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The Investigation of Green Roof and White Roof Cooling Potential on Single Storey Residential Building in the Malaysian Climate

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Abstract**—**The phenomenon of global warming or climate change has led to many environmental issues including higher atmospheric temperatures, intense precipitation, increased greenhouse gaseous emissions and increased indoor discomfort. Studies have shown that bringing nature to the roof such as constructing green roof and implementing high-reflective roof may give positive impact in mitigating the effects of global warming and in increasing thermal comfort sensation inside buildings. However, no study has been conducted to compare both types of passive roof treatments in Malaysia in order to increase thermal comfort in buildings. Therefore, this study is conducted to investigate the effect of green roof and white painted roof as passive roof treatment in improving indoor comfort of Malaysian homes. This study uses an experimental approach in which the measurements of temperatures are conducted on the case study building. The measurements of outdoor and indoor environments were conducted on the flat roof with two different types of roof treatment that are green roof and white roof. The measurement of existing black bare roof was also conducted to act as a control for this study.

Keywords**—**global warming, green roof, white painted roof, indoor temperature reduction.

I. INTRODUCTION

GLOBAL warming or climate change has become a global nightmare. Global warming lead to climate changes in which the world experiences rising temperatures and sea levels, changes in precipitation and severe droughts and floods. Global warming results when the energy received from the sun in the form of short-wave radiation was absorbed by the land and the oceans. As the earth surface becomes warmer, this energy was then reflected back to the atmosphere in the form of long-wave infrared radiation. Atmospheric greenhouse gases which comprises water vapour, carbon dioxide, ozone, methane and nitrous oxide created a ‘blanket effect’ which trap and re-emit some of this long-wave radiation into the atmosphere and thus increase the earth temperature by 35^0C[1]. Carbon dioxide is the most significant greenhouse gas said to be the main cause of global warming and climatologists worldwide agreed that the increase in carbon dioxide concentration in the atmosphere was due mainly to human activities[2][3][4]. As the CO_2 in the atmosphere increases, the ability of the earth’s surface to reradiate heat to the atmosphere is lessened since it acts like a blanket over the surface and keeps the earth warmer than it would otherwise be[5]. Recent research has discovered that the ability of the ocean to absorb CO_2 from the atmosphere has decreased due to global warming. Therefore, the CO_2 concentration in the atmosphere is predicted to be continuously increasing. Plants naturally play a very important role in absorbing CO_2 from the atmosphere in order to counter the detrimental effects of the greenhouse gases. However, continuous deterioration of green areas due to the urbanization process has created an unhealthy environment and has become another contributor to climate change. Deforestation is believed to be another major cause of global warming. The cutting and burning of about 34 million acres of trees each year resulted in an increase of 25% carbon dioxide entering the atmosphere[6]. Environmental pollution is becoming more common in the urban areas and has produced many negative environmental impacts to society. One of the effects is an urban heat island phenomenon in which the temperature in urban areas is higher than the surrounding area. Climate change not only gives impact to the environment but also to the natural heating and cooling processes of buildings. The warmer outside temperature will affect the indoor temperature and thermal comfort of buildings [7]. When the outdoor air temperature increases, buildings will experience indoor discomfort and this situation will lead to a higher demand for mechanical ventilation and increased energy consumption in buildings. Various studies have shown that passive and low energy cooling are the most preferred techniques used to minimise the solar load and conductive daytime heat gain through the building. The roof, which is the hottest part of a building is the most suitable element that should be taken care of in minimising heat gain throughout the building. Among the popular passive cooling techniques of roofs are green roof and reflective roof. Green roof is defined as a roof that supports vegetation [8]. It is also known as eco-roof, living roof, planted roof or vegetated roof which uses plants to improve roof performance and appearance [9]. Green roof is also referred to as roof garden in some places [10][11]. This kind of roof can be divided into two types which are intensive and extensive green roofs. An intensive green roof requires deeper substrates which is at least 15 cm (6 inches) deep and generally known as a roof garden while extensive green roofs require shallow substrates of between 2 to15 cm (0.8 to 6 inches). Intensive green roofs are usually accessible to the public and require regular maintenance while extensive green roofs are normally inaccessible to the public and require minimal maintenance[11],[9]. Green roofs could give many environmental benefits to the buildings and occupants including improving thermal performance of buildings by providing large surfaces with vegetation[12]. In

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2001, Niachou A, *et al.* published the results of a study on indoor and outdoor microclimate before and after the installation of a green roof on a building which concluded that the indoor temperature values in the building with green roof are lower during the day. The results show that the surface temperature of a non-insulated building without green roof vary from 42^0C to 48^0C while the surface temperature of a green roof on non-insulated building are lower and ranging from 28^0C to 40^0C. The incidence of the large temperature differences was due to the installation of a green roof and this could contribute to energy saving potential[13]. In Japan, a group of researchers have conducted field measurement of a roof lawn garden planted on non-woven fabric on an actual three-storey pre-cast reinforced concrete building. The reduction of roof slab surface temperature from 60^0C to 30^0C was observed during the measurement and an estimated 50 percent in heat flux was deducted by simple calculation[14]. The above finding was supported by a study conducted in Singapore on the thermal performance of extensive rooftop greenery systems. The result shows that the green roof tends to experience lower surface temperature than the original exposed roof surface and the heat flux through the roof structure was greatly reduced after the installation of the green roof system. In areas well covered by vegetation, over 60 percent of heat gain was prevented by the implementation of a green roof system[16]. In Central Pennsylvania, the Penn State Center for Green Roof Research has developed a green roof field experiment which consists of 6 separate experimental buildings i.e. three buildings were developed with green roofs and the other three were constructed with dark roofs. The temperature, meteorological conditions and water retention and runoff were monitored on the roofs. The hourly averages of temperature data were taken every five minutes and the data demonstrates the cooling potential of green roof surfaces compared to dark impervious roof surfaces. A peak temperature of 30^0C or lower was measured on the green rooftops[17]. In 2008, Spala *et al*. found that the installation of a green roof on an office building in Athens presents a significant contribution to energy saving during the summer periods and a remarkable reduction of building cooling load was estimated during the simulation study. However, the effect of green roof installation was not significant during winter because the variation of heating load was quite small. Green roof can also effectively reduce the need for air conditioning in summertime thus contributing to energy saving in buildings[18]. A comparative study of passive cooling effect of green roof in a high-rise building was conducted in the hot-humid climate of Malaysia in 2008. The study concluded that passive cooling by green roof is recognized as one of the most effective means in reducing indoor temperature of buildings under hot-humid tropical climates. The maximum outdoor surface temperature reduction of up to 19.8^0C and the reduction of indoor ceiling surface temperature of up to 3^0C were recorded on the green roof compared to the bare roof[19]. Several studies were undertaken to compare the surface temperatures of green roof and white roof in order to evaluate the cooling potential of both types of roof. In 2003, a study was conducted in Penn State University, New York to evaluate an energy balance between a white roof and a green roof by using the simulation of green roof surface temperature with a raised albedo on a calibrated control roof model. The results concluded that green roof cooled as effectively as the brightest possible white roof (albedo value in range of 0.7 to 0.85 are among the brightest surfaces available from white coatings) but, without the need of regular washing unlike white roof[17]. Another study was conducted in June 2008 to compare the temperature behaviours between unprotected black roof, green roof and white roof. The result demonstrated that the surface temperature of green roof remains cooler than white roof and much cooler than on a black roof even on a very hot day [20].From the above literature, it is confirmed that green roof is able to provide a cooling sensation to buildings and better temperature reduction than white roof especially during the summer periods. However, no comparative study between these two roofs has been carried out in Malaysia (which experiences hot-humid climate condition all year round). This study is especially significant on a single storey residential house in order to reduce indoor discomfort due to heat gain from roof. Therefore, the objective of this study is to identify which roof could provide a better indoor cooling performance specifically in single storey residential houses in the Malaysian climate. In order to get a more reliable data on their indoor and outdoor effects, a comparative study of these two roofs and also with black bare roof (which acts as a reference roof) were conducted on the same roof starting from 8th June 2009 until 4th July 2009.

II. MATERIAL AND METHODS

A. Case Study Building

The study was conducted on the flat roof of a single storey detached house within the University Sains Malaysia, Penang campus. This single storey detached house was constructed of brickwork and exposed to full sunlight during the day. The bedroom which was constructed with a concrete flat roof and located at the rear of the house was selected to be the test room for this study. This bedroom was attached to another room at the kitchen and isolated from the main building. This room was of east-west orientation and seems to experience higher temperature during the daytime hours due to full sun exposure. The room measuring 3.05m x 2.73m x 3.05m consists of a door and a window on one side of the brick wall. The flat roof surface was insulated with bituminous felt which was black in colour. Outdoor and indoor environments i.e. outdoor and indoor air temperatures, outdoor and indoor surface temperatures, solar radiation, indoor wind speed and indoor humidity were measured to evaluate the thermal performance of the room underneath the roof. The measurements were conducted on the same room with different roof treatment namely bare roof, green roof (using potted plants) and white roof. 6 days' measurements for each roof were conducted on different weeks with the measurements of the bare roof acting as control for this study. Since the room was located at the rear of the house and attached to another room and a kitchen, only the roof on top of the test room is going to be measured, the rest of the flat roof was covered by plywood to minimize the transfer of heat onto the test roof surface. The case study building for this research is shown in Fig. 1.

Fig.1 Test room located at the back of the main building

B. Plant Selection for Green Roof

Green plants which are more resilient to higher air temperatures and can uptake the highest amount of carbon dioxide were chosen as the plants for the green roof in this study. The procedure for plant selection was conducted on 1st July 2008 at Marine Research Station, Muka Head, Teluk Bahang, Pulau Pinang which involved 5 different types of potted plant(*syngonium podophyllum (*arrowhead plants*)*, *ipomoea batatas* (sweet potato), *jasminum sambac, ipomoea horsfalliae* (cardinal creeper) and *ipomoea pes-caprae* (beach morning glory)). *Ipomoea pes caprae* has been selected as the sample for green roof due to its capability to uptake higher amount of carbon dioxide and resilience to higher outdoor temperatures as compared to other plants.

C. The Measurement

The measurements of indoor and outdoor microclimates of test room with different types of roof treatments were conducted on different days starting from 8th June 2009 until 4th July 2009. Each type of measurement was conducted within one week's durations. The first week measurement was conducted on a room with green roof and the measurement of the room with black bare roof was conducted on the following week. The measurement of the white roof was conducted during the succeeding week after the roof was painted with white paint. 102 pots of *ipomoea pes caprae* were placed on the roof to fully cover the test roof during the first week of measurement that was from 8th June 2009 until 13th June 2009. The measurement of bare roof was conducted on the following week after the roof has been emptied of potted plants which was from 15th June 2009 until 20th June 2009. The measurement of white roof was only conducted on 29th June 2009 until 4th July 2009 after the existing black roof was painted white. A data acquisition system was installed in the test room. The outdoor air temperature, solar radiation, outdoor surface temperature of roof, indoor air temperature, indoor surface temperature of roof i.e. ceiling surface temperature, indoor humidity and indoor wind speed were monitored during the experiment. The door was shut during the measurement while the window remains opened during daytime hours and was shut during night-time hours. Seven sensors have been placed on top of the roof and in the test room underneath. Three sensors were placed on top of the roof that is a LI-200SA pyranometer to measure global radiation, a 1906 NRG 110S temperature sensor with radiation shield to measure ambient air temperature and a surface temperature sensor to measure the surface temperature on the test room. Another four sensors were placed inside the test room namely an indoor air temperature sensor, an indoor air velocity sensor, an indoor surface temperature sensor and an indoor relative humidity sensor. The pyranometer was set at 340mm from the roof surface while the outdoor temperature sensor was set at 350mm from the roof surface. Indoor surface temperature sensor was placed on the ceiling surface. The indoor air temperature and indoor air humidity sensors were placed at 2.58m from the floor while the indoor wind speed sensor was placed at 2.49m from the floor. The placement of all sensors is illustrated in Fig.2. The data were logged every 15 minutes using the data acquisition system. Since data collection for all types of roofs was obtained from different days of measurements, the average 6 days' readings for every type of roof were analysed. Indoor and outdoor air and surface temperature behaviours were analysed in order to study their cooling potentials. The roof condition before and during the experiment is shown in Fig. 3 and 4.

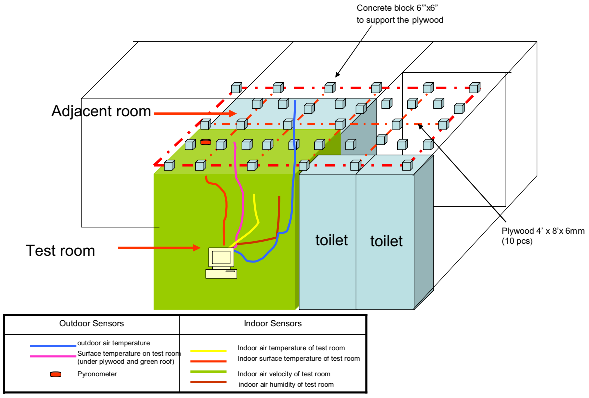

Fig.2 The placement of sensors on case study building

(a) (b)

Fig.3 (a) Black bare roof before the experiment; (b) black bare roof during the experiment

(a) (b)

Fig. 4 (a) Roof filled with potted plants (*ipomoea pes capre*); (b) White roof with outdoor surface temperature sensor placed on it surface

III. RESULT

A. The intensity of solar radiation

Average solar radiation recorded during the measurement of all roofs is displayed in Fig.5. Solar radiation started to rise from 8am in the morning and reached its maximum value between 11am in the morning and 3pm in the afternoon in all cases. Its intensity rapidly declined towards late afternoon until almost 8pm in the evening. The maximum solar radiation recorded during the measurement of black bare roof, green roof and white roof are 1009, 1126 and 1048 W/m^2 respectively. Solar radiation intensity fluctuated due to the variation of cloud cover.

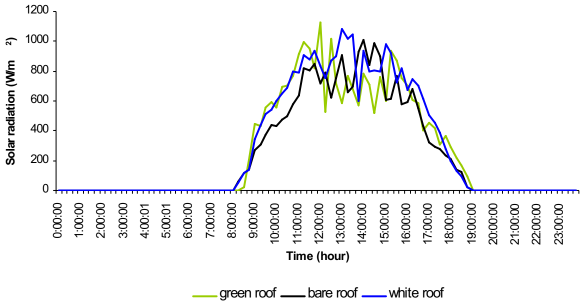

Fig. 5 Comparison of average solar radiation between black bare roof, green roof and white roof for six days' reading

B. Outdoor and Indoor Air Temperatures and Surface Temperature Profiles for All Roofs

The measurement of indoor and outdoor microclimates of buildings was conducted on different weeks starting from 8th June 2009 until 4th July 2009. The measurement on each roof was conducted for a period of six days' duration in continuous weeks. This procedure produced a different climatic data especially on solar radiation and ambient air temperature profiles. To analyse these data, average six days' reading for all variables is used.

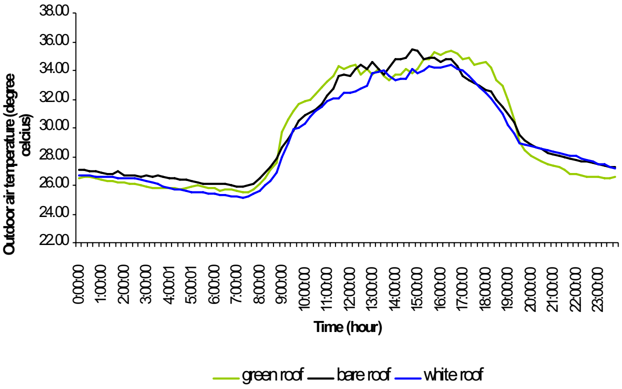

Fig.6 Comparison of average outdoor air temperature between black bare roof, green roof and white roof for six days' reading

The average outdoor air temperature profile for each roof is shown in Fig. 6. The average air temperature difference between the three types of roof is between 0.01^0C and 1.91^0C. The average outdoor air temperature for green roof was higher than black bare roof and white roof from 9 am in the morning until 1.15pm in the afternoon and 7.45pm in the evening until 3.45am in the morning, whereas outdoor temperature profile for white roof was lower than both black bare roof and green roof during daytime hours despite the presence of high solar radiation intensity compared to those roofs. However, when comparing the outdoor surface temperature among the three roofs, the green roof demonstrated a very impressive temperature reduction compared to the white roof and the black bare roof especially during daytime hours between 9am in the morning until 7pm in the evening as shown in Fig. 7 (a). The average outdoor surface temperature difference between the black bare roof and the white roof was quite small at 0.68^0C. The highest average temperature difference between the black bare roof and the green roof was recorded at 4.62^0C between 11am in the morning and 5pm in the afternoon (with the highest temperature difference of 5.74^0C recorded at 2.45pm in the afternoon). Meanwhile, the average outdoor surface temperature profile for green roof was lower than the outdoor surface temperature observed on white roof almost at all time except between 7 and 8 o'clock in the morning. This result shows that green roof is able to prevent heat penetration on the roof surface and reduce the indoor ceiling temperature. The comparison of average temperature reductions for each roof is shown in Fig. 7 (b), (c) and (d).

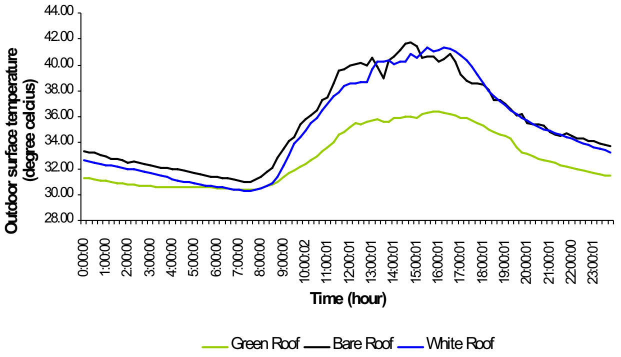

Fig. 7(a) Comparison of average outdoor surface temperatures between black bare roof, green roof and white roof for six days' reading

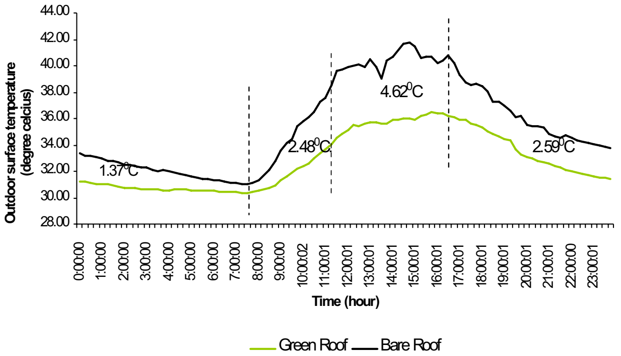

Fig. 7 (b): Comparison of average outdoor surface temperatures between bare roof and green roof for six days' reading.

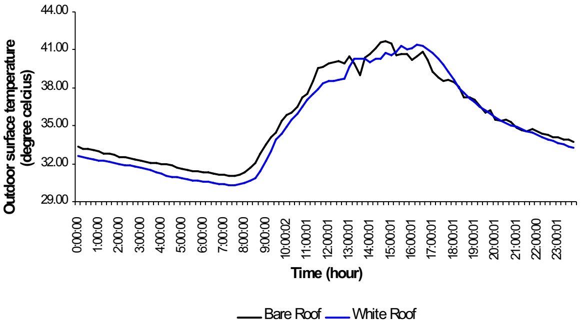

Fig. 7 (c) Comparison of outdoor surface temperature between bare roof and white roof for six days' reading

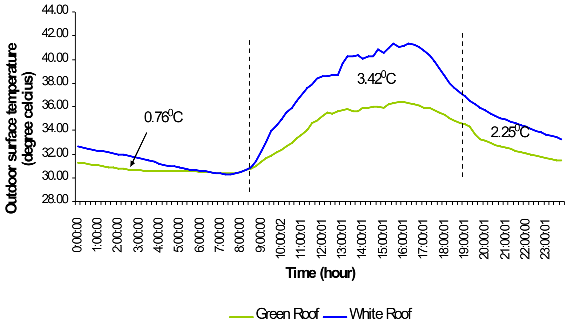

Fig.7 (d) Comparison of outdoor surface temperatures between green roof and white roof for six days' reading

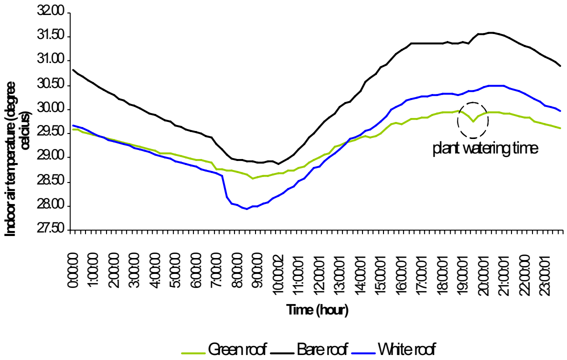

Fig.8 (a) Comparison of average indoor air temperatures between bare roof, green roof and white roof for six days' reading

Fig. 8(a) shows the average six days' reading of indoor air temperatures for all three types of roof. Again, the graph demonstrated a lower value for green roof's indoor air temperature in comparison with black bare roof at all times during the day. However, its value was above that of white roof between 1o'clock in the morning and 1o'clock in the afternoon. The highest average temperature difference between black bare roof and green roof during daytime hours was recorded at 1.55^{0}C between 4 o'clock in the afternoon and 9 o'clock in the evening. During the measurement period, the plants on the green roof were watered once a day to ensure their survival. The watering of plants on the green roof was carried out between 7 and 8 o'clock in the evening for every day. Hence, the indoor air temperature recorded during these hours (which can be seen on the graph) was the lowest. The average indoor temperature range from 28.58^{0}C to 29.96^{0}C was observed in the room underneath the green roof whereas, temperature ranges from 28.88^{0}C to 31.58^{0}C and 27.95^{0}C to 30.50^{0}C were observed underneath the bare roof and white roof respectively. The minimum and maximum temperature differences of 0.21^{0}C and 1.73^{0}C were observed in the experiment at 10.00 o'clock in the morning and 7.30pm in the evening underneath black bare roof and green roof. Meanwhile, the highest temperature difference between green roof and white roof was recorded at 0.7^{0}C at 8 o'clock in the morning. The average indoor air temperature for all roofs started to increase from 10am in the morning until 9pm in the evening and after that starts to gradually decrease. This was because the roof started to absorb heat during daytime hours and slowly released the heat stored during night time.

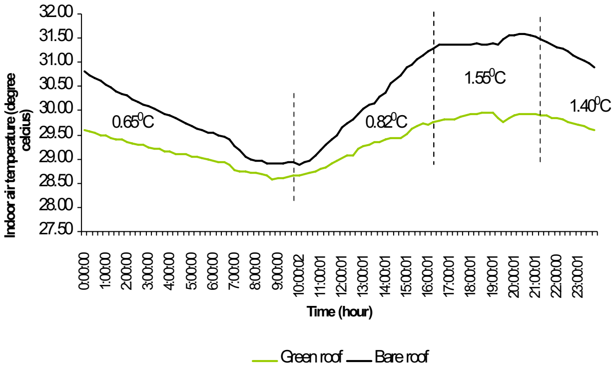

Fig.8 (b) Comparison of average indoor air temperatures between black bare roof and green roof for six days' reading

Fig.8 (b) shows average indoor temperature differences between bare roof and green roof. The maximum temperature difference of 1.55^{0}C was observed between 4pm and 9.45pm. The highest temperature difference between indoor air temperatures of green roof and black bare roof was 1.73^{0}C at 7.30pm and the minimum value was 0.21^{0}C at 10 o'clock in the morning. Meanwhile, the maximum average temperature difference between black bare roof and white roof was only 0.97^{0}C between 10 o'clock in the morning and 12 midnight with the maximum value of 1.16^{0}C recorded at 7.45pm (as shown in Fig. 8 (c)).

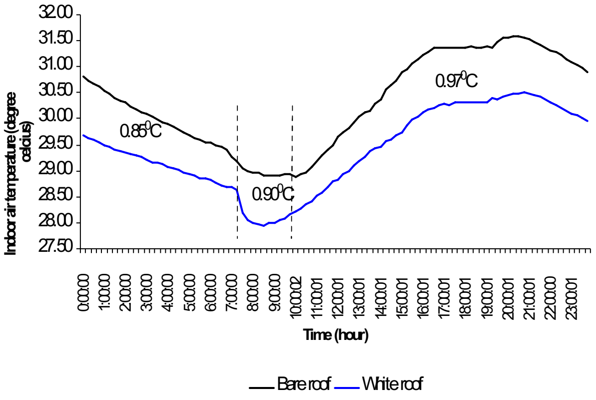

Fig. 8 (c) Comparison of average indoor air temperature between black bare roof and white roof for six days' reading

Fig. 8 (d) demonstrates the average temperature difference between green roof and white roof during the experiment. Indoor air temperature profile for green roof was lower than white roof during critical daytime hours which is from 1.30 pm until 1.15 am. From the result, it was inferred that potted plants can significantly reduce the surface temperature and the air temperature of the room underneath.

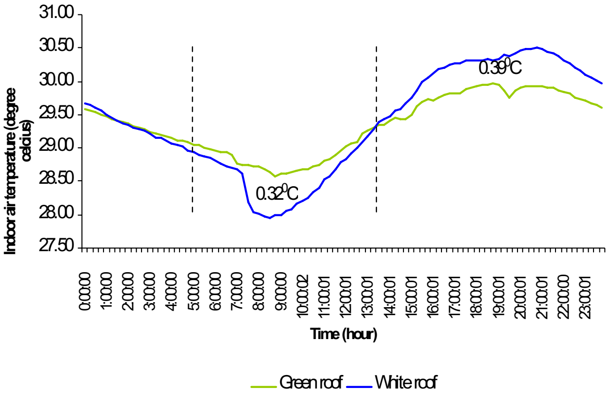

Fig. 8 (d) Comparison of average indoor air temperature between green roof and white roof for six days' reading

In order to evaluate the cooling potential of green roof and white roof, the indoor surface temperature of those roofs were examined. The result is shown in Fig. 9 (a), (b) (c) and (d). Fig. 9 (a) shows the indoor surface temperature profile for all roofs. The average indoor surface temperature of black bare roof exhibits the highest value which was 41.73^{0}C recorded at 2.45pm in the afternoon. On the other hand, the maximum average indoor surface temperature value (for six days' reading) for green roof and white roof are 36.44^{0}C and 41.37^{0}C respectively. The maximum average indoor surface temperature difference between black bare roof and green roof was 7.86^{0}C at 4.45pm in the afternoon and minimum value was 0.63^{0}C at 8.30am in the morning. The average temperature difference between these two roofs was as high as 6.85^{0}C observed from 1 o'clock in the afternoon until 8 o'clock in the evening (as shown in Fig. 9 (b)). Meanwhile an average indoor surface temperature difference between white roof and black bare roof was only 5.30^{0}C recorded at 4.15pm in the afternoon. The average temperature difference between 1 o'clock in the afternoon and 8 o'clock in the evening for these roofs was recorded at 4.74^{0}C (as shown in Fig. 9 (c)). This result shows that average indoor surface temperature reduction for green roof was markedly high due to the installation of potted plants on the rooftop.

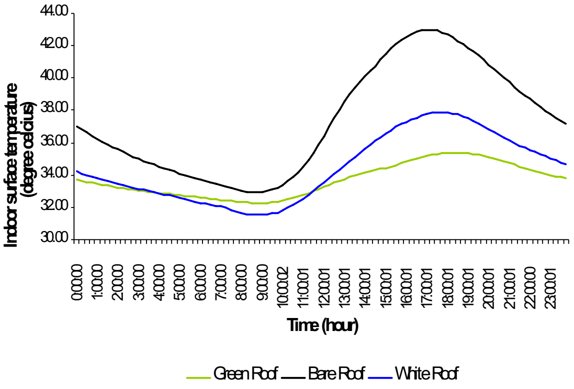

Fig. 9 (a) Comparison of average indoor surface temperature between black bare roof, green roof and white roof for six days' reading

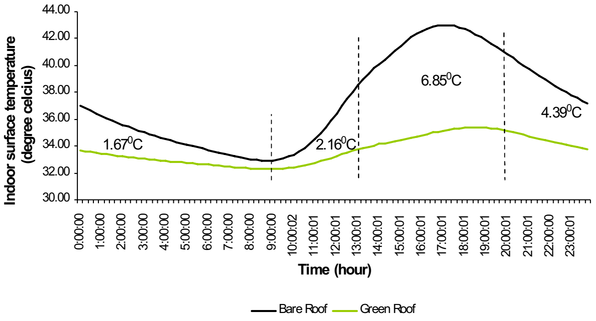

Fig. 9 (b) Comparison of average indoor surface temperature between black bare roof and green roof for six days' reading

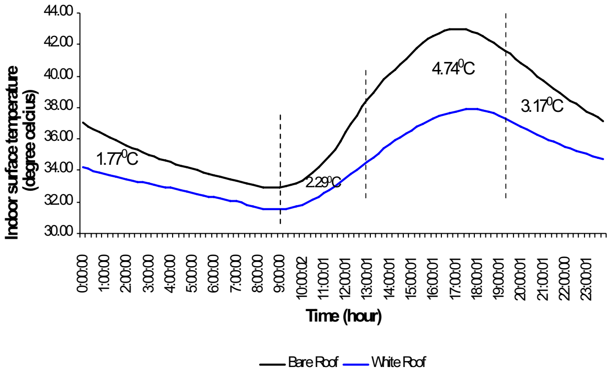

Fig. 9 (c): Comparison of average indoor surface temperature between black bare roof and white roof for six days' reading

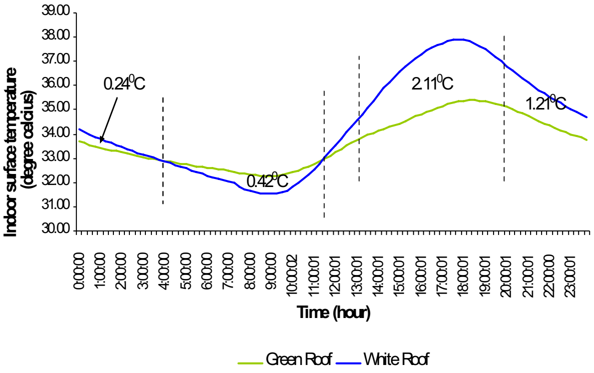

Fig. 9 (d): Comparison of average indoor surface temperature between green roof and white roof for six days' reading.

C. Indoor Relative Humidity Profile for All Roofs

Indoor relative humidity is inversely proportional to indoor air temperature in which higher air temperature results in lower relative humidity. Fig. 10 (a) shows the average indoor relative humidity pattern for all types of roof. Average indoor relative humidity for black bare roof was lower than the other two types of roof at all times especially during the afternoon hours due to higher indoor air temperature. The difference in average indoor relative humidity for all roofs is shown in Fig. 10 (b), (c) and (d). The indoor relative humidity patterns are proportional to average indoor air temperature recorded for all roofs.

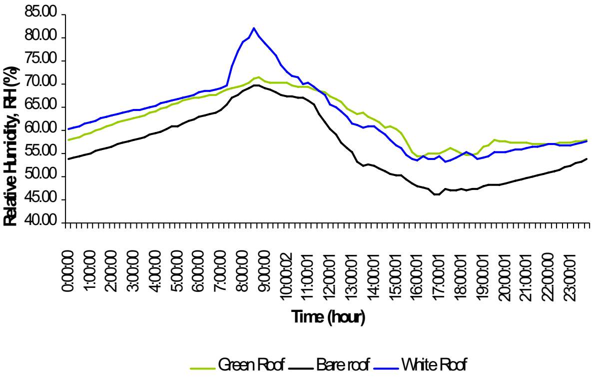

Fig.10 (a) Comparison of average indoor relative humidity between black bare roof, green roof and white roof for six days' reading

IV. CONCLUSION

Green roof has proven to be a promising technique in reducing indoor air temperature and providing positive environmental impact to buildings and the environment.

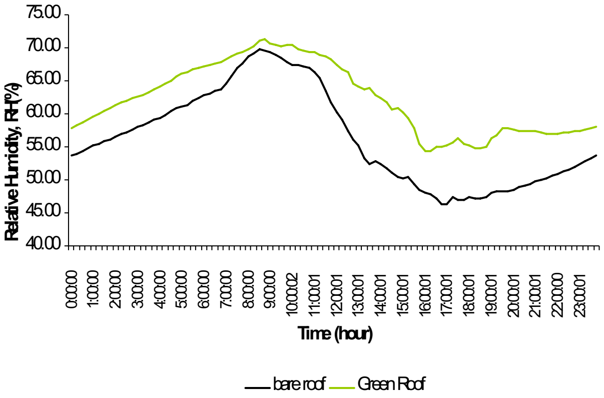

Fig.10 (b) Comparison of average indoor relative humidity between black bare roof and green roof for six days' reading

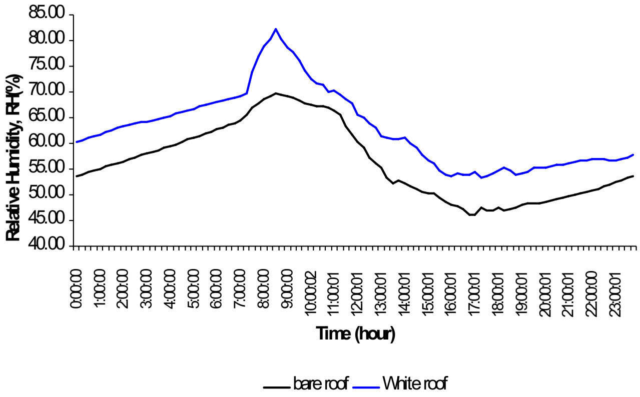

Fig.10 (c) Comparison of average indoor relative humidity between black bare roof and white roof for six days' reading

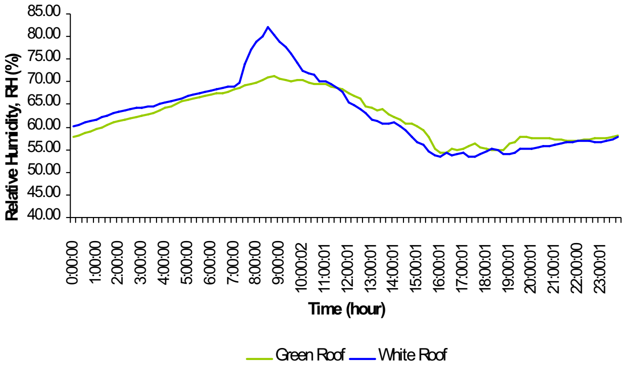

Fig.10 (d) Comparison of average indoor relative humidity between green roof and white roof for six days' reading

V. DISCUSSION

The result obtained from this field experiment confirmed that green roof and white roof have potential cooling effects that can be used to cool the roof and the room underneath it in the Malaysian climate. When compared to black bare roof, both roofs exhibit promising air and surface temperature reductions which could reduce indoor discomfort if constructed well. However, green roof have the ability to lower the indoor air temperature better than white roof by providing shades and evapotranspiration to the roof. The role of plants in providing shades and preventing the surface from direct penetration of solar radiation is never in doubt. Even in the case of higher solar radiation, and higher outdoor air temperature, green roof could still provide a cooling sensation in indoor spaces by lowering the indoor air temperature. White roof can reflect heat back to the atmosphere by long wave radiation and thus lower the indoor air temperature. However, the outdoor surface temperature will still be high due to the reradiating of heat by the roof surface. Apart from that, white roof also needs to be regularly maintained because it gets dirty easily after a few years of construction. Its bright surface also has a tendency to produce glare especially during bright daytime hours. Indoor wind speed was irrelevant in this experiment since there was no cross ventilation available during the measurement period since the door was shut at all times (except during the process of data downloading).As a conclusion, by putting plants on top of the roof, the indoor air temperature of the room underneath was significantly reduced. This could also reduce the outdoor surface temperature (which could not be provided by white roof) as well as reducing the heat island effect in urban areas thus creating a healthy outdoor environment by reducing carbon dioxide concentration in the atmosphere.

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