Study on the thermal and visual performance due to highly reflective façade in Singapore

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Abstract: This study preliminarily investigates the impact of highly reflective building façade material on the thermal and visual performance of surrounding buildings in the tropics. A 9-story commercial building with curved stainless-steel façade was observed and indicated as the source of reflective glare. Field measurement was conducted on nearby a 4-story school building which is directly affected. Indoor globe temperature, glass and wall surface temperatures, and illuminance were measured in six selected classrooms. Parameters such as weather condition, horizontal location, vertical location, and shading were analysed based on the data collected from the on-site measurement. The measurement data on a sunny day and a cloudy day were selected and compared. From the measurement data, it is found that weather condition plays a vital role in determining both indoor thermal and visual performance; while horizontal and vertical locations also have a considerable effect. On the other hand, horizontal overhangs can help to reduce air temperature, surface temperature and illuminance value which can help to achieve a better indoor thermal and visual environment.

Keywords: Reflective material; building façade; thermal performance; visual performance.

1. INTRODUCTION

Using highly reflective materials such as glass or metal claddings has become more popular for high-rise buildings in Singapore. However, the preference for reflective materials produces glare that may affect the thermal and visual environment of the surrounding developments. Moreover, when the skyscraper has curved shapes and reflective walls, discomfort glare will occur and result in increased temperature and illuminance in the surrounding developments.

Previous studies have been carried out to observe the relationship between the building façade and glare. Araji and Boubekri (2008) studied the impact of window size on vertical illuminance and glare; while Konstantzos and Tzempelikos (2015) analysed daylight glare probability in offices with dynamic window shades through experiment and computer simulation. Ochoa and Aries (2012) looked into the design optimization criteria for windows which can provide high visual comfort. Konstantzos and Tzempelikos (2014) investigated the correlation between Daylight Glare Probability and indoor illuminance by conducting experiments in a full-scale office which was designed with dynamic shading controls. Meanwhile, Ishak and Wong (2018) examined the effect of building façade reflectivity on outdoor visual comfort in the tropical climate.

However, there is a lack of studies on the impact of highly reflective building façade on the indoor thermal and visual environment of surrounding buildings, especially in the tropics. Therefore, this study embarks with the following objectives:

- to study the impact of highly reflective building facade on the indoor thermal environment of surrounding building;
- to study the impact of highly reflective building facade on the indoor visual environment of surrounding building;
- to analyse the impact of urban parameters (vertical location, horizontal location, and shading) and weather parameters on the impact of highly reflective building facade.
2. FIELD MEASUREMENT

The case study is a 9-story commercial building which is developed with a curved stainless-steel façade, as shown in Figure 1; this has been determined as the source of reflective glare based on received complaints from nearby buildings several years back. Hence, field measurement was conducted in one of the nearby building, a 4-story school. The distance between the affecting building (building A) and the affected building (building B) ranges from 30 to 60 meters, as illustrated in Figure 1.

In Singapore, the daily temperature profile is relatively uniform with small diurnal change. The relative humidity is high, and the rainfalls are abundant. The daily average outdoor dry-bulb temperature lies between 25-32°C (Hong 1999). As April is the warmest month among the whole year, the field measurement was conducted from 1st of April to 4th of May 2018 in this study.

Based on site visits and feedback from the management team of the building B, six classrooms were selected for the field measurement, three rooms for each level 2 and 3. These rooms are affected by the reflective glare due to the stainless-steel façade of the building A. Figure 2 displays the location and alignment of the selected measurement points in the building B. To note, there is an overhang shading at the 4th floor. Moreover, due to the concave design at point 3-3 and point 2-3, the shading effect from the overhang at these points are more apparent than others. The field measurement was conducted during the school vacation period; hence, the air conditioning system was off.

The surface temperature of the brick wall (outside and inside) and window (outside) were measured by using HOBO thermocouple sensors and data loggers. The aluminum tape was posted on both the internal and external glass surface at the measured point to provide thermal insulation. Globe temperature sensors and data loggers were installed 30cm away from the internal side of the window to measure the globe temperature near the window area. To mitigate the glare issues caused by the reflective metal façade, the affected building has been installed with 3M™ sun control window film on the windows facing the reflective façade. Based on our test, the internal illuminance is approximately 7% of the corresponding
external illuminance measured. Hence, Illuminance sensors and data loggers were installed on the external side of the glass surface to measure how much illuminance coming to the external surface of each classroom. All sensors were installed at 1.6 m height; except for those sensors logging the wall surface temperature, which were installed 10 cm below the windows. All data loggers were set at 1-minute logging interval.

3. RESULTS

29th of April and 1st of May were chosen to show how different weather condition affects thermal and visual performance significantly. 29th of April was a clear sunny day with high incoming solar radiation during the daytime. Whereas 1st of May was a cloudy day with relatively low solar radiation and rainfall from 10 am to 5 pm.

Figure 3: Solar radiation and rainfall on 29th of April and 1st of May

To understand the impact of reflective façade of building A on building B, selected measurement points were compared under different weather conditions. Indoor globe, glass surface, and both internal and external wall surface temperatures were analysed to understand the building thermal performance. Meanwhile, illuminance level was analysed to assess the visual performance.

Figure 4 to Figure 8 show the measurement results of the indoor globe, external glass surface, internal and external wall surface temperatures, and illuminance on the 29th of April and 1st of May. Overall, for all the five parameters mentioned above, the differences among the six measured points were less significant on a cloudy day (1st of May) compared to a sunny day (29th of April). The illuminance trends for the six points on a cloudy day were more analogous to the trend of incoming solar radiation compared with the illuminance trends on a sunny day. While for the sunny day, an obvious increase in illuminance from 7:00 to 9:00 can be observed. Based on sunpath simulation, the affecting façade is directly exposed to the sun during 7:00 – 9:00 while the affected building is not exposed to the sun during the same period. Table 1 summaries the average results during 7am-7pm and 7am-9am on the two selected days.

Figure 4: Results of the globe temperature on 29th of April and 1st of May
Figure 5: Results of the external glass surface temperature on 29\textsuperscript{th} of April and 1\textsuperscript{st} of May

Figure 6: Results of the external wall surface temperature on 29\textsuperscript{th} of April and 1\textsuperscript{st} of May

Figure 7: Results of the internal wall surface temperature on 29\textsuperscript{th} of April and 1\textsuperscript{st} of May
Figure 8: Results of the illuminance on 29th of April and 1st of May

Table 1: Summary of measurement results

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Period</th>
<th>Date</th>
<th>2-1</th>
<th>2-2</th>
<th>2-3</th>
<th>3-1</th>
<th>3-2</th>
<th>3-3</th>
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<tr>
<td>Globe temperature (°C)</td>
<td>Daytime (7am-7pm)</td>
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<td>28.37</td>
<td>27.59</td>
<td>29.24</td>
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<td>26.73</td>
<td>27.83</td>
<td>27.68</td>
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<td>7am-9am</td>
<td>29th Apr</td>
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<td>28.00</td>
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<tr>
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<td>28.46</td>
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<td>28.57</td>
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<tr>
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<td>3802.79</td>
<td>3734.38</td>
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<td>4364.08</td>
<td>4932.07</td>
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</tr>
<tr>
<td></td>
<td>7am-9am</td>
<td>29th Apr</td>
<td>11837.83</td>
<td>7002.17</td>
<td>5924.92</td>
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<td>7571.25</td>
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<td></td>
<td></td>
<td>1st May</td>
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<td>3478.00</td>
<td>3351.08</td>
<td>4196.42</td>
<td>3974.00</td>
<td>3334.08</td>
</tr>
</tbody>
</table>

* The results of the points at the same level were compared. The highest values were highlighted in red colour; the medium values were highlighted in orange colour; and the lowest values were highlighted in blue colour.
4. DISCUSSION

4.1 Impact of weather condition

4.1.1 Building thermal performance

Point 3-1 was selected to demonstrate the impact of weather condition. As shown in Table 1, during the daytime, the globe temperature was 1.4°C higher on a sunny day compared with a cloudy day. While the increase in external glass surface temperature, external wall surface temperature, and internal wall surface temperature were 3.96°C, 3.20°C, and 0.94°C respectively. Table 2 describes the daily average indoor globe temperature, the external glass surface temperature, the external wall surface temperature and the internal wall surface temperature on both selected days. One can observe that the external surface temperature can increase up to 2°C when during a sunny day. Higher solar radiation during the daytime also results in a higher internal wall surface temperature throughout the whole day.

<table>
<thead>
<tr>
<th></th>
<th>Indoor globe temperature (°C)</th>
<th>External glass surface temperature (°C)</th>
<th>External wall surface temperature (°C)</th>
<th>Internal wall surface temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29th April</td>
<td>28.49</td>
<td>30.12</td>
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<td>28.70</td>
</tr>
<tr>
<td>1st May</td>
<td>27.62</td>
<td>27.82</td>
<td>28.10</td>
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<tr>
<td>Difference</td>
<td>0.87</td>
<td>2.30</td>
<td>2.03</td>
<td>0.75</td>
</tr>
</tbody>
</table>

4.1.2 Building visual performance

From Table 1, it can be observed that the illuminance level was reduced to more than half on a cloudy day during the daytime. While during 7am-9am, the average illuminance level was reduced to almost 1/3 on a cloudy day compared with a sunny day.

4.2 Impact of horizontal location and shading

To analyse the impact of horizontal locations on the respective indoor thermal and visual environment, two groups of measurement points were selected and compared, namely group 1 (2-1, 2-2, and 2-3), and group 2 (3-1, 3-2, and 3-3). Globe temperature, glass surface temperature, external and internal wall surface temperatures and illuminance at those points were analysed.

4.2.1 Building thermal performance

Globe temperature

As shown in Table 1, for group 1, the highest indoor globe temperature occurred at 2-1, followed by 2-2 and 2-3 on both the two selected days. Whereas for group 2, the highest indoor globe temperature occurred at 3-3, followed by 3-1 and 3-2. From 7 am to 9 am, the building A façade was directly exposed to the sun, which caused reflected sunlight entered the affected classrooms. For the two groups, the points which are nearest to the affecting façade (point 2-1 and 3-1) showed the highest globe temperature during 7am - 9am on 29th April.

Glass surface temperature

During the daytime on 29th April, the glass surface temperature at point 2-1 which is closest to the affecting façade was higher than the glass surface temperature at point 2-2 and 2-3. The same phenomenon can be observed in group 2. From Figure 5, it can be observed that the trend of external glass surface temperature at point 2-1 and 3-1 shows a noticeable increase from 7 am to 9 am on 29th April.

Wall surface temperature

On 29th April, for group 1, both external (W2) and internal (W1) wall surface temperatures were decreased as the distance between the measuring point and the affecting façade increases. But for group 2, point 3-3, which is at the concave wall, showed the lowest external wall surface temperature during the daytime but the highest internal wall surface temperature throughout the whole day. Point 3-1 which is nearest to the affecting building showed an obvious increase in external wall surface temperature from 7 am to 9 am.
4.2.2 Building visual performance

On 29th April, for the two groups, the illuminance level was decreased as the distance between the measuring point and the affecting façade increases. For point 2-1 and 3-1 which are nearest to the affecting building façade, the internal illuminance peaked at 8 am when the affecting façade was directly exposed to the sun. From 7 am to 9 am, the average illuminance level for point 2-1 and 3-1 was higher than the average illuminance level during the daytime, whereas for other points, the average illuminance during the daytime was higher than that during 7am - 9am.

4.3 Impact of vertical location and shading

To analyse the impact of vertical location on the respective indoor thermal and visual environment, three groups of measurement points which located at different levels but share the same horizontal location were selected and compared, namely group 3 (point 2-1 and point 3-1), group 4 (point 2-2 and point 2-3) and group 5 (point 2-3 and Point 3-3). Compared with the other groups, those two points in group 5 are designed with concave. The following discussions were based on the results collected from the sunny day (29th April).

4.3.1 Building thermal performance

Globe temperature

As shown in Table 1, during the daytime, the points located at the higher level showed higher globe temperatures compared with the points located at the lower level. This is mainly because level 2 is at a lower level, and the reflected sunlight from the affecting façade may be blocked by the trees. During 7am - 9am, the average temperature difference between the points which within the same group (0.31°C for group 3, 0.18°C for group 4, and 1.54 °C for group 5) were lower than the average temperature difference during the daytime (0.73°C for group 3, 0.49°C for group 4, and 2.06°C for group 5). The two points in group 5 which are designed with concave showed the largest temperature difference.

Glass surface temperature

As shown in Figure 5, the glass surface temperatures of those three points located at level 3 were higher than that of the corresponding points at level 2. The average temperature difference between the points which share the same horizontal location were 0.78°C for group 3, 0.48°C for group 4, and 1.04°C for group 5 during the daytime, and 0.24°C for group 3, 0.30°C for group 4, and 0.32°C for group 5 during 7am - 9am.

Wall surface temperature

As shown in Figure 6 and Figure 7, during the daytime, both external (W2) and internal (W1) wall surface temperatures of the points at level 3 were higher than that of the points at level 2. For the points which share the same horizontal location, the two points which are designed with concave (point 2-3 and 3-3), also showed the highest temperature difference both in external and internal wall surface temperature during the daytime.

4.3.2 Building visual performance

Overall, the three points which are located at level 3 had higher illuminance values compared with the three points which are located at level 2 during the daytime. The average illuminance difference between the points which are within the same group was 1454 lux for group 3, 1398 lux for group 4, 1094 lux for group 5 during the daytime. During 7am - 9am, the illuminance level at point 2-1 was 729 lux higher than the illuminance level at point 3-1. Whereas for another two groups, the illuminance level at level 3 was higher than the illuminance level at level 2, the difference was 569 lux for group 4, and 414 lux for group 5.

5. SUMMARY

The internal and external heat sources are two main contributors to the increase in air and surface temperature, where the internal heat source comprises occupants, lighting, and equipment. It is important to note that the measurement was conducted during the school vacation period. Hence, the selected classrooms were not occupied with all air conditioners and other electrical systems turned off. Thus, the internal heat sources are excluded from the analysis.

Weather condition plays a vital role in indoor thermal and visual performance. The average external glass and wall surface temperature can increase up to 2°C on a sunny day which has high incoming solar radiation compared to a cloudy day.

Horizontal location also affects the indoor thermal and visual environment. Points which are located near the affecting façade tend to have worse thermal and visual performance.

In addition, vertical location is another significant factor that will affect both the indoor thermal comfort and visual
comfort. Data analysis has provided a conclusion that temperatures and illuminance at the higher level will be higher than that at the lower level. This can be explained by the fact that the level 2 of the affected building is near the ground and the reflected sunlight from the affecting façade can be obstructed by ground objects such as trees.

Furthermore, in the field measurement, it was found that the shading provided by the eave of flat roof affects the indoor globe temperature and façade surface temperature significantly. It also helps to reduce illuminance level to achieve a better indoor visual environment according to the design standard.

6. FUTURE PLAN

Future study will be focusing on the relationship between design parameters and glare. More field measurements will be conducted in other types of buildings. Parametric study through computer modeling will also be conducted to propose a guideline for building designers.

ACKNOWLEDGEMENTS

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References


