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Optimization of skylight composition for cooling and lighting energy efficiency (Case Study: G-building ITATS)

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Abstract — *The increasing concern on sustainable and environmentally friendly design over the past three decades has encouraged architects to look back at their own tradition in creating built environments. They realize that building should bear connection with place. In the tropics, buildings should respond to the climate. High solar radiation and temperature are particularly critical from the point of view of architecture design. Multi-storey buildings are especially vurnarable as far as heat is concerned. Greater area of the facade is exposed and will be the main source of heat input, which in turns will have an impact on energy use and comfort. Careful considerations on the design of envelope and roof are proved to be of advantage in terms of energy performance.*

This research aims to find the optimum composition of skylight and opaque roof for atrium of middle-rise wide span buildings, especially in relation to cooling energy and daylighting. Sample of middle-rise office buildings in Surabaya were taken random. Simulation was conducted to predict energy performance for cooling energy and daylight distribution of the building. Energy performance of the buildings were found to bear some relations to the percentage of fenestration roof in atrium.

Keywords— Atrium, Cooling Energy, Daylight, Energy Efficient, Middle-rise, Tropics.

I. INTRODUCTION

Indonesia is a develop country with high density of population. In Indonesia, the biggest energy uses comes from commercial sector such as mall, hotel, and office building. Commercial building consumes about 52% energy of total energy use and 60 % of the energy use allocated for air conditioning system. High temperature, humidity and solar irradiance are the problem of thermal comfort in warm humid country like Indonesia. About 55% of heat gain in the building comes from building façade, it means there'll be significant saving of energy use when architect design the building façade carefully. Climate should be considered when the architect's design any building [1].

Energy consumption of building can be cut by a good design, compact massing and landscaping, perfect façade material choice, and climate must be a factor to determine all of that. Tropical climate especially warm humid area, has a lot advantages and challenges for the architect [1&2]. Indonesia for example, it's tropical country with warm humid character. Sun is shining all year in this country , it can be an unlimited energy for us, and at the same moment can be source of heat gain in the building which is make the cooling load higher and make the energy consumption of air conditioning increase. Overheating external façade can be happen because of wrong choice of façade material. Architect supposed to be careful when design great opening in façade or atrium because poor thermal performance of fenestration wall or roof [3]. Most of fenestration envelope material such as clear glass, fiber glass, or poly carbonate has huge u-value and little decrement factor. It means the material accept a lot of heat and transfer it a lot in to the building. This is not good.

Previous research said octagonal building consume less energy compared by another building form in the same volume [4]. Another research tell more compact the design of the building cooling energy consumption will be less too [5]. Bulky building consumes less cooling energy than multiple building in same volume.

Day lighting can be another problem in bulky building design. Usually day light transmit only in to the perimeter area, need more strategies to enter the sun light into the building such as light shelf, atrium, high area of opening, light pipe, and so on. The common and simplest solution to enrich the penetration of sun light of the building is creating atrium and skylight. Roof is one of building envelope which is transfer a great heat into the building

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[6], so it's being important to design carefully and consider about material composition for atrium roof.

II. METHODOLOGY

This research aims to analyze composition of roof material especially for atrium in wide span middle-rise building to optimization cooling energy on it. This research use experimental method with simulation to test the correlation between percentage of fenestration roof and cooling energy consumption. Calculation of cooling load in the building and simulation of each type of heat gain of the building is used to evaluate thermal energy performance of the building

This research will compare some models of atrium roof based on sample has been chosen before. In this experiment there is a base case (the existing model) and modification on percentage of fenestration roof in that atrium. This simulation use software Ecotect 2011. Base case of this experiment is existing model of G building ITATS, atrium with 50% of fenestration roof. Previous research [6] test the building performance with 10%, 20%, 30% and 40% WWR (Windows to wall ratio). This research will use that percentage for fenestration roof.

III. RESULT AND DISCUSSION

G buiding of ITATS is a building used for collage such as office department, Architecture studio and classroom. This building has 4 storey and 4 department ue this building for educational process: department of architecture, civil engineering, product design, and environmental engineering. This building is bulky, it has 31 m wide (fig.1). There are A lot of opening on its envelope so a lot of day light enter the building.

Ground floor of this building used as office of the departments, and communal area. Space under the atrium used as hall. This hall is multifunction, regularly student held exhibition of their work in this hall. Band competition, sport, and fresh student orientation usually held on this place. Fig 2 shows interior and exterior of the G building of ITATS. Varies daylight needed in each function of rooms in this floor. Canteen needs approximately 300 lux of daylight. Office departments need about 400 lux of daylight. Workshop which need high detail work needs 900 lux for lighting

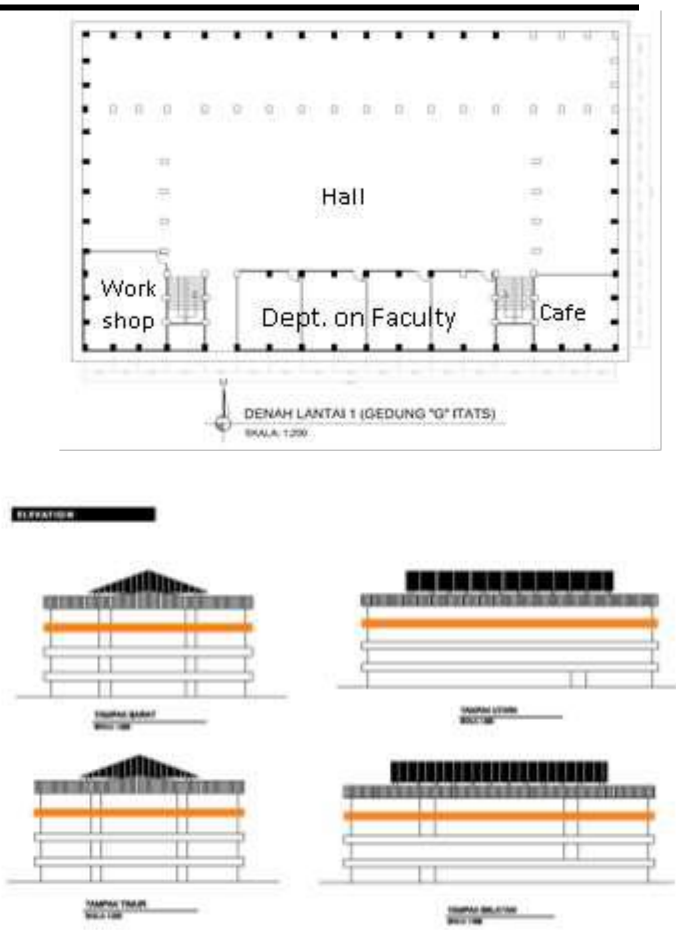

Fig. 1: Plan and elevation of G building of ITATS

1st floor of this building used as classrooms. Level of daylight for this room approximately 400 lux, and for thermal comfort temperature supposed to be in 24-27°C and 40-60% Relative humidity. 2nd floor of this building used for architecture studio. This room needs more daylight for better performance. It needs about 600 lux. There some classrooms and laboratories In this floor which require different amount of daylight. Unfortunately opening design for each room are same. 3rd floor of this building used as product design studio, library, and laboratory. This is the top floor of the building and perimeter room doesn't have any ceiling. On top of the perimeter use concrete roof without any insulation. It makes this floor has the worst thermal performance.

Fig. 2: Interior and façade of the case study

3.1 Composition of Skylight and Daylight Performance

Generally the amount of daylight which is enter the building decrease proportionally by the decrease of the percentage of fenestration roof on the atrium, but the total of daylight are not really different (table 1). This happen because the WWR of each room are wide enough so each room have a good daylight distribution.

Table.1: Daylight Factor on G building

Floor	Room	Standar DF (%)	Daylight Factor (%)				
			BC	Mod.1	Mod.2	Mod.3	Mod.4
GF	Canteen	4	4.8	4.8	4.8	4.8	4.8
	Office Dept	4	4.7	4.8	4.5	4.3	4.3
	Workshop	9	6.7	6.7	6.7	6.7	6.7
	Hall	4	10.7	10.7	9.0	8.7	7.0
1st	Class room	4	9.0	8.9	8.5	8.4	8.0
2nd	Class room	4	8.7	8.5	8.5	8.3	8.0
	LAB	9	8.5	8.8	8.8	8.0	8.0
	Studio	6	9.0	9.3	9.3	9.0	9.0
3rd	Class room	4	9.0	8.9	8.5	8.4	8.0
	Library	4	9.0	9.8	9.8	9.7	9.5
	Workshop	9	8.7	9.5	9.5	9.3	9.0
Average			8.1	8.3	8.0	7.8	7.5

The data obtained in the base case is the result of field measurements, it does not show too much difference with the simulation results. The lighting on the ground floor looks less than another floor. The higher the floor, the more amount of natural lighting that enters the room. This is reasonable because the higher the floor of the building, the fewer barriers or obstruction around the building can block light from entering the building.

On the ground floor besides being blocked by surrounding buildings, there are also some trees planted not far from the windows so that it reduces the number of daylight. Generally, daylight which enter the rooms in ground floor has fulfill the standard (fig. 3). Lighting at workshops that entered around 600 lux, quite a lot actually, it's just that it is less than the standard requirement for workshops so additional lighting is needed in this room. It is better to add a few light points to help the glassware when needed to assemble goods (add task lighting, not general lighting).

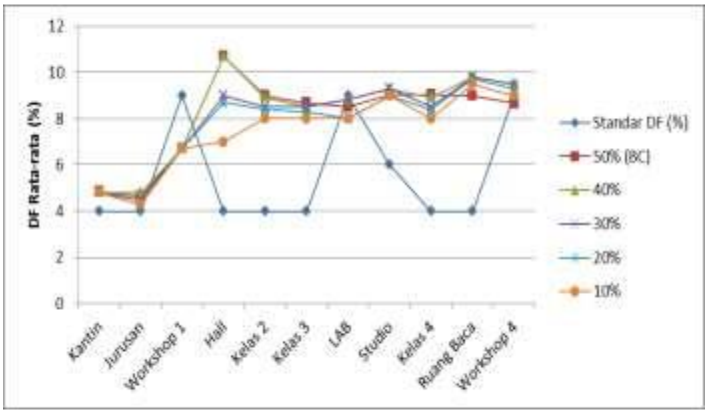

Fig 3: Daylight Factor (DF) in each model

In Hall, the amount of natural lighting entering is still very high even though the use of skylights in the atrium has been reduced, this is caused by:

1. The atrium roof uses a skylight type, so that the incoming sunlight is mostly a direct beam that is strong enough. So even though the amount of small translucent roof still allows more direct light to enter
2. The use of white and glossy ceramics also affects the reflectance of light that has entered. White and shiny layers cause more sunlight to be reflected in the room so that the potential for glare in the room is greater.
3. Open space around the hall (Fig.1) allows the amount of light from the north side and more buildings to enter, moreover other buildings are only on the south and east sides of the building. The north and west sides do not have any obstruction, allowing more sunlight to enter the hall.

Classrooms on 1st, 2nd, and 3rd floor do not experience many changes with a reduction in the percentage of translucent roofs in the atrium. The amount of incoming lighting is almost double the required standard. The good thing is that the lighting distribution on the 2nd floor is evenly distributed so it does not have the potential to cause glare in the room if the building user looks at the window (figure 4). The excessive amount of lighting in this class causes users to have difficulty seeing the presentation on the LCD screen. On the other hand, this classroom is sure to not use lights during the day when the weather is sunny.

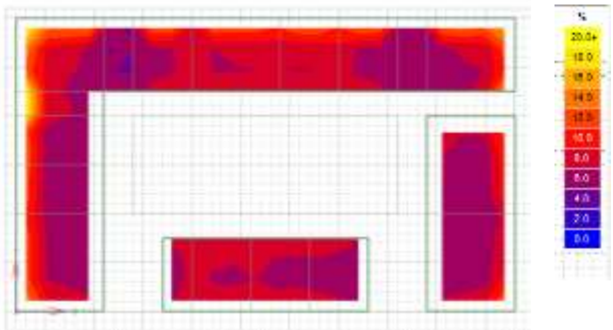

Fig 4: Daylighting distribution on 2nd floor

Fig. 5: Daylighting distribution in LAB on the 3rd floor

Laboratory and Workshops on the 3rd and 4th floors have sufficient amount of lighting. The distribution of natural lighting is fairly evenly distributed in the room (Figure 5 & 6), most of the side near the window, both the outer and near the atrium windows have sufficient lighting. The central area of this room is darker than the surroundings.

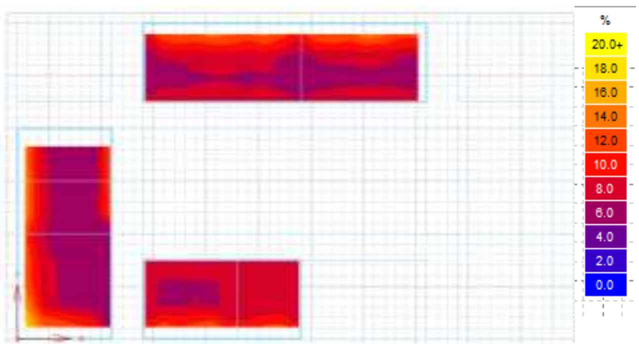

Fig 6: Daylighting distribution in workshop on 3rd floor

From the picture of the distribution of indoor lighting and the simulation results in the graph in Figure 4.3 it can be concluded that the reduction in the number of translucent roofs at the atrium does not have a large effect on the building's perimeter, but gives a significant influence on the room just below the atrium . This happens because:

1. The amount of WWR in a building that is large enough to allow light to enter from the translucent wall. Skylights are not the only source of light in the room in building G
2. Skylights help equalize the amount of light entering the room so that the quality of natural lighting in buildings is also better

3.2 Skylight Composition and Thermal

The cooling energy in building G is far above the standard (Fig.7). To be low energy building, commercial buildings must consume maximum cooling energy of 47kWh / m2 / Year or maximum total operational energy of 200kWh / m2 / Year. Building G consumes 10x cooling energy higher than the standard it should. It can be concluded that the energy performance of cooling in this building is very poor.

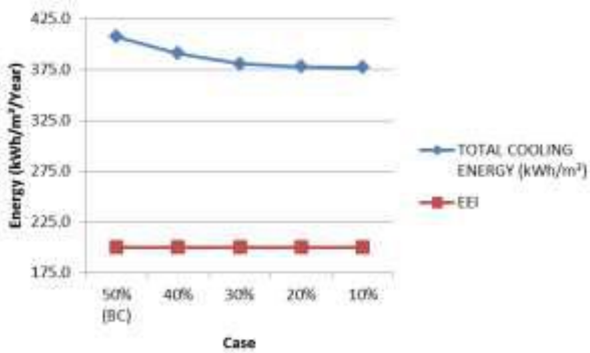

Fig 7. Energy consumption on each case

The amount of cooling energy in this building is caused by large heat propagation into the building. Most of the heat entering the building is transferred through the conduction stream (Fig.8). sQc is conduction heat flow, the heat flow flows from the building envelope that occurs 24 hours. To minimize sQc we have to design the walls and roof carefully. Too many windows on the wall, translucent roofs that are too large in the atrium, high u-value walls and roofs can cause a rise in conduction heat.

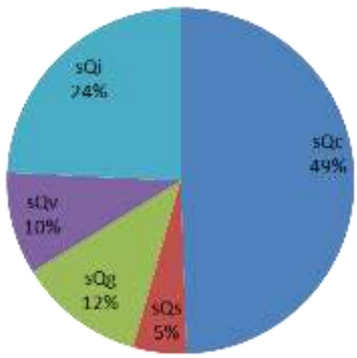

Fig.8: Gain breakdown in base case

sQi is the second highest heat flow from Fig.8. sQi means internal heat gain, heat from electricity and activity in the building. Electricity in this building is divided into three groups: Lighting, Air Conditioning, and electrical equipment. Thus the operational hours are long, the increase in the internal heat of this building increases. Incorrect window design is also the next factor to improve sQi. Actually, there are no windows in this building, only translucent walls. There is no window which means there is no air flow, and the wide area of the translucent wall makes the heat penetrating into the building still occurs and continues to increase again because there is no air flow to dissipate the heat. The only way to create thermal comfort in a windowless building is to use an air conditioning system. This means increased power consumption and internal heat gain.

The third highest type of heat in this building is radiation-induced heat. Irradiance Heat Gain is divided into two:

1. Direct Irradiance Gain (sQg) is radiation that comes and enters the building directly. Usually this type of heat flow occurs on transparent walls and roofs.
2. Indirect irradiance gain (sQs) is the radiation heat gain through an opaque surface. Sun radiation hits an opaque surface, and there are some that are reflected and absorbed. The heat absorbed will be transmitted to the building in a few moments depending on the material lag time

In this building sQg is much higher than sQs. There is a lot of solar radiation coming into this building from translucent surfaces. This atrium has a skylight of 50%, making the amount of direct irradiance that enters the building even higher. To be lower, the composition of transparent surfaces must be reduced. The amount of radiation that hits the surface of the building on the horizontal side is also relatively large.

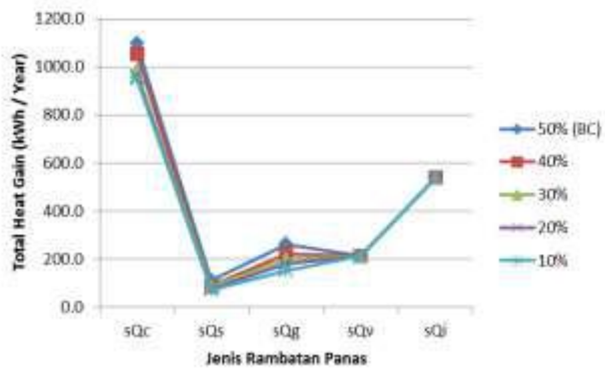

Fig.9: Gain breakdown on each model

sQv is heat that enters due to ventilation, or heat entering the building through the building's air flow (convection). This building does not have a window does not mean it has no air flow at all. All rooms use AC which usually has an exchange value of 2 ACH, so the ventilation obtained by this building comes from this AC system flow. This building uses air conditioning in total, so the ventilation gain of the building is quite low.

Reducing the extent of translucent roofs turns out to have little impact on conduction and radiation heat flow directly into the building (Fig.9). internal heat and conduction heat do not change because the volume of the room and user activity do not change.

Although the amount of cooling load is very high because there are too many transparent fields on the wall, energy must still be used as much as possible on the building without sacrificing thermal or visual comfort in the building. Figure 10 shows a comparison of the inner chamber temperature that can be created by each case for the same outer space temperature. Skylight buildings up to 20% are able to provide lower indoor temperatures than outdoor temperature.

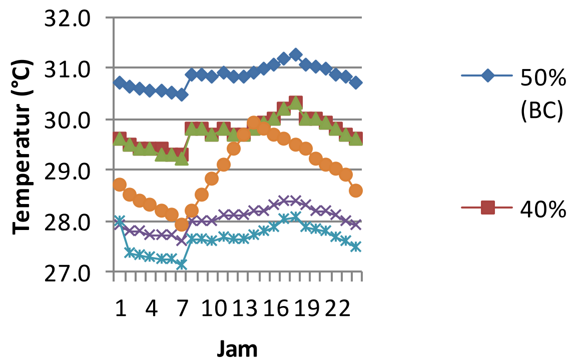

Fig 10: Indoor air temperature G building of ITATS in each case

IV. CONCLUSION

The natural lighting performance in the G building of ITATS is quite good, but the thermal performance of the building is very bad. Many transparent fields on the wall make this building include too much heat. Clear glass used in windows also has poor quality for thermal so that the energy needed for the building is very large. Reducing the number of transparent roofs at the atrium up to 20% can help reduce cooling loads without reducing visual comfort in the building.

The use of blinds or curtains on the window is highly recommended, especially in classrooms because the lighting needs there are not too high while the amount of light entering is quite large. Although the percentage of small skylights that enter the class is still very large due to the large number of openings in the wall.

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