Effects of Green Roof in Reducing Surface Temperature and Addressing Urban Heat Island in Tropical Climate of Malaysia

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Urban heat island (UHI) in cities across Malaysia has worsened due to rapid development and construction. Previous research highlight temperature difference between Putrajaya and its suburban neighbouring area is as high as 5˚C. Green roofs in urban areas can be used as a green intervention strategy to reduce UHI impact by increasing air moisture and surface wetness through its plants, which consequently decreases surrounding air and surface temperature. Green roofs also provide additional insulation that reduces heat transfer into buildings, therefore reducing cooling demand and operational energy in buildings. Conventional building roofs in tropical climate have measured surface temperature up to 60˚C, compared to surrounding irrigated grass and water bodies that are measured as low as 15˚C. This paper compared surface temperatures of green roof and conventional non-green roof case studies in a tropical climate setting, to combat urban heat island effect. A triangulation technique was adopted, using a case study analysis with an in-depth structured interview and physical fieldwork investigation. The findings concluded that green roofs had significantly lower surface temperature compared to non-green flat roof. This paper provides evidence that supports green roof as a green intervention strategy in reducing urban heat island and encourage building designers to maximize under-utilized spaces of roofs to increase urban greenery coverage.

Keywords: Green roof, comparing surface temperature, urban heat island, tropical climate, Kuala Lumpur and Putrajaya.

1. INTRODUCTION

The building sector is responsible for a significant portion of global greenhouse gas (GHG) emissions, consuming 51% of global electricity in 2010 and contribute to the urban heat island (UHI) phenomena (IPCC, 2014). According to Oke (2011), UHI is the warm temperature characteristics of a built area within city centres compared to its surrounding rural area's lower temperature and is connected to the after effect of urban development. When buildings are built so closely to each other, heat produced by people, cars, buses and other buildings are trapped within the city centre (National Geographic, 2019). Moreover, the building materials absorbs heat, which makes the area surrounding buildings warmer than open spaces (Rutledge et al., 2011). Every surface has a different thermal characteristic based on its surface moisture, thermal radiative and aerodynamic properties (Oke, 2011). The actual temperature of the surface depends on the ability of the surface to balance the energy from the radiation, sensible and latent heat from the sun (Oke, 2011). These energies will then be exposed to the solar and infrared radiation that reflects onto and from the sun, sky, and the surroundings like trees, walls, road, fields, roofs, and walkways (Oke, 2011).

Nevertheless, the Intergovernmental Panel on Climate Change (IPCC) highlights that the building sector has one of the biggest climate change mitigations potentials with cost effective strategies and substantial co-benefits (IPCC, 2014). Based on the International Council for Local Environmental Initiatives (ICLEI) guidelines, one of the efforts to reduce UHI is green roof. Green roof is a roof of a building that is covered with vegetation, plants, planted over a waterproofing membrane (Oke, 2011; Zhang et al., 2020). A green roof acts as a sustainable design that brings many environmental benefits such as reducing stormwater runoff, lowers the energy used for cooling, creating a green area in a building and the heat island effect (Fitchett et al., 2020). Green roofs are best used in the city because of its ability to absorb greenhouse gases such as carbon dioxide, pollutants, and dust (Fitchett et al., 2020).

Cities in Malaysia such as Kuala Lumpur, Penang, Putrajaya and Johor Bahru are affected by UHI (Krishnan, 2007) due to rapid development, deforestation and anthropogenic emissions (Global Forest Watch, 2019). Research shows the temperature difference between Putrajaya and its suburban neighbouring area is as high 5˚C (Krishnan, 2007). Kuala Lumpur has been reported to have a temperature rise of 0.6˚C every decade (Ramakreshnan, 2018), and in 2012 the city had an increase of 1.5˚C of UHI Intensity, compared to 1985 levels (Elsayed, 2012). UHI Intensity (UHII) can be defined as the temperature difference between urban and suburban areas with regards to degree of urbanization (Lee et al., 2020). The rising temperature in Kuala Lumpur and Putrajaya are due to dense urban structures, rapid population growth and expansion of city development, which have led to a significant UHI effect (Wong et al., 2017).

There is also lack for national policy or guideline for green roofs in Malaysia (Mahdiyar et al., 2020), which suggest a low uptake on green roof implementation in the building sector. A recent study conducted by Mahdiyar et al. (2020) highlighted barriers to green roof implementation in Malaysia are lack of awareness and knowledge, and high initial construction cost. This paper is aimed to study the benefits of green roof in addressing UHI and to determine the cooling effects of green roof based on surface temperature reduction of the building, by measuring and compare surface temperatures of green roof and non-green roof case studies. This case study approach is based on buildings with green roof and non-green roof that are located within urban areas of Putrajaya dan Kuala Lumpur area that are affected by urban heat island.

1.1 Urban Heat Island

The distinction of temperature in categorizing UHI can be made by surface UHI and atmospheric UHI (Hove et al., 2015). Surface UHI is the difference in surface temperature in both urban and rural area meanwhile atmospheric temperature is the difference in air temperature. Besides that, the atmospheric UHI can be divided into two types which are Urban Boundary Layer (UBL) and Urban Canopy Layer (UCL) (Oke, 1987). UBL-UHI starts from the rooftop and treetop level up to the point where urban landscapes no longer influence the atmosphere while UCL-UHI is in the layer of air where people live, from the ground to below the tops of trees and roofs (Akbari et al., 2019). The depiction of these components of UHI is shown in Figure 1. This paper focuses more on UCL-UHI because it refers to the outdoor thermal comfort and is more commonly referred to regarding urban heat (Hove et al., 2015). The surface temperatures influence the air temperature in the canopy layer, closest to the surface, for instance, vegetated areas like parks and water fountain have cooler surface temperature, hence, cooler air temperature. The increased surface temperature due to UHI effect can cause surface temperatures up 60 ˚C, which will directly and indirectly increase the energy usage in buildings to accommodate the hotter temperature and increase cooling demand (Andrade et al., 2007; Rinkesh, 2019).

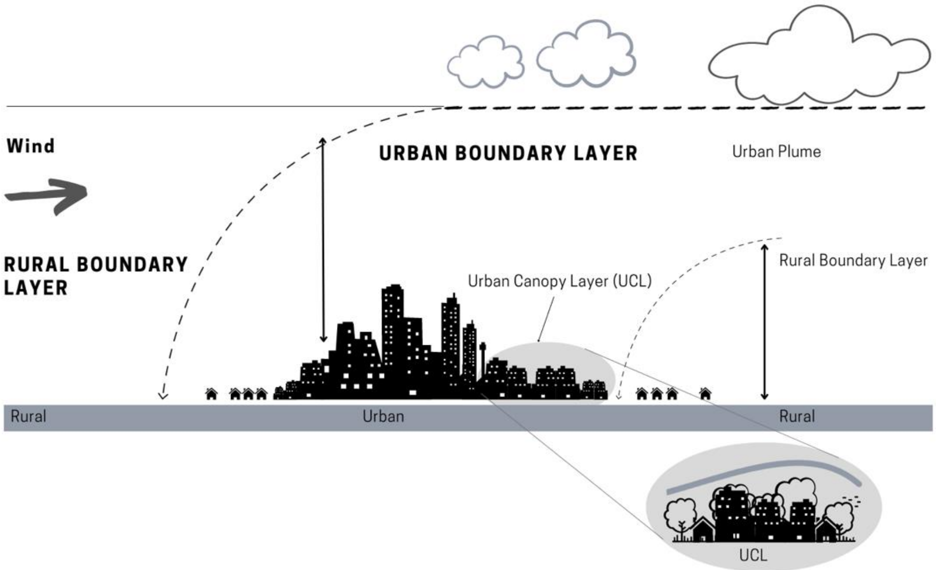

Figure 1 Main components of the urban atmosphere
Source: Adapted from Voogt (2004)

Planting trees and vegetation on ground level will decrease surface and air temperature by providing shade and cooling through the process called evapotranspiration (Environmental Protection Agency, 2019). Additionally, trees and vegetation improve air quality and reduces exposure to UV radiation (Environmental Protection Agency, 2019). Trees planted near parking areas and streets reduce evaporative emissions from gasoline and clean the air from pollutants (Ault, 2016). Additionally, pavements in the city, in parking lots, streets and sidewalks can be replaced with cooler coloured paving materials for solar reflectance. Solar reflective pavements are coated with a reflective surface coating, reflective aggregate, and a clear binder or a reflective. The advantages of using cool pavements are cooler surrounding air, improve night-time visibility and reduce stormwater runoff (Ault, 2016). Concurrently, porous asphalt and pervious surfaces also filters pollutants (Walker, 2013), and enhance stormwater permeability and infiltration into natural groundwater (Ault, 2016), which reduces water runoff during heavy rains.

There are several green intervention strategies to mitigate urban heat island in the city, but with the lack of open areas in the city, the solution to the UHI phenomenon is limited. The two most common green intervention strategies in urban areas and dense cities are green walls and green roofs (Zaid et al., 2018). A green wall or vertical greenery system are vertical surfaces that are covered with vegetation (Zaid et al., 2018). A green roof or also known as rooftop garden, is the vegetative layer grown on a rooftop (Shafique et al., 2018). Green roofs provide urban heat mitigation at low cost, cooling effects to the building through insulation therefore reducing energy use in the building (Samsudin, 2019a). Another strategy to reduce urban heat island is cool roof, where the cool roof is made out of a material or coatings to reflect heat and sunlight away from the building instead of absorbing it (Li et al., 2014). Cool roofs are made by coating roofs with white or special reflective pigments that reflect sunlight and protect the roof from ultraviolet (UV) light, chemical and water damage (Ault, 2016). Green and cool roofs are useful to keep the building cool and reduce the roof temperature which automatically lower the amount of air conditioning needed during hotter days (Environmental Protection Agency, 2019).

1.2 Benefits and Importance of Green Roof

Green roof is a common method in reducing urban heat island because it is easily designed and planned for new developments, but also a feasible intervention for the existing building with flat roofs (IPCC, 2014; Shafique, Kim, & Rafiq, 2018). A green roof usually consists of several layers and components, which include water proofing membranes, root barrier, drainage material, filter layer, insulation, vegetation, and substrate (Government of South Australia, 2010) (refer Figure 2). However, green roof structure varies depending on its location and requirement. Each component and layers of green roof is important and should be selected for its best quality to ensure optimum result of aesthetic, economic and environmental benefits. The average life span of green roof is between 40 and 55 years (Shafique et al., 2018).

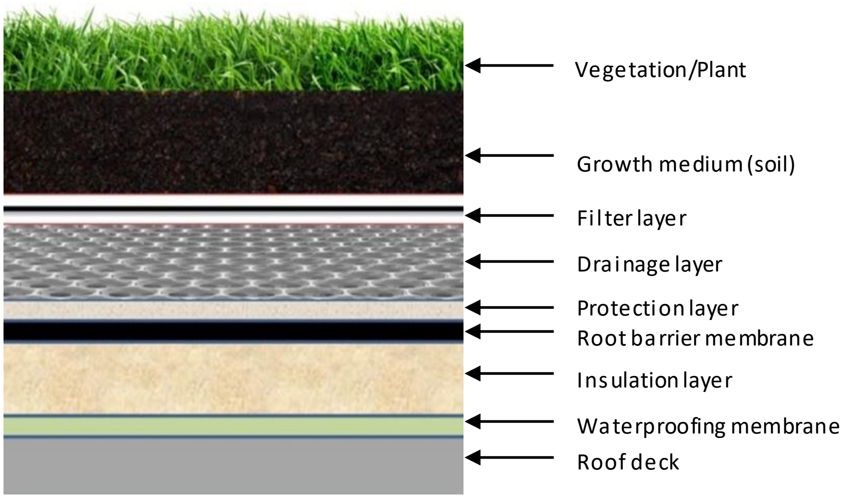

Figure 2 Cross-section of a green roof
Source: Adapated from Shafique et al. (2018)

There are various benefits of green roof which are storm water retention to reduce peak flow and runoff, water quality enhancement for water utilization, thermal benefits to improve and reduce energy costs, air cleaning for easy comfort into urban areas, noise reduction, ecological benefits, social benefits and economic benefits (IPCC, 2014; Shafique et al., 2018). Green roofs can also be used as a stormwater management strategy in urban areas as the different layers like vegetation and substrate has the ability to store large amounts of water (Stovin, Vesuviano, & Kasmin, 2012). The growing medium also absorbs a lot of water, and the vegetation planted can increase evapotranspiration, which lowers the peak flow and runoff of stormwater. The substrate layer of green roofs can also store abundant rainwater as it absorbs high moisture contents (Francis & Jensen, 2017). Furthermore, green roof can improve water quality as the green roof substrate and vegetative layers absorb pollutants and heavy metals from rainwater (Francis & Jensen, 2017). Extensive green roof improves water quality by reducing ammonia nitrogen in runoff water compared to natural rainwater (Berndtsson, Emilsson, & Bengtsson, 2006).

Green roof can significantly reduce the surface temperature in the urban areas with its plant's solar reflectivity and absorption, which subsequently reduces the building's cooling energy demand (Shafique et al., 2018). Green roof also acts as an additional thermal insulation to the building, which reduces cooling demand, hence reducing energy cost (Li et al., 2014).

Moreover, green roof improves roof membrane longevity by physically protecting the roof membrane against ultraviolet (UV) light and reducing fluctuations in temperature (Oberndorfer et al., 2007). This is because conventional dark roofs with waterproofing membrane deteriorate rapidly causing the membrane to become brittle which consequently became more easier for the membrane to be damaged by the expansion and contraction caused by the fluctuating roof temperatures (Oberndorfer et al., 2007).

Green roofs in the tropical climate reduces surface and air temperatures through surface heat fluxes (incoming solar and long wave radiation), sensible heat flux (the difference in air and surface temperature), and latent heat flux (difference in vapour presence of air and saturated vapour pressure for the surface) (Yang et al., 2018). The thickness of soil in the green roof construction leads to higher insulation and thermal mass of the roof, while higher leaf area index decreases soil evaporation, dissipates heat more effectively and reduces sensible heat flux to the atmosphere (Yang et al., 2018). However, higher leaf area index and vegetation can increase latent heat flux due to evapotranspiration and require higher maintenance than green roof type with grass (Yang et al., 2018). Studies comparing the cooling effects of green roofs and cool roof have shown that cool roofs can reduce heat gain more effectively, as cool roof reflects the incoming solar radiation and decrease sensible heat flux (Imran et al., 2018, Yang et al., 2018). Cool roofs use white materials or artificial white paint to reflect income solar radiation, which consequently decreases net radiation within the building and reduce air-conditioning demand (Yang et al., 2018). Cool roofs also have been shown to reduce heat gain by 8%, while green roofs only by 0.4%, and have higher mitigation potential compared to green roof (Yang et al., 2018).

However, green roofs and green walls can help mitigating climate change effects in urban areas with the plant's carbon sequestration potential (IPCC, 2014; Zaid et al., 2018; Shafique et al., 2020), while cool roofs do not. Green roofs also act as ecosystems and represent ground-level greeneries that are not on conventional roofs, which increases urban biodiversity (Oberndorfer et al., 2007; IPCC, 2014). These biological systems and the interaction of organisms that inhabit them creates opportunity for interdisciplinary research between the greater urban environment and constructed ecosystems (Oberndorfer et al., 2007). Green roofs and gardens can also contribute to emotional and mental wellbeing of building occupants, where accessibility and design of functional gardens on the roof can function as a green and open space for building occupants to destress and get closer to nature (RICS, 2018).

2. RESEARCH METHODOLOGY

This paper adopted a mix methods approach of both qualitative and quantitative methods to triangulate its data and findings. The triangulation technique is achieved by adopting a case study analysis, an in-depth structured interview and physical fieldwork investigation. This triangulation technique allows for better interpretation as it is viewed from different perspectives and provides better validity and reliability as it widens the range to a broader view (Jick, 1979). The case study approach explores empirical investigation in a contemporary event within its real-life context, highlighting the boundaries between event and context when there is no clear evidence related to them (Yin, 2007). A case study is defined by an interest in individual cases whereby the methods of investigation of the case study is not what is vital, but the object of study is (Stake, 1998), and the present object of investigation is green roof's effect on surface temperature reduction.

Qualitative research using a case study employs various data collection methods to examine events and understand situations that arise in society (Chigbu, 2019), and this research conducts an in-depth structured interview, as well as physical fieldwork investigation. Qualitative method is a method where interpretation and links need to be connected through because there is a gap in the theories and is useful when there is little information about a topic or unknown variables (Jick, 1979). Qualitative data were collected from in-depth structured interviews done in 2019 with relevant maintenance personnel of the case studies. Interviews are often used as complementary research method in the social sciences because they give the opportunity for a qualitative in-depth understanding, open discussion, and more informal, free interaction between the interviewer and the interviewee (Potter, 2002; Winchester, 1999; Sarantakos, 2013). Interviews were conducted with building managers of case study buildings to learn more in-depth on the missing information. The interviewees were selected based on their involvement and expertise in building or facilities maintenance and green roof maintenance, the building manager for Case Study A and the assistant engineer for Case Study B. In-depth interviews provide an understanding and description of people's personal experiences, which then leads to an understanding of how and why an event occurs (Johnson & Onwuegbuzie, 2004). The interview questions were divided into several sections (refer Table 1) to give a more in-depth detail of the green roof/non-green roof construction, maintenance, and estimated benefits. The interviews also provided access for researcher to acquire building plans for the case study buildings. The interview questions were based on elements and checklist presented in the Royal Institution of Chartered Surveyors (RICS) Professional Guidance Green Roofs and Walls (2016).

Table 1 In-depth Structured Interview Sections

No	Part	Detail
1	Demographic of Interviewee	Provides personal information of the building manager like profile, work position, education background and other relevant information.
2	Details of building case study	To gain knowledge on the building history and background like building age, green roof construction and layers.
3	Estimated benefits of green roof to building	To understand impact and benefit of green roof to working environment, electricity reduction and other benefits.
4	Details of green roof maintenance	To gain information regarding the maintenance details of green roof on the building case study like scheduling, elements, and costing.
5	Personal opinion	Information regarding his professional opinion on what could be improved and recommendations.

The case study approach also collected quantitative data by conducting physical fieldwork investigation to measure surface temperature of case study buildings. The quantitative data are surface temperature in degree Celsius and collected using a Thermal Infrared Camera. Consequently, the surface temperature of the ceiling level directly below the roof section were also measured to calculate the reduction of temperature, and consequently compared between the green roof and non-green roof case study buildings. Daytime surface temperature of a green roof is substantially lower than conventional building roofs because of the evapotranspiration process (Li, Bou-Zeid, & Oppenheimer, 2014). The impact of green roof on urban heat island is more significant during daytime due to increased evapotranspiration and lower during the nighttime, therefore the physical fieldwork measurement was done during daytime, with same time of day recorded between the two case study buildings.

A weather station meteorology reading (The Weather Exchange, 2020) was also collected for the days of fieldwork physical measurement to ensure similar temperature and humidity reading, so that the instrumental surface temperature data collected will not be impacted by other parameters in comparing the roof and ceiling temperature of the two case study buildings in different places and time. The two case study buildings are located in UHI impacted zone of Putrajaya and Kuala Lumpur that are located in the Greater Kuala Lumpur area (refer Figure 3) (PWC, 2017).

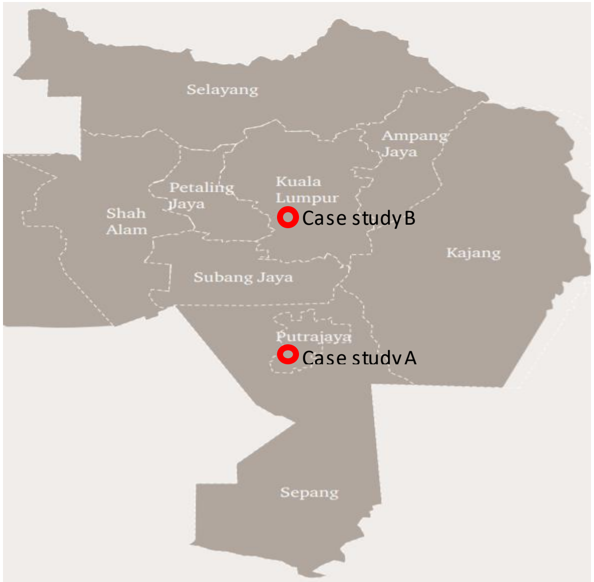

Figure 3 Greater Kuala Lumpur Map and Case Study Location
Source: Adapated from PWC (2017)

The Greater Kuala Lumpur area experience similar regional climatic conditions with no significant seasonal variation in meteorological parameters. The general meteorology data during the physical instrumental measurement for case study A and B is shown in Table 2. As the research is not comparing measurements between different green roofs, other parameters that usually affect the boundary conditions of heat and moisture exchange between surface and atmosphere temperature in the tropical climate, such as heat transfer coefficient, thickness, and materials) (Yang et al., 2018), were excluded.

Table 2 General details of Case Study A and B Data Collection

Case Study	A	B
Day and Date	Tuesday, 26/2/2019	Friday, 10/5/2019
Location	Klang Valley	Klang Valley
Time	10.30am	10.30am
Atmosphere Air Temperature	35℃	36℃
Weather Station Temperature	30℃	32℃
Weather Station Humidity	62%	62%

The case study buildings were designated into three sections to provide three surface temperature readings of the same level, to provide a more accurate and reliable data. Case Study A building's green roof surface is designated as A_1, B_1 and C_1, while the corresponding surface temperature of the ceiling directly below is designated as A_2, B_2, and C_2. Case Study B's non-green roof surface temperature is designated as X_1, Y_1 and Z_1, while the corresponding surface temperature of the ceiling directly below is designated as X_2, Y_2 and Z_2. Figure 4 presents the location of surface temperature measured in the case studies, A_1 for the roof surface temperature and A_2 for the corresponding ceiling surface temperature. Finally, the research analyses these data and measurements to compare findings of surface temperature reduction for green roof and non-green roof buildings, using this formula: $A_2 - A_1$ = Temperature difference in A.

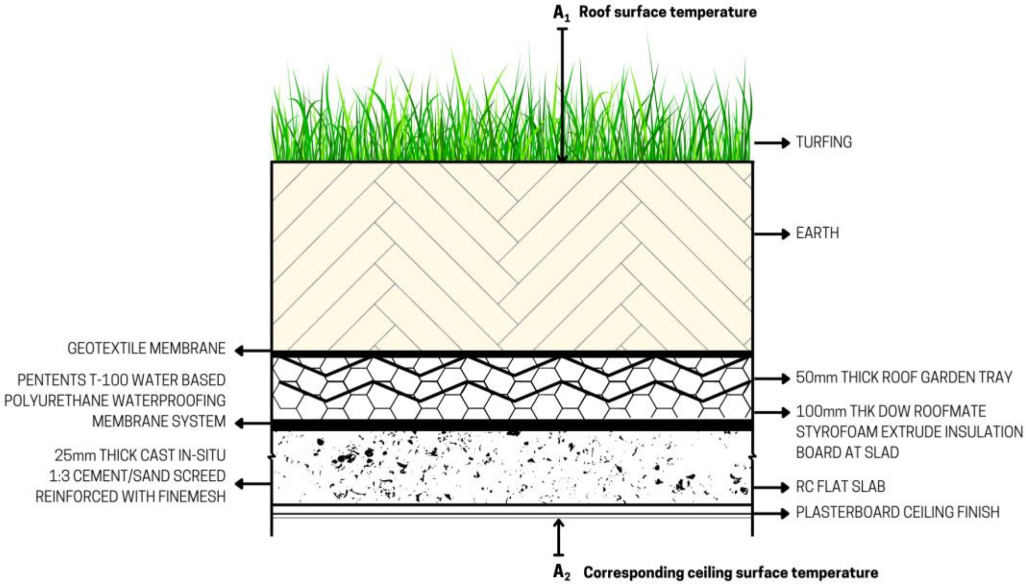

Figure 4 Typical Cross Section of Green Roof and Location of Surface Temperature Measured in Case Studies (*Source: Adapted from (Samsudin, 2019b)*)

2.1 Case Study A

Case study A was constructed in 2007 and completed in 2010 and has a total of eight levels with meeting rooms, offices, multi-purpose hall, theater room, green roof and many more. The gross floor area of the building is 14,230m^2 and has a green landscape area as wide as 3,600m^2. Case study A is one of the few pioneering green buildings in Southeast Asia, as it was designed to showcase technologies to reduce energy consumption and water usage, promote the use of sustainable building materials and provide enhanced indoor environmental quality. There are ten main green elements that are integrated in the building such as building integrated photovoltaic (PV) panel, glass dome, rainwater harvesting, roof light through, greeneries on the roof, insulated concrete roof, roof/floor slab cooling, slanting façade, sloping roof for PV installation purposes, and glass entrance canopy with water elements. The green roof has cooling benefit the building in terms of reducing the electricity bills, as it reduces the demand for lower air-conditioning temperature. Interviewee A disclosed that the annual electricity reduction for Case Study A is about 2,197 kWh (Samsudin, 2019a).

Case study A has been awarded with Malaysia's Green Building Index (GBI) and Singapore's Green Mark Platinum green rating tools. It has also received awards from the global ASHRAE Technology Award 2013 (2nd place) and regional ASEAN Energy Award 2012 for its technology and energy efficiency (Samsudin, 2019b). The green roof in Case Study A is located at the eighth floor of the building where the services like extractor exhaust fan, roof light through, rainwater harvesting system, glass dome and photovoltaic panels are located. The green roof was installed together during the construction of the building as it was designed pre-construction. The type of green roof installed is extensive green roof as the growing medium planted is grass. Extensive green roof in Case Study A requires very low maintenance, which requires mowing once a month. It is also low cost because it does not require irrigation system and is used for ecological and insulative protective layer for the building. Figure 5 shows the location of the surface temperature measured for Case Study A building, where the green roof is labelled as A_1, B_1 and C_1, and the corresponding ceiling surface temperature directly below it as A_2, B_2, and C_2.

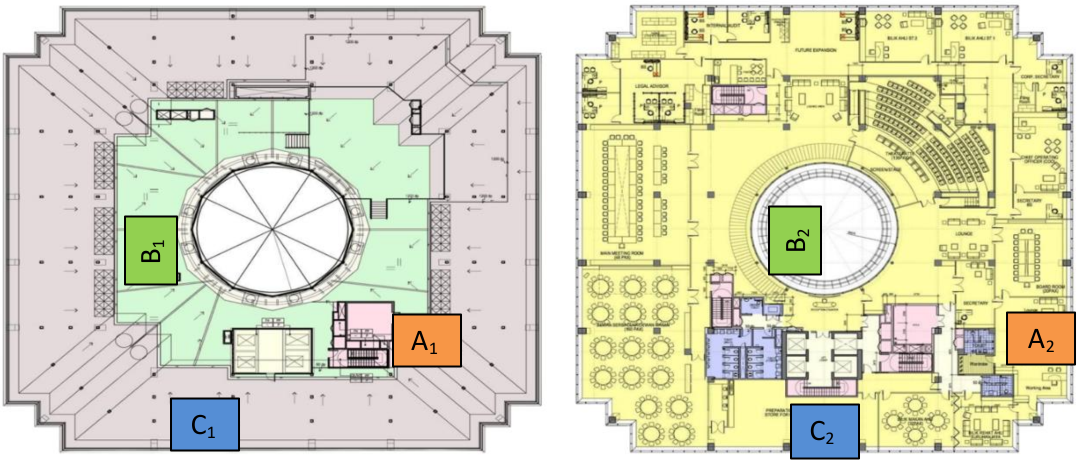

Figure 5 Surface temperature measured for Case Study A

2.2 Case Study B

Case study B is a non-green roof building. This building finished constructed in 2011 and took 30 months to complete. Case study B was built using an alternative industrialized building system with steel formwork system. It has a total of 11 levels consisting of auditorium, offices, student center, library, lecture rooms and administration office. This building is owned by the government and functions as an institutional building.

The surface temperature measured for this non-green roof Case Study Building B was conducted on the eleventh floor, where building services are located and where the roof slab is exposed directly to the sunlight. Interviewee B highlighted that utilizing the roof space to locate building services utilizes this unoccupied space and provides access to the services. The location of measurement for non-green roof surface temperatures are located at X_1, Y_1 and Z_1 on Figure 6, and the corresponding ceiling surface temperature directly below are located as X_2, Y_2 and Z_2 on Figure 7.

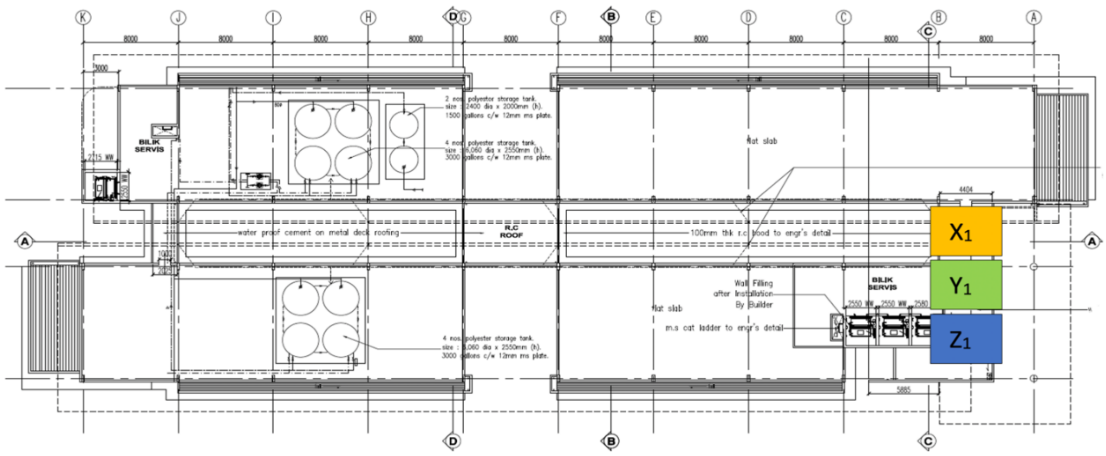

Figure 6 Eleventh level floor plan of Case Study B

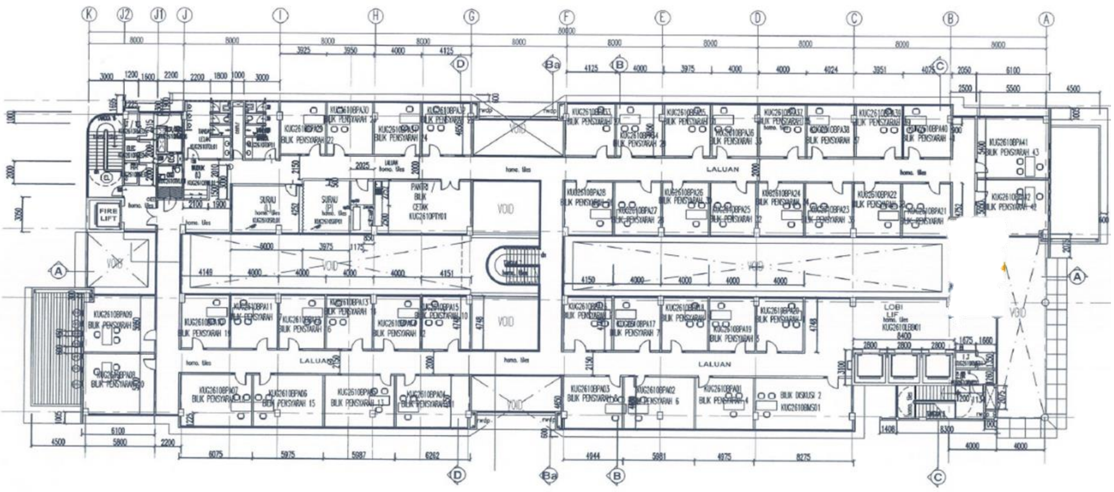

Figure 7 Tenth level floor plan of Case Study B

3. RESULTS

3.1 Qualitative Analysis - Interviews

Qualitative data were collected from in-depth structured interviews done in 2019 with relevant maintenance personnel of the case studies. The interviewees were selected based on their involvement and expertise in building or facilities maintenance and green roof maintenance. In-depth interviews provide an understanding and description of people's personal experiences regarding to the construction, benefits and maintenance of green roofs/non-green roof. Table 3 shows the summaries of the in-depth interview findings conducted for the interviewees.

Table 3 Summaries of the in-depth interview findings conducted for the interviewees

QUESTIONS	INTERVIEWEE A (CASE STUDY A)	INTERVIEWEE B (CASE STUDY B)
Part A: Demographic of Interviewee		
1. Occupation	Building Manager	Assistant engineer
2. Educational background	Mechanical Engineering	Engineering
3. Working experience	2 years at Diamond Building	Not stated
Part B: Details of Green Roof/Non-Green Roof		
1. When was the green roof/non-green roof installed?	2010	2012
2. What are the components of green roof/non-green roof on this building?	Greeneries (grass)	Serve as a purpose for building services (water tank, air-conditioning system)
Part C: Benefits of Green Roof/Non-Green Roof		
• How does the green roof /non-green roof benefit this building?	The green roof has benefited the building in terms of reducing the electricity bills. This is because the green roof can reduce the demand for lower temperature in air-conditionings therefore reducing the energy demands which subsequently reduces the electricity bills.	Improves aesthetics of the building and utilizing the rooftop space.
• To what extend do they cool the building?	Users of the building set the air-conditioning units to a higher temperature.	There is no cooling effect towards the building.
• How much difference does it make in terms of electricity bills?	It is recorded that the indoor temperature in the building is as low as 24°C and annual energy and money	-

	saved is 2,197 kWh and RM872,237, respectively.	
• How does the green roof impact the surrounding working environment?	The cool temperature in the building increases the comfort of the users which also increases their productivity.	It isolates the services of the building that generates noise which increases productivity of users in the building.
Part D: Maintenance of Green Roof/Non-Green Roof		
1. What are the maintenance elements of the green roof/non-green roof? Elements like: a. Expert gardener b. Soil replacement c. Watering system	The green roof requires very low maintenance which is mowing once in a month. There is no need for expert gardener's expertise to do the grass-cutting and soil replacement to be done every 5 years.	Non-green roof requires minimal maintenance of only checking by authorised person once a month to detect any damaged structures.
2. How much is the green roof/roof maintenance cost monthly/yearly?	RM50-RM100 per month for grass cutting.	None.
3. Is there anything that can/should be improved?	No.	There is still space that could be utilise for other purpose like storeroom.
4. Do you think that the urban heat island can be curbed if more buildings implement green roof?	Yes.	Yes.

3.2 Case Study a Temperature Analysis

The three locations where the measurements of the surface temperature and its corresponding infrared thermal camera imaging were taken on Case Study A's green roof at A_1, B_1 and C_1 is shown in Figure 8. The emissivity on the thermal infrared camera was set on 0.9 for the moist surface which is set for grass. Meanwhile, the temperatures recorded for these locations are shown in Table 3. The average surface temperature of Case Study A's green roof is 22.9℃.

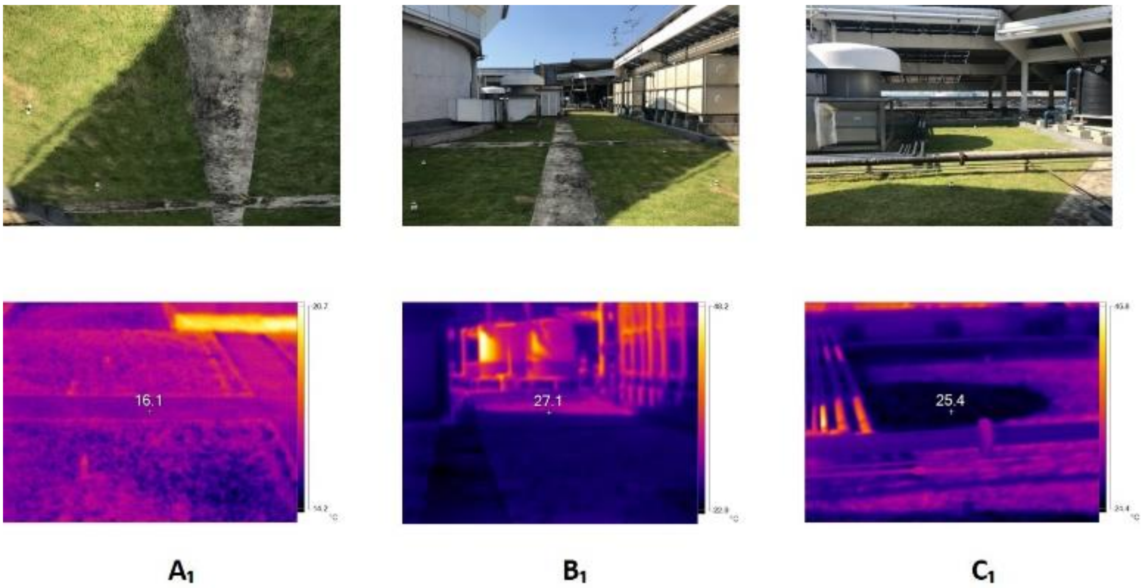

Figure 8 The surface temperature A_1, B_1 and C_1 on Case Study A's green roof

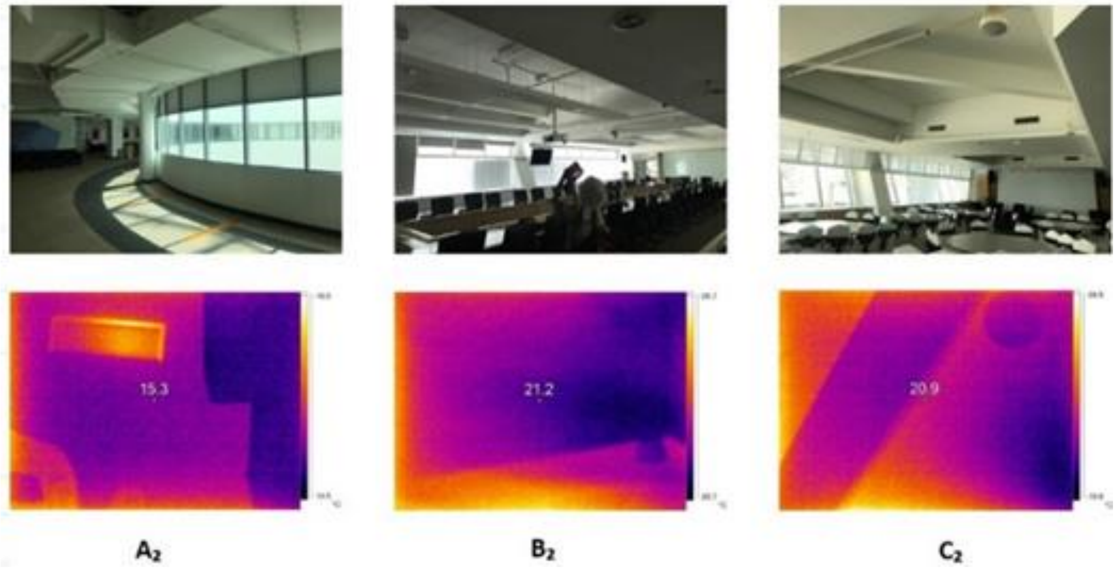

Figure 9 The ceiling surface temperature A_2, B_2, and C_2 on Case Study A's interior

Consequently, the surface temperature measurement of the corresponding ceiling of the floor directly below the green roof surface were taken to determine the reduction of temperature inside the building. Figure 9 shows detailed locations of the ceiling directly below as A_2, B_2, and C_2. The importance of taking the reading of the surface temperature of the ceiling is to see the temperature difference it brings to the inside of the building. The temperatures taken of the ceiling from inside the building were in the corridor, meeting room and also inside a multi-purpose hall, respectively. The average temperature of locations A_2, B_2 and C_2 is 19.1℃ (refer Table 4).

Table 4 Surface Temperature of Case Study a Green Roof and Corresponding Ceiling

	Green Roof Surface temperature			Corresponding Ceiling Surface Temperature		
Location	A_1	B_1	C_1	A_2	B_2	C_2
Surface Temperature (℃)	16.1	27.1	25.4	15.3	21.2	20.9
Average Surface Temperature	22.9			19.1		

In this case, locations A, B and C have a difference in temperature of -0.8℃, -5.9℃ and -4.5℃ respectively meanwhile the average temperature difference is -3.7℃ (refer Table 5). This shows that the green roof can reduce the temperature in the building hence lowering the demand in usage of air-conditioning.

Table 5 Case Study B surface temperature difference

Locations	Surface Temperature (℃)	Temperature Difference (℃)
A_2	15.3	-0.8
A_1	16.1	
B_2	21.2	-5.9
B_1	27.1	
C_2	20.9	-4.5
C_1	25.4	
Average Temperature Difference		-3.7

3.3 Case Study B Temperature Analysis

Case Study B is used as a non-green roof building comparison as the data taken is on the roof slab concrete surface with no green roof or any protection layer. The construction of the surface is of typical flat roof that consists of mortar, reinforced concrete slab, light-weight concrete for slopes, water-proofing membrane, thermal insulation, asphalt membrane, cement mortar and cement slabs. Figure 10 shows the images on the thermal infrared camera together and its comparison on Case Study B at the three different locations X_1, Y_1 and Z_1. The emissivity of the camera was set at 0.85 to accommodate the concrete surface The detailed temperature is shown at Table 6. The average surface temperature of these locations is 46.7 ℃.

Similar to Case Study A, the surface temperature of the corresponding ceiling underneath locations X_1, Y_1 and Z_1 are labelled as X_2, Y_2 and Z_2 (refer Figure 11). The temperatures measured inside the building is to determine whether there is a cooling effect on non-green roof as compared to green roof. Table 6 presents the surface temperature taken for all these locations, and the average surface temperature level of the corresponding ceiling directly below the roof is 49.4℃.

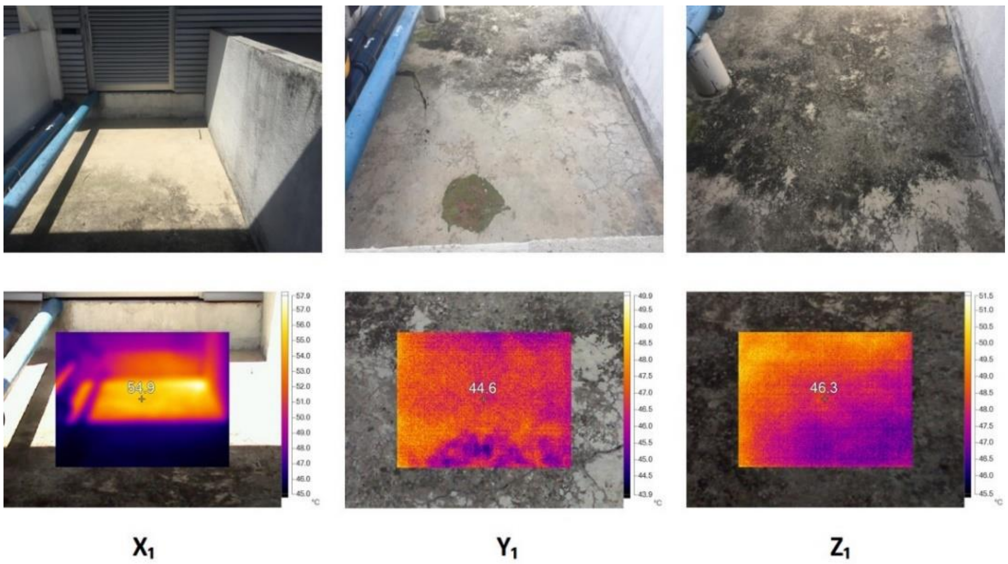

Figure 10 Surface temperature at three different locations X_1, Y_1 and Z_1 at Case Study B (non-green roof)

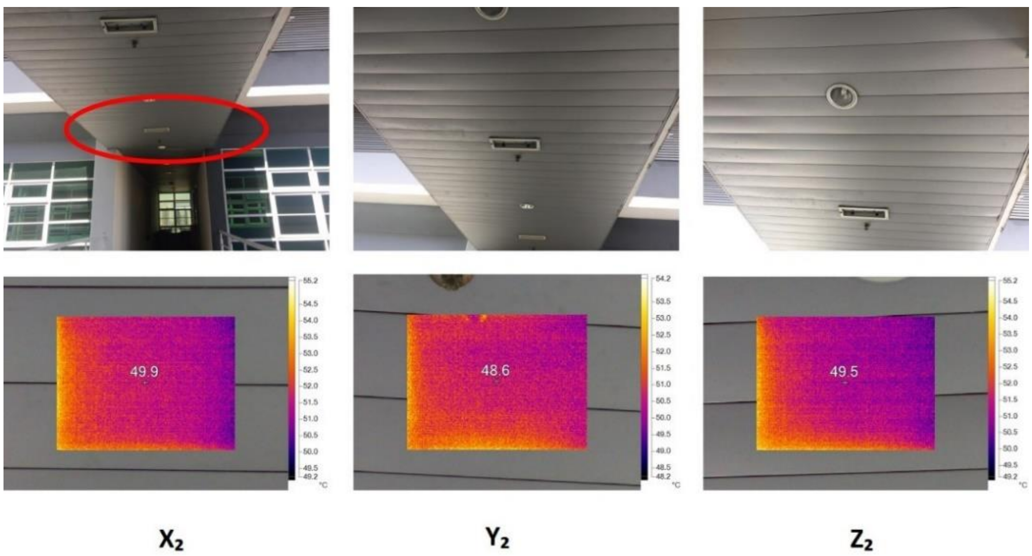

Figure 11 The ceiling surface temperature X_2, Y_2, and Z_2 on Case Study B's interior

Table 6 Surface Temperature of Case Study B Non-Green Roof and Corresponding Ceiling

	Green Roof Surface temperature			Corresponding Ceiling Surface Temperature		
Location	X_1	Y_1	Z_1	X_2	X_2	Z_2
Surface Temperature (℃)	49.3	46.3	44.5	49.9	48.7	49.7
Average Surface Temperature	46.7			49.4		

Based on the readings taken on the surface temperatures of Case Study B's non-green roof and the corresponding ceiling directly under it. The data shows that the non-green roof slab surface temperature is lower than its corresponding ceiling surface temperature. The difference in surface temperatures of locations X, Y and Z increases by 0.06℃, 2.4℃ and 5.2℃ respectively meanwhile the average temperature increased is 2.7℃ (refer Table 7).

Table 7 Case Study B surface temperature difference

Locations	Surface Temperature (℃)	Temperature Difference (℃)
X_2	49.9	0.6
X_1	49.3	
Y_2	48.7	2.4
Y_1	46.3	
Z_2	49.7	5.2
Z_1	44.5	
Average Temperature Difference		2.7

4. DISCUSSION

The summary of comparison between case study A and B is made on the difference of surface temperatures of green roof (case study A) and non-green roof (case study B) (refer Table 8). This difference signifies that green roof has the ability to reduce surface temperatures efficiently compared to non-green roof. Subsequently, the surface temperatures and the corresponding ceiling directly under the roof measured in both case study A and B respectively are also compared. This is important to measure the insulative capacity between the green roof and a conventional flat roof and thermal transference into the building.

Table 8 Surface temperatures of green roof (case study A) and non-green roof (case study B)

Case Study	Average Temperature (℃)		
	Roof surface temperature	Ceiling surface temperature	Surface temperature difference
A (green roof)	22.9	19.1	-3.7
B (non-green roof)	46.7	49.4	2.7
Difference of Surface Temperature	23.8	30.3	6.4

The roof surface temperature difference between Case Study A and B is very significant, measured at 23.8℃ difference. This is because the Case Study A green roof has reduced the overall roof surface temperature, similar to other research findings that highlight green roof plants' solar reflectivity and absorption capacity to reduce sensible heat flux (Shafique et al., 2018, 2020; Yang et al., 2018). Additionally, there is an increase in ceiling temperature inside the building in Case Study B without a green roof, compared to the ceiling surface temperature of Case Study A with a green roof that lowers the temperature inside the building, with a decrease in ceiling temperature of -3.7℃. This is because the green roof in Case Study A acts as thermal insulation to the building, presenting similar results as Li et al. (2014) and Yang et al. (2018), and the absent of green roof on Case Study B has direct heat transfers into the inside of the building resulting higher ceiling temperature. The conventional non-green roof is not able to absorb or reflect the sunlight back towards the atmosphere which makes the temperature inside of the building high. This explains why the surface temperature on the ceiling under (X_2, Y_2 and Z_2) is higher than the surface temperature directly exposed under the sunlight (X_1, Y_1 and Z_1), as there is no protective layer on the non-green roof and the heat is absorbed into the building. This could affect occupant discomfort and increase energy consumption due to higher demand need to cool the higher indoor temperature.

5. CONCLUSION

This paper has measured and compared surface temperatures of green roof and non-green roof case studies, which supports green roofs as a strategy to reduce the Urban Heat Island (UHI) effect and mitigate of climate change by cooling the surrounding environment and air, and reducing building surface temperature that consequently leads to reduced operational energy for cooling demand. The UHI phenomenon is due to the increased built-up area that reduces natural surfaces like vegetation, open area and water bodies, which results in higher surface and air temperatures (Hove et al., 2015). This consequently increases energy consumption, elevate emissions of air pollutants and greenhouse gases, impaired water quality, and lastly compromises human health and comfort (Akbari et al., 2017). Therefore, there is need to integrate green intervention strategies such as green roof to reduce UHI as it could cause adverse effects to human life. The green roof components reduce surface temperature and acts as a medium to absorb sunlight is the vegetation layer, through evapotranspiration (Yang et al., 2018). Green roof also acts as an additional thermal insulation to the building resulting in cooling effects and reduced energy consumption and cost (Li et al., 2014). However, these green roof benefits are dependent on the type of green roof (extensive or intensive) and the layers of green roof, such as water proofing membranes, root barrier, drainage material, filter layer, insulation, vegetation and substrate (Government of South Australia, 2010; Shafique et al., 2018).

After comparing the surface temperature of both case studies, it is found that the extensive green roof in Case Study A has a significantly lower roof surface temperature compared to the conventional non-green flat roof, 22.9℃ and 46.7℃ respectively, which amounts to a substantial 23.8℃ difference in temperature. This proves that green roofs are effective in reducing roof surface temperature, which can subsequently lead to reduced energy consumption and cooling demand of the building to potentially reduce the UHI impact. The green roof cooling effects can also be seen in corresponding ceiling surface temperatures in Case Study A and B where the ceiling directly under the green roof is measured at 19.1℃ for Case Study A and 49.4℃ for the conventional flat roof of Case Study B. Findings also illustrates that the green roof in Case Study A acted as thermal insulation to the building that decreased the corresponding ceiling surface temperature by -3.7℃. This study has determined the cooling effects of green roofs in tropical climate conditions based on reduced roof surface temperature compared to conventional non-green roof flat roof surface temperature, and the corresponding ceiling surface temperature. However, this paper is limited to presenting two case study buildings measurement and are not without limitations, as the surface temperatures can be influenced by external factors that are out of the scope of this paper.

Nonetheless, this study confers that green roofs can be an effective climate change and UHI mitigation strategy in the tropical climate, in line with the IPCC Fifth Assessment Report that highlights the building sector has one of the highest mitigation potentials at minimal cost (IPCC, 2014). As Malaysia currently does not have a national policy or guideline on green roofs, it is hoped that findings from this study can inform Malaysian policy and encourage building designers to integrate green intervention strategies such like the green roof in future building design and refurbishment projects.

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APPENDIX 1:

Interview questions

1. Demographic of Interviewee
   - Full name
   - Educational background
   - How long have you worked in the building?

2. Details of building case study
   - Owner of building:
   - Date of completion:
   - Age of building:
   - Number of levels in this building:

3. Estimated benefits of green roof
   - How does the green roof benefit this building?
   - To what extend do they cool the building, in terms of kWh if available?
   - How much difference does it make in terms of electricity bills?
   - How does the green roof impact the surrounding working environment?

4. Details of green roof/roof and maintenance
   - When was the green roof/roof installed?
   - What are the components of green roof/roof on this building?
   - What are the maintenance elements of the green roof/roof? Elements like:
     - Expert gardener
     - Soil replacement
     - Watering system
   - How much is the green roof/roof maintenance cost monthly/yearly?
   - Is there anything that can/should be improved?

5. Do you think that the urban heat island can be curbed if more buildings implement green roof?