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A Study of Heat Insulation Methods for Enhancing the Internal Temperature on Artificial Stingless Bee Hive

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ABSTRACT

The stingless bees have gained a large popularity among the beekeepers, particularly in tropical and subtropical regions such as the Americas, Africa, and Southeast Asia. This is because the honey of stingless bees has a distinct flavour and is highly valued for its medicinal qualities. Traditionally, stingless bee colonies constructed from wood logs are fragile and vulnerable to outside attacks. These predator or parasite attacks can cause Colony Collapse Disorder (CCD) if not eliminated. Thus, a PVC, 3D-printed PET-G, and acrylic artificial hive has been created to replace the old one. According to earlier research, stingless bees are especially susceptible to temperatures above 38°C. This paper's main goal is to discuss the results of studies on the best artificial hive insulation method. Over a month and a half, clay, wood powder, polystyrene, bubble aluminium foil, and a water- cooling system were tested as insulators. Results shows that artificial hives with bubble aluminium foil have the biggest average difference between internal and external temperatures (6.4°C) and are closest to traditional hives (8.6°C). The average temperature difference between the artificial hive's exterior and inside was 2.9°C without heat insulation. Clay-insulated artificial hives have the lowest standard deviation value for humidity at 0.46. Since temperature is vital to stingless bee survival, bubble aluminium foil container is the best insulation solution since it increases heat resistance more than other materials.

Keywords: Heat Insulation, Stingless Bee Hive, 3D-Printed, Artificial Hive

1. INTRODUCTION

Stingless bees are known for non-venomous bee species that can produce delicious honey [1]. There are over 500 known species of stingless bees, and they are found in tropical and subtropical regions throughout the world [2]. One of the main benefits of stingless bees is that they are regarded as more environmentally friendly than other bee species. Stingless bees can thrive in a variety of habitats and require less management and maintenance than other bee species. In addition, stingless bees are less susceptible to disease and parasites, making them a more sustainable honey production option [3]. Recent research has also shown that stingless bee honey may have potential as a treatment for a variety of health conditions, such as inflammation, allergies, and even cancer. For example, a study conducted by [4] found that stingless bee honey had significant anti-inflammatory effects in an animal model of colitis. Similarly, another study by [5] found that stingless bee honey had potent anti-cancer activity against human colon cancer cells.

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However, most beekeepers keep their stingless bees in wooden logs that they are very fragile and susceptible to enemy attacks from outside. Because the hives are not very strong, they can easily be destroyed and invade by animals, predators or parasites that will result in Colony Collapse Disorder (CCD) [6–8]. This can result in significant losses for beekeepers, both in terms of the bees themselves and the honey they produce. Additionally, the fragile nature of these hives can make it difficult to transport them or move them to different locations, which can limit their usefulness for beekeepers who need to manage their hives over time. Consequently, artificial stingless bee hive designs that are sturdy and more durable must be developed to guarantee perpetually increased production. This artificial hive has been designed with multiple types of food-safe and long-lasting materials, including Polyvinyl Chloride (PVC), 3D-printed Polyethylene Terephthalate Glycol (PET-G), Acrylic, and ice cream sticks [9–11]. These materials are also commonly used in food packaging and other applications involving food contact. Following the completion of this artificial hive, an IoT system is installed to monitor and record data such as the internal temperature, external temperature, internal humidity, and external humidity of the hive. Due to previous study, the survivability threshold for stingless bees cannot be exceed 38°C [12]. Due to the fact that the heat insulation on PVC (artificial hive) is inferior to that of wooden log (Traditinal hive), experimental heat insulation materials and method including clay, wood dust, polystyrene, bubble aluminium foil and water-cooling system, have been attached to the artificial hive. This experiment seeks to identify the best heat-insulating material whose performance is most similar to that of traditional hive. This experiment will employ a number of analysis techniques, such as averaging method for temperature difference between external and internal, and standard deviation for internal humidity for each of selected insulation methods.

2. DESIGN AND HEAT INSULATION EXPERIMENT

The studies were conducted at the backyard of the Robotic Lab at Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis (UniMAP) in Perlis, Malaysia. The entire experiment lasted approximately a month and a half, from January 17, 2023, to March 6, 2023. In advance of conducting any experiments, an artificial hive based on Figure 1 has been designed and built. This artificial hive has two main parts, the brood compartment below and the honey compartment above. This is because the stingless bees construct their honey pots on top of their brood cells as it is part of their natural behavior. Afterward, the internal and external temperature and humidity data for the traditional hive as illustrated in Figure 2 and the artificial hive as depicted in Figure 3 were monitored. The data are collected using the Internet of Things (IoT) system and uploaded to the ThingSpeak. This system is entirely operated by a NodeMCU ESP8266 microcontroller, which comes with a ready-made Wi-Fi system and two DHT22 sensors for measuring the internal and external temperature and humidity of the hive.

Due to it being the case that the artificial hive's temperature frequently exceeds 38 degrees Celsius, which can induce CCD, it is necessary to conduct experiments on heat insulation in this artificial hive. The artificial hive's heat-insulating methods are to be set up within the air jacket that is labeled in Figure 1 for temperature improvement. Thus, certain materials and systems are installed on the new hive to prevent external heat from penetrating its interior. Clay, polystyrene, wood powder, bubble aluminium foil, and a water-cooling system were among the methods utilized in the experiments.

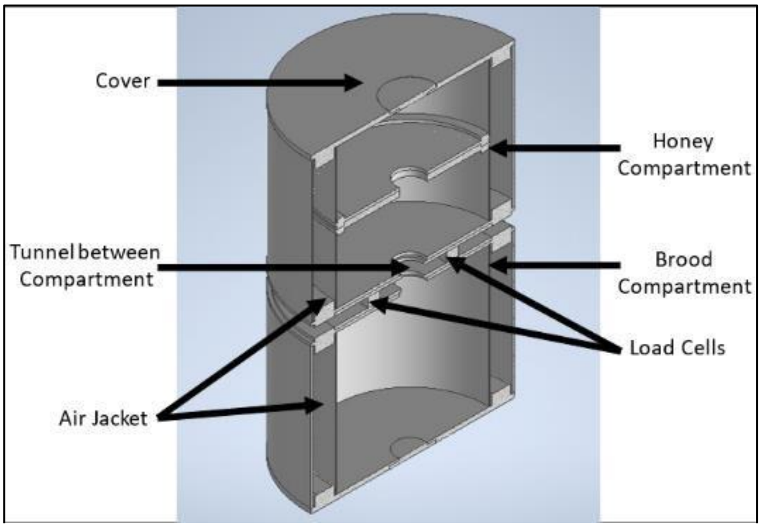

Figure 1. Drawing of Artificial Stingless Bee Hive

Figure 2. Traditional Stingless Bee Hive

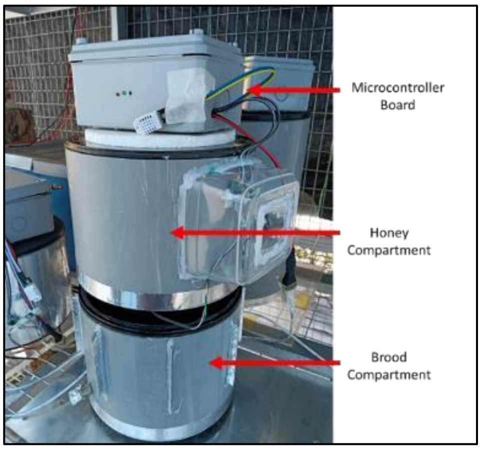

Figure 3. Artificial Stingless Bee Hive

In the case of clay, wood powder, polystyrene and bubble aluminium foil, these materials are filled in air jacket between the outer PVC and inner PVC as illustrated in Figure 4 till Figure 7. The clay layer provides thermal mass to regulate temperature and absorb moisture, while the wood powder layer adds an additional insulating layer with air pockets to trap heat and prevent condensation. Polystyrene is a lightweight and effective insulating material that is commonly used in construction and packaging. When placed inside the inner PVC layer, it can help to regulate the temperature and humidity inside the hive. It does this by reducing heat transfer between the interior and exterior of the hive, thereby keeping the hive warmer in colder temperatures and cooler in warmer temperatures. Bubble aluminium foil is another insulation material that is commonly used in beehives. It is made up of layers of aluminium foil with air pockets trapped between them. The air pockets provide an insulating barrier that helps to regulate temperature and humidity inside the hive. As for water cooling system as depicted in Figure 8, it works by circulating water through the hive, using the copper coil pipe to extract heat as displayed in Figure 9 and then dissipating that heat through the radiator. The water pump is responsible for maintaining the flow of water, while the radiator acts as a heat sink to prevent the water from becoming hot. This system can help regulate the temperature inside the hive, keeping it at a comfortable level for bees.

Figure 4. Artificial Hive with Clay

Figure 1. Artificial Hive with Wood Powder

Figure 2. Artificial Hive with Polystyrene

Figure 3. Artificial Hive with Bubble Aluminium Foil

Figure 8. Artificial Hive with Water Cooling System

Figure 9. Copper Coil Pipe for Water Cooling System

Implementing the data obtained from the IoT system described previously, the difference in between the internal temperature and external temperate of every type of insulation method is calculated as according to Equation (1). Then, this difference data will be filtered by dissipating the negative values resulting from subtracting the external temperature to the internal temperature. With the help of these differences, it is possible to demonstrate the effect of an increasing external temperature on the internal temperature. This filtering is performed so that if the external temperature falls below the internal temperature, it will not be considered since it will not harm the stingless bee colony. Finally, the method of averaging as per Equation (2) will be applied to monthly sample data for every type of hive. In terms of thermal insulation, the result of the average difference that is the highest and closest to the traditional hive will be considered the most effective.

As for humidity, the standard deviation using Equation (3) of the internal humidity data will be used to compare the dispersion of each different type of insulation method. The outcome with the smallest standard deviation is considered to be optimal because it can maintain humidity in the hive for a prolonged amount of time to produce a consistent honey concentration.

$$Difference\ Temperature, \Delta \mathrm{T} = \text{External Temperature}, T_{ext} - \text{Internal Temperature}\ T_{in} \quad (1)$$

$$Average, \bar{X} = \frac{\sum Sample\ value, X}{No.of\ Sample, n} \quad (2)$$

$$Standard\ Deviation, S = \sqrt{\frac{\sum (X_i - \bar{X})^2}{Sample, n - 1}} \quad (3)$$

3. RESULTS AND DISCUSSION

From January 17 to March 6, 2023, the results were successfully recorded using IoT technology for about a month and a half. However, sample data for two weeks, beginning on February 16, 2023, and ending on March 1, 2023, were used to make more accurate calculations because the weather during these two weeks is more consistent than the overall data. In order to differentiate the data between these heat insulation methods, it is necessary to subtract the external temperature of the hives from the internal temperature of the hives as described in Equation (1) when determining the results. The obtained results are either comparable to or superior to the traditional hive, making the method highly applicable to the artificial hive. In other words, the temperature with the highest average result from the subtraction is considered the ideal. This is because the indoor temperature is significantly lower than the outdoor temperature, proving that the outdoor temperature has less influence on the indoor temperature.

These data are then plotted on a line graph, as illustrated in Figure 9. This graph displays all 14 days of sampled data from five artificial hives with various heat insulation methods (Clay, polystyrene, wood powder, bubble aluminium foil, and a water-cooling system), one artificial hive without heat insulation, and one traditional hive. According to the graph, the maximum value of temperature difference for traditional hive, artificial hive without insulator method, artificial hive with clay, artificial hive with polystyrene, artificial hive with wood powder, artificial hive with bubble aluminium foil, and artificial hive with water-cooling system are respectively 8.6°C, 2.9°C, 5.5°C, 4.1°C, 5.2°C, 6.4°C and 5.2°C.

The difference between the external and internal temperatures increases as the external temperature rises, which occurs as the morning approaches noon. At this point, the internal temperature is still low, but the external temperature influences or flows into the interior. Given the reason that the highest maximum temperature differential is traditional hive because it naturally has the ability to effectively maintain the internal temperature. However, due to several reasons perforated and vulnerable to enemy attack, it will only be used as a reference to compare with data from artificial hives with insulation methods in this experiment. The artificial hive (Bubble aluminium foil) demonstrates the highest maximum temperature difference of 6.4 degrees Celsius when compared to other artificial hives. The lowest maximum temperature difference is only 2.9 degrees Celsius which is from the artificial hive without Insulators. Therefore, in Figure 10, the line graph highlights the results from artificial hive (Bubble aluminium foil) in comparison to traditional Hive as reference and to the lowest results, which are artificial hive without Insulator. It is clear from this graph that most everyday observations from the artificial hive (Bubble aluminium foil) are higher than those from the artificial hive without Heat Insulator. In fact, there are some days where the difference in temperature for artificial hive (Bubble aluminium foil) is higher than the reference result of traditional hive, namely on 22/02/2023, 25/02/2023, 28/02/2023 and 01/03/2023.

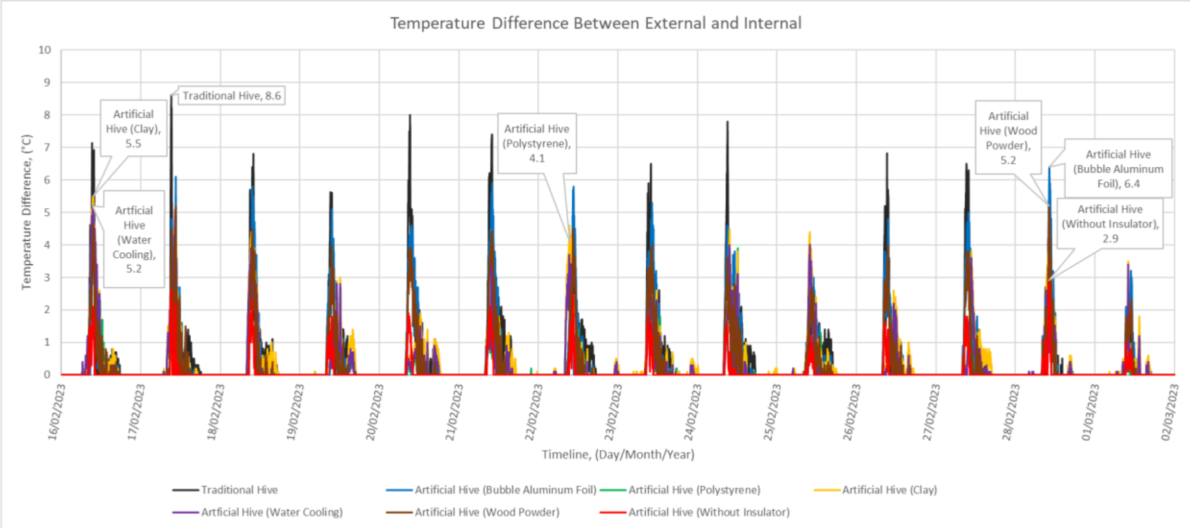

Figure 9. Graph of Temperature Difference Between External and Internal Artificial Hive

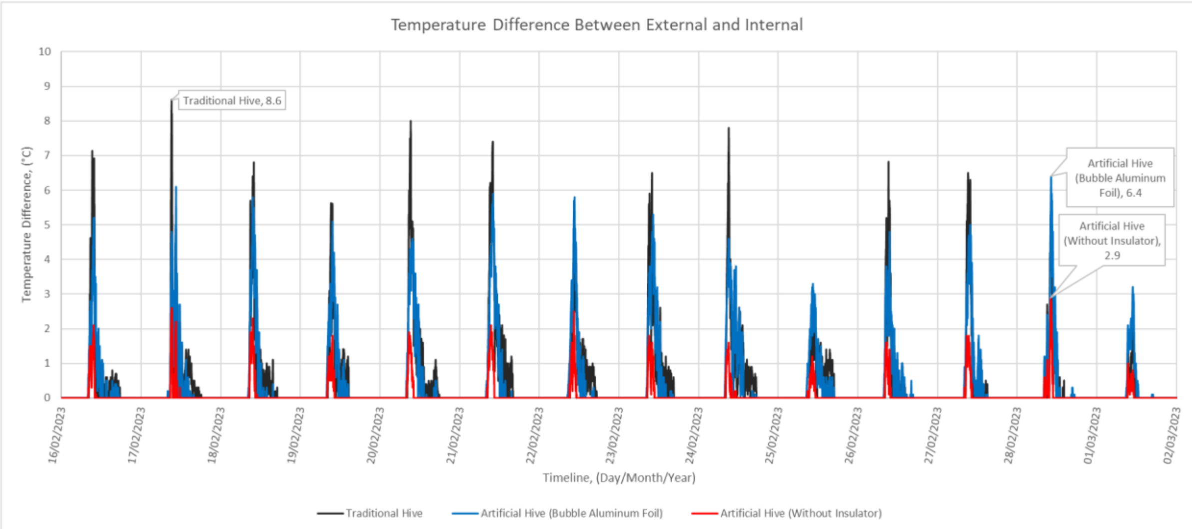

Figure 10. Graph of Temperature Difference Between External and Internal Artificial Hive Highlights for Traditional Hive, Artificial Hive (Bubble aluminium foil) and Artificial Hive without Insulator

Besides using the maximum temperature difference method, the averaging method as written in Equation (2) is also used to determine which insulator method is the most suitable to use. This averaging method also uses the result temperature difference between external and internal of artificial hive. The result of calculating the average and maximum temperature difference between external and internal is then included in Table 1. In this table, artificial hive (Bubble aluminium foil) has the maximum average temperature difference at 1.82°C, while artificial hive without Insulator has the lowest at 0.92°C. Even the average value of temperature difference for the Traditinal hive is 1.55°C less than that of the artificial hive (Bubble aluminium foil).
The results of the experiment showed that the artificial hive with bubble aluminium foil as the insulation method exhibited the highest maximum temperature difference compared to the other artificial hives. This means that the bubble aluminium foil insulation was able to create a greater temperature difference between the external and internal temperatures of the hive. The reason for this can be attributed to the insulation properties of bubble aluminium foil. Aluminium foil has reflective properties that can help reduce heat transfer. When applied as insulation to the surface of the hive, it reflects a significant portion of the external heat back,

preventing it from penetrating the interior of the hive. This results in a higher temperature difference between the internal and external temperatures. On the other hand, the artificial hive without any insulation method exhibited the lowest maximum temperature difference. Without insulation, the hive is more susceptible to heat transfer, allowing external heat to flow into the interior and minimizing the temperature difference. The traditional hive, although not used as a direct comparison due to its perforations and vulnerability to enemy attacks, still served as a reference point. It naturally possesses the ability to effectively maintain internal temperature, and therefore had the highest maximum temperature difference among all the hives tested.
In summary, the bubble aluminium foil insulation method demonstrated superior performance in maintaining a higher temperature difference between the external and internal temperatures of the hive. Its reflective properties helped to prevent external heat from entering the hive, making it the most suitable insulator for the artificial hive in this experiment.

For the humidity results, the data taken is only the internal humidity data of the hives for all types of experiments. The hive with the highest average value calculated using Equation (2) and the smallest standard deviation value calculated by Equation (3) is considered to have the most consistent moisture level. A hive with a consistent humidity value is the finest hive for maintaining the ideal humidity level in honey produced by stingless bees.

Based on graph in Figure 11 and Table 1, the artificial hive with clay may exhibit the highest mean humidity which is 87.52% due to its inherent properties. Clay has the ability to absorb and retain moisture. When used as an insulating material, it can absorb moisture from the hive's surroundings and maintain a higher level of humidity within the hive. This property of clay contributes to the higher mean humidity observed in the artificial hive with clay. Clay also helps regulate moisture levels by slowly releasing the absorbed moisture back into the hive. This controlled release can create a more consistent and higher average humidity within the hive. The artificial hive without any insulating materials likely has the lowest mean humidity that which 59.44% due to its lack of insulation. Without proper insulation, the hive may be more susceptible to external temperature and humidity fluctuations. This can result in lower humidity levels within the hive, as moisture may escape more easily. The artificial hive using bubble aluminium foil as an insulating material demonstrates the highest standard deviation of humidity that is 2.38. Bubble aluminium foil is a reflective material that may impact the temperature and humidity regulation within the hive. The reflective surface could cause variations in heat retention and dissipation, leading to fluctuations in humidity levels. The artificial hive with clay as the insulating material exhibits the lowest standard deviation of humidity in which 0.46. Clay has moisture-absorbing properties and can help maintain a more stable environment by absorbing excess moisture and releasing it slowly. This slow moisture release can contribute to a more consistent humidity level, resulting in a lower standard deviation.

In summary, the highest mean in the artificial hive with clay can be attributed to its moisture absorption and retention properties, as well as its ability to regulate moisture and provide insulation. Conversely, the lowest mean in the artificial hive without insulators is due to the lack of insulation and moisture regulation. The highest standard deviation in the artificial hive with bubble aluminium foil can be linked to the temperature fluctuations caused by its reflective nature, while the lowest standard deviation in the artificial hive with clay is due to its moisture regulation and insulation capabilities.

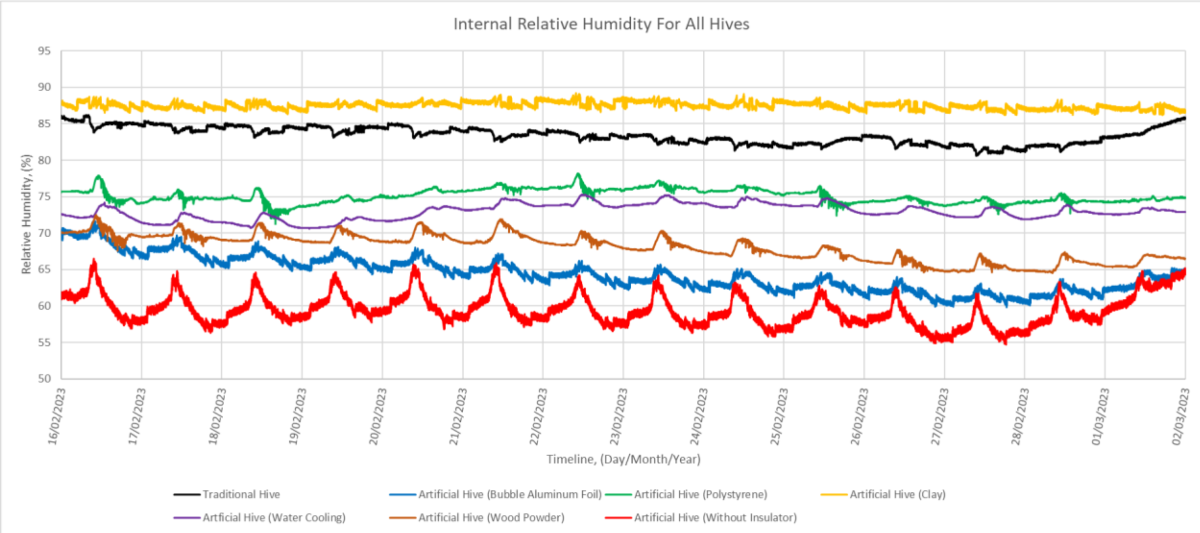

Figure 11. Graph of Internal Relative Humidity for All Hives

Table 1 Maximum and Average of Temperature Difference for Every Hives

Hives	**Maximum of Temperature Difference, $T\Delta_{max}$ (°C)**	**Average of Temperature Difference, $T\Delta_{avg}$ (°C)**	**Mean of Internal Relative Humidity, RH_{avg} (%)**	**Standard Deviation of Internal Relative Humidity, RH_s**
Traditional Hive	8.6	1.55	83.41	1.14
Artificial Hive without Insulator	2.9	0.92	59.44	2.11
Artificial Hive (Clay)	5.5	1.13	87.52	0.46
Artificial Hive (Polystyrene)	4.1	1.06	75.09	0.92
Artificial Hive (Wood Powder)	5.2	1.51	68.03	1.82
Artificial Hive (Bubble Aluminium Foil)	6.4	1.82	64.39	2.38
Artificial Hive (Water-Cooling System)	5.2	1.16	72.93	1.08

4. CONCLUSION

In conclusion, the highly perforated traditional hive led to the development of an artificial hive design in order to make the colony sturdy and prevent attack or invasion by stingless bee enemies. Using PVC, 3D-printed PET-G, and acrylic, an artificial hive was effectively created.

However, an issue with heat has arisen in artificial hives, in which external heat readily penetrates internal heat. Therefore, five kinds of insulation techniques, including clay, polystyrene, wood powder, bubble aluminium foil, and a water-cooling system, were attached to an artificial hive and their effectiveness was evaluated. In terms of temperature, the artificial hive with bubble aluminium foil is the finest due to its average temperature difference between the exterior and interior which is 6.4°C. In contrast, artificial hives made of clay have the lowest standard deviation for humidity that is 0.46. Given that the temperature of the hive is crucial because it affects the survivability of stingless bees, the bubble aluminium artificial hive is an excellent option for use with artificial hives.

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