Jurnal Teknologi

Full Paper

URBAN HEAT ISLAND MITIGATION USING GREEN ROOF APPROACH

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Article history
Received
23 February 2017
Received in revised form
11 October 2017
Accepted
15 January 2018
Published online
1 April 2018

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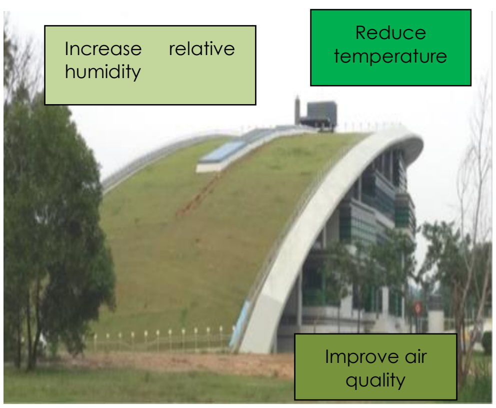
Graphical abstract



Abstract

In urban environments, vegetation has largely been replaced by impervious and often dark surfaces. These conditions contribute to an Urban Heat Island (UHI) effect. This phenomenon is demonstrated in many cities and produced effects such as higher atmospheric temperatures, intensive precipitation, excessive solar radiation and increasing air pollution. Therefore, reducing the surface temperature of roofs in a building may play an important role in improving the conventional roof surfaces with green roofs that offer much lower temperatures throughout a day to reach their thermal performance and reduce the absorption of solar radiation. Thus, this study is focused on determining the effectiveness of the existing green roof in reducing the ambient temperature and humidity of the air above it by comparison with conventional open roof top without vegetation. This study also aims to evaluate the potential of green roof to reduce the air pollutants in improving air quality in urban cities. As a result, by adopting green roof system, it has reduced temperature during the hottest hour in a day at 1230 hour (hr) by 4.3°C when compared to open roof. Green roof has also recorded higher percentage of humidity compared to open roof. Most importantly, it was proven through this study that green roof has the potential of absorbing pollutants in the air by reducing the concentrations of Sulphur dioxide (SO_2), Ammonia (NH_3), Nitrogen dioxide (NO_2), Ozone (O_3) and Carbon monoxide (CO) compared to open roof. Thus, green roofs can be considered to be one of the effective methods to mitigate UHI effects in urban cities.

Keywords: Urban Heat Island, green roof, temperature, humidity, air pollution

Abstrak

Dalam persekitaran bandar, tumbuh-tumbuhan sebahagian besarnya telah digantikan dengan permukaan kedap dan gelap. Keadaan ini menyumbang kepada kesan Pulau Haba Bandar (UHI). Fenomena ini dapat dilihat di kebanyakkan bandar dan menyumbang kepada kesan-kesan seperti suhu atmosfera yang tinggi, hujan intensif, radiasi solar melampau dan pencemaran udara yang semakin meningkat. Oleh itu, dengan pengurangan suhu permukaan bumbung di bangunan maka ia dapat memainkan peranan penting dalam memperbaiki kesan haba di bandar. Ia boleh dicapai dengan menggantikan permukaan bumbung terbuka tradisional dengan bumbung hijau yang menawarkan suhu yang rendah sepanjang hari dengan mengurangkan penyerapan cahaya matahari. Oleh itu, fokus kajian ini ialah untuk menentukan keberkesanan bumbung hijau yang sedia ada dalam mengurangkan suhu ambien dan kelembapan udara di atasnya berbanding bumbung terbuka tradisional tanpa tumbuh-tumbuhan. Kajian ini juga bertujuan untuk menilai potensi bumbung hijau untuk mengurangkan pencemaran udara dan memperbaiki kualiti udara di kawasan bandar. Menerusi kajian ini, sistem bumbung hijau berjaya mengurangkan suhu pada waktu yang paling panas iaitu pada jam 1230 sebanyak 4.3 °C berbanding bumbung terbuka. Bumbung hijau juga telah mencatatkan peratusan kelembapan yang lebih tinggi berbanding bumbung terbuka. Ia juga terbukti melalui kajian ini bahawa bumbung hijau mempunyai potensi untuk menyerap bahan pencemar di udara dengan mengurangkan kandungan Sulfur dioksida (SO_2), Ammonia (NH_3), Nitrogen dioksida (NO_2), Ozon (O_3) dan karbon monoksida (CO) berbanding bumbung terbuka. Secara keseluruhan, bumbung hijau boleh dianggap sebagai salah satu kaedah yang berkesan untuk mengurangkan kesan UHI di kawasan bandar yang pesat dengan pembangunan.

1.0 INTRODUCTION

In this new era, technology is growing rapidly. Progress of a nation can be seen from the density of population and development of technology in certain sectors. Rapid development country like Malaysia, capital city Kuala Lumpur exhibit the phenomena known as Urban Heat Island (UHI) effect, with temperature exceeding in those areas by as much as 5° C [1].

As cities grow and more development occurs, the natural landscape is replaced by roads, buildings, housing developments, and parking lots, there are large area replacement of vegetated surfaces with paved and impervious surfaces in the urban area have caused the temperature in the area to increase compared to the surrounding rural area and this phenomena defined as UHI.

Heat island area apparently the temperature is higher at day time. In the decade, it is assumed that the global rate of urbanization will increase by 70% of the present world urban population by 2030, as huge mass of emerging and population migration from rural to urban or suburban areas continues due to development. Thereby, the negative impacts related to urbanization is rise up to concern to public around worldwide due to heat islands can affect communities by rising summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat related illness and death, and water quality [2].

Urban area possessed continuous increasing temperature data from 1965 to 2006, show significant increases in temperature, indicating a strong UHI effect over the region. Data showed urban station is over 4°C warmer than rural. Rapid development indicates low vegetation surrounding which tall buildings are easily seen around cities like in Kuala Lumpur, Malaysia. When houses, shops, and industrial buildings are constructed close to one another, it can create an UHI. Building materials are usually very good at insulating, or holding in heat. This insulation makes the areas around buildings warmer, causing night time warmer due to heat loss are poor and it is a big storage of heat.

Adding to all the these, urbanization also increases temperature affecting the environment due to human influence on global warming takes many forms, human carbon dioxide emissions, building emission, cars and factories, are always burning off energy, whether they are jogging, driving, or just living their day-to-day lives and these energies are usually escapes in the form of heat. The higher the population in an area, higher is the amount of heat released.

UHI contributes to energy demands in the summer, straining energy resources. The energy used in electric fans and air conditioning ends up contributing to an even hotter UHI. Because of these negative effects, city-dwellers, architects, and designers all have to work to reduce people's impact on urban areas. One of the many methods to mitigate UHI is by implementing green roof system, in which roof of a building is covered with vegetation and plants, helps to cool things down. Plants absorb carbon monoxide, a leading pollutant. They also reduce the heat of the surrounding areas. Therefore, urban vegetation can reduce air pollutants through a dry deposition process and micro climate effects (Yang *et al*., 2008). Apart from that, heat island mitigation of the UHI effect can be accomplished through the use of lighter-coloured surfaces in urban areas, which reflect more sunlight and absorb less heat [3]. Thus, the main objective of this study is to analyze the comparison between a green roof and conventional roof without vegetation to mitigate the UHI.

Nevertheless, the limited number of studies on the air pollutant removal capacity of green roofs does not provide enough information for people to judge their effectiveness in air pollution control. Therefore, this study is also focused in assessing the potential pollutants removal by comparing the sample data between green roof and open roof without vegetation.

2.0 METHODOLOGY

2.1 Study Area

The green roof building that was selected as study area is Heriot-Watt University located at Putrajaya, Malaysia. The selected study area is the first green campus that built in extensive green roof above 5 storey from ground level. This worth 35 million pound campus has 4.8 acres beside a lake and surrounded with other buildings and also plants creating excellent environment. Study area is an extensive green roof dimension with 300 m long and 30 m wide, total area of green roof is 9000 m^2 as shown in Figure 1. Green roof is one of the recognizably sustainable features of the campus.

Figure 1 Side view of green roof

The study area is also nearby International Convention Centre, Hotel Pullman Putrajaya Lakeside, Tourism Malaysia Building and Gas District Cooling Plant 3 as shown in Figure 2.

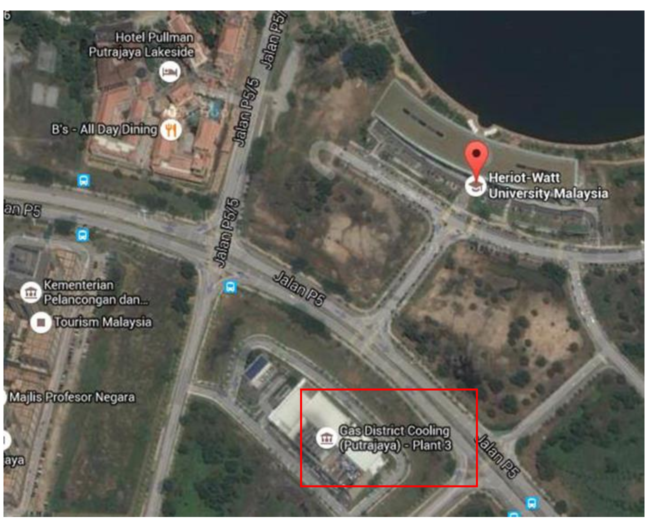


Figure 2 Building nearby study area, that might affect data is Gas District Cooling Plant 3 which will release pollutant gases

This green roof is environmental friendly and the campus consisted of passive design features such as campus lighting is powered by natural daylight and there is also rainwater storage to harvest rainwater to water grass on green roof, which optimized air conditioning with thermal control systems.

2.2 Data Collection and Parameters Studied

Data collected at study area are including Carbon Monoxide (CO), Ammonia (NH_3), Oxide Nitrogen (NO_2), Oxide Sulphur (SO_2), Ozone (O_3), humidity and temperature. Data were collected on two different locations at study area which consisted of green roof with living grass and open roof without vegetation as shown in Figure 3. Data were collected for every half an hour from 0800 hours to 1700 hours at these two locations, and the sample data were compared. The main reasons the data were only collected from 0800 hours to 1700 hours are because of time constraint the researcher faced and these hours are considered peak hours with busy traffics which will contribute to more accurate results.

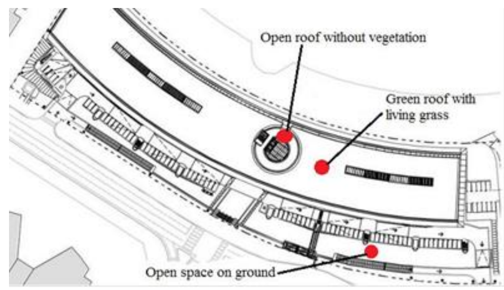


Figure 3 Aerial view of sample data collection

2.3 Equipment

Testo 175 H1 and Gray Wolf equipments (Figure 4) were used to indicate the air quality such as CO_2, NH_3, NO_2, SO_2, temperature and humidity. Testo 175 H1 equipment is able to detect temperature and humidity and has data logger which has a large display and alarm indication that makes it easy for continuous monitoring of temperature and humidity. It consists of temperature data logger, batteries, wall mount, lock, certificate of conformity with internal NTC thermistor provides reliable temperature monitoring with a small footprint, external humidity probe for quick, accurate measurements, large easy to read backlit display, large data memory capable of storing 1,000,000 measurements. Graywolf equipment is able to measure air quality, toxic gas, industrial gases, temperature and other environmental measurement applications.

Figure 4 The probe is set up 300 mm above the ground to collect data

3.0 RESULTS AND DISCUSSION

3.1 Temperature

The differences in temperature between the green roof with vegetation and the open roof without vegetation have been recorded and computed. The lowest temperature usually occurs a little while after sunrise, explaining the reason for the minimum temperatures recorded around 8-9 am for both roofs (Figure 5). Significant difference in temperature between these two roofs was observed as the day progresses and reaches its peak at 1230 hr with a temperature difference of 10.4% or by 4.3°C. The green roof with vegetation indicated a lower temperature during the hottest hour in a day, while the open roof area without vegetation that is directly exposed to the sun indicated a higher temperature in the same particular hour. Therefore, it illustrates that green roof is capable of reducing the temperature by absorbing the thermal heat radiated by the sun even during the hottest hour in a day. It proves that even in the harshest thermal environment, vegetation on green roof is able to improve the condition of an exposed roof. Extensive green roof is also able to reduce the overall ambient temperature in an area [4].

Moreover, green roof is much cooler than open roof (Figure 8) because the grasses on green roof are being watered twice a day and grasses able to absorb heat compared to open roof without vegetation. Open roof is impervious area which allows more heat radiation directly hit on ground unlike green roof. Besides that, open roof with impervious surfaces contributes to lesser evaporation compared to vegetated area, as such building materials such as concrete and asphalt will raise the local temperature by reflecting the radiated solar energy [4]. Besides that, building itself can create heat due to various materials, therefore, light colour materials are used as an optional to reduce heat absorption [5]. Increased temperature can also be related to air pollution concentration [6].

Vegetation on the green roof can produce evapotranspiration to cool the air in the vicinity. Green roof in tropical climates helps minimizing solar radiation and lower the air temperature. When surrounding environment has lower temperature, reduction of indoor temperature up to approximately 5% was observed when green roof system installed [4].

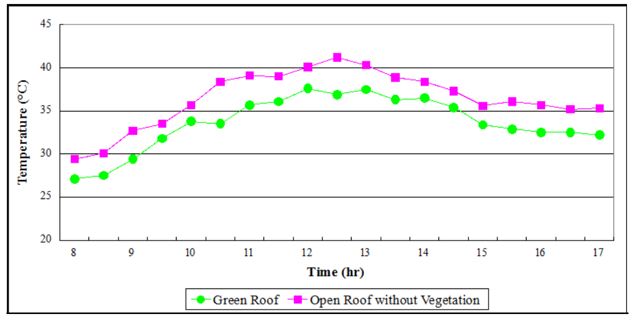


Figure 5 Comparison of temperature between green roof and open roof without vegetation

3.2 Relative Humidity

Vegetation improves humidity in air, by going through evapotranspiration. Evapotranspiration process carry out by the vegetation releases water vapor into the air on the rooftop and this will help to maintain the relative humidity even during the hottest hour in a day. Evapotranspiration not just cools the air but also hold moisture to it, raising humidity levels. High humidity can reduce the surrounding temperature and provide a comfort level for human in which it can reduce health risk like heat stroke [7]. Vegetation intercepts radiation and provides shade area that can help to reduce the temperature. In this study, the percentage (%) difference in humidity between green roof and open roof is compared.

Initially, humidity (%) of both green roof and open roof without vegetation were higher in the morning as early as 0800 hr with 85.1% and 74.2%, respectively (Figure 6). As the temperature gradually increased in day time, humidity (%) started to decreased slightly towards the afternoon from 1200 hr to 1300 hr with average humidity of 65% and 55%, respectively. However, it is worth to note that, even during these peak hours, humidity (%) of green roof is significantly higher by 10% when compared to the open roof without vegetation at the same particular hours mainly because green roof has vegetation to hold up moisture in air. According to Shaharuddin [8], green roof can lower the ambient air temperature as much as 1.5°C throughout a day and slightly change during non-rainy day as range 1.6°C to compared to rainy day will lesser than 1.5°C in Malaysia when implemented green roof system.

Heat directly heated on open roof where there is no vegetation and material low albedo reflection will absorb more heat. It is advisable to use 'cold' materials in building as it have lower surface temperature that affect thermal exchange with air

[9]. Besides, evapotranspiration from soil vegetation systems can reduce urban temperatures, where vegetation give protection from solar radiation, reduce temperature, purifying the air, and improve storm water management.

It can be concluded that the humidity for both roofs dropped accordingly along with the increased in temperatures above the roofs. Therefore, there is a negative correlation between humidity and temperature. The water holding capacity of the air will increase dramatically if the temperature increases as well. However, the amount of water remains the same, but not the ability of the air to hold water. The relative humidity of a warmer air which can hold more water is less than the same air at a lower temperature.

Overall, green roof data shows that vegetation helps in providing moisture into air in order to decrease surrounding temperature to build a comfort level for human. Green roofs created a beneficial micro climate within their area and contribute to improving the micro climate in urban centers that significantly reduce the heat island effect. Vegetation plays an important role in surface cooling in the presence of high moisture levels by evaporating and removed latent heat from soils and transpiration from plant [10]. Most of the urban fabric lacks of water retention ability when comparing to natural surfaces such as forest and plants. In urban areas, where the fraction of the surface covered by vegetation is particularly low and surfaces tend to be water-resistant, potential surface cooling due to the loss of latent heat from vegetation and soil is reduced [10].

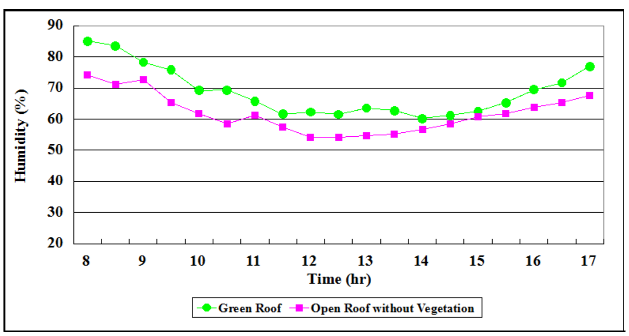


Figure 6 Humidity of green roof compared to open roof without vegetation

3.2 Sulphur Oxide

According to this study, green roof contributes in improving air quality in cities by reducing the air pollutant particles and compounds with its plants and growing medium as well. Green roof is expected to improve the air quality on the roof which include sulphur dioxide (SO_2). SO_2 is a pungent and irritating smell toxic gas at standard atmosphere. SO_2 is formed when sulphur is exposed to oxygen at high temperatures during fossil fuel combustion and oil refining, or metal smelting. SO_2 is toxic at high concentrations. Most power plants produce electricity by releasing huge quantities of by products such as Nitrogen and SO_2, these oxides particles react with moisture and other chemicals in the air to form more acidic pollutants, known as acid rain.

In this study, the differences in SO_2 amount between green roof and open roof for a period of time in a day were compared. Figure 7 illustrated the amount of SO_2 in the air above green roof and open roof.

The amounts of SO_2 for these two locations are fluctuated throughout the day. But the SO_2 concentration on the green roof is significantly lower when compared to the SO_2 concentration on open roof, with the highest reading of SO_2 on green roof being 0.3 mg/m^3 (0.106 ppm), and the lowest was 0 mg/m^3. Higher SO_2 content can be observed from 1130 hr to 1300 hr where the temperatures are higher in the day, with highest SO_2 concentration recorded at 0.8 mg/m^3 (0.284 ppm) in air above open roof. The result shows that green roof has successfully reduced the concentration of SO_2 in the air above it by 62.5% compared to open roof. However, the surrounding air contaminants at the study area might be slightly affected by the nearby cooling plant which emits minimum level of ozone gasses which contributes to the detected higher SO_2 on roof without vegetation. The results of SO_2 were also considered to be influenced by motor vehicles emissions, particularly from buses, lorries and trucks near the study area. Whereas, green roof has lower level of SO_2 reading because it has vegetation which can absorbs chemical particles and advantage to filter dust and smog particles that contain various pollutants like CO_2, sulphur acid, nitrates and other harmful materials. In one of field study, they have measured the concentration of air pollutants and particulate matters on a roof with 4000 m^2 area in Singapore, they found that the level of SO^2 in air above the roof after the installation of green roof was reduced by 37% [11].

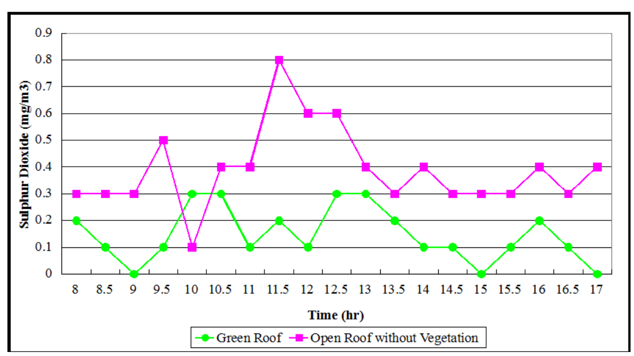


Figure 7 The graph illustrates the amount of SO_2 in the air on green roof and open roof. Higher SO_2 content could be observed during higher temperature, 1130 hr to 1300 hr.

3.4 Ammonia

Ammonia (NH_3) is a common substance can be found where there is vegetation. At normal environmental conditions, pure NH_3 is a very distinct odour, pungent-smelling, corrosive gas. The main sources of NH_3 are natural that can be from human activities, fertilizers for farm crops, lawns, and plants. Many households utilize industrial cleaning products which contain NH_3. The harm caused by NH_3 in water sources is becoming more serious, since it is very toxic to aquatic organisms. Low concentrations of NH_3 in soil are natural and actually important for plant nutrition.

In this study, NH_3 content was observed to be higher on green roof compared to open roof without vegetation mainly due to the fertilizer (Figure 8). Higher levels of NH_3 in air may occur when fertilizer with NH_3 or ammonium compounds is applied to vegetation. Green roof vegetation was fertilized once a week and when the watering of grass takes place, fertilizers will be diluted and causing run off from green roof. Therefore, it can be assumed that fertilizers in vegetation will affect the NH_3 reading for green roof. Besides that, there are also hotels and households in nearby area, which can explain the possible human activities causing the emissions of NH_3. NH_3 emissions from non-agricultural sources contributes to small fractions of total NH_3 emissions such as human breath and sweat, cigarette smoking, or household products such as cleaning agents. Significant NH_3 emissions also occur from road transport.

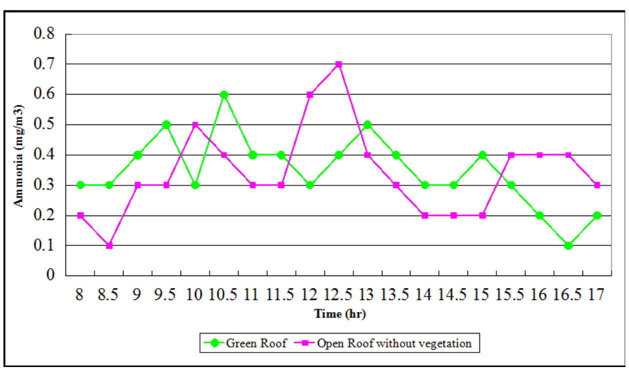


Figure 8 Ammonia content on green roof is higher than open roof

3.5 Nitrogen Oxide

Nitrogen oxide (NO_2) is a highly reactive gas and formed by oxygen and nitrogen. It reacts at high temperatures during combustion. Emissions of NO_2 are mainly from the combustion of fossil fuel and biomass burning. Concentrations of NO_2 in areas near roadways are apparently higher. Moreover, NO_2 is also one of the sources that form acid deposition and subsequently forming acid rain.

NO_2 also can be found in power plant emissions. The reaction that happen when NO_2 mix with other air pollutants such as ozone, sulphur oxides, and particulate materials can cause respiratory diseases and increase risk of heart [12]. NO_2 resulting from combustion of fossil fuels can form ground level ozone that results in respiratory problems, premature deaths, and reductions in crop yields e all of which have economic impacts [13].

In this study, it can be observed that open roof has higher level of NO_2 than green roof (Figure 9). It can be assumed that, nearby gas district cooling plant releases minimum level of natural gasses by products and therefore, it which might affect the results of NO_2 on open roof. However, green roof recorded a lower level of NO_2 reading. Vegetation and plants on green roof help in removal of pollutants thus reducing air pollution. Plants take gaseous pollutants into their stomata which intercept particulate matter with their leaves, and they able to break down certain organic compounds such as poly-aromatic hydrocarbons in their plant tissues or in the soil [14].

A study in Chicago showed by covering 20% of the roof surface with vegetation, the reduction of NO_2 was between 806.48 and 2769.89 metric tons depending on the type of plants used [15]. These estimates were reached by assuming the NO_2 uptake rates by green roof plants were constant.

Furthermore, studied area is also near roadways where the traffics are quite busy during the day time. This directly contributes to the release of NO_2 that comes from vehicles into atmosphere.

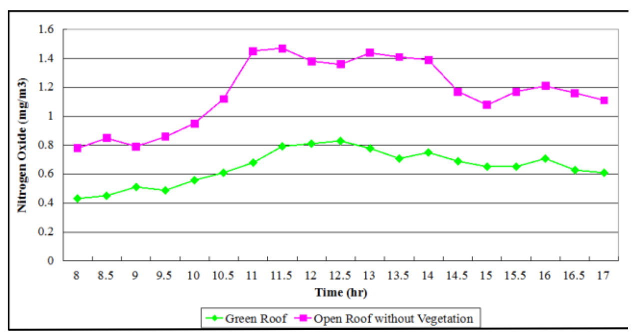


Figure 9 NO_2 levels on green roof and open roof most concentrated from 1130 hr to 1300 hr

3.6 Ozone

Ozone (O_3) is produces by chemical reaction of nitrogen oxide and volatile organic compound in presence of sunlight. O_3 emission can be from industrial, electric utilities, motor vehicle exhaust, gas vapour and chemical solvents. O_3 is dangerous particularly for children, the elderly, and people of all ages who have lung diseases such as asthma. Ground level O_3 can also have harmful effects on sensitive vegetation and ecosystems.

For this study, every half an hour data of O_3 were taken from morning to evening. Fluctuated patterns of O_3 readings for green roof and open roof were observed (Figure 10), however, green roof recorded lower O_3 levels of all times compared to open roof. Highest reading of O_3 for open roof was 0.04mg/m^3, while, for green roof was 0.03mg/m^3 with 25% total reduction in O_3 level. Grasses on green roof help to absorb and reduce air particles in air. Studies show that trees could contribute significantly to air pollution reduction in cities [16]. Vegetation able to indirectly reduce the air pollutants by cooling surface temperatures through transpiration and also by providing shade, which will decreases photochemical reactions that form pollutants such as ozone in the atmosphere [14].

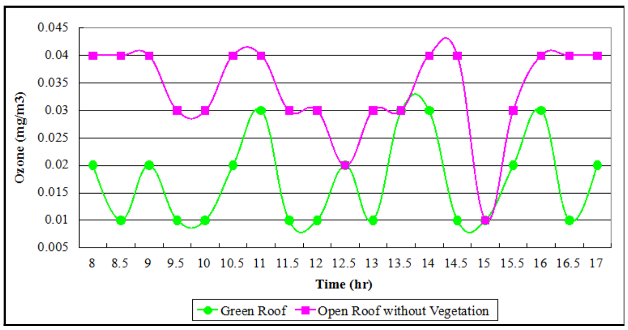


Figure 10 Ozone levels for green roof and open roof without vegetation

O_3 levels are higher on open roof without vegetation mainly because there is no vegetation around to absorb the pollutants emitted from the Gas Cooling District Plant 3. Moreover, to worsen this circumstance, urban areas are normally having lesser space for plant to grow due to impervious areas such as parking lots, road, rooftops and housing. Therefore, rooftop to replace impervious surfaces with vegetation is encouraged [17] because green roofs are able to reduce heating and also provide cooling for building and mitigating UHI problem in a community. The cooler environment slows down photochemical reactions and leads to less secondary air pollutants, such as O_3 [9].

3.7 Carbon Monoxide

Carbon monoxide (CO) is a colourless, odourless and tasteless gas which is emitted from combustion burning processes. CO mostly comes from mobile sources that emitted into air. CO can cause threat to health by reducing oxygen in blood that delivers to our organ and tissue. When CO is at extremely high level, it can cause death to human.

In this study, CO levels for open roof were higher compared to green roof for the whole sampling duration from 0800 hour to 1700 hour (Figure 11). The readings of CO for green roof are considered quite low with few zero readings indicating no CO emission at the time of 0800 hour, 0900 hour, 1100 hour, 1300 hour and 1630 hour. These basically showed that roof with vegetation helps in reducing harmful air particles in the atmosphere and decreasing air contamination, thus improving towards a healthier environment. In urban environment, plants have been used long time ago as a part of toxic air elimination and gases like particular matter, NO_2, CO_2, SO_2 and CO [4].

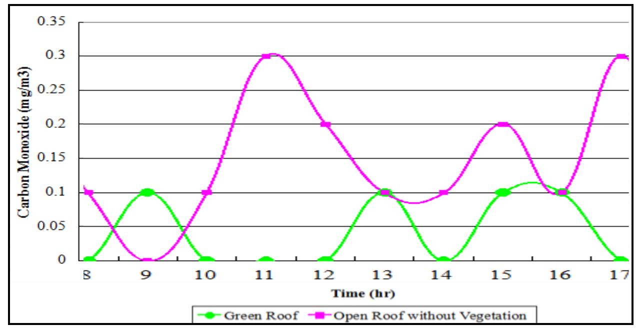


Figure 11 Carbon monoxide levels for green roof and open roof without vegetation

4.0 CONCLUSION

The study of UHIs mitigation by introducing green roof has achieved its objective. The field studies and research that have been carried out have shown the main purpose of implementing green roof is to lower the ambient temperature on the rooftop in order to reduce the formation of UHI in urban area. The maximum temperature difference recorded for green roof during the hottest hour in a day which is at 1230 hr is found to be by 4.3°C when compared to open roof without vegetation. The highest temperature recorded on green roof is 36.9°C, and the highest temperature recorded on open roof without vegetation is 41.2°C. Thus, we can conclude that green roof provide lower ambient temperature than conventional rooftop and is an effective method to be used to mitigate UHI effect. Lower humidity (%) was recorded on the open rooftop without vegetation when compare to green roof where it has higher humidity in the same hour. The lowest humidity recorded for green roof is 60.2%, whereas the lowest humidity recorded on open roof without plant is 54.1%. The grass on green roof carry out evapo-transpiration process which will release moisture in to the air above the green roof and the moisture trapping soil underneath the grass help the green roof to retain its humidity even in the hottest hour of the day. From the results, it can be seen that the air above the green roof contained lesser concentrations of air pollutants such as NO_2, CO_2, SO_2, O_3 and CO compared to open roof. Thus, this study has proven our hypothesis that green roof is able to improve local air quality in the vicinity of the campus.

Acknowledgement

The authors fully acknowledged Universiti Teknologi Malaysia for the fund and Herriot Watt University, Putrajaya for the granted permission to use their premises for data collection which makes this research viable and effective.

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