PERFORMANCES OF FACADES OF BUILDINGS IN MITIGATING THE URBAN HEAT ISLAND EFFECT

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ABSTRACT

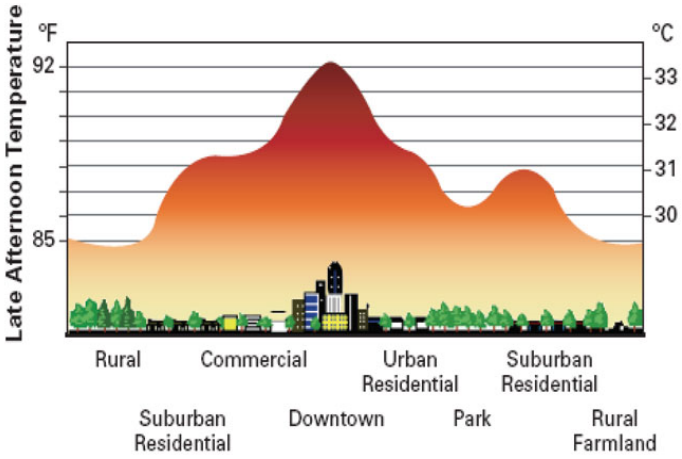
A building's façade plays an important role in moderating the overall performance of buildings. Apart from its aesthetic and visual impacts, a façade influences the thermal performance within the building as well as its immediate environment. In achieving sustainable development and reducing the Urban Heat Island (UHI) effect, efficient façade systems and products must be appropriate to the climatic characteristics. UHI is the effect of the increment of anthropogenic ambient temperatures in urban areas as compared to the rural areas. Buildings and urban development in cities are the causal links of UHI leading to greater use of energy consumption. In Malaysia, temperatures in cities are 6 – 7 degrees higher and the Green Building Index (GBI) (amongst other energy ratings) is taking that responsibility to ensure that not only energy but also thermal performances of buildings are optimized. One of the criteria in GBI to increase a building's overall performance lies in the ability of facades to moderate and augment a building's internal and external temperatures. This study considered the impact of the facades of buildings on the thermal performances of outdoor environments immediate to buildings in an urban setting in mitigating urban temperatures. Several building facades from both GBI and non-GBI rated buildings in Klang Valley were the test cases in this investigation. The GBI certified buildings tested used curtain-walling or glass facades (GF). The non-GBI buildings tested used double skin façade (DSF) and other skin (opaque) facades. Data monitoring was conducted, and results showed that temperatures surrounding the DSF were lower than the GF prompting need of better facade designs in mitigating the Urban Heat Island effect for the tropical climate. The significance of this paper is as a guideline to building designers and authorities in making decisions for achieving overall efficiency in new buildings and even for existing ones. The design considerations for the façades of buildings are crucial in aiding to mitigate the UHI effects.

Keywords: UHI, GBI, double-skin façade, glazing facade, tropical climate

INTRODUCTION

Malaysia is becoming amongst the most modern and urbanized nation in the region. With the progress, cities are growing and tall buildings sprouted with no end in sight. However, the rapid effects of urbanization accumulated negative environmental impacts like the production of pollution, production of waste heat from human activity and increment of ambient air temperatures, especially in the urban areas (United Nations, 2014). Most notably air conditioners and internal combustion engines, the modification of the physical and chemical properties of the atmosphere and the covering of the soil surface are causes increasing urban air temperatures which is known as the Urban Heat Island (UHI). UHI is defined as the rise in temperature of any man-made area, resulting in a well-defined, distinct "warm island" among the "cool sea" represented by the lower temperature of the area's nearby natural landscape (Smet, 2014). Large urbanized regions have been shown to physically alter their climates in the form of elevated temperatures relative to rural areas at their periphery (Elsayed, 2012), as seen in Figure 1.

Figure 1: Urban Heat Island Profile.
Retrieved from: http://www.extension.org/pages/66920/urban-heat-island



The effect of metropolitan regions is not only confined to horizontal temperatures but also to the vertical direction with far-reaching consequences. Studies have shown that the thermal influence of a large city commonly extends up to 200-300 m and even to 500 m and more (Sani, 1990). In Kuala Lumpur, Sani (1990) found that temperatures were normally higher in the central district than in the rural areas around the city and the intensity of heat island was greatest during the day. The maximum heat island intensity for Kuala Lumpur / Petaling Jaya twin cities was between 6° and 7°C.

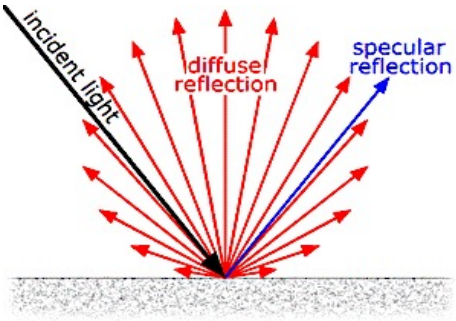
However, to compensate these impacts on the environment, and there were significant changes to be made to reduce effects of both scenarios for global climate change, and to the effects of global warming on regional-level climate. Dealing with both sustainability and possible impacts of climate change, different countries began to respond to these issues and looking for ways to move towards a sustainable built environment, adapted for climate change (Reed, Bilos, Wilkinson, & Schulte, 2009). Buildings with the integration of environmental sustainability and other aspects of the design are created as early as in the late 19th and early 20th century (Cassidy, 2003). And these sustainability-rating tools play a major role in the level of sustainability in a building. Varieties of assessment programs continue to develop in the Southeast Asia region. In 2008, Malaysia's industry recognized the Green Building Index (GBI) as green rating tool for buildings to promote sustainability in the built environment and raise awareness among Developers, Architects, Engineers, Planners, Designers, Contractors and the Public about environmental issues and responsibilities to the future generations (GBI, 2008).

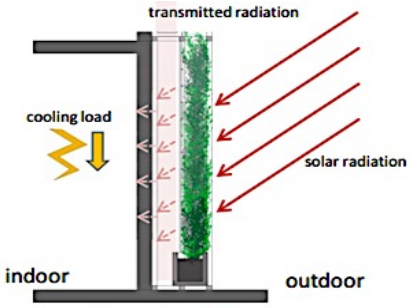
Facade and its Performance

Facades play important roles in the design of the urban and environment. The façades of a building generally make up the exterior of a building: the four sides (if applicable) and also the roof. In architecture, the facades of a building are often the most important element from a design standpoint, as it sets the tone for the rest of the building (Huxtable, 2004). The building envelope has a large impact on the thermal and visual comfort of occupants as well as the energy demand of a building (Halawa et al., 2017). The sustainable building envelope is the best approach to improve a building's efficiency with environmental benefits and responsiveness to existing infrastructure (Larsen, Filippín, & Lesino, 2014; Vox, Blanco, & Schettini, 2017). The best approach requires building facades to be designed to minimize energy consumption and thereby, reduce greenhouse gas emissions. To reduce energy use in buildings and improve outdoor thermal performance it is necessary to optimize the design of the facades (Alonso et al., 2017; He, et al., 2018). With the ratification of green rating tools such as GBI Malaysia, designers and engineers applied sustainable facades to the buildings with various sustainable façades, such as the low – e or double glazing, double façade, bio or green façades etc.

The study emphasized the essential role of the building facades to moderate and mitigate adverse thermal impacts on the outdoor environments. The design and materials of facades of buildings have a significant impact on the thermal performance of urban environments. Materials of facades influenced the development of urban heat islands. Radhi, Assem, & Sharples (2014) assert that a concrete or brick surface diffuses light and heat. Approximately, 10 to 20 percent of the beam of light that hits the building gets reflected, and that light scatters in all directions and so did the heat. A green façade absorbed most of the light and solar radiation falling upon it, reducing the internal cooling load and external reflected heat. See Figure 2.

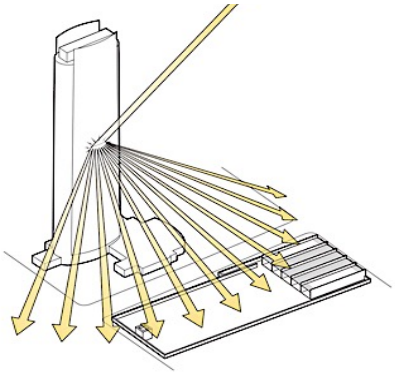
Figure 2: Reflected heat from Concrete Facade & Green Façade. Retrieved from: https://slideplayer.com/slide/5106789/

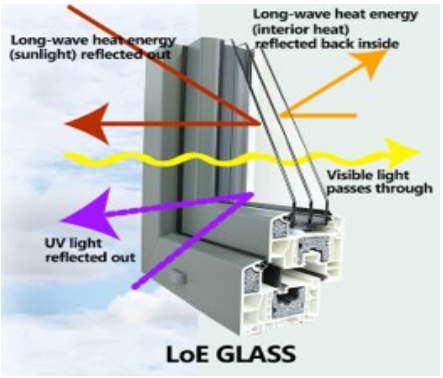




By contrast to the double facade, a glass surface can reflect almost 100 percent of the sunlight that hits it and can reflect that light back out in one direct beam (Ferro, 2013; Scale et al., 2017). Buildings with a fully glazed façade are not typically recommended for tropical locations because of the admission of large amounts of solar radiation (Halawa et al., 2017). See Figure 3.

Figure 3: Reflected heat from glass facades and the Low – E Double Glazing Façade. Retrieved from https://gfycat.com/gifs/search/sculpture





AIM AND OBJECTIVE

This study aimed to investigate the impact of facade designs and materials on their immediate outdoor space. Many studies have confirmed that UHI effects have increased and one of the main causes is the reflection of solar radiation off the facades of buildings to the environment. Studies of facades too are mainly concentrated on the impact on the indoor environment, rather than to the outdoors. Thus, this study focused on the impact on facades reflecting heat to the outdoors and to examine how different façade designs and materials influence the outdoor temperatures. The facades of interest were selected from both GBI and pre-GBI buildings in the Klang Valley (greater Kuala Lumpur).

METHODOLOGY

The methods undertaken for this study will be in 3 parts:

Part 1: Temperature monitoring was taken with Onset® Hobo outdoor data loggers at the immediate outdoors space adjacent to the buildings. Open areas close to the GBI and non-GBI buildings were monitored to profile the reflected heat and in terms of outdoor temperature in °C. The data loggers were located away from the shade of the buildings in an open area. The monitoring of indoor temperature (wherever possible) was also done to compare the differences of temperatures in shaded and un-shaded areas with the reference temperature taken from the Malaysian Meteorological Department. Temperatures were measured continuously for the duration of 6 days. The data recorded were at a one-hour interval, at every point.

Part 2: 3D models of both case study buildings were simulated in ECOTECT software to verify the temperature findings from Part 1. The simulation profiled the reflected temperatures from each case study. The simulation gave results on how much heat is trapped on the ground level of the buildings.

Part 3: Purposive interviews were conducted to relevant persons related to the buildings. Building managers of the case study buildings and experts and professionals with good knowledge of UHI, building facades and green or sustainable designs were the target respondents. The interviews were conducted to gain further information on the subject matter to support the findings of the study.

CASE STUDIES AND FINDINGS

The study considered the facades of buildings and their thermal impact on the surroundings. Two types of facades were of interest: Glass façade (GF) and double skin facades (DSF). The GF buildings were GBI certified – meaning that they have met the minimum sustainable requirements, as set by the GBI Malaysia (2008). The DSF buildings were from the pre-GBI era but were also designed sustainably.

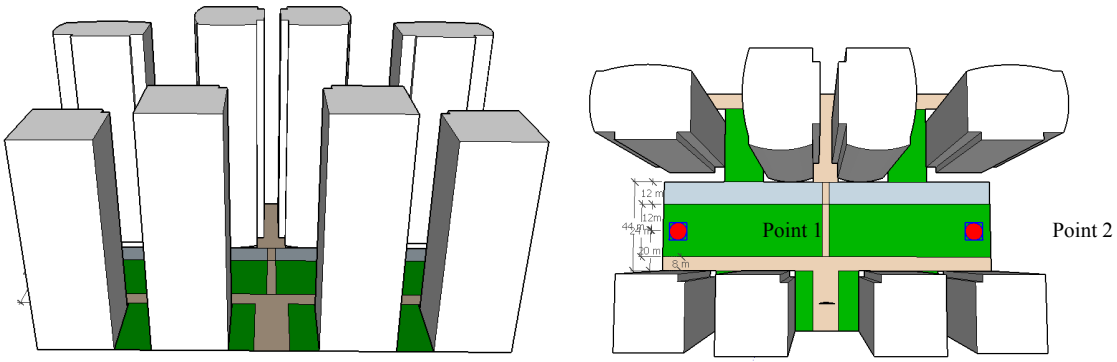
Case Study 1: GBI certified buildings.

Case Study 1 (CS1) was self-sustained offices and commercial development, known as The Horizon, located at Bangsar South, as in Figure 4. The Horizon consisted of two rows of four 13 to 20-story office towers in each, facing each other across an open space of 44 m wide. The open space consisted of a paved road and with generous gardens on the left and right side of the road. This mixed development obtained certification for its energy and water efficient features such as using low-e double-glazed glass, motion and carbon dioxide sensors, solar panels and rainwater harvesting systems.

Figure 4: The Horizon Bangsar South GBI certified building with Low-e Double Glazing Facade

Facades of The Horizon Bangsar

Marked location of The Horizon at Bangsar South. Retrieved from: https://www.propertyguru.com.my/commercial-property/the-vertical-for-sale-by-felix-goh-24989495

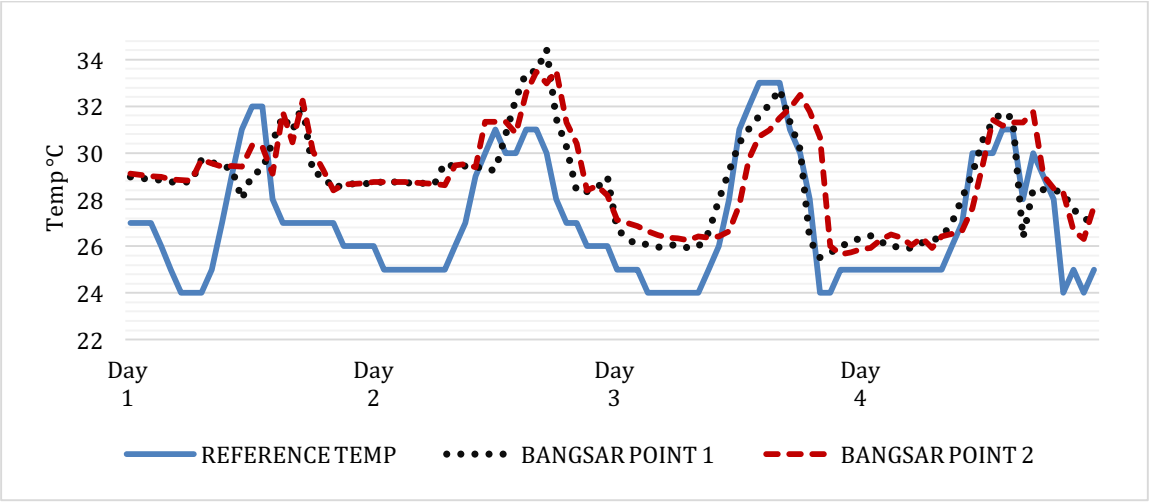


Model of the Horizon Bangsar & locations of data loggers in Ecotect.

FINDINGS

In general, the results indicated that the monitored temperatures are similar or higher than the reference temperature. However, Day 3 posed the highest temperature difference of up to 3 – 4 degrees higher. The results inferred that the reflectance quality of the glass facades was significant and able to deteriorate the street environment. Another interesting observation was that the monitored temperatures were always 2 – 3 ºC higher at night even when the reference temperature is the coolest, suggesting heat retention properties of the materials used. Heat seems to be stored at the open area for the following 12 hours even after the drop of temperatures during the night. The monitored temperatures of all the days recorded is shown in Figure 5. There were two days, however, that the recorded temperatures followed closely the reference. This occurrence was when it was cloudy and raining on both days.

Figure 5: Average Temperatures recorded at The Horizon (Glass Façade)



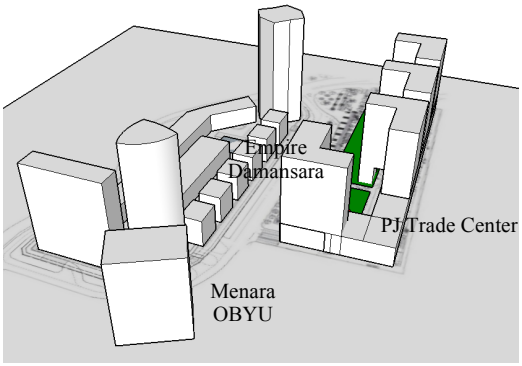
A simulation of the temperature profile was undertaken in ECOTECT also shows the numbers in the charts showing the trapped heat in the open area on the ground level even though the area was naturally ventilated with lush greenery. The indoor temperature was not recorded since the Horizon is a boutique office complex, using full mechanical cooling and the temperature is controlled by sensors throughout the time.

Case Study 2: Double-Skin Facades (DSF): Non-GBI buildings

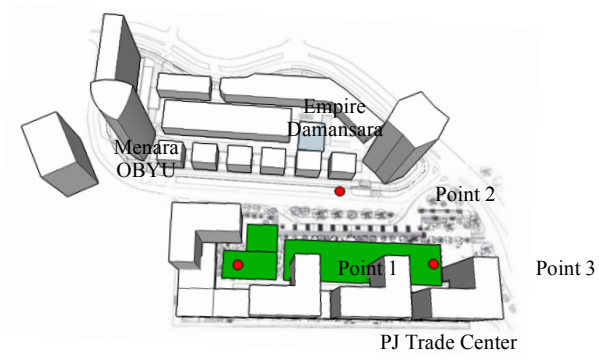
Case Study 2 consisted of three buildings within the same vicinity in Damansara Perdana, Selangor. The buildings were completed before 2009 when the mandatory GBI took effect to all commercial buildings. The buildings were the PJ Trade Center, Empire Damansara and Point 92 (Menara OBYU) surrounding the open area at Damansara Perdana (Figure 6). The buildings mostly used DFS as the building envelope but with different materials.

Figure 6: Damansara Perdana with pre-GBI certified buildings and their various facades

i. PJ Trade Center ii. Empire Damansara iii. Menara OBYU



3D model of Damansara Perdana



Locations of the data loggers (in red)

i. PJ Trade Center (PJTC)

The building consisted of 4 tower blocks and each block belonged to different owners. Each block was connected at the podium level and the corridors are naturally ventilated. The building's façade was designed based on two main ideas. The first idea was to craft an energy-efficient and environmentally friendly building with simple local materials, mainly overburnt bricks, concrete ventilation blocks, and fair-faced concrete. Secondly, was to create a building that will weather naturally and elegantly in the harsh tropical monsoon climate, requiring minimal maintenance of the façade in the long term (Low, 2009). These facades were not only protecting the building from the sun but also, they act as a screening for the service area facing the main road. Plants have also grown that punches through the holed façade creating a large green screen.

ii. Empire Damansara

Empire Damansara's five towers comprised a hotel, SOHO units, and corporate offices as well as a heritage-themed village of F&B and retail units that draws inspiration from the old New World warehouses (Taylor-Foster & Brittain-Catlin, 2017). The building Façade was designed for this mixed commercial development varies with different types of Double Façade system based on the typology and uniqueness of the buildings. The residential buildings used the mesh grades to create a visually contrasting façade that serves as shading as well as covering the services of the building. The commercial and office buildings used vertical and horizontal metal fins as shading for the building envelope. The fins were applied across all four elevations, mostly at the east and west side of the building for maximum coverage as well as allowing the visibility from inside.

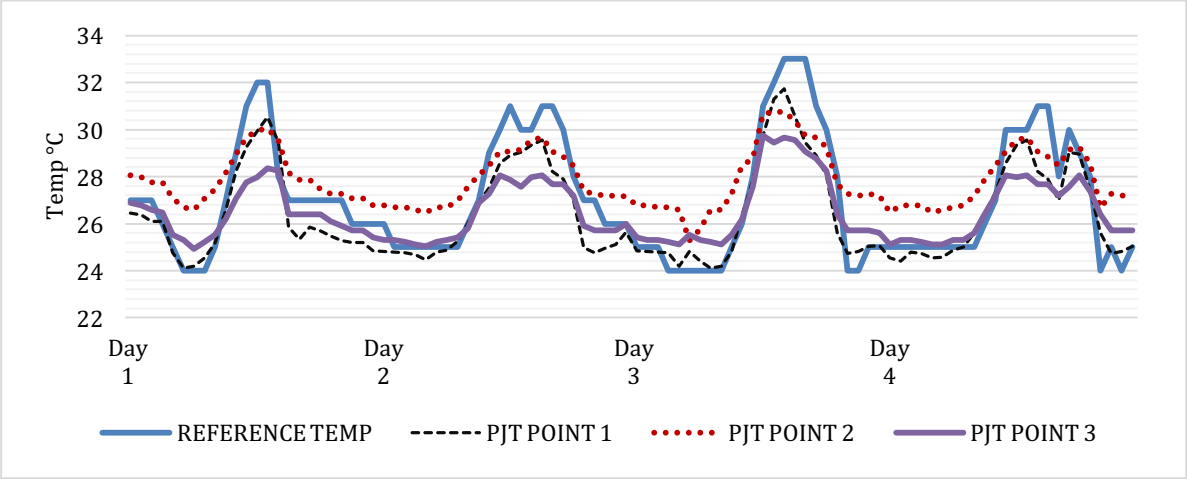
iii. Menara OBYU

Menara OBYU was a 19 story tall building with 12 stories of offices and 7 levels of car park. The offices building tightly secured to the access for the high level, yet the designer has created a common area, which is planted with trees, which are to be used as roof terraces. Therefore, it is possible to bring in fresh air for a naturally ventilated atmospheric condition to the courtyard area. Moreover, by cutting out facade for green areas where space is not needed enhances the presence of balconies and elevated external terraces on the elevation. Thus, it has should also reduce heat buildup inside these tall atriums given where, the use of any form of mechanical fans or venting systems are unnecessary to provide cooling to these areas (zlgdesign, 2012).

FINDINGS

Temperature data were monitored at three different points at the open area next to PJ Trade center. The findings showed that the temperatures were 2 - 3˚C lower at all three points as compared with the reference temperature, as shown in Figure 7.

Figure 7: Average Temperature for Non-GBI building Façade

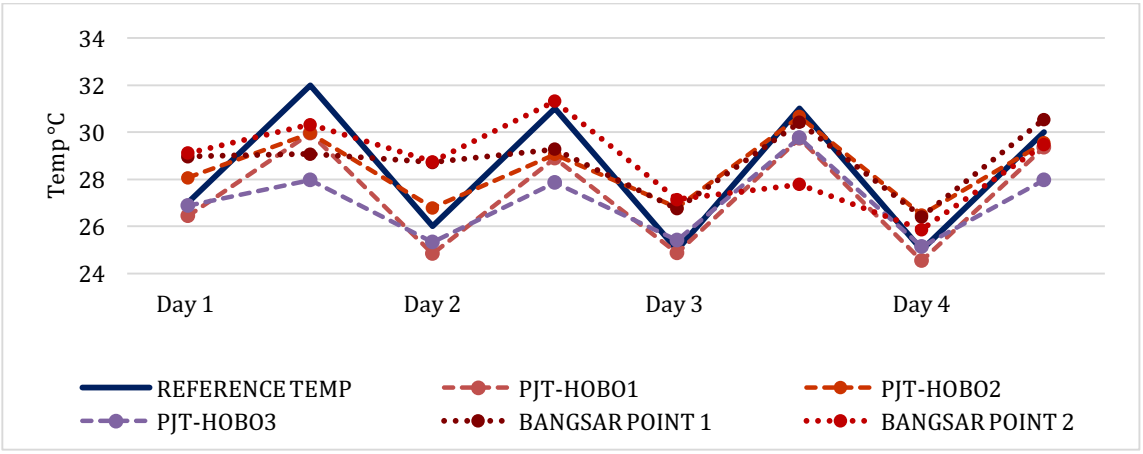


The natural ventilation and the building facades mostly influenced the temperature difference for the outdoors, which also has played an important role in cooling the spaces. In the Double Skin Façade concept, hot air is flushed out from the space and cool air take over if the building is naturally ventilated. The designers have applied that concept well to achieve the energy-efficient and eco-friendly façade design features. The temperature simulation profile also shows the significantly lower heat readings for this location with 2 -3 degrees difference to the reference temperature.

COMPARISONS OF CASE STUDIES

Facades have a large impact on the impression of a building as well as conditioning their immediate outdoor space. Sustainable facades do have added benefits to the ecological infrastructure. After analyzing the case studies, it was clarified that buildings with façade systems such as double façade, green facades do play a role in reducing the heat and the surrounding urban context. From Figure 8, it can be analyzed that the temperature recorded at the surrounded open area of the GBI certifies buildings using low-E glass facades stayed relatively higher compared to the non – GBI buildings with double façade and green facades surrounding their immediate open space. The temperature difference between the two is as high as 3- 4 ˚C.

Figure 8: comparison of Average Temperature for GBI & Non-GBI building Façade



FINDINGS FROM INTERVIEW SURVEY

From the interviews to the expertise regarding the topic, most of the respondents were aware of the UHI and the drawbacks from the building façade systems. The façade systems majorly contributed to reducing energy use of the building. Therefore, in context of achieving sustainability and reducing the UHI effects, respondents said that it is the responsibility of the building sector to have considerations on the efficient façade systems and products that are acceptable for the tropical climate and the users. Some of the responses from the interviews opined that as the climate conditions change during the day and year, the façade has to respond dynamically to these changes; and solutions cannot be the same for different contexts and they have to be connected to the socio-economic reality of each country or region. Furthermore, solutions for the problem is already given and achieved by the designers as DFS. But the problem is whether to apply it to the building façade system seems questionable as it contributes to the cost factor or the decision of the owner.

CONCLUSION & RECOMMENDATION

After analyzing the case studies, it can be clarified that the façades of buildings do play a role in reducing the heat and cooling of the building. From the data monitoring and the simulations, it can be seen that the non-GBI buildings with double façade (DF) or green facades systems (GFS) were more responsive to the tropical climate. It can be concluded that temperatures of the GBI buildings in Bangsar with the Low-e glazing facades resulted in much higher readings on the immediate environment by 3 - 4 ˚C. This could be the consequence of the excessive use of glass, which reflected much of the solar radiation onto the open areas at ground level, thus increasing the ambient air temperature. It was also observed that the temperatures remained a few degrees higher throughout the night implying released heat from the facades and surface materials in the open area.

Moreover, the DSF of the non-GBI buildings with facades responsive to the climate reduced their immediate outdoor temperature by 1˚C to 4˚C accordingly. The recorded nighttime temperatures were almost similar to the reference temperature indicating less build-up of heat from the surrounding buildings. It is inferred that the façade materials and DSF system moderated the ambient temperatures mitigating the UHI effect in this area. The temperature was also recorded in the unconditioned indoor areas. Results indicated these spaces were 1 - 2˚C cooler than the reference temperature. The reduced temperatures would have a huge effect on the energy consumption for cooling of the building. Our built environment should inspire us and make us feel proud of our local and urban areas and diverse heritage. It should provide environments that contribute to our physical and mental health and enhance creativity and productivity. Our built environment also needs to be flexible and adaptable to future uses and be resilient to cope with the local effects of climate change. Designers and architects are the main persons to point in the right direction for the new developments and contribute to achieving a suitable design for the tropical climates and consequently reducing the UHI effect.

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