HEAT TRANSFER ANALYSIS OF VERTICAL SHADING DEVICE IN OFFICE BUILDING IN MALAYSIA USING COMPUTER SIMULATION

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ABSTRACT: *The architectural trends of glazed facades have brought more daylighting and transparency into buildings, although with large glazed areas comes a large amount of solar radiation which can be wisely utilized for better environmental building design. However, glazed envelopes can cause excessive heat gain into the building, where potential sources of unwanted overheating and glare effects that cause indoor discomfort to the building occupants. Therefore, shading devices were designed to prevent excessive solar radiation and to distribute daylight evenly into the interior spaces. However, shading devices design are based on more of aesthetic value for the building façade, whereas, in the design of shading system, there are a variety of consideration related to the shading type, material properties and many more. In order to enhance the daylighting performance, a shading device, should play a more efficient role in order to control the heat gains into the building. Therefore, a study was conducted on heat gains particularly for vertical shading device in office building using computer simulation. The study used 'ECOTECT Software' to perform passive heat gains breakdown calculation. 'ECOTECT Software' has been used to calculate the distribution of daylighting needed for interior spaces in the building. A field measurement was conducted to find the minimum and maximum temperature in office building by using data logger. The experiment tests variables such as the distance between shading device from glazing area, materials and thicknesses of the shading device. The results from data logger showed that the minimum indoor temperature was 29.50C while the maximum indoor temperature was 340C. This data is to justify the simulation result in order to compare the heat gains before and after the test variables was conducted. The investigation found that the vertical shading device with 150mm gaps from window has better reduction of temperature gains into building. In addition, the analysis also found that with 150mm thicknesses and made by concrete of vertical shading device has a lower rate of heat transfer. The study, therefore, proposed that these criteria should be taken into consideration in the pre-design phase of an office building in order to apply appropriate shading device in avoiding unnecessary heat gains into the office building.*

Keywords: shading device, air temperature, office building, field measurement, computer simulation

1. INTRODUCTION

The climate of Malaysia is driven by its equatorial position, extensive coastlines on tropical seas and monsoonal winds. The impact of solar radiation incident on the east façade in Malaysia is critical from 09:00 – 12:00 hours and 13:00 – 17:00 hours for the west oriented facades. Beyond this limit the building itself gives shade as the sun position is behind the respective facades. Malaysia has lowest solar altitude angles (VSA) for east orientation in the morning hours. This implies that between 08:00 and 09:00 hours in the morning, most of the incident radiation transmits through the fenestration system more than 90%. However, solar gain due to direct solar radiation incidence on the vertical surface is low between 08:00 – 09:00 hours compared to the higher solar altitude. Vice-versa, although there is a high intensity of global solar radiation (>600W/m^2) around noon the fraction of radiation transmitted is lower (less than 40%) than at low solar altitude solar positions [1]. In many office buildings, solar radiation is usually controlled with shading devices. These devices range from complex controlled layered louvers and screens to fixed exterior fins or shelves, and simple interior blinds. All of these devices can reduce cooling energy consumption by reducing the flux of energy from the outdoor environment to the internal space, and can also be used to mediate daylighting and radius of indoor lighting [2].

Heat gain appears to be a serious problem in buildings, as it gives serious impact of the increasing cooling load on the building in Malaysia [3]. Shading device is a device which has been designed to control the solar penetrating into the building while to reduce glare to the building occupants. There is a difference of building with shading device and building without shading device. The building façade with glass without shading device can cause excessive solar heat gain while the building with shading device reduces heat gain more than 50% [4]. Perhaps a study which investigates on heat gain [4] could remedy the situation. A combination of shading devices and clear type of glass provides the admission of daylight through the clear glass more than any other special type of glass, and protection for the window glass from any direct solar radiation that might cause excessive solar heat gain. Removing redundancy from shading device achieved more admission of daylight and increased admission of solar radiation. Thus, value judgment should be made about this fact.

Having its basic form, shading device provides privacy for occupants with no need to use internal blinds or curtains that might block the whole view. There is a problem in terms of design where the design of the shading itself is overdesigned with its thicknesses. This is a serious problem occurs where it is obstructing the whole view and prevent a daylighting penetration into the building which can cause maximizing the usage of artificial lighting in the building [5]. In fact, the thicknesses of the shading device itself give a big impact on the heat gain to the building which can reduce about 10-15% of the heat gain [5]. In order to offer appropriate application of thicknesses, it is important that a rigorous simulation must be conducted to determine the right thickness of shading device to be applied to the building.

The majority of heat gain occurs through the glazing area without shading device while the heat gain increases because of false application of the material properties applied to the shading device [6, 7]. This problem has negatively impacted the thermal comfort of building occupants. A possible cause of this problem is the selection of material properties of shading device either reflective material or absorptive material. The reflective material like steel or metal has a good conductor and less dense material, but poor absorber of thermal energy, thus gives a reflection on the daylighting into building to glazing area transiently which can cause heat gain into the building. Unlike absorptive material like concrete, it has a good conductance of thermal energy which can restore the heat gain in a slower rate. By using concrete as, shading device is good as to reduce thermal gain into building up to 5-10% [8]. Heat trap and heat transfer are a major caused of heat gain to the building. This is because of the thermal conducted from the shading device can cause either the heat is trapped or transferred. These two conditions indicate the importance of the study on the distance of shading device from glazing area. The further gaps between the shading device and window area can reduce heat gain into the building up to 10-15% decreased. However, it is related to the rate of heat transfer of material properties of shading device. Therefore, it is crucial that a precise study must be conducted to determine how the distance of shading device from glazing area works and what type of material properties with appropriate thicknesses need to be applied to the shading device in order to lower the temperature gain into the building.

The solar radiation climatic element could be that solar radiation from sunlight accounts for the solar heat gain indoors. The heat transfer from outdoor toward building interiors, and the prime cause to such a transfer was the temperature difference between the indoors and the local environment outdoors. Nevertheless, the solar radiation is not th only factor causing the temperature build up indoors, outside air temperature as well as the internal heat gain such as light sources, human beings and process work are also have a role in the play. Besides, other factors could be the rate of ventilation and the relative humidity of air, but to some extent [9].

Radiant heat passes through the glazing and is absorbed by building elements and furnishings, which then re-radiate it. As a concern, the re-radiated heat has a different wavelength and cannot pass back out through the glass as easily. In fact, the thickness of the wall or shading device itself gives a big impact on the heat gain to the building. In addition to that, the walls and roof surfaces are important to reduce heat gain, particularly if they are dark colored or heavyweight material [10].

The wall thickness with appropriate selection of material property help much in reducing the thermal gains because to get the equilibrium within outside temperature, and indoor temperature is hard to be achieved. The temperature is proportionate with the wall thickness where the heat was conducted and radiated with the wall thickness. The heat energy is spread to the whole material due to molecular movement as for the equilibrium condition, whereas the material absorbs radiation once it is heated. In this way, heat is conducted away from the source of energy as the material distributes the energy evenly throughout its mass.

In addition, the external walls have significantly greater temperature differential than internal walls. Therefore, thermal mass must be insulated externally. The useful thickness of thermal mass is the depth of material that can absorb and re-release heat during a day-night cycle [8]. For most common building materials is 50-150mm depending on material conductivity. The conduction is to show how absorbed solar energy moves through a material which is always in a direction away from the source of heat to attain equilibrium. Unlike solar energy, radiant energy is limited to infrared radiation emitted from a material at low temperatures. To the extent to which a material emits thermal energy depends both on the temperature of the material and nature of its surface [7].

Generally, Malaysia is using concrete, aluminum and steel for construction materials as for shading device. This is due the availability of the materials in this country. Thus, concrete is the famous and common material which has been used for many years. In the current situation, designers tend to use a lightweight material such as aluminum and steel in building construction. It is the fastest way in construction which can be custom made like a pre-cast construction. However, with the rapid construction, not much research was explored on the effectiveness of using these materials in construction industry, especially on the application of shading device in order to reduce the thermal gains in the building. The common sizes of thickness and gaps between shading and glazing are 50mm to 150mm. This range is appropriate to apply for shading device construction.

The basic purpose of simulation is to focus on the underlying mechanisms that control the behaviour of a system. More practically, simulation can be used to predict the future behaviour of the system, and determine what we can do to influence the future behaviour. It is also to study the current problem with the system so that we can minimize the problem and maximize the quality or function of that system. The vast development in technology, the invention of new software tools to solve the dilemma in design and construction of energy efficient building enable cost, time and energy saving [11].

2. RESEARCH METHODOLOGY

The methods uses are field measurement and ECOTECT Analysis as computer simulation. This study investigates certain variables on shading device, which are the thickness of shading device, material properties of shading device and the distance of shading device from the glazing or window area. Since the investigation focus on the variables, the size of the office room has to be standard. Besides, the validation of the computer software has been tested by comparing the results from field measurement and computer simulation. As a result, there is not much discrepancies found with the software. A typical office room with standard measurement has been chosen as a modelling tool and measured with simple investigation data logger. Results are compared with the computer simulation. In the meanwhile, the purpose of field measurement is also to identify the temperature difference between the outside temperature and indoor air temperature.

The research was conducted in two phases which are field measurement in realistic condition and computer simulation. The measurement tool used in the field measurement is a data logger (HOBO E-348-U12-011). The floor-to-ceiling height of the measurement test room is 3m. The parameters applied for the field test are air temperature and relative humidity. The field measurement was scheduled for 13 February 2014 from 1.00pm to 20 February 2014 to 1.00pm. It was a one week test. According to Meteorological Department of Malaysia (MET), the temperature value is very high during this period. There were two instruments were setting up in an office room with vertical shading device, which is located at Taman Melawati, Kuala Lumpur. The data collected from the two instruments were summed up and averaged one hour interval in order to obtain the more compact data.

The model was drawn directly in ECOTECT software. About eleven zones were created to identify and to simulate the heat gain in office room. From eleven zones, only one zone was selected as tested model. The model represents the zoning area with shading device where all the chosen variables were applied. The models created were based on the matrix system. The rest of the zones represent the site context of the surrounding building in order to get the accuracy of the result of the heat gain. The basic geometry of each zone is the rectangular and the normal size of office room is 4m x 3m equal to 12m2. The model use for this research in ECOTECT is space-based model.

The space-based model in rectangular shape was created with specific dimension as stated before. The dimension of each zone was using the reference point in X-axis, Y-axis and Z-axis. The application of the axis is to make sure the dimension of the zones is accurate and zero error in thermal calculation. The zone 8 (tested model) was designed with shading device and the material properties were assigned to each zone. All zones indicate different material properties based on different elements of building envelope such as wall, floor, ceiling and roof. The glazing was also applied to the zones for the thermal calculation.

The ECOTECT simulation produce many outputs on thermal analysis, such as hourly temperature profile, hourly heat gains and losses, monthly loads/discomfort, passive adaptively index, temperature distribution, fabric gains/indirect solar, temperature/gains comparisons and passive gain breakdown graph. The passive gain breakdown graph will be used in this research because it compromises six heat transfer mechanism to derive final output for thermal analysis. This output is the most appropriate to be used in analysing the heat gains in the building. The passive gain breakdown graph will produce conduction value, sol-air value, direct solar value, ventilation value, internal value and inter-zonal value in a percentage (%) and W/m2.

This research is only focused on three variants on size of thickness, types of materials and distances between shading device from the glazing area. The recommendation for the thickness of shading device starts at minimum 50mm and end at maximum thickness with 150mm. It is because the thickness with over 150mm will be overshadowing the glazing area as well as might block the outside views to the building occupants. These thicknesses are common for building materials, especially for material conductivity in absorbing and re-release the heat. It is the same principles applied for a distance between the shading from the window.

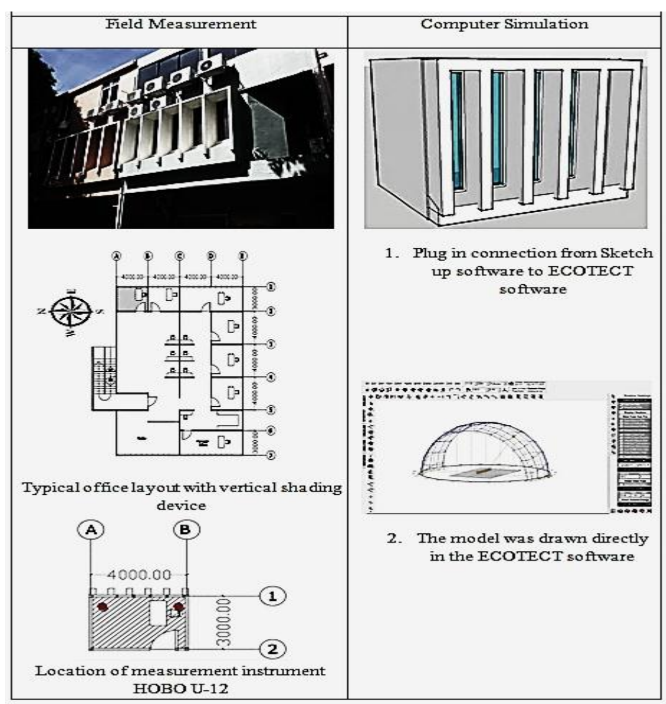

Figure 1. Typical office with vertical shading device

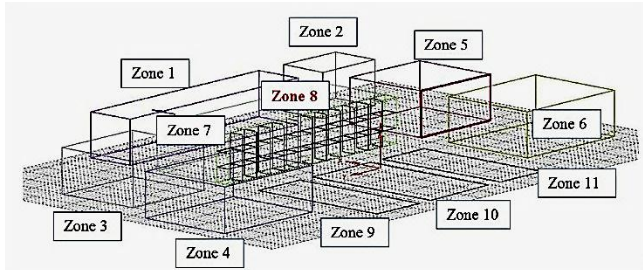

Figure 2. Blocks of building setup as zones in ECOTECT analysis

As per Malaysian application, the common materials applied to construct shading device are concrete, aluminum and steel. There is the temperature differential between indoor and outdoor with these materials. The material with high conductivity will reduce heat gains into the building. Concrete is heavy in characteristics, but easier to get and supply as Malaysia is famous with the concrete construction. Steel is lightweight and user-friendly materials and mostly be used in current construction while aluminum is lightweight and corrosion-resistant, has a good thermal and electrical conductivity with a moderately high coefficient of expansion. The energy transfer between internal and external surfaces is merely related to the material properties [12].

3. FINDINGS AND DISCUSSIONS

The purposes of field measurement are; 1) to analyse the indoor air temperature difference in office room with vertical shading device and 2) to prove the validity of the ECOTECT software. The temperature difference was measured from this data. In result, the highest indoor temperature is about 330C while the highest outdoor temperature is 420C (meteorological data), which means, the temperature difference is only 90C. The minimum indoor temperature achieves is at 29.50C and average indoor temperature is at 31.50C. In addition, the minimum relative humidity in this office room is 40%, the average is 50% and the maximum relative humidity is about 80%. With reference to temperature difference result, this is to justify that, the existing shading device in this building is not very well reduces the temperature gains to the building. The shading is probably acts as buffer which is only to block the sunlight from entering into the building. The temperature charts for vertical shading devices showed 100% of accuracy in generating the results on air temperature and relative humidity between computer simulation result and field measurement result. However, the graph for vertical shading on relative humidity showed 75% accuracy for less than or equal to 20% and 25% non-accuracy for more than 20%. The research outcome shows that ECOTECT software can perform accurately in nearly all the analyst hour in the condition of air temperature and relative humidity. The acceptable percentage difference between field measurement results and computer simulation results is in the range of 15% - 20% [13] while another person [14] stated that the discrepancies of acceptable percentage difference to validate the computer software can be 20% or less. Thus, in this research, if the percentage difference was less than or equal to 20%, the software was considered accurate.

A total of ten graphs was calculated and had been analysed. The models were generated from variables studies with three variables of each model. The analysis has also clarified the effective of the thickness, material properties and the distance of shading device from the wall to be concerned.

Table 1: Results of passive gains breakdown for all models

Models	Direct solar	Sol-air	Conduction	Ventilation	Internal
Model A	32.6%	19.6%	31.2%	9.5%	7.2%
Model B	30.0%	19.6%	35.1%	8.7%	6.6%
Model C	29.9%	19.7%	35.1%	8.7%	6.6%
Model D	32.6%	19.6%	31.2%	9.5%	7.2%
Model E	32.6%	19.6%	31.1%	9.4%	7.2%
Model F	29.9%	19.7%	35.1%	8.7%	6.6%
Model G	29.9%	19.7%	35.1%	8.7%	6.6%
Model H	32.6%	19.6%	31.1%	9.4%	7.2%
Model I	32.5%	19.6%	31.2%	9.5%	7.2%
Model J	29.9%	18.9%	30.9%	7.5%	0.0%

The result indicates that most of the heat gains derive from direct solar and conduction. This explains that the further distance applied can reduce the thermal gains into the building. This is also justifies that temperature gains through conduction depends on the material properties. The rate of heat transfer has four factors which are temperature difference, length, cross-sectional area and material properties. In conduction, heat is transferred from a hot temperature location to a cold temperature location. The transfer of heat will continue as long as there is a difference in temperature between the two locations. Once the two locations have reached the same temperature, thermal equilibrium is established and the heat transfer will stop. The temperature gain applies between outdoor temperature and indoor temperature to achieve this thermal equilibrium.

A variable that affects the rate of conductive heat transfer is the distance that the heat must be conducted. Heat escaping through the distance of the shading device from the glazing area and between the shading fins will escape more rapidly than through attached shading to the wall. The rate of heat transfer is inversely proportional to the thickness of the shading device. The thicker the shading device is, the lower the rate of heat transfer to the building. This increases the thickness of the materials through which heat is transferred, as well as trapping pockets of air between the fins of shading layers. Another variable that affects the rate of conductive heat transfer is the area through which heat is being transferred. For instance, heat transfer through windows of buildings is dependent upon the size of the window. Each individual particle on the surface of an object is involved in the heat conduction process. An object with a wider area has more surface particles working to conduct heat. As such, the rate of heat transfer is directly proportional to the surface area through which the heat is being conducted. The most variable of importance is the materials involved in the heat transfer. The heat is transfer from solar radiation to the shading device, to the wall and window. The materials of importance are shading device, wall and window. The rate of heat transfer depends on the material through which heat is transferred. The effect of a material upon heat transfer rates is often expressed in terms of a number known as the thermal conductivity. Thermal conductivity values are numerical values that are determined by experiment. The higher that the value is for a particular material, the more rapidly the heat will be transferred through that material. Materials with relatively high thermal conductivities are referred to as thermal conductors. Materials with relatively low thermal conductivity values are referred to as thermal insulators.

The solids like concrete offer the least resistance to transfer of heat by conduction. Conduction requires physical contact between materials through which the heat is transferred. A material temperature is related to the motion of the constituent molecules. The conduction process involves the molecule moving at higher velocities transferring their kinetic energy to the adjacent molecules which have lower kinetic energy. Therefore, it can be concluded that the shading device with 150mm gaps from the window has better reduction of temperature gains into the building. This is also justifies that the shading device with 150mm thickness has a lower rate of the heat transfer. This thickness is acceptable to apply because it does not genuinely block the entire view of the building. The result of heat gain explains that the further the distance is, the smaller the percentage of heat transfer into building. Thus, the distance is proportionate with the thermal gains result. The research also found that by using concrete as shading device appear to be a reliable material to be applied since its prevent the heat gains into the room. This is because of the characteristic of concrete which has a good conduction and as a heat store compared to steel and aluminium. When solar radiation penetrates to the building, the concrete shading device is slowly absorbed the heat and deliberately transfer the heat. This is quite interesting findings because as stated in physic law, the higher thermal conductivity is the better conduction flows in that material. Compared to the concrete and steel material, aluminium has the highest thermal conductivity. However, the passive gains breakdown shows inversely. This is due to the two variables, which are the thickness and the distance of shading device from the glazing area.

4. CONCLUSIONS

All the ten models have been tested through computer simulation. The best model that can reduce more on the thermal gains into the building is model J (150mm thickness, 150mm gaps and concrete material). From the final result of passive gains breakdown graph calculated that the thermal gains in the building is reduced from 31.2W/m2 to 29.9W/m2. Based on the findings of the research it is appropriate to make the recommendation to increase the performance of shading device in order to avoid the heat gains into a building as well as to achieve thermal comfort.

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