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THERMAL SIMULATION AND COOLING ENERGY SENSITIVITY ANALYSIS OF A TYPICAL *SHOPHOUSE* IN JAKARTA, INDONESIA

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ABSTRACT

In this paper, the results of simulating the cooling energy demand of a reference shophouse in Jakarta, Indonesia are presented. The building reference is a two-storey shophouse, of which ground floor is used as a shop and upper floor as a dwelling. The simulation and visualization tool used was DesignBuilder v.1.8 (www.designbuilder.co.uk, 2008), an Energy Plus based dynamic thermal simulation engine. First of all, a reference building was simulated, in order to obtain its cooling energy demand. The parameter setting for building envelope of this reference building was based on the data provided by the planner, PT. Jaya Real Property, Tbk. Subsequently a sensitivity analysis was done with the aim of obtaining the parameters that contribute significantly to the decrease of annual cooling energy demand. The parameters investigated were roof construction and insulation, building orientation, SHGC value, the value that represent the glazing's effectiveness in rejecting solar heat gain, and operating time and power of the cooling device. The simulation results show that building facing to the south gives the lowest annual cooling energy demand than other buildings which have north orientation, north-east orientation and south-west orientation, that is 3.65% less cooling energy demand than the reference building which has north orientation. SHGC of the glass will also contribute to the decrease of the annual cooling energy demand. By decreasing 50% of SHGC value will reduce annual cooling energy demand by 8.3%. It is also found that for a ventilated sloping roof construction, applying roof insulation has no significant effect on the reduction of annual cooling energy demand, except for the case that the schedule of the air conditioning in the upper floor is 24 hours always on. In the case of flat roof construction, insulated flat roof will give approximately the same effect as sloping roof. By limiting the power of the cooling device to 2kW which means reducing the investment cost, will reduce annual cooling energy demand by 2.07% of the building without roof insulation.

INTRODUCTION

Since in the middle of 2007, general public have predicted that the economic growth in Indonesia will come into a difficult period, following the increase of oil price as well as other commodities in the international market which will cause the failing of global economic growth. That condition obviously will influence the development of the domestic business sector, including property and houses.

On the other hand, it is informed that in 2005, the growth of construction projects, particularly *shophouses* in Jakarta, the capital of Indonesia was about 20-30% (www.property.net, 2005). Shophouse comes from two words, shop and house. It is a type of building, most often with two storeys, of which its ground floor is used as a shop (or other kind of business) and the upper floor is used as a house.

Since the last two decades, Jakarta has grown very rapidly. The development of the city also leads to the living style, which is more practice, effective, and efficient. This cause the rapid increase of shophouse construction as the alternative living place, which offers simplicity and practice to accommodate small-scale activities as well as time efficiency as dwelling function mixed with working place (Wahyuasih, 2007). Therefore, it can also be predicted that in the next five or ten years to come, many more shophouses will be built.

It cannot be avoided that the developments of cities contribute to some problems such as environment, safety, culture, and energy problems. The examples of energy problems occurred are the increase of the temperature of the environment, as well as the increase of energy consumption. Regarding shophouses, usually, the shape of these shophouse is longwise to the back and attached to each other. As a consequence, there is no window on its two sides and it causes the low level of comfort which leads to the usage of air conditioning in the building. Most often, the occupants use air conditioning which causes high consumption of energy. Therefore, it is very important to conduct research which will contribute to the formulation of a standard of low and efficient energy buildings, moreover, to give the alternative solution to increase the thermal comfort of the occupants.

Indonesia is a tropical country with a very hot and humid climate. In Jakarta for example, the temperature over the year and days varies typically between 25°C and 36°C, and the relative humidity is always above 60%. To achieve comfortable conditions for the occupants who live in this climate will influence the design of effective air conditioned buildings as well as low energy buildings.

A previous survey (PT KONEBA, 2006) shows the distribution of energy consumption in 60 buildings in Jakarta. It is explained that for 11 types of buildings, the consumption of energy is dominated by air conditioning system. The average consumption for air conditioning in these buildings was calculated to be 55% of the total energy demand. Therefore, it is important to obtain strategies how to reduce the energy consumption of air conditioning systems, specifically by reducing the cooling energy demand of the building without decreasing thermal comfort.

Former research presents that increasing indoor air set point temperature from 24°C to 26°C will reduce cooling energy demand by 13% (Andarini, et al, 2008). In addition, window to wall ratio for window faces to the north and g-value of the glass also give significant effect to the decrease of energy cooling demand. Based on the previous research, this research aims to obtain the most suitable strategy to reduce cooling energy consumption in shophouse buildings. The parameters to be investigated are the effect of installing roof insulation, the building orientation, as well as the effect of SHGC value of the glass, effect of the operating time and power of the cooling device. Moreover, this research is also focused on the integration of building simulation during the design phase.

METHOD

DesignBuilder program

DesignBuilder uses the calculation core EnergyPlus, powerful for modeling three-dimensionally building geometry as well as tool for building energy performance assessment. There are also CAD links into the 3D modeler as well as report generation facilities. DesignBuilder combines rapid building modeling with state of the art dynamic energy simulation (DesignBuilder 2006).

The reference building

The simulations were undertaken using the shophouse building which is designed by PT. Jaya Real Property, Tbk, located in Jakarta, Indonesia. This type of building consists of two storeys, of which its ground floor used as a shop (or other kind of small-scale business) and the upper floor used as an apartment.

It is usual that the buildings' developer build shophouses as mass constructions, as shophouses have similar design of floor plan, dimension, materials and finishing. In addition, mass constructions economically benefit to the developer concerning time consumption and materials' expenditure. From the data design, it is informed that there will be some building blocks built and each block has different orientation such as north, south, southwest and northwest. The building faces to the north assume as the reference building. Figure 1 shows the perspective drawing of this block of shophouse buildings.

Figure 1 Prespective Drawing (Jaya Real Property, PT. Tbk, 2008)

It can be seen that the main difference of this block of shophouses is only on the façade design, and typically the design of its floor plan for attached buildings is mirroring.

Figure 2 Building Geometry

Figure 2 shows the geometrical building using DesignBuilder. The area of ground floor is 34.4 m² and upper floor is 27.9 m². The height of ground floor is 3 m and upper floor is 3.23 m. The total volume of ground floor is 103.2 m³ and upper floor is of 90.1 m³.

For both ground floor and upper floor the rate of infiltration due to leakages of the building envelope is assumed with 0.5 air change per hour. Moreover, there is also natural ventilation, hygienic ventilation depending on the occupancy in the ground floor and upper floor of 7.5 l/s/person, respectively.

There is also roof space above the upper floor which is unoccupied and unconditioned, except its constant infiltration rate is assumed with 0.5 air change per hour. The area of this roof space is 25.9 m², and its volume is 13.75 m³.

DESIGN AND ENERGY SIMULATION

Weather data

The climate data used in this simulation is based on the weather data of Jakarta, Indonesia, generated by Meteonorm 6.0 (Meteonorm, 2007). Jakarta is the capital city of Indonesia, and is located at western part of Java Island, at 6.09° south latitude and 106.49° longitude. The elevation is only 4 m above sea level. Jakarta lies in the tropical climate, which has rainfall peak season in January and its dry season low point is August.

The profile of hourly temperature, direct normal solar and diffuse horizontal solar radiation is described in Figure 3, which shows that the hourly air temperature during a year fluctuates between 22°C and 35°C. The weather data also informs that the average humidity during the year ranges from 60% to 96%.

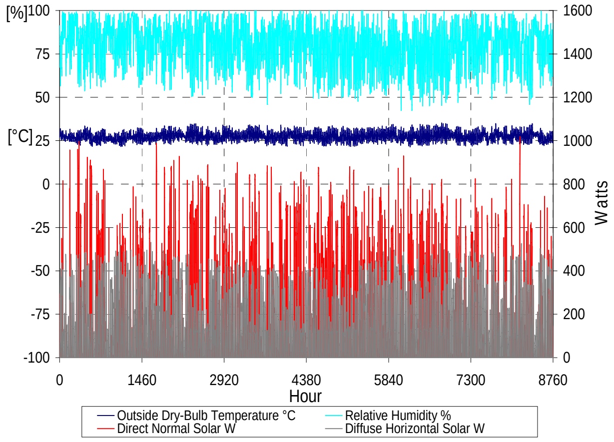

Figure 3 Weather Data of Jakarta, Indonesia (Meteonorm, 2007)

Ground temperature

As a tropical country, Indonesia always receive solar radiation during a year, therefore, there is no significant fluctuation of air temperature as well as ground temperature.

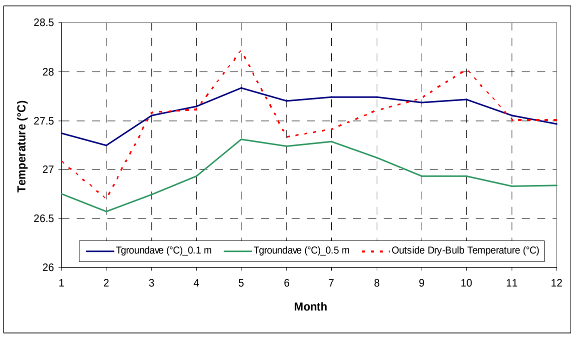

Figure 4. Ground Temperature Profile

Figure 4 shows annual disturbed ground temperature below the building used in this simulation. This ground temperature's profile was obtained by a ground temperature simulation utility using EnergyPlus.

It can be seen that the average monthly ground temperature difference between slab depth of 0.1 m and 0.5 m is less than 1°C, and the average annual ground temperature ranged between 26.5°C and 27.8°C, which means the annual variation is insignificant. Therefore, in case of applying insulation for the ground floor slab will not give significant effect in reducing the cooling energy of the building.

In addition, as the indoor air temperature set point of 26°C has no big difference with ground temperature, therefore, heat transfer between ground and ground floor is not significant.

Constructional properties

Table 1 shows the U values of the reference buildings envelope. The materials for the building envelopes such as wall, floor, floor slab, roof, ceiling and window glazing were set as designed by the planners of this building. The glazing material is single glass, with the SHGC value of 0.816 and light transmission of 0.883. The absorption coefficient of the sloping roof was set to 0.3.

Table 1
U Value of reference building

COMPONENT	U VALUE (W/M²K)
Wall	2.235
Ground Floor	3.916
Floor Slab	1.315
Roof Slab	4.411
Sloping Roof	3.201
Glazing	6.189

Internal gain

The internal gains of the reference office building consist of occupancy, computers, and lighting. Occupancy density is assumed to be 0.12 people/m² for each floor, or in the case of full occupancy this assumption results to a total of 4 people being simultaneously present in each floor. As there are different functions of each floor, the activity schedule are also different. The ground floor which is functioned as shop or small office has an occupancy schedule of Monday – Saturday 08.00 – 18.00 and based on ISO – 7730 standard (1994) one person will dissipate heat to the surroundings at a rate of 100 W. This value also refers to the scenario of degree activity as seated at rest, that one person dissipates sensible heat of 60 watts and 40 watts for latent heat.

The occupancy schedule for upper floor is set as a domestic family weekday, which is Monday to Saturday, from 07.00 to 09.00, and from 16.00 to 23.00. From 23.00 to 07.00 it is assumed that the activity of the occupants are sleeping. During Sunday the occupancy schedule is set to be from 07.00 until

23.00, and after 23.00 until 07.00, it is also assumed that all occupants are sleeping.

The internal gains due to the computers and other electrical equipments such as television and cash register assumed to be 4 W/m² in the ground floor and 1.7 W/m² in the upper floor. Lighting will contribute to the heat dissipation of 15 W/m² and 10 W/m² in the ground floor and upper floor, respectively. Both follow the occupancy schedule of the respective floor.

HVAC

Based on the weather data, it is known that this building is located in a very hot and humid area that obviously has a very high cooling energy demand and no heating demand throughout the year. Therefore, it is also designed to use air conditioning in order to reach comfort indoor air temperature in occupied zones. The cooling schedule of ground floor follows the occupancy schedule, and for upper floor, the cooling schedule is Monday to Sunday from 21.00 until 05.00. As recommended in previous research (Andarini, et al, 2008), the set point indoor air temperature of this building is set to 26°C.

SIMULATION RESULTS AND ANALYSIS

Simulations were carried out based on the setting explained above, and the results of this building simulation are used as base case. Afterward, the sensitivity analysis is carried out in order to investigate the effect of parameters variation such as roof insulation, building orientation, SHGC value, operating time and power of the cooling device, to the change of cooling energy demand.

Roof insulation

Applying roof insulation intends to reduce the heat entering the room by solar radiation absorbed in the roof.

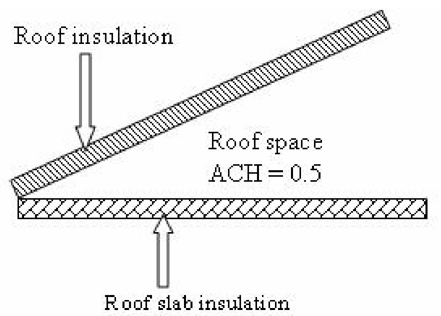

Figure 5 Roof insulation installation.

The simulations were done by assumming two difference strategies of insulation placement, those are placing the insulation just below the inclined surface of the roof (hereafter is called as 'roof insulation') and applying insulation above the ceiling of the upper floor, which is then called as 'roof slab insulation', as depicted in Figure 5.

The simulation result shows that installing roof insulation will cause temperature during the day lower than that of without insulation. It is because roof insulation reduces the U value; therefore less heat will be transferred into the roof space during the day as the effect of absorbed solar heat of the roof. But during the night, less heat is released as heat is trapped inside roof space as an effect of installing roof insulation. Therefore, the benefit of installing roof insulation is reducing temperature of roof space during the day.

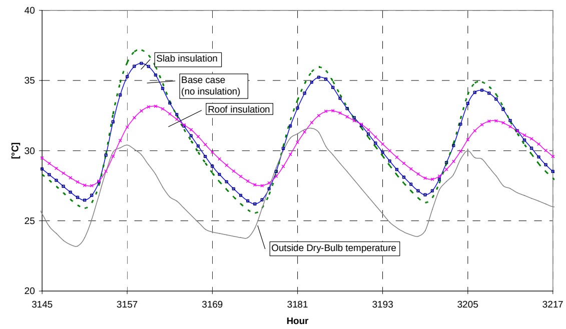

Figure 6 Temperature profile inside roof space

Applying roof slab insulation will cause high heat gain of the roof space during the day as there is no insulation on the roof layer. However, there is not too much heat entering the lower zone as there is insulation between these two zones which is placed above the roof slab. Yet it also releases significant amount of heat to the cool-night air during the night. It means that installing roof slab insulation will benefit in releasing warm air to the ambient during the night.

Figure 6 shows the temperature profile inside the roof space taken for only three days as an illustration, and the temperature comparison while there is no roof insulation, installing roof insulation, and applying roof slab insulation.

In summary, to reduce roof space temperature significantly can be achieved by installing roof insulation during the day and using roof slab insulation during the night.

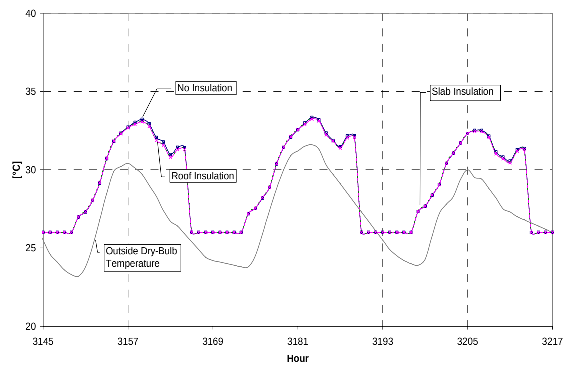

Figure 7 Temperature profile of upper floor

Figure 7 shows the temperature profile inside the upper floor. It can be seen that there is no significant effect in the temperature reduction during the day and night either by applying roof insulation or roof slab insulation.

The effect of applying roof insulation and roof slab insulation to the profile of the cooling energy demand of the upper floor is depicted in Figure 8.

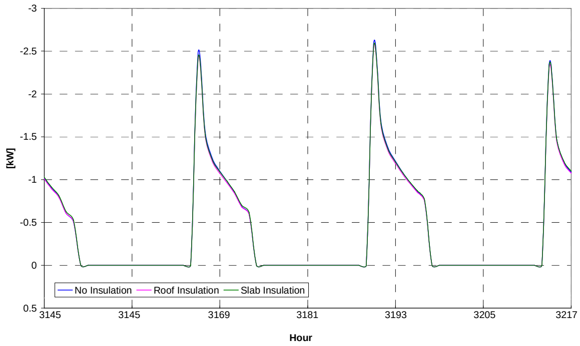

Figure 8 Comparison of cooling energy in the upper floor

As there is no significant difference of temperature in the upper floor, therefore, the cooling energy demand of the upper floor will also not be affected by the installation of either roof insulation or roof slab insulation.

In a year, it can be summarized the minimum, maximum and average temperature inside roof space and the difference of those value regarding roof insulation placement.

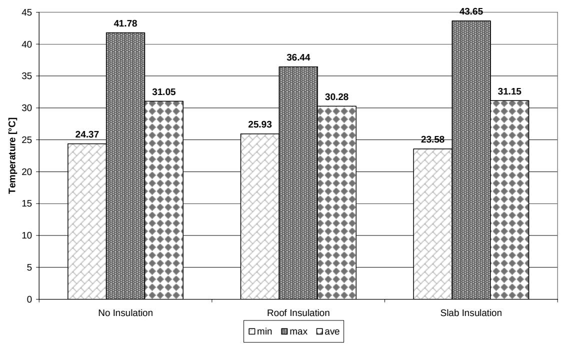

Figure 9 Comparison of minimum, maximum and average temperature inside roof space

Figure 9 shows the comparison of roof space temperature. It can be seen that installing roof slab insulation will give the highest maximum temperature compare to base case and roof insulation. However, its minimum and average temperature are the lowest compare to the others cases.

In general, applying roof insulation and roof slab insulation will only give effect to the temperature reduction of roof space, but not to the reduction of the building's cooling energy demand.

Building orientation

An other parameter that influences the cooling energy demand is the building's orientation. The base case orientation is 0°, or building faces to the north. As mentioned before, the planner has designed a building complex which consists of several building blocks, and each block faces to different orientation such as south (180°), north east (45°), and south west (225°). As this type of building attached to other buildings, then it is assumed that side wall are adiabatic.

Figure 10 shows the percentage difference of the cooling energy demand compare to the base case as the effect of different orientations.

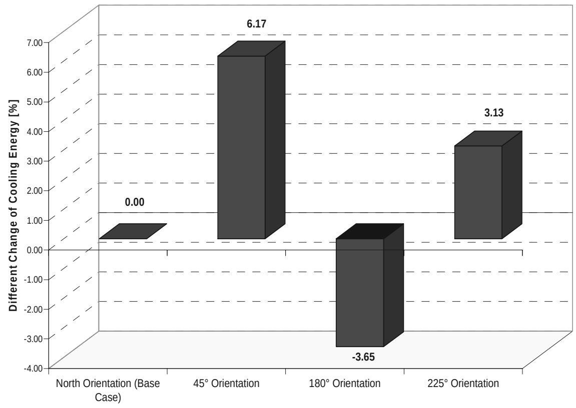

Figure 10 Effect of building's orientation to the cooling energy demand.

It can be seen that building facing to the south will have less cooling energy demand than building facing to the north. It is because Jakarta is located in the tropic of which solar radiation available through the year, and has very high solar angle, thus the dominant source of solar gain is at the north windows. Therefore, a building facing to the south will have less solar gains on the north wall, and as results, heat gain through north wall will be smaller than buildings facing to the north. For other building orientations, it is obvious that buildings facing to the northeast or southwest will produce more heat gain accordingly.

A factor that influence the difference of cooling energy demand for different building's orientation is the heat transfer through the building envelope as shown in Figure 11.

With the change of building orientation, it is noticeable that buildings' envelopes will also contribute to the change of heat gain and heat loss through the buildings. As a consequence, it will effect to the cooling energy demand of the building.

As it is mentioned before, solar gains are very high for buildings facing to northeast and southwest which is described in Figure 11, even higher if building facing to the east and west. Overall, building which facing to northeast has the highest heat gains compare to other building. In contrast, building which faces to the south has the highest heat losses.

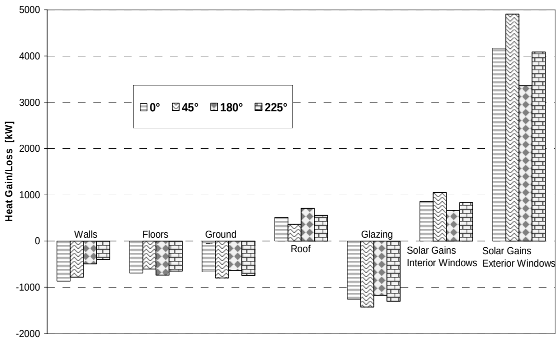

Figure 11 Comparison of heat transfer through building envelopes for different building orientation

SHGC value of glazing material

SHGC value is a coefficient which represents heat transmitted by a certain type of glazing material. The value range from 0 to 1, of which a lower value representing less heat transmitted, consequently there will be less solar energy entering the building. For buildings in tropical climate, it is suggested that glazing material should have low SHGC value but high light transmission value as it will cause less heat gain entering the building but still transmit natural light during the day.

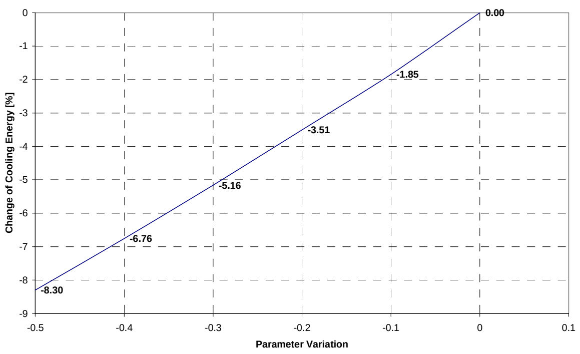

Figure 12 Effect of SHGC

Figure 12 shows the percent change of cooling energy of the building concerning change of SHGC value. It can be seen that reducing SHGC value by 50% or 0.5 will cause reduction of cooling energy by 8.3%.

Effect of limited power and operational time of cooling device

Limiting power of cooling equipment means reducing the investment cost. From the thermal building simulation of the base case, it is found that the maximum power was 3.9 kW. Figure 13 shows the comparison of annual cooling energy demand as the effect of limited power of the cooling device. It can be seen that there is no significant difference of annual cooling energy demand when the power is limited into 2 kW, indicates that the peak cooling load of the building is about 2 kW.

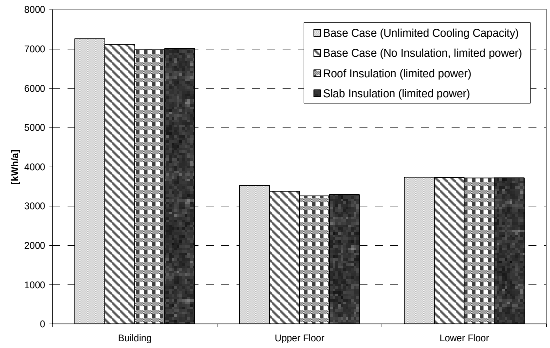

Figure 13 Comparison of annual cooling energy as the effect of limited power of the cooling device.

Other simulations were done in order to see the effect of operational time of cooling device to the annual cooling energy consumption. The simulations were done by setting on the operational time of cooling device in the upper floor for 24 hours. The annual cooling energy consumptions between scheduled operational as set in the base case and setting on for 24 hours were compared. Subsequently, it is compared the effectiveness of installing roof insulation when the cooling equipment in the upper floor operates for 24 hours.

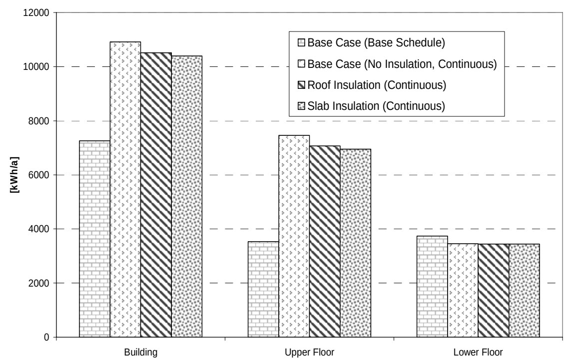

Figure 14 Comparison of annual cooling energy as the effect of operational time of the cooling device

The results show that there is significant increase of building’s annual cooling energy demand when the cooling device in the upper floor operates for 24 hours, mainly as the effect of doubling in the annual cooling energy demand of the upper floor. In comparison of installing roof insulation and roof slab insulation, it also can be seen that there is a decrease on cooling energy on the upper floor compare to that without insulation.

Comparison with flat roof

The assumption of flat roof design was also simulated in order to see the effect of applying roof insulation on the cooling energy demand.

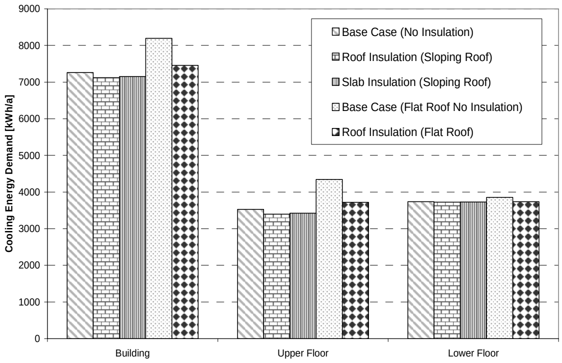

Figure 15 Comparison of annual cooling energy between sloping roof and flat roof

Figure 15 shows the comparison of annual cooling energy between sloping roof and flat roof. It can be seen that in the case of flat roof construction, insulated flat roof will reduce the annual cooling energy demand, and it gives approximately the same effect as sloping roof which is indicated by the similar value of annual cooling energy demand.

CONCLUSION

It has been simulated the cooling energy demand of a reference shophouse in Jakarta, Indonesia. The building reference is a two-storey shophouse, of which ground floor is used as a shop and upper floor as a dwelling. The simulation results show that building facing to the south gives the lowest annual cooling energy demand than other buildings which have north orientation, north-east orientation and south-west orientation, that is 3.65% less cooling energy demand than the reference building which has north orientation. By decreasing 50% of SHGC value will reduce annual cooling energy demand by 8.3%. It is also found that for a ventilated sloping roof construction, applying roof insulation has no significant effect on the reduction of annual cooling energy demand, except for the case that the schedule of the air conditioning in the upper floor is 24 hours always on. In the case of flat roof construction, insulated flat roof will give approximately the same effect as sloping roof. By limiting the power of the cooling device to 2 kW which means reducing the investment cost, will reduce annual cooling energy demand by 2.07% of the building without roof insulation.

REFERENCES

Andarini,R., H. Schranzhofer, W. Streicher. 2008. Energy simulation for a typical small office building in Indonesia. Proceeding *The First International Conference on Building Energy and Environment, Dalian – China, July 2008.* 254 -261.

Badan Standardisasi Nasional. 2002. Tata cara perancangan konservasi energi pada bangunan gedung. *Standard Nasional Indonesia, SNI 03-6759-2002*.

DesignBuilder 1.2 . 2006. User Manual. *DesignBuilder Software, Ltd*.

Fuad H. Mallick. 1996. Thermal comfort and building designs in the tropical climates. *Energy and Buildings*, (23), 161-167.

ISO-7730. 1994. Moderate thermal environments – Determination of the PMV and PPD indices and specifications of the conditions for thermal comfort.

Jaya Real Property, PT, Tbk. 2008. Drawing Ruko Althia, Jakarta, Indonesia.

KONEBA, PT. 2006. Energy Distribution of Buildings, Survey results in 60 buildings in Jakarta, Indonesia.

Kouba, R., Streicher, W. 2002. Definition of reference office building IEA SHC Task 25 Solar Assisted Air Conditioning of Buildings.

Mason, M. 2003. Estimating the real energy consumption of buildings, *ECOLIBRIUM™ - JUNE*, 26-29.

Meteonorm Version 6.0.0.7. 2007 *METEOTEST, Switzerland*.

M.S. Hatamipour, H. Mahiyar, M. Taheri. 2007. Evaluation of existing cooling systems for reducing cooling power consumption. *Energy and Buildings*, (39),105-112.

Sherman, Max. 2001. The residential Ventilation Standard. *EETD Newsletter.*

Tablada, Abel, et al. 2005. Thermal Comfort of Naturally Ventilated Buildings in Warm-Humid Climates: field survey *PLEA2005 - The 22nd Conference on Passive and Low Energy Architecture.* Beirut, Lebanon.

Tri Harso Karyono. 2000. Report on thermal comfort and building energy studies in Jakarta – Indonesia. *Building and Environment*. (35), 77-90.

Wahyuasih, Christine. 2007. Masalah dan dilema perkembangan ruko dalam arsitektur lingkungan perkotaan dan permukiman di kawasan Jakarta dan sekitarnya. Universitas Budi Luhur, Jakarta.

www.greenhouse.gov.au/yourhome/technical/fs17.ht

www.designbuilder.co.uk

www.property.net