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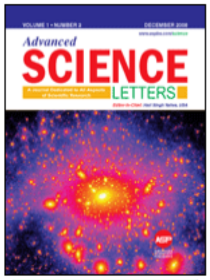

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A SPECIAL SECTION

Selected Peer-Reviewed Articles from the International Conference on Architecture and Built Environment 2016 (ICABE 2016), Kuala Lumpur, Malaysia, 5–6 October, 2016
Guest Editors: *Mariana Mohammed Osman, Muhammad Faris Abdullah, and Alias Abdullah*
Adv. Sci. Lett. 23, 6029–6030 (2017)
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RESEARCH ARTICLES

Remarkable 3-in-1 Pakis-Stem Green Roofs for Saving Thermal Flat Rooftop
Danny Santoso Mintorogo, Wanda K. Widigdo, and Anik Juniwati
Adv. Sci. Lett. 23, 6173–6178 (2017)
[Abstract] [Full Text - PDF] [Purchase Article]

Remarkable 3-in-1 Pakis-Stem Green Roofs for Saving Thermal Flat Rooftop

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The green councils in the world are often promoting green buildings in terms of energy savings by mitigating the thermal load on buildings,especially thermal rooftop, into the room. Green roofs can be the most effective to lower roof thermal in tropical regions, but complicated and costly to build a perfect green roof even for a simple extensive green rooftop. This research looks for a remarkable growing medium for constructing green roof. Pakis-stem blocks can perform a 3-in-1 function: as a light-weight growing medium for green rooftops, an easy-to-form urban farming in private buildings or residences, and an eco-friendly external roof insulation. After a deep measurement on the rooftop surface and room thermal behaviour, the pakis-stem green rooftop can reduce 16.4°C of surface dry-bulk temperature and approximately 7°C ambient room dry-bulk temperature lower compared to conventional rooftops at noon. Furthermore, the surface temperature and ambient room air temperature difference between Pakis vegetative green rooftops and miana scrub green rooftop is approximately 7°C and 3°C respectively.

Keywords: The Lightest Green Roof Growing Medium,Urban Farming, Eco-friendly External Rooftop Insulation.

1. INTRODUCTION

The urban city is growing rapidly, constructing lots of new landed houses, middle high-rise offices, and tall commercial buildings, resulting in more hard surfaces (pedestrians' sidewalk, parking lots, concrete rooftops) than green open spaces (gardens, urban forests, children playground yards, and city parks) which leads to Urban Heat Islands (UHI).Urban Heat Islands in a city tends to be warmer (around 1-3°C) at a calm nighttime than the surrounding sub-urban and rural areas[1]. On a sunny day, rooftop and pavement surfaces exposed to solar radiation tend to have surface temperature 27° to 50°C[1] hotter than the ambient air temperature (around min. 22.6° to max. 33.7°C) in the city of Surabaya, Indonesia[2].

One way to mitigate UHI is planting larger and lusher trees and using reflective surfaces (cool roofs), as well as planning green roofs or vegetable roofs and porous pavements. The intensity of solar radiation, which mostly causes the heat in any countries, is deposited in those materials.

The solar radiation in Surabaya, Indonesia, is very high due to the sun lattitude on 7°17-21' Southern hemisphere and longitudinal 112° 47' East. Table 1 indicates the monthly average horizontal global solar radiation, that has around 400 Wm^{-2} in dry seasons and 300 Wm^{-2} in rainy seasons in the year of 2008[3].

Table.1. Surabaya's Monthly Average Horizontal Global Solar Radiation (Wm^{-2}) in 2008

Dry seasons		Rainny seasons	
May	369	January	327
June	360	February	255
July	382	March	297
August	414	April	357
September	415	November	304
October	440	December	271
Average	397	Average	302

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The research objectives are: First, looking for an easy-to-remove or attachable growing medium for the type of extensive green roofs; Second, finding the new light-weight growing medium that will fit on the existing rooftop structures; Third, promoting extensive-green-rooftop urban farming, which will create a better outdoor ambient thermal environment and mitigate the UHI effect[4]. High solar radiation intensity impacts on concrete rooftop, especially on the flat bare roofs which are not covered by any external insulations, let alone unused outdoor rooftop spaces. It becomes a huge source of thermal roof, affecting the cooling load and the UHI. To solve this problem, a new organic material called Pakis-stem, which comes from Pakis trees (figure 1 left), is cut into blocks (figure 1 right), which then are used to create remarkable 3-in-1 result. First, it becomes the lightest and easiest growing medium for extensive green roofs; Second, it promotes urban farming (resulting in sustainable economic: People can plant organic vegetables on their rooftops, even on commercial buildings'); third, it acts as as external eco-friendly insulation to mitigate the flat rooftop thermal.

The eco-friendly material: Pakis-stem (the lightest growing medium of green roofs)

Fig.1. A Pakis tree (left), the cut Pakis-stem blocks (right)

Table 2. Pakis Dimensions and Weights

Pakis Size	Dimension (l x w x t) cm	Sum in $1m^2$ (Blocks)	Areas (m^2)	Weight (Kg/m^2) Dry	Wet
Small	12 x 25 x 3	33	0.03	5.1	7.3
Large	32 x 15 x 3	20	0.05	5.2	7.4

The research does not use conventional soil for growing medium. Instead, it uses pakis stem blocks as organic material to achieve easy, neat, and eco-friendly growing substance.

Pakis-stems come in two different sizes and types; porous and semi-solid (denser stalks). The dimensions, weights and sum of blocks in one square meter Pakis stem sold in the flower market have two different sizes, as shown in table 2. One square meter of small Pakis stem consists of roughly 33 blocks, and dry Pakis blocks weigh almost 5 kilograms per square meter, whilst wet pakis blocks (immerse in water) weigh nearly 7.3 kilograms. There is a 10-gram difference in weight between the large pakis size and the small one, both in dry and wet condition[5].

To build a conventional green roof, either extensive or intensive,one will need to construct complicated component layers. All those components cause extra weights to the roof structure, either for new or old buildings[6], creating expensive building cost. That is why not every flat rooftop building assembles green roofs (figure 2).

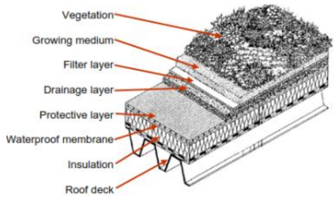


Fig.2. A Conventional Extensive Green Roof

Compared to the conventional extensive green rooftops, special encouraging Pakis-stem block rooftops are less complicated to build on the top of existing roof structures. Pakis-stem green rooftop layers can be installed on old and new structure buildings without altering too much construction (figure 3).

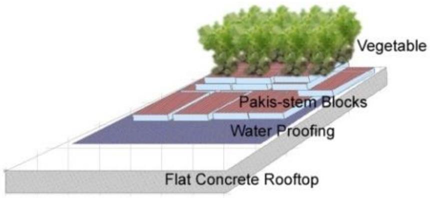


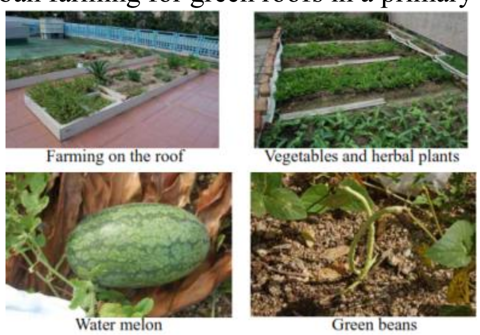
Fig. 3. Pakis-Stem Blocks Extensive Green Roof

Urban farming (agricultural green rooftop)

Plants used for the extensive green roofs are mostly grass, flowers, sedum, sempervivum and saxifraga, all of those which belong to succulent species. Succulent plants are not suitable for longer rainy seasons, as it will hold too much water on the growing medium. If green roofs are considered to contribute to a sustainable urban environment/city, agricultural or crop growing green roofs can be considered more to construct[7]. In Hong Kong, several pilot studies on sustainable rooftop farming had been done, for example, vegetables, herbs,

(Source: Sam C.M. Hui)

Fig. 4. Urban farming for green roofs in a primary school



in Hong Kong (pilot study)

watermelon, and green beans have been planted succesfully on a primary school (figure 4).

2. LITERATURE REVIEW

Many professionals have constructed typical intensive or extensive green roofs by means of soil as a growing medium. The purpose of constructing a green roof is mostly to measure the reduction of the rooftop surface and the ambient air temperature, as well as the surrounding reflected long-wave radiation due to the rooftop lawn[8].

Wong N.H, in his research on comparing intensive and extensive system of green roofs, showed that the surface temperature of the intensive green roof (without any green plants) on bare soil could reach 57^{o}C. Meanwhile, the surface temperature of the extensive system can reach approximately 60^{o}C, and over 70^{o}C on the metal roof system[9].

Another research had been done on extensive green roof with three different plants, which are Sedum Spurium (LS), Sedum Kamtchaticum (PK), and Sexangulare (LA). The result was that a combination of lava rocks and Sedum Spurium (LS) is the best roof insulation in reducing the rooftop thermal[10].

A field-measurement research study on thermal evaluation of green roof presented in the first North American Green Roof Infrastructure Conference in Chicago pointed out that green roof layers could mitigate the rooftop surface temperature fluctuations to around 45^{o}C lower compared to the reference rooftop (conventional flat bare rooftop). In addition, the green roof membrance can reduce the temperature fluctuation to approximately 6^{o}C a year[11].

3. RESEARCH METHODOLOGY

Measurement instrument

Two sets of measurementinstrument from ONSET – American companywere used for measuring ambient air temperatures and flat rooftop surface temperatures. HOBO data logger U12 can measure ambient air temperature (-20^{o} to 70^{o}C) (fig. 5A) and external TMCx-HD water/soil temperature sensor probe can measure surface temperature (air/surface: -40^{o} to 100^{o}C) (water: -40^{o} to 50^{o}C) (fig. 5B).

Fig. 5. HOBO data logger U12 (A), thermal probe (B)

Vegetable plants

Two types of vegetables were observed to find out the most suitable and sustainable shading domain (the level of density of the leaves). The vegetables were green *selada keriting*(lettuce) (fig. 6 A) and *sawi hijau* (mustard greens) (fig. 6 B).

Fig. 6. Baby *selada keritinghijau* (A), *sawi hijau* (B)

Tested Models

Two types of built-model were used. One model represented the conventional flat concrete rooftop, and the other represented a green roof covered with pakis stem blocks as a growing medium on which those vegetable seeds are planted (measuring for a week) (fig. 7). Then, the detachable polybags of miana plants were substitued with pakis-stem blocks, and were measured for another week. (fig. 8).

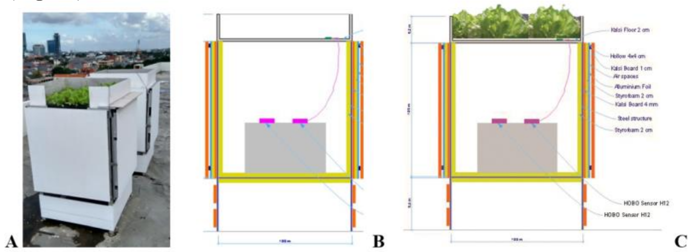


Fig. 7. The two tested models: (A) represented the conventional flat roof model, (B) represented the green model for measuring with Pakis-stem blocks *slada keriting* and miana plants (C).

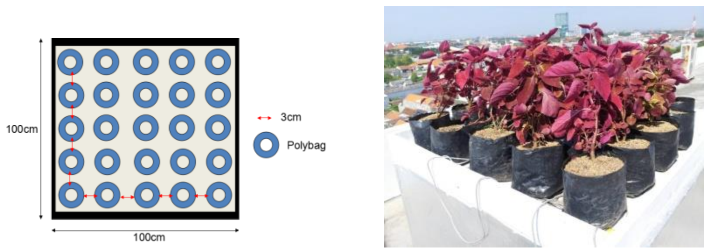


Fig. 8. The tested Green roof model with removable miana scrubs in polybags.

Pre-tested for thermal balancing of the test models

Two types of built-model were pre-tested to find the thermal balance on both models. Pre-measuring of the two models tookplace for two weeks. The thermal results both the surface temperatures and the room model ambient air temperatures were almost equal (Tabel 3).

Tabel 3. Pre-tested surface and room modeltemparatures

Types	Reference model Average temperature (°C)	Pakis green roof model Average temperature (°C)
Rooftop surface	31.6	31.2
Room model	30.4	30.4

Research procedures

The two test models were tested for two months, starting from June to July. In each month, the thermal data was separated into two categories: on hotdays (full-day sun for gathering maximum rooftop and room model ambient dry-bulk temperature behavior). Furthermore, the data of surface and room model temperatures in one month was calculated to find the average.

The Pakis-stem model was built in these steps. First, the Pakis-stem blocks were laid down on a flat concrete rooftop of the tested area, which was on the rooftop (7th floor) of Petra Christian university. Two kinds of seeds (*selada keriting* and *sawi hijau*) were planted on the pakis stem blocks, then were sprayed lightly with water by using water sprinklers (to make sure the seeds did not fall down into the Pakis-stem blocks). After around 3 weeks, *selada keriting* and *sawi hijau*, along with the Pakis blocks were moved to the green rooftop model to start the thermal measurement (fig. 9). After a week measuring on pakis-stem blocks with *selada keriting*, the miana scrub was also measured for a week on green rooftop model.

Fig. 9. Seeding on the top of pakis blocks (A), Spraying water gently (B), Sprouts appearing after 3 weeks (C).

4. EXPERIMENT RESULTS

Vegetated Rooftop

After planting and moving those two types of vegetables to the Pakis-stem green roof model in the third week, only *selada keriting hijau* had a prolific growth (fig. 10 A & B, *selada keriting* is planted on the green model). A month after, *sawi hijau* still did not grow well compared to *selada keriting hijau*. *Sawi hijau* may have to be planted another time (fig. 10 A, behind *selada keriting*). Both vegetables on Pakis green rooftop model were sprayed plain water twice a day except in rainy days. After 1.5 months, the vegetables were watered only once a day or every two days due to the thickness of the Pakis growing mediun (3 layers are around 9-10 cm).

Fig. 10. Vegetables on green roof model (A), *Selada keriting* after two months (B),

Thermal characteristics on tested models

The data of surface temperatures and ambient air temperatures, as well as the average, of the room reference model and pakis green model were categorized under hot, cloudy and rainy condition. The data includes the tested results on both models (reference model and Pakis green model) in June and July 2016,

Table 4.1 shows the measurements average data on both ordinary flat roof model (Reference Model) and Pakis green roof model with planted *vegetables green selada keriting* in June and July 2016. Flat roof surface temperature and room model temperature had the same values in June and July. There was 0.5°C temperature differences between surface and ambient room temperature on the green model in June, and 0.7°C temperature differences in July (table 4).

Tabel 4. Average surface and ambient air room temperatures on reference and Pakis green models (June & July 2016)

Types	Reference model average temperature (oC) (June)	(July)	Green pakis model average temperature (oC) (June)	(July)
Surface	28.4	28.9	27.2	27
Room	28.4	28.9	27.7	27.7

Figure 11 shows the comparison of the surface temperatures on common flat bare rooftop, Pakis-stem blocks green rooftop, and Miama flower plant green rooftop. Not being covered with a growing medium and plant involvement on hard rooftop surface, the maximum temperature of the hard surface can get to around 45°C at noon, to two hours after noon. The daytime (6 am – 6 pm) daily variation of maximum surface temperatures was around 21°C, and the night time (6 pm – 6 am) daily surface temperature variation was around 4°C. With the installed vegetation, the maximum surface temperature of Pakis-stem blocks and lettuce was around 30°C. Meanwhile, with installed Miana scrubs, the maximum surface temperature was about 35°C. *Selada keriting* green roof had the lowest thermal performances compared to the Miana scrub green rooftop and conventional roof on daytime. The dry-bulk surface temperature difference of the Pakis-stem green roof to Miana scrub rooftop, and to the conventional rooftop were 12°C and 16.4°C respectively. Nevertheless, the nighttime (6 pm to 6 am) surface thermal performances of the Pakis green rooftop were around 2°C higher compared to the thermal surface reference model, and 3°C higher compared to the Miana scrub green rooftop at 6 am (fig. 11).

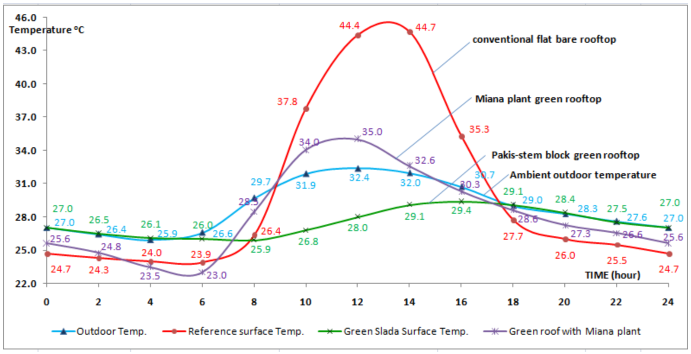


Fig. 11. Average surface temperatures on reference, pakis-stem and miana scrub green rooftop on hot days in June 2016

The thermal surface of Pakis green rooftop could lower the temperatures due to the Pakis-stem blocks and vegetables on the top of it, which acted as an external roof insulation (protecting rooftop from the heat of solar radiation) during daytime. On the contrary, the stored heat on the rooftop trapped in Pakis green roof and Miana scrub polybag green roof was hard to lose heat, or slow to release to the cool night sky because something blocked the surface of the green rooftop. That is why the thermal surface performances on conventional rooftop were better during the nighttime. The conventional flat rooftop was free to lose the stored heat once the outdoor ambient air temperature was lower than the stored heat.

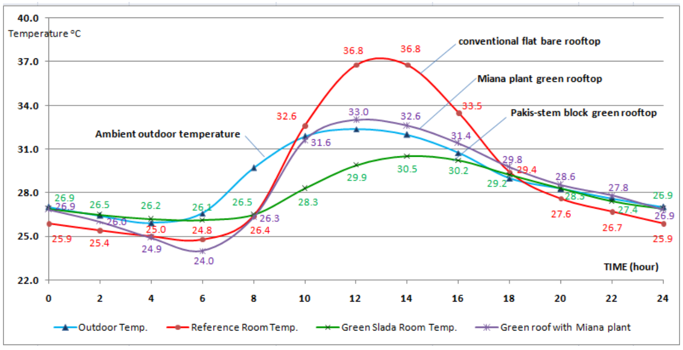


Fig. 12. Average room model temperatures on reference, pakis and miana scrub green rooftop on hot days in June 2016

After having surface temperatures measured from all systems (conventional, Pakis, and Miana scrub green roofs), the room ambient air temperatures of both models can becalculated. The ambient air temperature on the conventional rooftop model was the highest compared to the Pakis-stem *selada keriting* and Miana scrub rooftop. The Pakis-stem blocks *selada keriting* green roof had the lowest ambient air temperatures during daytime. It can be noticed from figure 12 that the room thermal of Pakis-stem vegetative green roof was about 7°C lower than the conventional flat bare rooftop, but it was still 3°C lower compared to the same green rooftop (Miana scrub) during the daytime.

4. CONCLUSIONS

Along with the conventional roof as the reference model, two different combinations of growing medium and vegetation in a built-up green roof models were tested simultaneously. The varying parameters of the tests were the growing media; Pakis-stem blocks and soil in polybags. Two vegetation types were planted; *selada keriting* as urban farming vegetation and Miana scrub as green roof flower.

Selada keriting on Pakis-stem blocks vegetative green rooftop turned out to have the lowest thermal performances compared to the Miana scrub green rooftop and the conventional rooftop. The daily temperature differences between the two rooftops (the conventional and Miana scrub rooftop) and the inside ambient air temperature were the lowest. The thermal surface fluctuation differences of the Pakis-stem *selada keriting* green roof to the Miana scrub green roof and to the conventional flat roof at noon time were 7°C and 16.4°C. The Ambient room air temperature differences were 3°C to miana scrub rooftop and 7°C to common flat rooftop at noon. Those room thermal differences are huge for energy saving. Pakis-stem blocks, as a growing medium, as a sustainable urban farming domain, and as an external eco-friendly insulation for a green rooftop, demonstrate to be very effective, easy to construct, and is low maintenance.

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