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THE POTENTIAL OF COOLING EFFECT USING PALM OIL CLINKER AS DRAINAGE LAYER IN GREEN ROOF SYSTEM

K. A. Shahid, Sharifah M. Syed-Mohsin and Norhaiza Ghazali
Faculty of Civil Engineering & Earth Resources, University Malaysia Pahang, Kuantan, Pahang, Malaysia
E-Mail: khairulanuars@ump.edu.my

ABSTRACT

Research on green roof has been quite intensive in the past decade. Many researchers have studied on the cooling effect of green roof without focusing on an alternative to replace the conventional material in green roof system. The needs to use waste material become more essential to ensure the environmental sustainability. Hence, this paper reports on the use of palm oil clinker as drainage layer in green roof system and also the cooling potential of green roof under Malaysia climatic condition. Hydraulic conductivity was investigated through constant load permeameter test and the cooling effect was studied by means of experimental green roof in cubicles. The analysis of thermal performance was carried out by using CLTD/CLF/SCL method. It was found that palm oil clinker is suitable to replace conventional materials as drainage layer in green roof system and it is also found that the green roof could reduce the air temperature inside the experimental cubicles hence reduced the heat gains.

Keywords: green roof, environmental sustainable, palm oil clinker, hydraulic conductivity, heat gains.

1. INTRODUCTION

In recent years, there have been an increasing numbers of researchers in Malaysia interested in doing research in green roof, which is already popular among European countries. The application of green roof is considered new in Malaysian context but it has shown an increasing numbers of building owner in Malaysia who installed the green roofs in order to achieve green building status. Persatuan Architect Malaysia (PAM) has been collaborating with Association of Consulting Engineers Malaysia (ACEM) to initiate the green building status by introducing some criteria to be fulfilled prior the green building status being awarded. The criteria known as Green Building Index (GBI) and the objective are to give certification to the building for green status [1]. The GBI rating assessment has stated that the green roofs are essential elements to be awarded as green building status. Thus, it led green roofs technology to be part in construction industry in Malaysia [2].

In the past years, many researchers have found that green roof can has a lot of environmental benefits such as it helps to reduce the aspect of pollution in the urban environment. Besides, it has an ability to monitor the storm water by reducing runoff. Spala et al. [3] have conducted a green roofs experiment on office building in Athens and have discovered that green roof could significantly save energy and contributes to reduction of cooling load. Studied by Rumana & Mohd Hamdan [4] on cooling effects in green roof reported that the surface outdoor temperature reduction is up to 19°C on the green roof whereas the reduction of indoor ceiling surface temperature is up to 3°C. G. Parez et al. [5] have studied the use of rubber crumbs as drainage layer in green roof as potential energy improvement material and concluded that the extensive green roof could be a passive energy saving during summer in continental Mediterranean climates. Furthermore, the rubber crumbs could possibly use as a drainage layer in green roof system. Ismail et al. [6] has carried out an experiment to find the cooling potential of potted green roof on single storey residential building in Malaysia and found that the green roof could reduce the air temperature and surface temperature inside the building. In addition, the green roof could increase the indoor relative humidity, which relates with thermal comfort inside the building. As Malaysia is one of the countries that is located at the equator which considered as hot and humid climate throughout the year with heavy rain on specific periods it will be beneficial if green roofs were installed by every building owner.

Green roof can be divided into two categories namely intensive and extensive green roof. The intensive green roof normally has deep substrate layer, big shrubs and vegetative layer consist of varieties of plants and trees. It is normally required a large surface area and proper irrigation system in order to provide adequate water to the plant. On the other hand, the extensive green roof required shallow depth of substrate layer, with small plants and sedum and it's only required a less maintenance [7]. The green roof system generally consist of three main layers namely drainage layer, substrate layer and also vegetation layer. The substrate layer is a layer that provides a growing medium for the plant and usually top soil or garden soil is used. Drainage layer form by porous stone materials or polyethylene nodular panel used to provide good drainage and aeration to the plant roots.

Environmental sustainability is a global issue recently. The need to use waste materials is essential to ensure the environmental sustainability. The polyethylene nodular panel used as drainage layer in green roof system will lead to environmental destruction in order to produce the material. It also leads to an increase in waste materials arise from later processing of the materials and those waste materials will increase the landfill area. Therefore, recycling is the best practice in order to minimize the waste material. A research done by G. Parez *et al*. [8] have proven that rubber crumbs can be used to replace

conventional materials as a drainage layer in green roof system.

Malaysia is among the world's largest producers and manufacturers of palm oil products. The process of extracting the palm oil involved burning of fibers and husk inside the boiler under a high temperature. This process is to generate the steam engine for oil extracting process. The process of extracting the oil will also produce a waste product called palm oil clinker. It is an artificial aggregate. According to lightweight aggregate classification, palm oil clinker is categorized under unprocessed by-product material. The porous texture condition and low density are the main properties that make the clinker suitable to be used as replacement materials in conventional green roof system. In order to support environmental sustainability, the best practice is to recycle or reuse the waste material as substitution to other material.

In this research, the possibility of using palm oil clinker as drainage layer in green roof system was investigated. The palm oil clinker is used to replace the porous stone materials such as expanded clay, expanded shale and pumice which are currently being used as drainage layer in green roof system. The fine aggregates produced from clinker are lightweight, porous, and irregular in shape and thus having low values of bulk density and specific gravity [9]. The cooling effect in green roofs using palm oil clinker as drainage layer was also investigated. The analysis of heat gains were conducted in order to evaluate the cooling effect of the green roof using CLTD/CLF/SCL method. The use of palm oil clinker as drainage layer in green roofs system could possibly reduce the waste material produced by palm oil industry. Thus, the palm oil clinker will indirectly promote an environmental friendly and sustainable design of green roof system. The green roof installed on a building could possibly reduce the outdoor and indoor air temperature leading to passive energy saving.

2. METHODOLOGY

2.1. Drainage ability of materials

Palm oil clinker was collected at palm oil factory near Felda Lepar Hilir, Kuantan, Pahang. Then it was crushed and sieved into three different sizes 2 mm, 5 mm and 10 mm as shown in Figure-1(a). The three samples were tested to see the drainage ability of the palm oil clinker and compared with conventional stone material (pumice). Saturated hydraulic conductivity was investigated. This parameter can be determined through constant load permeameter test as shown in Figure-1(b).

Figure-1. (a) Different sizes of palm oil clinker and (b) constant load permeameter test setup.

The experiments were done individually for every singles size of the palm oil clinker (drainage layer). Then, those samples were tested with adding substrate layer on top of them (substrate layer + drainage layer). The saturated hydraulic conductivity is calculated using Darcy's law with following expression:

$$Ks\left[\frac{cm}{h}\right] = \frac{V[cm^3] * L[cm]}{A[cm^2] * \Delta t[h] * h[cm]}$$

where Ks is the saturated hydraulic conductivity, V is the cumulative volume of percolated water, L is the length of sample in column, A is the cross-section area of the flow, Δt is the duration of the test and h is the hydraulic pressure difference.

A few experiment trays were installed in order to investigate the behaviour of green roof system and the effects when palm oil clinker is used as drainage layer. The experimental trays have 5 cm of substrate layer and 4 cm of drainage layer and the materials used for substrate and drainage layer is the same with the ones used in constant load permeameter test. Two numbers of plants were studied namely Creeping Ox-Eye (Wedelia Trilobata) shown in Figure-2(a) and beach morning glory (*Ipomoea pes-caprae*) shown in Figure-2(b). The Creeping Ox-Eye (Wedelia Trilobata) is chosen because it can make a dense cover by spreading like a mat while the beach morning glory (*Ipomoea pes-caprae*) is chosen due to its ability to tolerate with high ambient temperature which is required for green roof plants.

Figure-2. (a) Creeping ox-eye (wedelia trilobata) and (b) beach morning glory (*Ipomoea pes-caprae*) in experimental tray.

The parameter that was analyzed in this experiment is the plant development. Nine numbers of experimental trays were prepared taking into account the four drainage materials, two plant species and one control tray which has no plant in it.

2.2. Experimental green roof in cubicles

One of the objectives of this research is to study the potential of cooling effect in extensive green roof using palm oil clinker (POC) as drainage layer particularly in Malaysia climatic condition.

Three concrete cubicle were built with the same dimension of 2 x 2 x 2 m. The cubicles were built using bricks and the walls were plastered using cement. The roof for the three cubicles were flat and insulated with bituminous felt.The cubicles were located in University Malaysia Pahang, Malaysia and all cubicles were built using the same materials. The creeping Ox-Eye was chosen to be planted on the roof of two cubicles because from the experiment, it has shown no sign of stress and the plant developed fast. The composition of materials of the roofs for the three cubicle are as in Table1:

Table-1. Three cubicles with different material compositions.

Cubicles	Material Composition
1. Control	Bare roof
2. Pumice + Green Roof	Extensive green roof 5cm of soil for substrate layer 4cm of pumice for drainage layer
3. POC + Green Roof	Extensive green roof 5cm of soil for substrate layer 4cm of POC for drainage layer

The measurement of outdoor and indoor temperature was conducted using temperature sensor connected to data acquisition system and data was logged every one hour. The temperature was recorded for five days in the month of October 2014. In order to evaluate the thermal performance of each roof system, a sensor was installed in each cubicle to measure the air temperature inside the cubicles. The air temperature sensors were placed at the same location for each cubicle with height of 1.00 m from the floor. The outdoot air temperature were measured using the same sensors and were placed at 5.00 cm from the outer roof surface.

After all measurement of indoor and outdoor temperature for the three cubicles were recorded, an analysis of heat gain were conducted to evaluate the cooling affect of the green roof. The purpose of this calculation is to evaluate the performance heat gain of cubicle with green roof and compared to the control cubicle. The analysis of heat gain was calculated using Cooling Load Temperature Differential (CLTD) and Cooling Load Factors (CLF) according to ASHRAE 1997 Fundamental Handbook. The heat gains were calculated based on three main elements for the cubicles namely conduction of heat gains through wall, conduction of heat gains through door structure and conduction oh heat gains through roof. The summary of equation and sources for calculation of heat gains is listed in Table-2.

Where R is resistance, U is heat transfer coefficient, CLTDc is corrected cooling load temperature different, Tm is outside design dry bulb temperature, DR is daily range and A is effective area roof/wall.

Table-2. Summary of equations for calculation of heat gains.

Type of Heat Gain	Equation Used	Sources
i) Conduction of Heat Gains through walls	$Q = UA\,(CLTD_c)$ $U = 1/\sum R$ $CLTD_c = CLTD + (25.5 - T_r) + (T_a - 29.4)$	Table 11, Table 18 and Wall 3 Table 32 ASHRAE 1997, Chapter 28
ii) Conduction of Heat Gains Through Door Structure	$Q = UA\,(CLTD_c)$ $U = 0.13\,W/m^2.^0C$ $CLTD_c = CLTD + (25.5 - T_r) + (T_a - 29.4)$	Table 7 ASHRAE 1997, Chapter 28
iii) Conduction of Heat Gains through Roof	$Q = UA\,(CLTD_c)$ $U = 0.13\,W/m^2.^0C$ $CLTD_c = CLTD + (25.5 - T_r) + (T_a - 29.4)$	Table 7 ASHRAE 1997, Chapter 28

3. RESULT AND DISCUSSION

3.1. Drainage ability of material

Shown in Figure-3 is the saturated hydraulic conductivity for drainage layer materials (palm oil clinker) for three different sizes namely C-Small (2 mm), C-Medium (5 mm) and C-Big (10 mm) and pumice (3-10 mm) as control material. The result showed that, the saturated hydraulic conductivity for three different sizes of clinkers were fall within the range of 1550 cm/h to 1800 cm/h. The control material (pumice) recorded a value

within the range of clinkers. This indicated that palm oil clinker has the ability to drain the water fast and comparable to control material (pumice). The hydraulic conductivity of the palm oil clinker is proportionate to the size of clinker. The bigger size of clinker will gives a higher value of hydraulic conductivity.

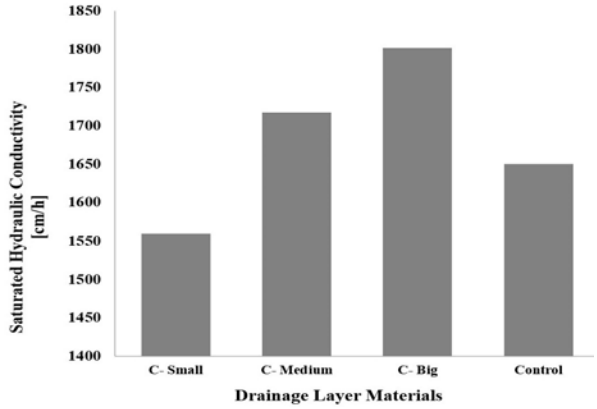

Figure-3. Saturated hydraulic conductivity of drainage layer materials.

Shown in Figure-4 is the saturated hydraulic conductivity for drainage layer material (clinker) and substrate layer material (soil). In the first case (Figure-3), only drainage layer is considered. Thus, water can easily pass through the medium. In the second case (Figure-4), substrate layer was added on top of drainage layer. As can be seen in Figure-4, the hydraulic conductivity has been reduced about 2 times lower than the values in Figure-3. This is due to effect of substrate layer that has an ability to retain water and also the effect when water brings down the soil particles to fill the pores in drainage layer. Thus, the hydraulic conductivity is reduced. Based on Figure-4, it can be observed that the two sizes of clinker which are the smallest size (C-Small) and the medium size (C-Medium) have a closer value to Control (pumice) which indicates that both the two sizes can be used interchangeably in green roof system as drainage layer.

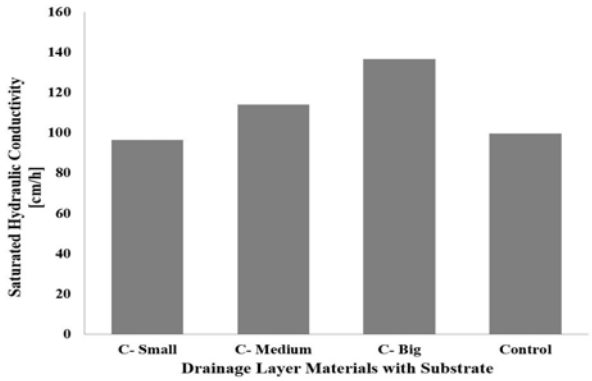

Figure-4. Saturated hydraulic conductivity of drainage layer materials with substrate layer.

Apart from investigating the ability of palm oil clinker to drain water, it is also essential to study the behaviour of the plant by means of experimental green roof trays. In general, the newly planted plant needs enough water and sunlight to survive with new environment if there is no effect on toxicities from substrate or drainage layer. Creeping Ox-Eye (*Wedelia Trilobata*) showed some symptom of stress due to dryness during the first week. This is probably because of Malaysia has a very hot and humid climate. Thus, the plant was watered about 1 L every day. After a week later, the plant had shown no stress symptom. Similar to beach morning glory (*Ipomoea pes-caprae*), it has shown a symptom of stress due to dryness for the first week. The frequency of watering is increase, then the plant become normal and adapt with new environment.

In term of plant development, both plants have shown no sign of stress for intoxication from palm oil clinker. It is evident that palm oil clinker be moderate replacement for pumice.

3.2. Experimental green roof in cubicles

Shown in Figure-5 is the average indoor temperature recorded five days in the months of October 2014 for three cubicles with two different green roof materials and one bare roof as control. The temperature sensor recorded the data between 8:00 AM and 5:00 PM. It is noticed from Figure-5, the indoor temperature with green roof cubicle shown a slightly lower temperature as compared to reference cubicle. Thus, it is shown that, green roof has a potential of cooling effect to the cubicle and it can be a good passive energy saving. The two cubicles with green roof but different material for drainage layer have shown only small difference in temperature and both cubicles have a similar trend. This suggests that there is no significant difference in term of material used for drainage layer as a part of green roof system. The maximum indoor temperature recorded at 3:00 PM by control cubicle with 41.4 ºC whereas both cubicles with green roof recorded 35.4 ºC and 35.3 ºC respectively. Thus, the temperature inside the both cubicles were about 6.05ºC higher lower than reference cubicle.

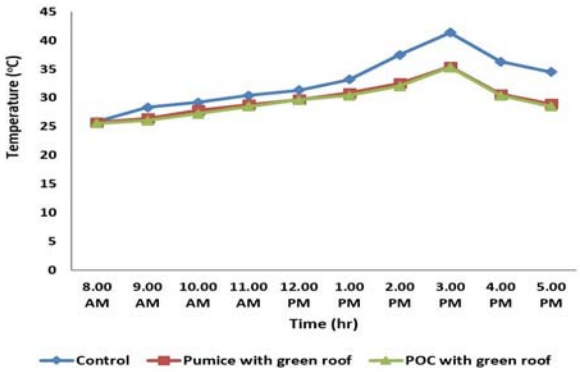

Figure-5. Average indoor temperature for three different cubicles.

Shown in Figure-6 is the cumulative heat gain of three cubicles considering conduction of heat gain through roof, wall and door from 8:00 AM until 5:00 PM. The control cubicle recorded an increasing of heat gains from 8:00 AM until 3:00 PM and has slightly decreasing from 4:00 AM until 5:00 PM. The two cubicles with green roof recorded an increasing of heat gain from 8:00 AM until 5:00 PM and the heat gains for both cubicles were about a similar reading. The control cubicle shown higher heat gain of all time if compared to the two cubicles with green roof. It revealed that green roof has a passive energy saving since it recorded smaller value of heat gain if compared to the control cubicle.

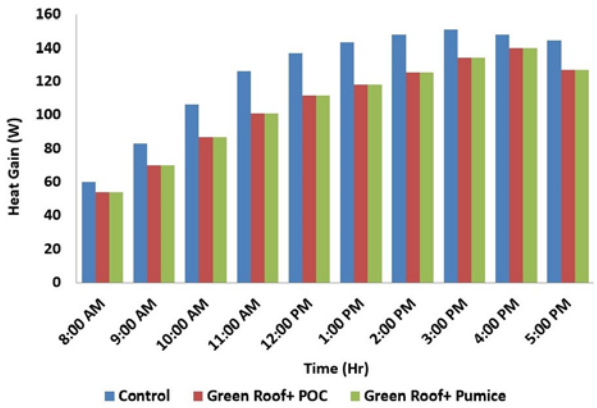

Figure-6. Analysis of heat gains for three different cubicles.

4. CONCLUSIONS

The lab experiment by means of constant load permeameter test and experimental green roof in cubicles were carried out to investigate the use of palm oil clinker as drainage layer and potential of cooling effect of green roof. Based on the analysis of the result, it can be concluded that:

- The constant load permeameter test, it was found that palm oil clinker has a good ability of draining the excess water based on its performance on hydraulic conductivity and infiltration rate. C- Big has showed the highest value for both hydraulic conductivity and infiltration rate. In general, all sizes of clinker used as drainage layer are suitable to replace the pumice or any other conventional materials used in green roof system.
- The field test on experimental tray, it was found that there is no effect in term of plant development when the palm oil clinker is used as drainage layer. This indicates that there is a possibility of replacing the conventional stone materials with palm oil clinker.
- By simply installing the green roofs in experimental cubicles, it can contribute to reduction of indoor air temperature in the range of 1ºC to 6ºC.
- Based on analysis of heat gains conducted on the three cubicles, the two cubicles with green roof recorded significantly lower heat gains as compared to cubicle without the green roof and thus provide a good thermal comfort.

In general, it can be conclude that the palm oil clinker is suitable to replace conventional materials as drainage layer in green roof system and it is proven that the green roof could reduce the air temperature inside the experimental cubicles and thus contributes to reduction of heat gains in the experimental cubicles.

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