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The Effect of Day Lighting Transmittance Through Window on Indoor Air Temperature

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Abstract: Natural lighting creates a strong and efficient stream of radiant energy and the concept is to allow day light into the area of spaces of buildings. Lighting is an important factor in building because it leads to increased energy consumption when the building has the poor lighting. Further analysis was conducted to investigate the relationship between indoor air temperature, illuminance level or solar radiation. This paper analyses the recent studies of the application of external shading device on its effect to reduce heat on indoor condition while providing appropriate level of illuminance. About 20 selected papers were reviewed and finally 5 screened papers were used extensively for analysis. The keywords used to identify the related papers at search engines were shading devices, illuminance level, solar radiation and air temperature. Based on the reviewed, it was found that by introduction of the external venetian blinds with at least 40° of slat angle can produce heat reduced by 8°C. Meanwhile, illuminance and solar radiation rate can be reduced by up to 376 lx and 21 W/mm² respectively. The relationship analysis shows that there was a moderate to strong correlation between the indoor air temperature and illuminance level (R=0.96 to R=0.55). The usages of shading devices were very important to install in the buildings because they can help the occupants to achieve the visual comfort.

Keywords: Shading Device, Temperature, Illuminance, Solar Radiation

1. Introduction

One of the most important parts of architecture are windows and well-known for enhancing the wellbeing and comfort of entire building. Moreover, windows not only play a key role for supplying light and viewing, but influencing the whole demand for energy in buildings [1]. Windows become one of the most significant elements for energy improvements in hot and cold region [2]. According to Li [3], day lighting is an efficient and one of the techniques to sustain and to boost visual comfort, energy efficiency and the development of green buildings. The surfaces on which exposed to the sun must be covered to prevent the transmittance of heat. Shading devices must be a main role because glass windows are the primary parts that allow heat to penetrate and thus increase the possibility of overheating [4].

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The opening window without any shading devices will make the heat absorbed uncontrollable and the optimum balance between heat and lighting in building cannot achieve. Using appropriate shading devices can help to reduce energy usage and kept the lighting levels in buildings within an acceptable range with fewer glares. As a result, shading devices are appropriate to provide shielding from too much solar irradiance while also reducing a building's air temperature during the summer [5].

Many previous studies have conducted the effect of external shading device, especially about their effect on building energy, illumination level, glare and indoor thermal gain. However, not many of them focus on the relationship of thermal gain and illumination rate. Moreover, many researches consider using computer simulation approach but there are lacks of documentation of the result based on actual field work. The major focus is the occupant energy behavior's diversity and diverse properties, which is influenced by a variety of internal and external, individual and contextual factors [6].

This study was conducted to examine the effect of venetian blind external shading on indoor air temperature, light transmittance value or solar radiation through window by the shades of specified tilt angles and to determine the relationship between light transmittance values with indoor air temperature.

2. Literature Review

2.1 Natural Lighting

Singh [7] in their study asserted that the sun creates a strong and efficient stream of radiant energy. Part of this light flux, known as sunlight, hits the surface of the earth after passing through the atmosphere. The existence of the radiant energy is diffused by several reflections as it travels through the atmosphere and creates diffuse light. The amount of daylight obtained by the building is continuously changing, since the sun is constantly changing its location relative to the building.

Al-Ashwal & Hassan [8] said in their study, good conditions for performing various visual tasks can be produced by daylight, as high levels of illumination are provided and excellent colour rendering and discrimination are permitted. However, poor daylight designs can lead directly to reflections due to the very high luminance and discomfort that can interfere with good vision.

According to Kumar M & Kranthi [9], the position of the sun in the sky has always been subject to certain changes throughout the season and affects the availability of natural light. The location of the sun is identified on the geographical location and geometric location is calculated based on true altitude and angle of azimuth. Usually, the day when the sun is higher will be brighter. The significant orientation of the buildings is analyzed considering the angle of the sun. The sun's movement from east to west, as well as its accompanying angle, affects the amount of daylight that enters the building.

2.2 Shading Device

Windows may contain a variety of elements, including shading devices. The architecture of these components represents a variety of functions, including thermal control. An external shading device on a building facade is a significant passive design technique as they minimize solar ray [10]. Al-Tamimi & Fadzil [4] also stated that the main function of a shade system is to shield a structure from direct sunlight. A study by Faisal & Aldy [11] stipulated that an attempt to minimize energy is the use of shading devices. Application of air conditioners requires a lot of energy, replacing natural light with architectural elements to minimize thermal building.

External shading devices come in a variety of shapes and sizes, including horizontal, vertical, and horizontal-vertical combinations. The thermal conditions within a building are greatly influenced by openings, particularly windows. Windows typically has a lot of aspects, some of which can be customized. These parts perform a variety of usages, including control the absorbed daylight, the prevention of glare and the prevention of direct solar radiation [12].

Zhang & Barret [13] stipulated that Venetian blinds are widely used today as they are highly adjustable and movable, allowing them to respond easily to the changing needs of occupants which are radiation levels, daylight or thermal needs. Tang & Chin [14] in their study asserted that heat gain is

controlled by external and internal blinds. Internal shades are utilized to shield against glare in Malaysia due to the bright cloudy sky present in tropical areas. External shades, on the other hand, are more effective than internal shades because they block solar radiation before it enters the structure. Internal shading, on the other hand, can work better than exterior shading devices in this tropical climate zone if the right type of internal shade is applied

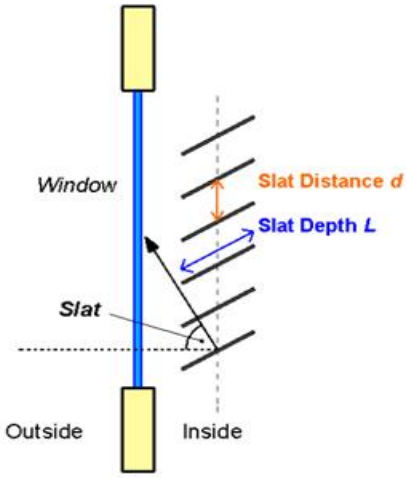

Figure 1: Schematization of Venetian blind [15]

2.3 Heat Transfer by Window

Zhang & Barret [13] also asserted that there are various windows blind systems are suggested to shield tenants from uncomfortable and to enhance the effect on energy usage in conjunction with other lighting or heating strategies and also stipulated in study that their results from research also check that the occupants use Venetian blinds as a replacer to control the ray radiation. ASHRAE 90.1-2007 has suggested that window-to-wall ratio of 0.24 is considered good to let optimum indoor daylight and natural ventilation.

The most spontaneous and quick method of controlling overheating in the environment is to open the windows [16].The opening window without any shading devices will make the heat absorbed uncontrollable and the optimum balance between heat and lighting in building cannot achieve. Using appropriate shading devices can help to reduce energy usage and kept the lighting levels in buildings within an acceptable range with fewer glares.

3. Methods

The method used consists of two main phases where the first phase was include conducting a systematic review for field measurement. While the second phase focused on data abstraction and analysis. The keyword used to obtain the related articles was the illuminance level, shading devices and the indoor air temperature.

3.1 Systematic Review Process

The review process was carried out in April 2021. In the first step keywords related to visual comfort of building in hot and humid climate were identified to classify the relevant posts, based on prior research and thesaurus. The recorded papers were searched through electronic databases such as Springer, ScienceDirect and Google Scholar. The keywords used are visual comfort, shading devices, illuminance level, air temperature and solar radiation. About 60 papers were identified at the first stage that related with the keywords.

Several factors for eligibility and exemption have been independently reviewed. However, the papers were chosen at the final stage of the study. The selected papers were picked on the basis of the key objectives of this review paper on the visual comfort range for buildings. The papers corresponding to the goals were specifically chosen at the conclusion of the journal eligibility decision. Before screening process, about 20 out of 60 papers were selected. Then, only 5 papers that fulfilled the criteria which are in consideration for selection which are containing information of base configuration or outdoor measured value, indoor air temperature, indoor illuminations rate and solar radiation rate.

The 5 papers were analyzed and evaluated. The formulated query, which responded to particular research, was focused. The data was duplicated by reading through abstracts and then relying on complete papers to define relevant themes and sub-themes. Qualitative analysis was a measure using content analysis to define themes related to visual comfort buildings. Sub-themes formed by typology were then arranged by the authors. This study focuses on the usage of the shading devices and the relation between the illuminance level and air temperature. Data comparison from every review of the included journal will be reported using the tabulation process.

3.2 Analysis Method

Various physical parameters were measured for the purpose of the study. Visual comfort was incorporated in nearly all studies, such as the estimation of general comfort parameters; including three environmental variables (i.e. air temperature, solar irradiance, and illuminance level). The measurements have been carried out using several instruments recorded in the reviewed paper such as pyranometer which used in measuring the solar irradiance, the LUX meter used to record the illuminance level, globe thermometer and temperature probe were used to record the air temperature.

Studies are mainly conducted in worldwide in both developed and developing countries and the analyses have been developed and described for the comparisons and contrasts between the studies and the relation between the above parameters. The room spaces were different in design dimensions and were using the suitable equipment. The value of illuminance level, air temperature and solar radiation were recorded to define the preferred or comfort temperature for building spaces.

4. Results and Discussion

The general finding of the reviewed studies that are summarized into the following sections: light transmittance value with indoor air temperature and blind tilt angle approach. The results were obtained based on survey conducted from the previous paper and all the data were compared with all cases.

4.1 Effect on Indoor Air Temperature

Based on the Case 1 [17], the study is carried out in Jordan, in workplaces with a south-west façade, in a hot temperature location. Figure 2 shows the temperature of the air in an office without shading devices compared to the temperature of the air in offices with shading devices. The maximum outdoor temperature, maximum temperature of base case and maximum temperature with shading device reach at 36.3ºC, 35.7ºC and 31.6ºC respectively. The shading devices play a big role in this study, as the air temperature is lower than the outdoors and base case, and the room with shade is always cooler than the other cases, as shown in the graph.

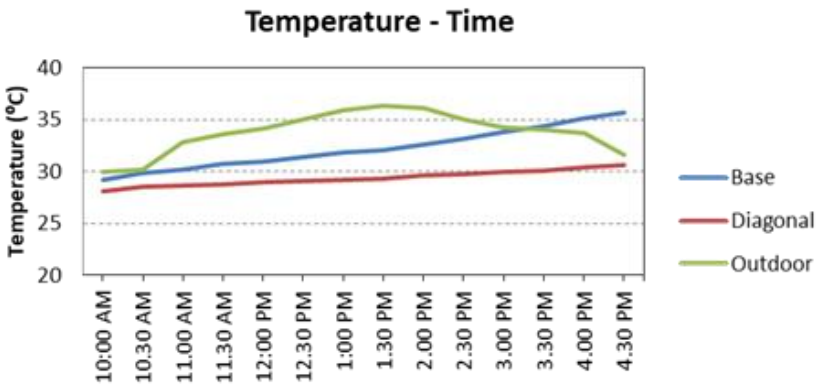

Figure 2: Temporal variation of air temperature indoor, outdoor and base case in Case 1 (re-plot based on [17])

Based on the Case 2 [18], the research was conducted in the office building in Montreal located in a tropical climate. Their paper also focuses on the effectiveness of shading device where the Venetian blind was used in this study. From Figure 3, it shows the outside air temperature (33.5ºC) is higher than the inside air temperature (28.9 ºC) and can achieve the visual comfort in the building. Because windows are the only structural element that can immediately transmit solar radiation into the internal building, shading mechanisms are required to limit solar penetration. The maximum and minimum average air temperatures were 25.15ºC and 26.2ºC respectively.

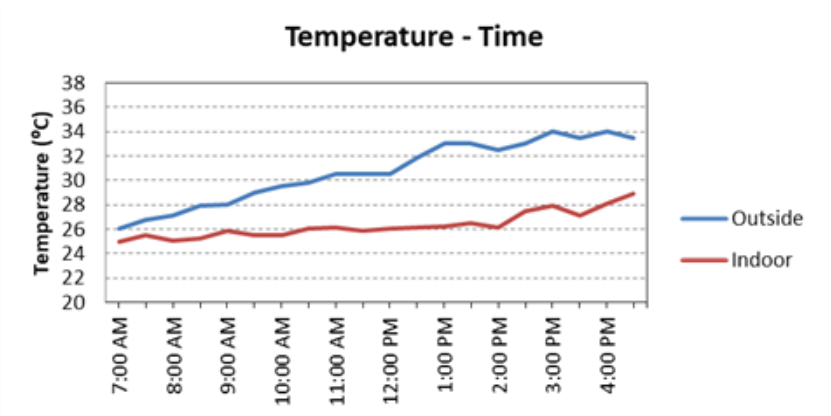

Figure 3: Temporal variation of air temperature indoor, outdoor and base case in Case 2 (re-plot based on [18])

Therefore, based on the Case 3 [19], the study was carried out in a building concept consisting of one test room created at the University of Perugia in Italy, with the window's face facing south. The result in Figure 4 show that the recorded outdoor air temperature (22.5ºC) is higher than the inside air temperature (12.25ºC), and this also proved that the installation of shading devices such as Venetian blind can help the occupants to achieve the visual comfort and they enable less excessive heat when the air conditioning system is not used, as well as improved indoor thermal comfort. The maximum and minimum average air temperatures were 17.65ºC and 15.75ºC respectively. When compared to the absence of any shading device to all the cases, the use of shading devices such as diagonal fins and Venetian blinds contributes to a decrease in energy requirements.

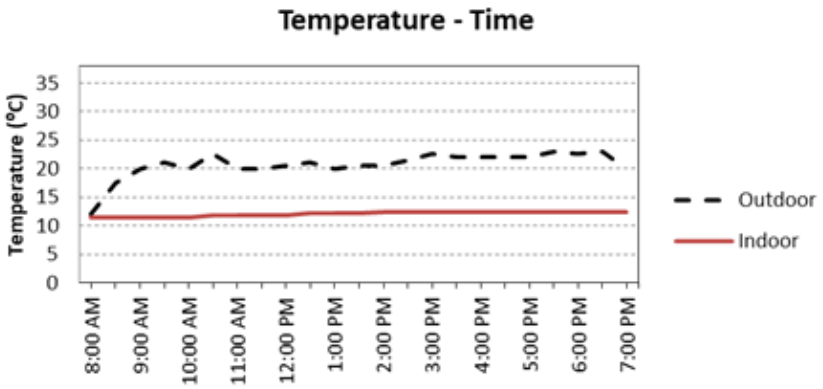

Figure 4: Temporal variation of air temperature indoor, outdoor and base case in Case 3 (re-plot based on [19])

Based on the Case 4 [20], the research was conducted in the existing home in Denver. Their paper also focuses on the performances of shading device where the Venetian blind was also used in this study. From Figure 5, it shows the outside air temperature (25.1ºC) is higher than the inside air temperature (23.9ºC) and can achieve the visual comfort in the building. The maximum and minimum average air temperatures were 24.5ºC and 23.9ºC respectively.

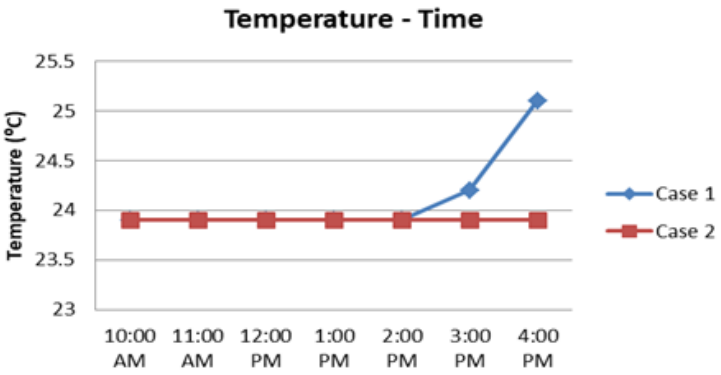

Figure 5: Temporal variation of air temperature indoor, outdoor and base case in Case 4 (re-plot based on [20])

4.1.1 Temperature Difference

The Figure 6 shows that the difference of temperature for all the cases (Case 1, Case2, Case 3 and Case 4). The shading devices can reduce the air temperature at average temperature 5ºC -8ºC. The usage of shading devices also proved that when the time from 1 pm – 2 pm, the air temperature is lower than other daytime recorded for all three cases, but overall, the shading can reduce the solar penetration through to the building spaces.

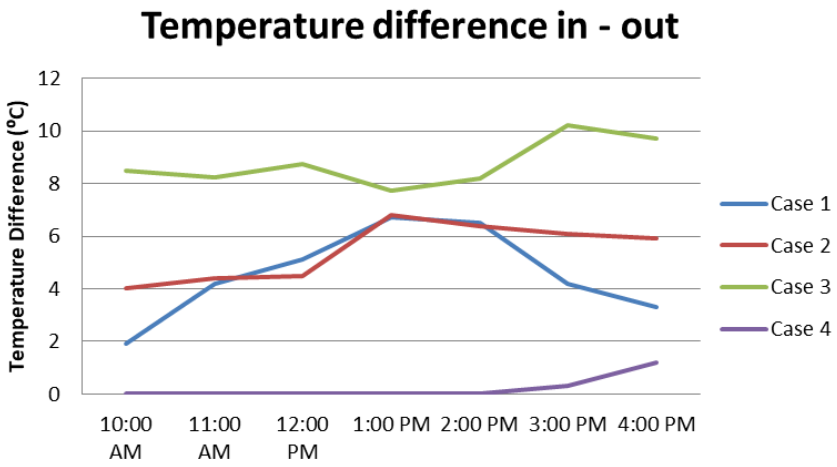

Figure 6: Temporal variation of air temperature difference between outdoor – indoor for all cases

4.2 Effect on Illuminance Level

Based on the Case 1 [17] in Figure 7 shows that the illuminance level when using the diagonal shading devices is lower than the base case. When the illuminance was low, the sensitivity to temperature was low and additionally, as the illuminance increased, the sensitivity to temperature increased. Although the shade devices reduced morning illuminance compared to no shading, the illuminance remained higher in the afternoon, allowing occupants to achieve comfort in the building spaces. The illuminance was reduced by shading devices from around 496 lx in the no shading case to around 120 lx for diagonal fins in the morning and with diagonal shading devices, the illuminance level was reduced from more than 1700 lx in the no shading case to around 390 lx in the evening.

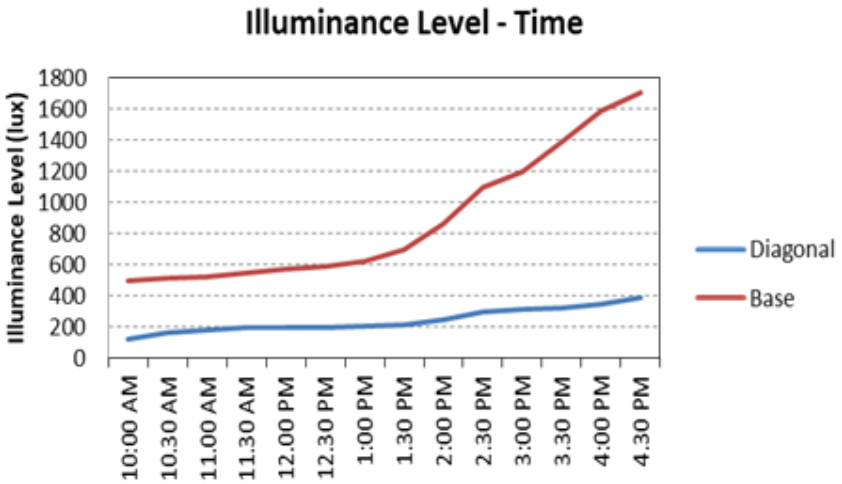

Figure 7: Temporal variation of illuminance level in Case 1 (re-plot based on [17])

Based on the Case 3 [19] in Figure 8 proved that the illuminance level with shading with 45º was lower compared to the base case because the Venetian blind with slat angle will prevent most of the incident direct solar penetration. The illuminance was reduced by shading devices from around 1120 lx in the base case to around 300 lx for blind with angle in the afternoon (1.30 pm). It can say that the blind with angle can reduce the solar penetration enter through the building spaces.

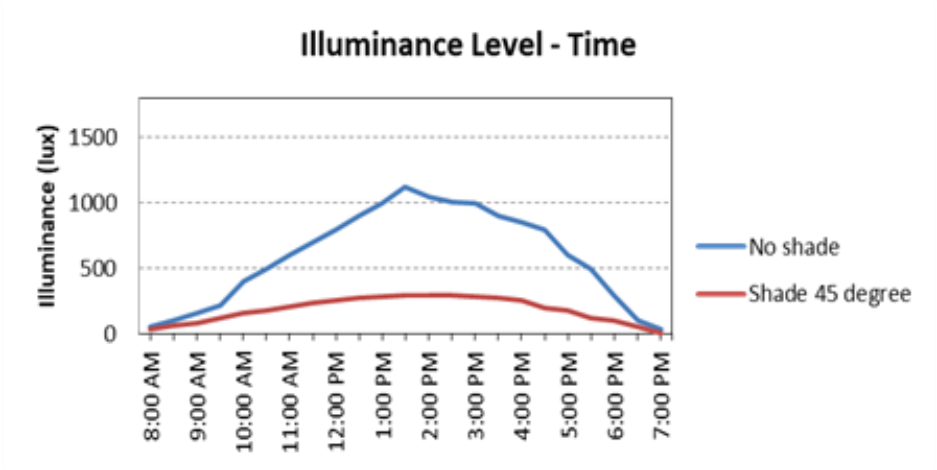

Figure 8: Temporal variation of illuminance level in Case 3 (re-plot based on [19])

Based on the Case 5 [21], the site location is at Freiburg, Germany in and the office spaces are south oriented. Figure 9 shows that major difference of illuminance level between base case and shading with 40º. The illuminance was reduced by shading devices from around 1000 lx in the base case to around 180 lx for blind with angle in the morning around 10.30 am. The figure also shows that from 8.30 am until 11.30 am, there were major difference of illuminance between base case and shading.

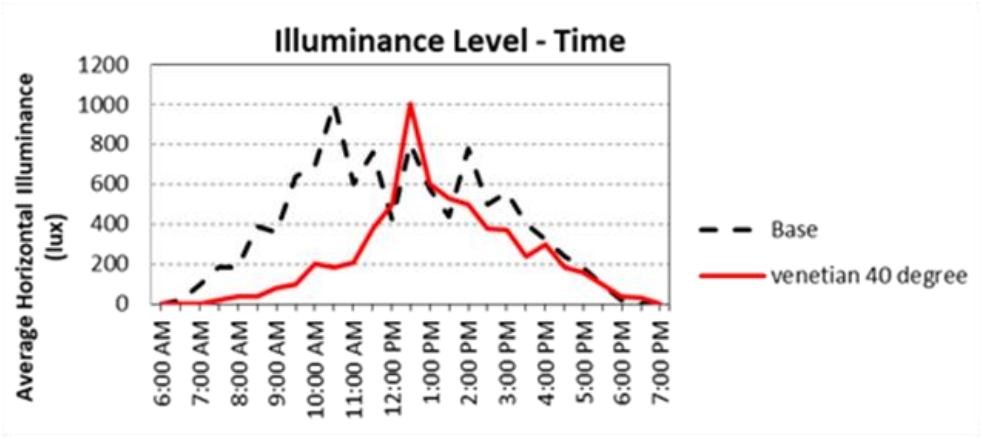

Figure 9: Temporal variation of illuminance level in Case 5 (re-plot based on [21])

4.2.1 Illuminance Level Difference

The Figure 10 shows that the difference of illuminance for all the cases (Case 1, Case2 and Case 3). The shading devices can reduce the illuminance level at average illuminance level at 390 lx. The usage of shading devices also proved that when the time from 7.00 am – 8.00 am and form 11.30 am – 12.30 pm, the illuminance level is lower than other daytime recorded for all three cases, but overall, the shading devices can reduce the solar penetration through to the building spaces.

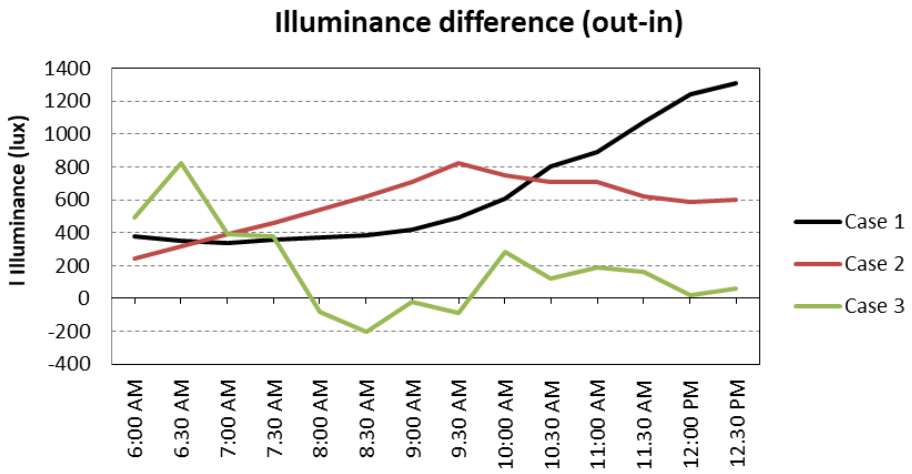

Figure 10: Variation of illuminance difference for all cases

4.3 Effect on Indoor Solar Radiation

Based on Khamporn & Chaiyapinunt [18], this paper also record the time variation of the transmitted solar radiation between outside and inside global. The shading device was used and only allow small amount enter to the building which is the lowest was 21 W/mm². It has been demonstrated that the slat angle has a greater impact on the amount of solar radiation transferred into the interior spaces. The venetian blind placed at 45º slat angle on the glass window enables the least amount of sun radiation into the room.

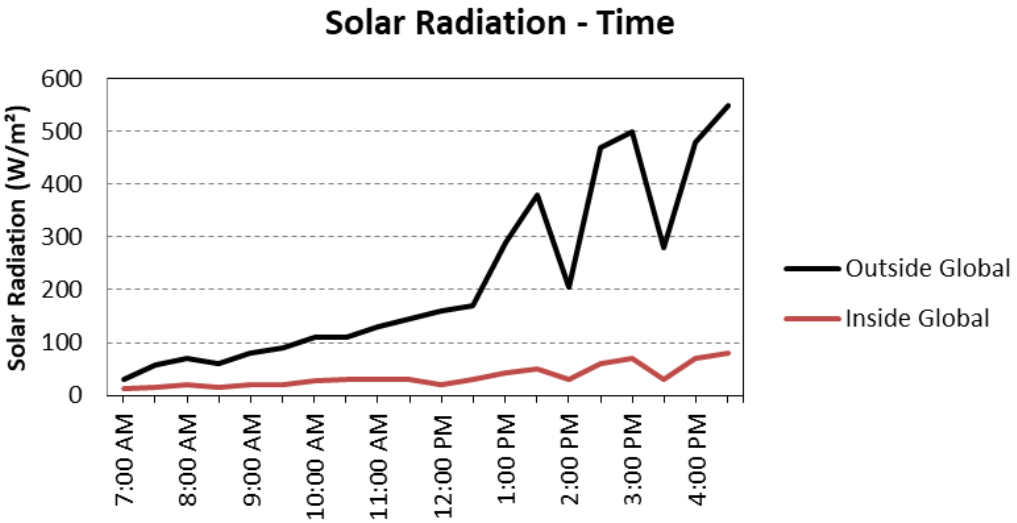

Figure 11: Graph of solar radiation against time (re-plot based on [18])

4.3.1 Solar Radiation Difference

Based on Figure 12, it shows that the difference of solar radiation between outside and inside global. The solar radiation that enters through the building was increasing at 12.30 pm until 4.30 pm. It can be concluded that when the shading devices such as Venetian blind is set to allow more solar radiation to enter a space and strike the occupant, the discomfort is caused primarily by the effect of solar radiation.

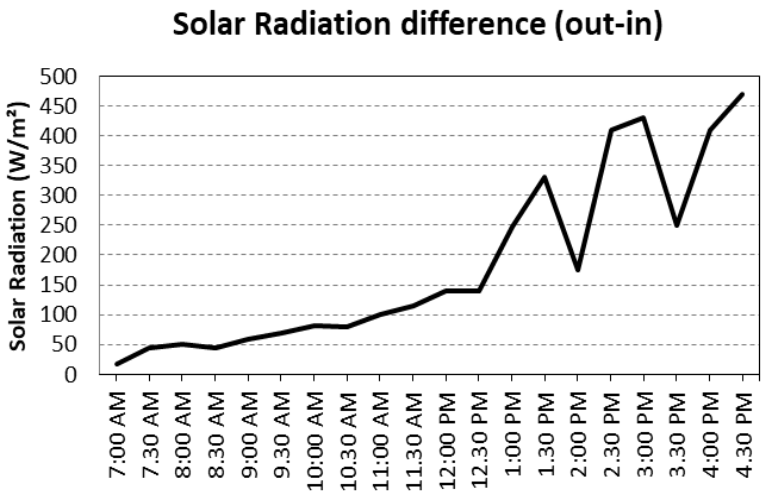

Figure 12: Graph of solar radiation difference

4.4 Analyses between Illuminance and Air Temperature

Based on the Figure 13, the graph shows the relationship between illuminance level and the air temperature for all cases. From Figure 4.12, the illuminance level was increasing due to the increasing of the air temperature and same goes to the Case 2. For the Case 1, the relationship strong is R=0.96. This show the Case 1 has higher exposed to illuminance and cause the temperature was increasing. To be noted, as 300 lx for reading or work in a room, it show the temperature around 29ºC, so it quite high. So need to consider reducing the heat gain during that level of illuminance.

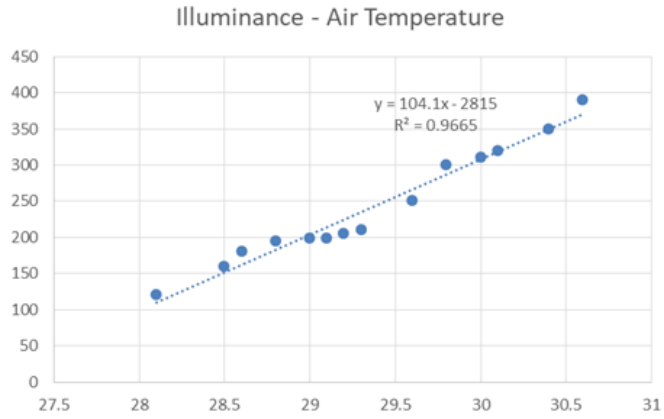

Figure 13: Graph of illuminance level against air temperature Case 1

It can be concluded that shading devices were very important in this case because they can reduce the energy consumption and will achieve the comfort in the building spaces. Therefore, based on the Figure 14, for the Case 2, the relationship is moderate which is R=0.55. This show the Case 2 has lower exposed to illuminance and temperature compared to the Case 1. For the Case 3, this data was not included in this paper because the data was not suitable to analyze and because of the temperature range is too small so, cannot provide the useful information about the effect of illuminance on temperature changes.

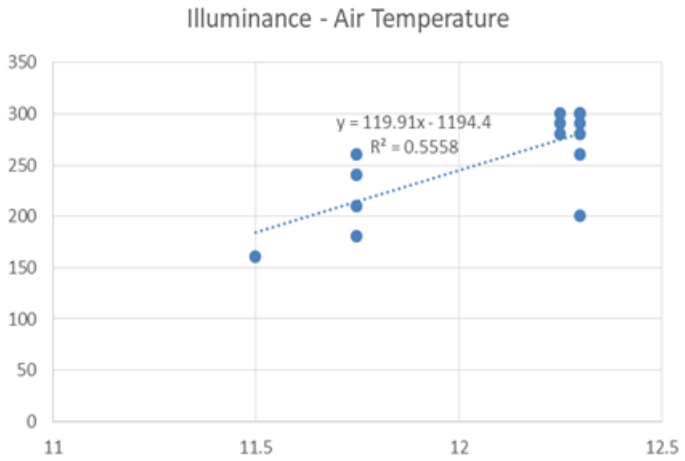

Figure 14: Graph of illuminance level against air temperature Case 2

5. Conclusion

The addition of shade devices will encourage residents to support energy-saving measures and building sustainability. The results show that Venetian blinds assist in maintaining a lower mean radiant temperature than the indoor air temperature, which is very important during the hot climate and the study also showed that shading devices such as Venetian blind could have a significant impact on indoor temperature conditions not only in office buildings with large glazed surfaces, but also in typical residential buildings with a more limited glazing-to-opaque ratio. The main source of discomfort is solar radiation is when the blind is in a way that will allow more solar irradiance into the room. By external shading devices, the indoor air temperature can reduce up to 8ºC on daytime. They also can reduce the illuminance up to 376 lx and also can reduce the solar radiation up to 21 W/mm². The relationship analysis shows that there was a moderate to strong correlation between the indoor air temperature and illuminance level (R=0.96 to R= 0.55). In conclusion, the usages of shading devices were very important to install in the buildings because they can help the occupants to achieve the visual comfort. Therefore, it is important to find the optimization balance between natural lighting and temperature gain.

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