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Towards energy efficient facade through solar-powered shading device

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Abstract

In tropical regions (23.50 N – 23.50 S), the east-west building facades receive the greatest amount of solar radiation for vertical walls. The need for glazing windows in that area sometimes cannot be avoided due to various reasons regarding to space planning inside the building. The presence of east-west glazing windows causes the increasing of air conditioning load of the building at a significant rate, which causes increasing energy usage. There are several external shading devices available to be used to limit the incoming low-altitude angle sunlight falling to that direction, however all the available sun shading devices are not adjusted and based on the fixed location as a part of building façade. Since the sun moves regularly according to its daily and seasonal path, generally the fixed external sun shading does not function well to reduce solar heat gain as well as to keep an indoor standard illumination level simultaneously.

The solar-powered automatic vertical shading device is the solution for the problem since it obstructs the direct solar heat using the received solar energy itself, and at the same time maintaining the required daylight illumination at an appropriate level inside the room. The research dealing with solar-powered automatic shading device was developed through integrated interdisciplinary and collaborative approach at the Center for Building Energy Study Petra Christian University Surabaya.

The broaden usage of this device also opens possibility toward a more specific culturally façade that encompasses functional needs, energy efficiency criteria, architectural aesthetic value, and cultural appearance of building.

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Keywords: *building façade; shading device; solar-powered automatic vertical shading device.*

1. Introduction

1.1. The importance of shading devices

Buildings account for a high proportion of resource use and waste generation. Research in USA (2005) reveals the facts as follows:
1. 14% of potable water consumption
2. 30% of waste output
3. 38% of carbon dioxide emissions
4. 40% of raw materials use
5. 24% - 50% of energy use

Based on typical energy consumption for commercial building and residential building, there are two major potential energy consumer which are HVAC system (heating-ventilating-air conditioning system: 55%-60%) and lighting system (27%-40%), although for some specific building, e.g. university campuses and offices, computers and office equipment play a significant role for the energy consumption too.

Generally, the profile of energy consumption in buildings is presented on these pie charts:

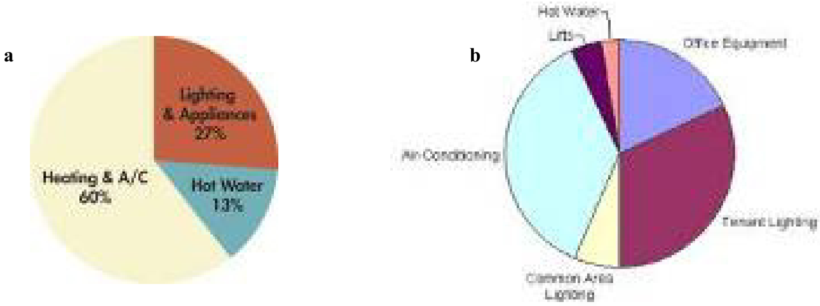

Fig.1. Typical building energy consumption (a) residential building; (b) commercial building

The capacity of HVAC is determined by the cooling load of building that consists of external and internal loads. While external cooling load comprises of:
1. Wall conduction
2. Glass conduction
3. Glass radiation
4. Ventilation
5. Infiltration
6. Roof conduction

The majority of external cooling load is dominated by solar heat gain through glass which is transmitting heat gain through conduction and radiation. The main strategy to decrease cooling load is to limit solar radiation through glazing component that can be done by selecting proper glass or designing appropriate shading device.

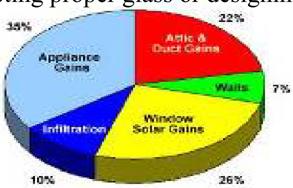

Fig. 2. Typical building cooling load

The majority of external cooling load is dominated by solar heat gain through glass which is transmitting heat gain through conduction and radiation. The main strategy to decrease cooling load is to limit solar radiation through glazing component that can be done by selecting proper glass or designing the appropriate shading device.

1.2. The solar path and solar radiation

In the equator area (23.50 S - 23.50 N - including Indonesia), the sun is almost directly overhead throughout the year. East and west orientations receive the most solar exposure here and therefore have the most potential for solar heat gains. The solar path diagram for equator area indicates that both North and South orientations also receive solar exposure for a portion of the year.

The amount of solar radiation differs according to the building orientation, thus the East –West walls (windows) receive greater amount than North- South walls (windows).

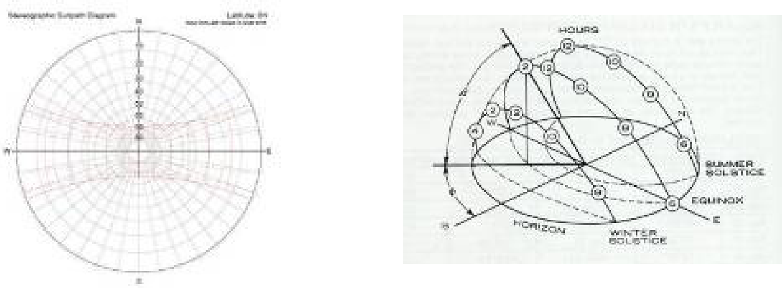

Fig. 3. Sun path diagram for the equator area

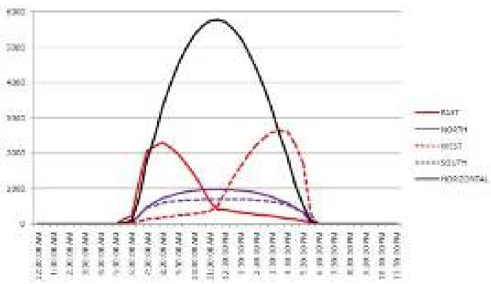

Fig. 4. Solar radiation graph for equator area (23.50 N – 23.50 S)
Source: Energyplus software by Jatmika et al.

1.3. Shading devices

Shading devices can significantly reduce building heat gains from solar radiation while maintaining opportunities for daylighting, views, and natural ventilation. Conversely, carefully designed shading device can admit direct solar radiation during specific times of the year when such energy is desired tom passively heat a building especially on the mountain/ high lands. While the window is often the focus of shading devices, walls and roofs can also be shaded to help reduce heat gains through the opaque building envelope. The main purpose of shading devices encompasses:

1. Thermal function: To reduce solar heat gains.
2. Physical function: To control views into and out of a building, reduce solar glare, provide rain protection for opening windows, to serve as part of a maintenance strategy.
3. Aesthetic function: To express architectural aesthetic by façade appearance.

Shading devices come in different forms:

1.3.1. Fixed Conventional Shading Devices:

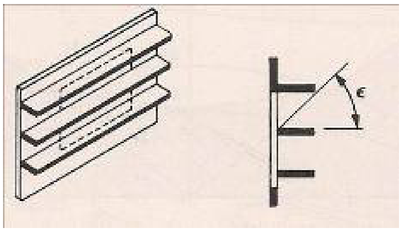

Fig. 5. Horizontal projection

1.3.2.Horizontal overhangs generally used to combat high-angle midday sunshine

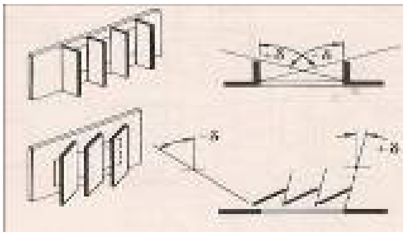

Fig. 6. Vertical projection

1.3.3.Vertical fins are used to indirectly block low-angle sunshine in the early mornings and late afternoons.

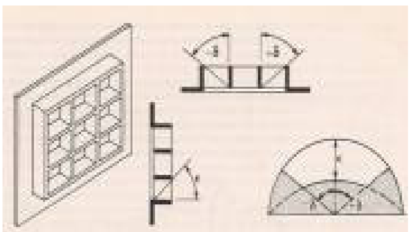

Fig. 7. Egg-crate shading device

A hybrid of the two previous shading devices and can be used in most facade orientation.

The problem of fixed shading device includes:
1. Potential reduction in daylight transmission causes reduction of required illumination level, so that to encourage usage of lighting.
2. Reduced accessibility to glass for cleaning and maintenance
3. Additional maintenance of shading device especially for metal sunshades with coated or anodized finishes
4. Cost and impact on ease of construction

1.3.4. Adjustable shading devices:

a. Manual: Limited flexibility and depends on human activity.
b. Automatic: Linked to daylight sensors and/or sun tracking systems to adjust the opening of the shading device depending on the sky conditions (full sun or overcast sky) and /or time of day (morning or afternoon).

1.4. The automatic vertical shading devices:

The advantage of automatic shading device:
1. Enable obtaining the required illumination level inside room due to automatic movement of vertical fins to trace the solar path. That means the reduction of energy due to lighting.
2. Enable reducing the thermal load due to obstructing direct solar heat gain so that decreasing of cooling load. That means the reduction of energy due to HVAC.

1.5. The solar automatic vertical shading devices:

The advantage of solar automatic shading device:
1. Enable obtaining the required illumination level inside room due to automatic movement of vertical fins to trace the solar path. That means the reducing of energy due to lighting.
2. Enable reducing the thermal load due to obstructing direct solar heat gain so that decreasing of cooling load. That means the reducing of energy due to HVAC.
3. Harnessing solar energy received by the shading device by converting solar energy to electricity (photovoltaic cell) as the motor power to move the vertical fins automatically.

2. Research Objectives and Intentions

2.1. The objectives:

1. To find prototype of solar automatic vertical shading device that can be used for east-west window to minimize solar heat gain.
2. The device has to be moved toward the solar path to obstruct solar heat gain directly
3. The device has to be capable to transmit day lighting to room inside to maintain the required illumination level.
4. The device has to be operated using the received solar energy

2.2. The intention:

1. Supporting non-renewable energy conservation programme by reducing energy due to HVAC system to achieve energy efficient building.
2. Supporting non-renewable energy conservation programme by reducing energy due to lighting system to achieve energy efficient building.
3. Encouraging renewable energy harnessing programme (solar energy) to achieve energy efficient building.

3. Research Method

The method to be used for this research is *illumination-based control* where the illumination level inside the room is maintained based on standard of 300 lux to encourage daylight utilization instead of lighting during the day. The illumination sensor inside the building orders the shading device to rotate and the shading device rotates regularly to follow the motion of the sun to resist direct sunlight while keeping the indoor illumination constant to 300 lux for general office work.

The method was conducted through integration of interdisciplinary approach leads to an Integrated Shading Device that comprises of:

1. Physical testing chamber

1. Defining testing chambers (3 chambers).
   Testing chambers consist of three chamber that are separated each other by partition.
   Testing chamber B1 has window with fully vertical shading device.
   Testing chamber B2 has window with perforated shading device.
   Testing chamber B3 has window without shading device as a reference of unobstructed window.
   Each chamber is equipped with 75 cm height table as a benchmark of standardized height working table.
   The location of testing chamber is on the roof top in order to get a direct sunlight and free from overshadowing of building around.
   Although the placing of model does not represent actual condition of generally side-window within a room, however the mechanism of moving blade that rotates regularly according to the need of minimum requirement illumination inside (300 lux reference level) allows controlling the required amount of daylight by opening or closing blades in accordance with adjustment of its angle of rotation.
2. Defining the shape and type of vertical shading blade
3. Defining material of shading device
4. Determining instruments and measuring method for temperature and illumination

Fig. 8. Testing chamber

Fig. 9.Vertical shading device and automatic control (a) Perforated vertical shading; (b) Fully vertical shading

2. Mechanical components:

1. Defining motion mechanism of shading

2. Determining main and supporting construction of device

3. Electronic control system:

1. Defining components of automatic electronic control Programmable Logic Control (PLC)
2. Defining illumination and thermal sensors, driver and feedback

4. Electrical components:

1. Defining electric solar system: *Photovoltaic Solar Cell,* DC motor, *Charge Controller*
2. Defining inverter and battery

Fig. 10. Photovoltaic module with inverter and battery

4. Experiment Activities

During operational stage, the shading device rotates automatically follows the sun motion while temperature and illumination level inside the chambers were measured.

At the testing chamber B3 (open window without vertical shading device) has results as follows:

1. Temperature measurements: 33.7^0C-34^0C
2. Illumination measurements:2340 – 3380Lux

At the testing chamber B1 (window with fully vertical shading device) has results as follows:

1. Illumination level is defined 300 lux as reference level.
2. Indoor temperature is measured.

At the testing chamber B2 (window with perforated vertical shading device) has results as follows:

1. Illumination level is defined 300 lux as reference level.
2. Indoor temperature is measured.

4.1. Time of measurement

Measurements were taken as representation of daily sun path (morning-afternoon) and seasonal path (October-December) where the western lowest altitude takes place.

a. Time of measurement: 300 minutes (10am-3pm)

b. Months: October-December 2012 and 2013

4.2. Measurement instruments

a. Lux meter + data logger

b. Globe Thermometer + data logger

Fig. 11. Measurement at testing chamber B1

Fig. 12. Measurement at testing chamber B2

Fig. 13. Measurement at testing chamberB3

5. Results and Dicussion

5.1. Results analyses

1. Since the predefined method to be used for this research is *illumination-based control* where the illumination level inside the room is maintained based on standard of 300 lux to encourage daylight utilization instead of lighting during the day, hence it can be observed that the mechanism of vertical blades succeed to maintain the benchmark of 300 lux through the usage of either fully vertical device or perforated vertical device.
   The actual illumination of chamber 3 (without shading device at all) soars up to 2300 – 3300 lux. The successful rotating blade works well to coordinate the required benchmark indoor illumination with the angle of rotating mechanism through the electronic control system and the solar powered vertical shading as an automatic rotating vertical shading device (sun-tracker) to follow motion of the sun daily.

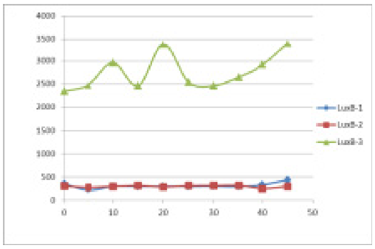

Fig. 14. Illumination level for all chambers

2. The outdoor temperature outside the window varies between 33.5^{0}C – 34.5^{0}C.
   The indoor temperature keeps relatively constant between 30.5^{0}C (perforated blade) to 31.5^{0}C (fully blade). The room temperature with no shaded window has moderate difference with shaded window (3^0 C) facing west due to limited space for the testing chamber (1x1m) allowing heat transfer through conduction among the chambers.
   The temperature difference of +/- 3^{0}C (by using vertical shading device) is sufficient to reduce the cooling load of air conditioning system with recommended room temperature of 25^{0}C., thus improving energy saving potential. Typical numbers of cooling load used in Indonesia for an office building are 146.53 W/m2 and sometimes 175.84 W/m2 or 205.15 W/m2. However with detailed design, modelling, simulations and exploring the potential possibility, this cooling load number can be brought down to the actual level of necessity, thus to obtain the appropriate AC sizing.

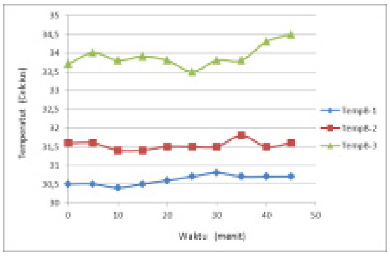

Fig. 15. Temperature level for all chambers

3. The comparison usage of fully vertical blade and perforated vertical blade indicates that perforated blade has a more uniform distribution of daylight to give a "steady illumination" inside the room. The punch-blade shape enables dispersion of light better than just ordinary reflected light of a fully blade as can be learnt from the following graph.

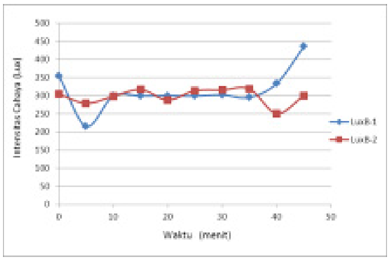

Fig. 16. Illumination level comparison of
fully vertical shading and perforated vertical shading

6. Conclusion

The objective of the research has been achieved:

1. To protect room from direct excessive solar radiation, thus to reduce cooling load of HVAC system. It means energy conservation through HVAC system.
2. To maintain illumination level at a reference level of 300 lux by optimizing daylight. It means energy conservation through lighting system.
3. To harness solar energy by using it automatically as renewable energy for shading device's mechanism. It means energy diversification from non- renewable energy to renewable energy.

7. Dynamic culturally façade for future

The broaden usage of the devices for buildings contributes significant energy consumption reduction towards energy efficient buildings, thus encouraging acceleration of national energy conservation program. The creative use of this devices open possibility for a dynamic façade that combines functional functions as well as architectural aesthetic especially when it is designed by using pattern and ornament of cultural heritage of the region.

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