A preliminary study on new cooling techniques for stingless bees hive

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Abstract. Stingless bees are a type of insect which are very sensitive to the changes of their surroundings, especially to severe heat wave. A report stated that at temperature as high as 38 ºC can cause death of the bees especially to the pupae. Therefore, the objective of this research is to evaluate new methods in regulating the temperature in the hive. To achieve this goal, two cooling methods were studied. One method is using greenroof, a type of roof which contains green vegetation and soil. It is used to cool down the space under the roof. Another method is using a photovoltaic (PV) powered thermoelectric cooler (TEC). Three units of MUSTAFA-hives were exposed under sunlight, one is without any temperature regulation and the other two hives used cooling techniques stated above. The temperatures inside each hive was measured at two points, and was compared with the hive without temperature regulation. It was found that, for the hive integrated with greenroof, the average hive temperature was about 3 ºC and 6 ºC lower in the honey cassette and brood-cells compartment, respectively. On the other hand, the hive with PV powered TEC recorded average temperatures of about 0.5 °C and 3 °C lower in honey cassette and brood-cells compartment, respectively. Therefore, it can be concluded that the implementation of greenroof or TEC could solve the problem of stingless bees' hive overheating. However, the greenroof has a better thermal performance, besides being economic and simpler solution.

1. Introduction

Stingless bees are fascinating creatures. They predate, *Apis* bees, the stinging honey bees, roaming the tropical earth for over 65 million years. They are diverse and although they share some similarities with *Apis* they are biologically distinct. Stingless bees' species are common to tropical and subtropical areas such as the Southeast Asia region. Diversity of stingless bees make classifying them a difficult task, especially in Indo-Malayan region [1]. Like honeybees, stingless bees produce honey in nest containing sterile workers and a queen. However, stingless bees produce less honey, and do not use water to cool their nest. [2]. Their hives usually consist of several sections including the brood cell area, as well as honey pot area. In tropical region, their nests are usually made inside trunk of trees.

Thermoregulation, or temperature control, of stingless bees' hives are crucial to ensure suitable condition for broodcell development. It has been suggested that the optimum range of temperature is between 31 ºC to 32 ºC [3]. In natural hives, thermostatic effect helps thermoregulation, where the wood insulation along with shades, are able to keep the temperature of the hive relatively constant [4]. Hive temperature of 38 °C and above can cause death in pupae development [5]. This is detrimental towards the growth of colony.

Typically, trees are cut down to obtain log containing the stingless bees' nests. The log is then attached with a topping compartment to facilitate the honey production. However, such practice can be damaging towards the natural ecosystem especially for tropical jungles and are not sustainable in long term. As stingless bees act as natural pollinator for tropical forests, the human disturbance to stingless bees community could potentially disrupt and alter the forest composition [6]. Hence, once a colony is obtained from a log, it can be put into artificial hives such as MUSTAFA-hives. Then, it can be split into two colonies. Once the colonies settled and become stable it can be divided again and again. The honey can be easily extracted as MUSTAFA-hives has separate honey cassette compartment. Thus, this minimizes the disturbance and intrusion into the colony.

Stingless bees' colonies in hives are often placed under trees or other suitable shaded areas. This is to prevent the hives from overheating especially in tropical hot and humid climate. However, this limited the area suited for beekeeping, leading to additional cost to build shading. Placing the hives under direct sunlight can cause temperature to build up and can be dangerous to the colony as brood cell cannot develop when subjected to extreme heat. Hence, suitable cooling method for hives may be developed to prevent overheating of hives when subjected to outdoor conditions without any shading.

One of the possible cooling technique is to use Thermoelectric Cooler (TEC). TECs are solid state heat pump based on Peltier effect. Essentially Peltier effect describes a phenomenon in a circuit with two different conductors, when current is applied, heat will be absorbed or rejected by the conductors depending on the direction of the current [7]. Although Peltier effect has been discovered back in 1834, only recently thermoelectric devices gained attraction. This is due to current development of semiconductor thermocouple materials. Such devices becoming more popular due to its miniature size and reliability with little or no need for maintenance as it has no moving parts.

Another possible cooling method is by using greenroof, a natural cooling technique that have been used for centuries [8]. Although the technique is centuries old, due to scarcity of planted surface in urban areas, greenroof become stabilising and efficient choice [9]. Essentially, a green roof is a type of roof made up of vegetation and soil as its outermost surface [10]. As vegetation have potential to provide cooling benefits [11], buildings using greenroof could reduce their inside temperatures as much as 3.4 ºC [12]. There are also various literatures regarding analysis and improving the thermal performance of greenroof. These include using compost waste and inorganic substance to improve the physical properties of greenroof [13], and also some analysis on thermal conductivity of greenroof [14]. Therefore, greenroof have potential to be adapted to cool stingless bees' hive.

Currently, photovoltaic (PV) powered TEC system for thermoregulation has been used in rearing honey bees, and the loss of bees were minimal while production of honey increased [15]. Some automated control of temperature and other microclimate parameters for honeybees has also been investigated [16]. Hence, TEC system for thermoregulation is a promising cooling solution for stingless bees' hive. However, using TEC system for stingless bees' hives thermoregulation are unheard of.

Researches on engineering application for meliponiculture especially in Malaysia are still scarce. At present, these include honey processing [17,18] as well as engineering economic analysis for stingless bees keeping [19] and a few literature reported on thermal regulation [20,21]

Thus, the main objectives of this study are to investigate the temperature profile of a hive exposed to outdoor conditions, and to evaluate the temperature regulation in the hive using greenroof and hive using PV powered TEC as cooling methods.

2. Methodology

An experiment was conducted at Universiti Malaysia Pahang, Pekan campus. Three identical MUSTAFA hives were exposed to outdoor conditions; without any shade. Two of the hives were fitted each with the cooling techniques respectively. Temperature readings were taken inside the broodcell compartment and honey cassette for each hives every five minutes during the day using thermocouples. The measurement was recorded by a temperature data logger (Lutron BTM-4208SD), which was then transferred into computer for further analysis.

Figure 1 shows the typical construction of a MUSTAFA-hive, where the hive is divided into three main components, which are the broodcell compartment, the honey cassette and the roof. In the brood cell compartment, a 25 mm diameter hole acts as the only entry and exit for stingless bees. The broodcell compartment is connected to the honey cassette with a 35 mm diameter hole. This provided access for the bees to store honey. These dimensions are optimised for rearing stingless bee of the *Heterotrigona Itama* species. Different species of stingless bees required different dimensions. The hives used in the experiment are all empty hives without colony, to ensure no thermal exchange occur with a living colony as well as to no disrupt them.

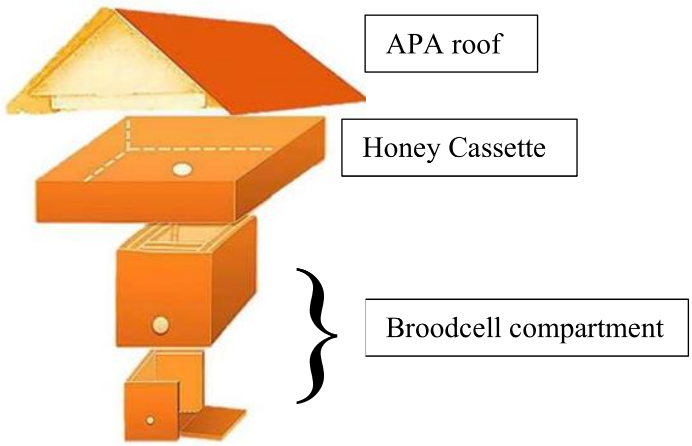


Figure 1: Typical construction of a Meliponiculture Using a Split-able Throne within Air-jacketed palace For Amplification-hive (MUSTAFA-hive)

Figure 2 shows the overall greenroof construction used in the experiment. The greenroof used was made up of four main components, which are the vegetation or the plant, some soil and sand mixture in semi dry condition, a polyethylene layer as root barrier, and wooden planks as roofing material and container.

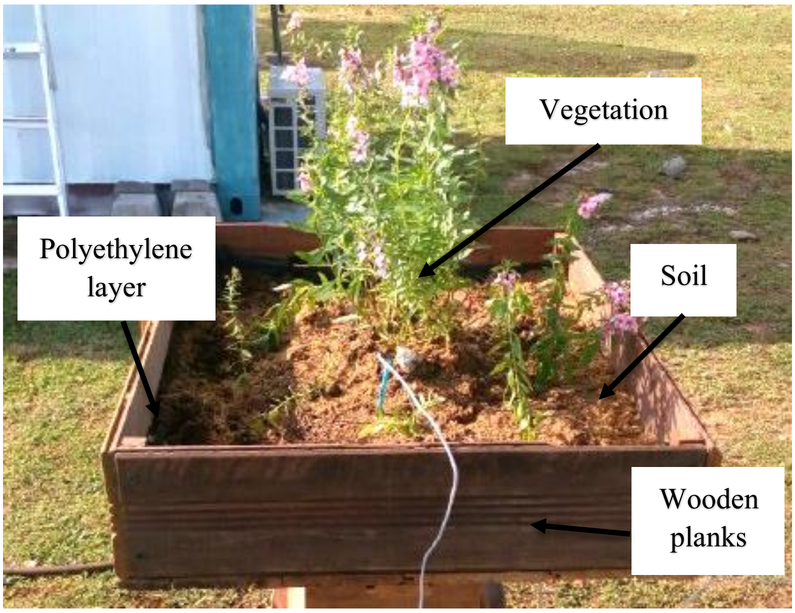
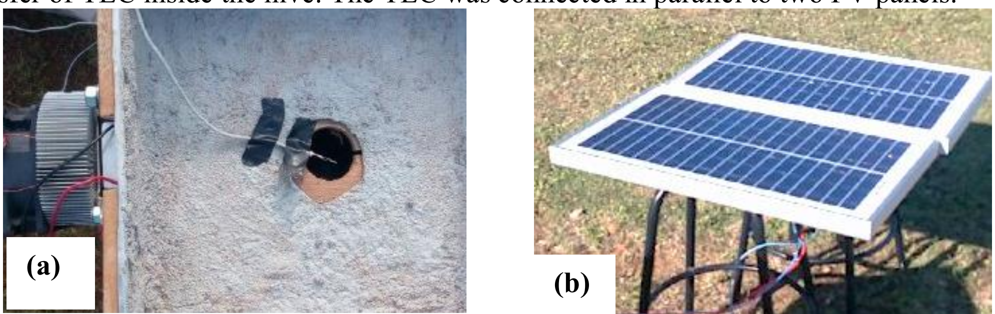


Figure 2: Greenroof used in experiment, made up of vegetation, soil and sand mixture, polyethylene layer, and wooden planks

Figure 3 shows the hive fitted with TEC setup, powered by PV panels. The cold side of TEC was positioned inside the honey cassette and the hot side was attached to a heatsink and fan outside. The inside of the honey cassette was also covered with aluminium sheet and some concrete to improve heat transfer of TEC inside the hive. The TEC was connected in parallel to two PV panels.



TEC fitted at the side of honey cassette, hot side coupled with a fan and the cold side attached to aluminium sheet inside honey cassette

PV panels position (parallel to the ground)

Figure 3: PV powered TEC system setup for experiment

The TEC system used in the experiment consisted of one TEC1-12706 module with two PV 240 panels. The performance specification for TEC1-12706 are shown in **Table 1Error! Reference source not found.**. Meanwhile **Table 2** shows the performance specification and dimensions of PV as provided by PV Hi-Tech Solar Sdn. Bhd.

Table 1: Performance specification and dimensions for TEC1-12706 [22]

Hot Side Temperature (º C)	25	50
Qmax (Watts)	50	57
Delta Tmax (º C)	66	75
Imax (Amps)	6.4	6.4
Vmax (Volts)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30
Dimensions	40mm x 40mm x 3.9mm	

Table 2: Performance specification and dimensions PV240 [23]

Model Name	PV 240
Number of Cells	60 cells in Series
Nominal Power @ STC (W)	240.00
Open Circuit Voltage (Voc)	37.95
Short Circuit Voltage (I_{sc})	8.67
Maximum Power Voltage (V_{mp})	30.51
Maximum Power Current (I_{mp})	7.88
Dimensions	1648mm x 991mm x 34mm
Weight	20 kg

Figure 4 shows the overall experimental setup. Three hives were exposed to outdoor conditions without any shades. The hive in the middle was fitted with a greenroof, the hive on the right was fitted with PV powered TEC system, and the hive on the left was not fitted with any cooling technique and acted as a control hive.

Figure 5: Overall setup, with thermocouples measuring temperatures inside honey cassette and brood cell compartment of each hives, connected to a temperature data logger

3. Discussion

Table 3 shows the maximum, minimum, and average temperature inside the honey cassette and broodcell compartment of each hives. The control hive showed that, without cooling technique, the maximum temperature in the broodcell compartment could rise as high as 39.8 °C while in the honey cassette the maximum temperature was at 34.7 °C. This showed the need for cooling especially in the broodcell compartment.

Table 3: Minimum, maximum, and average temperature readings at honey cassette and broodcell compartment inside the hive

	Honey cassette			Broodcell		
Temperature (ºC)	Control	Greenroof	TEC	Control	Greenroof	TEC
Minimum	30.1	28.3	29.7	30.6	27.9	30.0
Maximum	34.7	30.8	34.6	39.8	31.6	39.2
Average	33.0	29.7	32.5	36.7	30.2	33.4

Between the two cooling methods tested; the greenroof and the PV powered TEC, the greenroof showed most significant cooling, where the average temperatures recorded are, 29.7 °C and 30.2 °C in the honey cassette and broodcell compartment respectively. This translated to an average of 3.3 °C and 6.5 °C lower than the control hive. On the other hand, the hive fitted with TEC system, experienced less cooling effect in both compartments. The average temperatures are 32.5 °C and 33.4 °C in honey cassette and the broodcell compartment respectively. This constituted to temperatures reduction of a mere 0.5 °C in the honey cassette and 3.3 °C in the broodcell compartment compared to the control hive.

The cooling performance of TEC are less significant compared to greenroof, where the minimum and maximum temperatures recorded are no more than 0.6 °C lower in both compartments. Meanwhile, the greenroof recorded 3.9 °C and 8.2 °C lower maximum temperatures for the honey cassette and broodcell compartment respectively.

Figure 6 shows the temperature profile inside the honey cassette, represented by solid lines and broodcell compartment, represented by the pecked lines. The circle, triangle, and square marks represented the control hive, hive with greenroof and hive with PV powered TEC respectively.

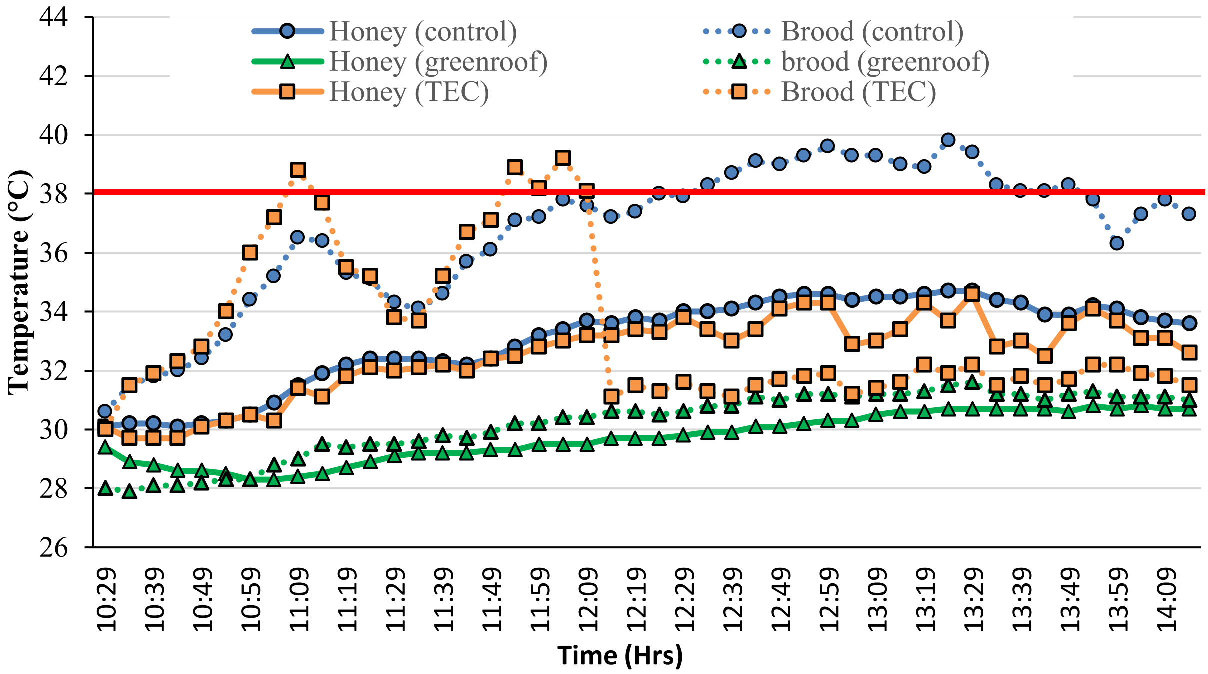


Figure 6: Temperature profile inside the broodcell compartment and honey cassette during the day for the control hive, hive with greenroof, and hive with TEC

In the control hive, the broodcell compartment experienced a prolonged temperature rise above 38 °C, more than an hour, recorded around noon. For a colony, such extreme temperature are lethal to pupae in the broodcell compartment [5]. This can cause the colony to collapse and die out. The broodcell compartment also recorded significantly higher temperature compared to the honey cassette. This could partly be due to the roof covering most of the honey cassette from sun radiation while less covering of the broodcell compartment. As the hive was a closed system, the hot air may be trapped inside the broodcell compartment with only one exit, disrupting natural hot air circulation upwards.

Temperatures in hive with PV powered TEC followed similar trend to control hive, up until before noon. In fact, in broodcell compartment the PV powered TEC recorded higher temperatures at several points in time. However, around noon, the cooling effect of TEC system started to show with significant temperature drop in the broodcell compartment. This could be explained by the sun radiation started to peak around noon. This lead to the PV panels to produce enough power for the TEC to cool down the hive. This could be solved by adding more PV panels or adding battery packs. However, this could add more cost to the overall TEC system. On the other hand, in the honey cassette, the cooling effect was low. This could be because of air convection inside the honey cassette was low, resulted in lower heat transfer.

The hive with greenroof recorded more stable temperatures, with the broodcell compartment recorded slightly higher temperatures than the honey cassette. When compared to the control hive, the temperatures were consistently lower than the control hive, showing significant cooling effect around noon. The temperatures recorded were close to optimum temperature for stingless bees broodcells such as *Trigona denoiti*, which the broodcell area optimum temperatures are between 31 °C and 32 °C [3].

4. Conclusion
Three hives were exposed to outdoor conditions. Two of the hives were fitted with greenroof and PV powered TEC, respectively. Another hive remained without any cooling technique, acting as the control hive. Overall, the broodcell compartment in all hives recorded higher temperatures compared to the honey cassette up until around noon. This could be explained by low air convection inside the hive, which caused most of heat transfer to occur inside the broodcell compartment. However, the hive with PV powered TEC showed different temperature profile around. This could be explained by the PV only receiving enough power around afternoon. In the control hive, the broodcell compartment experienced prolonged temperature rise above 38 °C of more around noon. This could lead to death of pupae in broodcell. On the other hand, it was found that the hive fitted with greenroof has an impressive cooling performance. The temperatures inside the hive fitted with greenroof were significantly lower than the control hive when exposed to outdoor conditions without any shades. The average temperature reduction from the experiment were 3.3 °C and 6.5 °C in the honey cassette and broodcell compartment, respectively. Although the hive with PV powered TEC had the cooling potential as shown around afternoon where the temperatures dropped significantly, more PV panels might be needed. Alternatively, the PV panels could be supplemented with battery packs to provide enough power for the TEC system. Thus, it can be concluded that the greenroof is a feasible and economical solution towards cooling stingless beess hives.

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