

This study focuses on the passive design of a retrofitted educational building. Three major subjects such as energy efficiency through retrofit building, facade design as passive strategies, and heat transfer in the building envelope will comprehensively be discussed below.

2.1 Energy efficiency through retrofit building

One of the efforts to enhance energy efficiency of both old and new buildings is by retrofitting, which is a technical intrusion to optimally utilize its energy [7]. The goal is the improvement of the building envelope, such as walls, roofs, floors, and façades which has the greatest influence on cooling loads. There are three categories that make up the energy retrofitting such as building envelope, mechanical and electrical systems [8]. Despite the fact that it requires a complex process due to the expenses, facade retrofit is considered as an answer to the problem of aging building stock.

2.2 Retrofit strategies on building facade

As the global energy crisis worsens, it is crucial to ensure and improve indoor thermal comfort while lowering energy usage. Therefore, design considerations such as various shading systems are needed to avoid direct solar exposure. In Singapore, there is a research about the effects of horizontal shading, resulting in the temperature reduced by 0.61 to 0.88 °C [9]. Another study applying the vertical shading in Malaysia resulted in the reduction of average 0.73 °C [10]. Additionally, the glass reflects a significant percentage of the sunlight, which needs a selective coating used [11]. Therefore, the shading and glazing are particularly significant in lowering the amount of heat.

2.3 Heat transfer in building envelope

Conduction, convection, and radiation are three heat gain and loss modes that influence building envelope [8] which is made up of opaque materials, as well as transparent features such as windows [12]. As a result, heat from solar radiation is the most visible load carried by the building envelope, influencing the thermal experience of the occupants. Heat transfer can be calculated in formula (equation 1) [13]. Meanwhile, to calculate the temperature difference, using the formula (equation 2).

$$Q = U \ x \ A \ x \ \Delta T \tag{1}$$

$$\Delta T = \frac{Q}{U \ x \ A} \tag{2}$$

Q = cooling load, amount of heat in from the side of the building (W, J/s, Btu/h)
U = U - Value of materials (W/(m^{2}K), Btu/(ft^2 h °F))

A = area exposed to heat (m^2, ft^2)
ΔT = sensible temperature, the difference between the temperature indoor and outdoor

Architects need to innovate crucial envelope components by a measurement of the external heat gain, known as OTTV, which shall not exceed 35 W/m^2 [14]. Transmittance, reflectance, and emittance of glass expressed by Light Transmittance (LT), Shading Coefficient (SC), and U-factor (U-value) [15]. The thermal transfer value (OTTV) for each wall plane can be calculated using equation 3 [14]:

$$OTTV = \alpha \{(UW(1 - WWR)\} \, x \, TDek + (SC)(WWR)(SF) + (Uf)(WWR) \, x \, \Delta TEq)\} \quad (3)$$

α = Absorbance of Solar Radiation
TDek = Equivalent Temperature Difference (K)
Uf = Fenestration thermal transfer (W/m^2.K)
Uw = Opaque wall thermal transfer (W/m^2.K)
SF = Solar Factor (W/m^2)
SC = Shading Coefficient
WWR = Wall to Window Ratio
ΔT = Temperature difference design between the outside and the inside

The following equation [11] is used to calculate the OTTV of the entire outer:

$$OTTV = \frac{\alpha\{(Uw(1-WWR)\}x \, \Delta Teq) + (SC)(WWR)(SF) + (Uf)(WWR)x\Delta TEq)\}}{A} \quad (4)$$

An = wall area that exposed to heat (m^2, ft^2)
OTTVn = the overall thermal transfer value of wall

3 Method

This study proposes three phases to explore the optimal scenario regarding room temperature in a retrofitted educational building as presented in Fig.1.

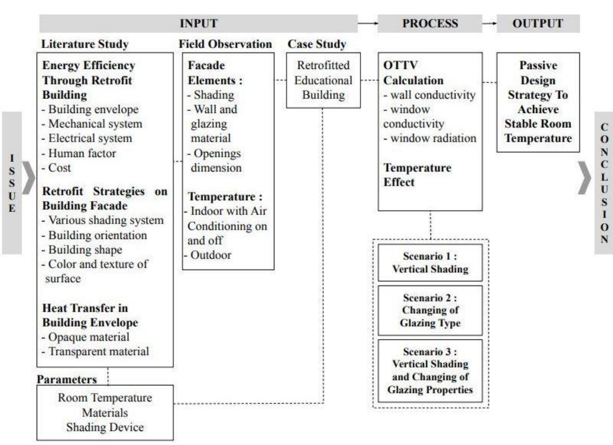

Fig. 1. Research framework

Source: Author's

Fig. 2. The case study

Source: Author's documentations

3.1 Input

Started with literature study, followed by field observation on facade elements, on site measurement of temperature and relative humidity on March 30, 2022 at 10.20 am until 12.32 pm. A data logger is used to measure the temperature (°C) and relative humidity (RH). Fig. 2 shows that the building consists of six floors with the openings mostly in the North and South.

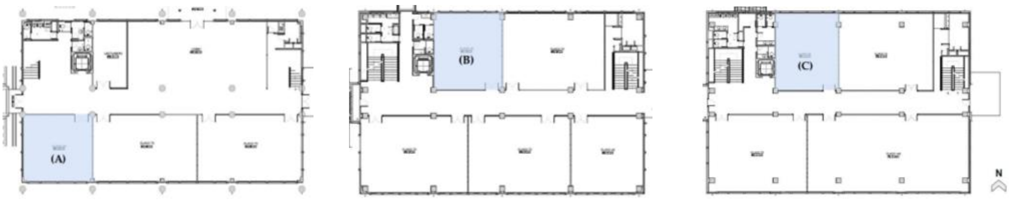

Fig. 3. The retrofitted educational building and the selected classrooms A, B, C
Source: Author's documentations

The selected classrooms show on Fig. 3; classroom A facing South on the 1st floor, classroom B on the 3rd floor facing North, and classroom C on the 5th floor facing North. Classroom C has the highest temperature 29,58°C and RH 64,35% followed by classroom B.

3.2 Process

Solar heat received on each facade measured with equation (3) and entire facade using equation (4). First, the OTTV calculation is carried out on the existing building. Second, the OTTV calculation is carried out with Scenario 1 by addition of vertical fin, Scenario 2 by changing of glazing properties, and Scenario 3 by the combination of vertical fin and changing of glazing properties. The temperature effect for Scenario 1 refers to a study due to the similar geographical condition [10]. For Scenario 2, use equation (1) and equation (2). Scenario 3 uses the sum of scenario 1 and scenario 2 temperature.

3.3 Output

The result of the OTTV calculation and the temperature effect between existing and proposed scenarios will be comparatively analyzed. The result will indicate the optimal scenario on facade modification to reduce energy consumption for cooling.

4 Result and discussion

4.1 OTTV calculation of existing educational building

Although horizontal shading has been put on the North and South, due to the large surface area of the clear glass, the OTTV are high. The South has the highest OTTV by 37,01 W/m^2, followed by the North by 36,73 W/m^2 because the number of openings on the South is more than others. OTTV of the West is 26,11 W/m^2, and the East is 23,71 W/m. Total OTTV of the building is 32 W/m^2.

4.2 Retrofit building strategies

Several scenarios are needed to decrease the OTTV, such as using additional shading and changing the glazing properties. Furthermore, the combination of using additional shading and changing of glazing properties will also be investigated. Therefore, there will be three scenarios in this paper.

4.2.1 Scenario 1: vertical fins

The vertical fins have a slope angle of 30°, 100 cm width and 420 cm height, and the distance is 150 cm. The vertical fins are placed in the North and South at the existing horizontal concrete shading which reduces sunlight, but still considering the ability to see the scenery outside as shown in Fig. 4. However, the OTTV calculation results for Scenario 1 indicates that the South has the greatest OTTV value by 31,83W/m^2 because the surface area is the largest compared to the others. The total OTTV decreased by 3,27W/m^2 from the existing OTTV which is 32,27W/m^2 to 29W/m^2.

detail

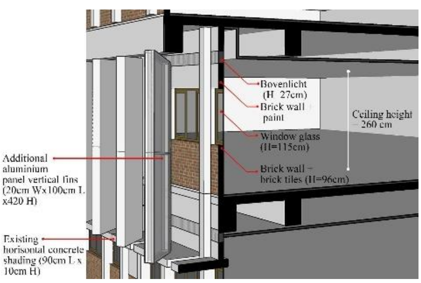

Fig. 4. Scenario the addition of fins on the facade
Source : Author’s documentations

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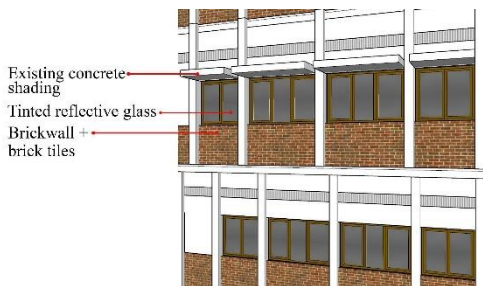

Fig. 5. Scenario 2 The changing of glazing
Source : Author’s documentations

4.2.2 Scenario 2: changing the glazing properties

Scenario 2 is changing the glazing properties from the clear glass to the reflective glass with grey color (tinted) which is the same with the glass on the West and East as shown in Fig. 5. The glass has a Shading Coefficient *(SC)* of 0.51, meaning the less the incoming radiation light. The total OTTV decreased by 4,25W/m^2 from the existing OTTV 32,27W/m^2 to 28,02W/m^2.

4.2.3 Scenario 3: combination of vertical fins and changing the glazing properties

Scenario 1 the use of vertical shading and Scenario 2 the change of glazing properties have a substantial impact on the OTTV. Therefore, Scenario 3 is created to see the possibility of a better impact by incorporating vertical fins and replacing the glass as shown in Fig. 6.

Fig. 6. Combination of Vertical Fins and Changing the Glazing Properties
Source: Author's documentations

Scenario 3 indicates the OTTV of the South decrease 9,59W/m^2 and the North decreased 10,32 W/m^2. The total OTTV decreased by 6,04 W/m^2, from the existing OTTV 32,27W/m^2 to 26,23W/m^2.

4.3 Temperature effect on different scenarios

- The resulting temperature refers to a study in the similar geographical condition done by Gimat & Sulaiman [10]. The study shows that vertical shading reduces the temperature by 0.73°C. Therefore, the effect of vertical shading can reduce the indoor temperature by 0.73°C.
- The effect of temperature on reflective glass is generated by calculating the heat transfer of the surface. We calculate both the North and South because they have a large surface area. The OTTV for the North is 26,69 W/m^2 and the South is 27,42W/m^2. Table 1 indicates the building information as follows:

Table 1. The North and South building information

	North	South
Wall	714 m^2	720 m^2
Window	128,23 m^2	165,6 m^2
U - Value wall	3,56 W/m^{2}K, consists of: External surface, brick wall, internal surface 3,56 W/m^{2}K x 0.85984 kcal/(h m^2 °C) = 3.0610304 kcal/(h m^2 °C)	
U - Value window	5,6 W/m^{2}K (tinted reflective glass) 5,6 W/m^{2}K x 0.85984 kcal/(h m^2 °C) = 4,81504 kcal/(h m^2 °C)	
Temperature (outdoor)	31,35 °C	
Temperature (indoor)	a (requested temperature)	

The temperature calculation includes the heat transfer through wall and glass areas on the North and the South are listed on Table 2. Equation (2) is used to calculate the temperature.

Table 2. Temperature calculation of the North and South

	Heat transfer through wall $\Delta T = \frac{Q}{U\ x\ A}$	Heat transfer through window	Temperature $\Delta T = \Sigma \Delta T$
North	(31,53 - a) = 26,69 / (3.0610304 x 714)	(31,5 - a) = 26,69 / (4,81504 x 128,23)	= 0,012 + 0,043 = 0,055 °C
	ΔT = 0,012	ΔT = 0,043	
South	(31,53 - a) = 27,42 / (3.0610304 x 720)	(31,53 - a) = 27,42 / (4,81504 x 165,6)	= 0,016 + 0,034 = 0,05 °C
	ΔT = 0,016	ΔT = 0,034	

From the calculation, the temperature of the North is 0,055 °C and the South is 0,05 °C. Therefore, the total temperature for both sides is 0,105°C.

- The temperature value for Scenario 3 is generated from the sum of temperature in Scenario 1 0.73°C and Scenario 2 0,105°C. The total temperature decrease is 0,835°C.

Table 3 indicates Scenario 3 has the lowest OTTV of 26,23W/m^2 as shown in Table 3 and resulted in 30,6°C of indoor temperature. Followed by Scenario 2 with the OTTV of 28,02W/m^2 and resulted in 31,4°C and Scenario 1 with OTTV of 29W/m^2 and resulted in 30,8°C. The findings show that changing the glazing type has a significant effect on lowering the OTTV than the vertical fins shading.

Table 3. Comparison of OTTV and Temperature

	Existing	Scenario 1: Vertical Fins (Shading)	Scenario 2: Changing of Glazing Properties	Scenario 3: Combination of Vertical Fins and Changing of Glazing Properties
OTTV North	36,73 W/m^2	31,31 W/m^2	29,67 W/m^2	26,69 W/m^2
OTTV South	37,01 W/m^2	31,83 W/m^2	30,26 W/m^2	27,42 W/m^2
Total OTTV	32,27 W/m^2	29 W/m^2	26,02 W/m^2	26,23 W/m^2
Temperature	31,53°C	30,8°C	31,4°C	30,6°C

However, further consideration is needed regarding the waste of existing glass because the retrofitting idea is having less impact on the environment in terms of waste and materials. Moreover, the cost of retrofitting may raise the question of whether this option is practical given the range of construction approaches available, even though the vertical fins and changing the glass type result in lower temperatures. As for the shading in the form of vertical fins, the external shading structure option provides ease of construction and low cost [16] which is in accordance with the low cost factor of retrofitting. Another possibility of future development of the shading device is to develop a shading device that can respond to the sun movement [17] and to improve interaction with electric lighting systems which yield a greater lighting energy savings [18].

5 Conclusion

Indonesia is one of the countries in the tropical region, in which buildings are exposed to intense sun radiation. Therefore, the proposed facade retrofit scenarios as passive design strategies were studied in terms of the optimal scenario regarding room temperature. The Scenario 3 combination of vertical fin and changing glazing properties is the optimal scenario. OTTV value was reduced by 6,04 W/m^2 and decreased the indoor temperature by 0,835°C. To reach the comfort level of 25°C, the building still needs to use an active cooling system. Despite all of the scenarios tested on building facades, active cooling is still required to achieve the appropriate temperature. However, a thorough cost analysis for the retrofit solutions needs to be done and overall building energy reduction values are required which can be suggested as a future follow-up investigation. The findings could be useful for architects to determine the appropriate facade strategy in the early design stage to improve the energy performance of existing buildings and contribute to the development of facade retrofit solutions.

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