Atrium Form and Thermal Performance of Middle-Rise Wide Span Building in Tropics

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Abstract. Energy use of a building usually increases as long as an increase of the surface area of the envelope. Heat transfer of the building through the envelope can be reduced by perfect design. Right building form and materials can reduce the heat transfer. Middle rise building has a quite high surface area of the roof, and in a tropical country, roof accepts the highest irradiance thus bring much heat to the building. In the same volume, compact building form is better in thermal performance, but large building usually need an atrium to help the natural lighting in the room. The atrium uses transparent roof or skylight. This transparent roof definitely can increase the heat gain to the building significantly. So this research aims to find the best form of atrium roof in middle-rise and large span building in the tropical region. This research aims to analyse the thermal performance of middle-rise and large span buildings and its relation to the form of the atrium. A sample of middle-rise office buildings in Surabaya was taken randomly. The simulation was conducted to predict thermal and cooling energy performance. Energy performance of the building was found to bear some relations to form of roof.

1. Introduction

One indicator of success in designing energy-efficient buildings is the achievement of optimisation of energy-saving lighting and ventilation in buildings. Moreover, the primary parameter that is crucial to the optimisation of energy is the total energy use of the building’s operations for one year.

The most significant energy use in the building sector in Indonesia is in energy cooling and the energy for lighting. The biggest cooling energy is due to the design of the building envelope which is not suitable for the tropics. Previous research shows that buildings with octagon form consume the least cooling energy, this also supports the Crawford [1] statement which states that the more compact the design of a mass of the building, the smaller the energy consumption of cooling. Another problem if using a large model is natural lighting that cannot reach the interior of the room. For this reason, wide-span buildings usually add skylights to the atrium so that natural light can enter the building. For the tropics, building envelopes that affect thermal comfort in a building consist of walls in each orientation and roof, therefore in addition to the composition of materials and openings on the walls, it is also necessary to pay attention to the roof design of the building.

The problem that often arises for building designs with lots of openings is the solar pass that comes in to make the heat gain in buildings increase, and the operational energy for cooling eventually increases as well. Especially for the roof, this horizontal surface side receives the largest radiation all year round compared to the other side of the building envelope, so it needs to be set the standard percentage of skylights in the atrium.
2. Literature Study

2.1 Energy Efficient Building
There are five basic requirements of a building. First, buildings must be made based on local
development culture; second, buildings must be able to control the internal environment for the
convenience of building users. Third, buildings must support users' social activities, fourth, they must
be able to react to external forces, such as traditional building structures that can withstand
earthquakes or land shifts or designs that are able to address climate problems. Fifth, buildings meet
the first to fourth requirements with reasonable and economic costs in the use of energy, both
embodied the energy and operational energy [2]. Energy-efficient buildings are buildings that have an
energy balance [3-4]. The factors include:
- Optimising the use of high internal heating load
- Avoid overheating
- Protection from solar irradiance and glare
- Optimisation of natural lighting
- Flexibility in replacement and maintenance of equipment in buildings without excessive energy
consumption

2.2 Building Form and Energy
Yeang [5] say that the shape of the building will affect the energy used in buildings. Rectangular and
north-south oriented structures will be better because the east and west sides get substantial radiation,
especially in the morning and evening so this side is attempted to have a small surface area. Szokolay
[6] explains that for buildings in Jakarta, the broad north side will receive far greater radiation because
this year the side will receive greater radiation than the south side. The best form of the building is a
form that has a low surface area so that the field that receives radiation and propagates heat by
conduction will be smaller. Depecker [2] says that the shape will be very influential with the cooling
load, the more fat the building and the more compact, the lower the cooling capacity will be. According to Heerwagen and Ling [7, 8], changing the shape by minimizing incoming radiation will
have a more significant effect on reducing cooling load compared to adding wall insulation, as in
Noerwasito's study which shows that buildings with a higher ratio of floor area to circumference small
will have a lower cooling load so that jagged structures will be better than square buildings with
straight walls, but Crawford [1] states that the orientation and floor area of the building does not
significantly influence the cooling load. The use of material has more influence on the energy used in buildings.

Olgyay [9] recommends a rectangular shape with a width and length ratio of 1: 1.7 is the most
effective form for a tropical climate. This form is considered to be the most effective way to overcome
cooling and heating problems in high concentrations. Jiniwati [10] suggested a cylindrical shape
because this form is best for minimising solar heat gain and solar heat loss in tall buildings. Ling [8]
links the way of a high-rise building in a tropical climate with insolation and gets the results of a
cylindrical and square building shape with a ratio of width and length of 1: 1 to minimise the influence
of direct and diffuse solar insolation. Jiniwati [10] produced the same rate as Olgyay; he stated that
the building with a north-south orientation and W / L ratio was 1: 1.7. in the same volume, the
Octagonal shape has the best thermal performance than a rectangle, L shape and H shape [11].

2.3 Building Envelope and Cooling Energy
Buildings in different locations should also have different sheath designs. The building envelope
design concept must be able to respond to climate problems and provide benefits concerning
investment costs and building operations. Outside air temperature and wind speed affect site
conditions. For sites with lousy weather, pure fabrication and installation materials are recommended.
Noerwasito [12] classifies buildings based on their building skin, thin sin, prone skin, thick skin,
buffering, and valve effect. Whereas Olgyay [9] classifies facade types based on the structure and how to install building elements.

2.4 Roof Design
Horizontal openings have two advantages:
a. Allowing illumination is not equally fair in a vast interior area, while natural light from openings is limited (Figure 1).
b. Horizontal openings also receive more light than vertical openings.

![Figure 1](image)

Figure 1. When natural lighting from openings is limited to the outer wall, openings on the roof will be able to flatten the lighting along a limited area of space

3. Method
This research aims to formulate the design of the atrium roof, in this case, the atrial shape of a middle-rise wide-span building to achieve cooling energy efficiency. The experimental method with simulation tactics was used to examine the relationship between the independent variable (atrium form) and the dependent variable (cooling energy). The software used in this simulation is Ecotect 2011.

3.1 Base Case Experiment
According to previous research, the best ratio of fenestration roof and the opaque roof is less than 10% (Laksmiyanti 2017). The object study of this research has been chosen randomly. Most of the multi-storey building has a rectangular. Laksmiyanti [11] found in Surabaya 63.3% middle rise building in Surabaya has a rectangular form, so the base case for this research is building in Surabaya which has a rectangular shape and having an atrium.

G Building in ITATS has been selected for the base case, and it has skylight type for the atrium (fig 3.1). In this base case, material for the opaque roof is galvalum, which is usually used in large span building. Material for fenestration roof is polycarbonate, as the real condition of the building.

3.2 Scenario Experiment
There is four common design in the atrium. So the model of an experiment in this research as his theory. Each model has 10% of fenestration roof (fig.2)

![Figure 2](image)

Figure 2. Illustration of atrium form in G building ITATS from right: Skylight for Base Case, monitor for model 1, sawtooth for model 2, clerestory for model 3.
4. Result and Discussion

4.1 Heat Flow to The Building
There are five types of heat gain in this building such as:

a. Conduction heat flow (sQC)
   This is a process of heat transfer from outdoor to the indoor environment through the building envelope. This heat transfer happens because of the temperature difference between indoor and outdoor. If the outdoor having higher temperature, the heat will enter the building and vice versa.

b. Indirect solar irradiance heat flow (sQS)
   This heat comes from sun radiation which is through the opaque envelope of the building. This heat flow happens on the day, but because it happens on opaque material, there is delay depending on the thermal character (time lag) of the material.

c. Direct solar irradiance heat flow (sQg)
   This heat transfer happens because of the radiation of sun through the fenestration envelope of the building. There’s no delay of the heat transfer.

d. Ventilation heat flow (sQv)
   It’s a convection heat flow. Heat transfer by the air flow of the building. All scenario experiment has the same volume of opening, same type of air conditioning and same air change per hour so the conduction heat flow will be same for all model (table 1).

e. Internal heat gain (sQi)
   This is heat gain from electrical equipment in the building. Because the floor plan of the building is the same in all scenario experiment, so this kind of heat gain will not be discussed in this paper.

| Heat Gain        | BC     | Model 1   | Model 2   | Model 3   |
|------------------|--------|-----------|-----------|-----------|
| sQC (kWh/year)   | 1089.69| 1091.43   | 1089.68   | 1090.72   |
| sQS (kWh/Year)   | 43.29  | 44.01     | 43.28     | 43.30     |
| sQg (kWh/Year)   | 171.28 | 164.61    | 170.68    | 171.71    |
| sQv (kWh/Year)   | 53.17  | 53.17     | 53.17     | 53.17     |

There are not a significant difference in conduction heat gain on each model because of the area of the roof materials almost the same. The contents of the roof are precisely the same, so each model has similar thermal properties and conduction heat gain. There’s no significant change in radiation heat flow on model 2 and 3 instead of model 1. The fenestration roof in model 1 face to south and north. Horizontal plane will accept the biggest irradiance and highest intensity, so model 1 enters the higher irradiance heat flow to the building than base case. Model 2 has inclined atrium, so the irradiance is lower.

Direct solar gain (sQg) in model 1 is the lowest of all models. sQg is direct irradiance through transparent building envelope. Base case has a fenestration roof in the horizontal plane so that it may accept a quite high amount of this heat gain. The sawtooth shape and celestory have sQg which is not too much different because it has the same translucent roof area that reaches the north side, while model 1 has only half. For the city of Surabaya, the number of irradiation for the year on the north side is higher than the south side, so that model 1 has the smallest number among all models.

4.2 Cooling Energy of Building
According to the data of the total amount of energy use for one year, model 2 has the worst performance of all models (Figure 3). If compared with the base case, models 1 and 3 have almost the same total energy use because the amount of heat flow into the building is also nearly the same. Referring to table 1, the highest heat propagation comes from propagation by conduction. The
distribution of conduction heat is influenced by the surface area of the shell and the thermal properties of the sheath, especially the conductance of the material. Model 2 has a sloping roof so that compared to the roof cover area on model 2 is bigger than the base model. In addition to the large surface area, galvalume has a high conductivity value, reaching 50 W / mK so that the conduction heat gain increases substantially resulting in improved cooling load and automatic cooling energy usage increases.

![Figure 3. Cooling load on each model (kWh/m²/Year)](image)

5. Conclusion
From the results and discussion above it can be concluded that atrial roof design that is good for long span buildings in the tropics is in the form of a monitor. This form has a smaller area of sheath than the others so that the incoming conduction heat is also lower. The division of transparent fields on the north and south sides makes this building have a small direct and indirect irradiance heat gain.

6. References
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