Comparison of Hive Insulation and Ventilation Compositions and Their Effect on Honey Bee Winter Endurance

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Abstract

Honey bee keepers are usually advised to winter their hives with a strong upper ventilation configuration in order to avoid too much water condensation in the hive. Additionally, many cold climate beekeepers may try to winter in non-insulated wooden hives as is typical of the configuration practiced in warmer southern climates. While honeybees can manage internal hive temperature and humidity in the summer, this task is more difficult in extreme cold climates where oxidative stress from extended exposure to cold prematurely ages the bees and lowers their immune system competency. Is upper ventilation required to keep the cluster dry and does one configuration increase survivability over the other in more extreme climates? Is it possible the clustering behavior we see in standard wood hives is a stress response to an unfit nesting site provided by the beekeeper? We will review the engineering behind hive thermodynamics and interpret data from an experiment conducted over the winter to determine the true effect of the various compositions on hive environments and honey bee endurance.

***Keywords**:* humidity, insulation, winterizing, condensation, ventilation

Introduction

Winter is the greatest reason for mortality even of honey bee races that have adapted to northern climates (Heinrich, 1993). To survive the cold, honey bee wing muscles shiver to maintain thoracic temperature. They may be working as hard as a bee in flight to achieve a high metabolic rate. At air temperatures less than 32 ºF the cluster increases the temperature of the core in order to keep the mantle bees warm, often exceeding 114 ºF at the core. However, a bee's life span may be reduced as the metabolic rate increases during shivering (Heinrich, 1993). Measures of CO_2 in the cluster center increase at about .5 percent for every 20 degrees drop of air temperature. Increased CO_2 is indicative of high aerobic metabolic rate which results in the production of reactive oxygen species (ROS) (Finkel, 2000). ROS are negatively charged molecules and free radicals which are highly reactive causing damage to various cellular components. Among many other stressors, the abiotic stressor of cold results in ROS. Low concentrations of ROS are necessary for organisms. However, high concentrations lead to oxidative damage at the cellular level. Additionally, multiple stressors can repress the immune response and antioxidative ability of honey bees making them more susceptible to biotic stresses like parasites and viruses (Li, 2018).

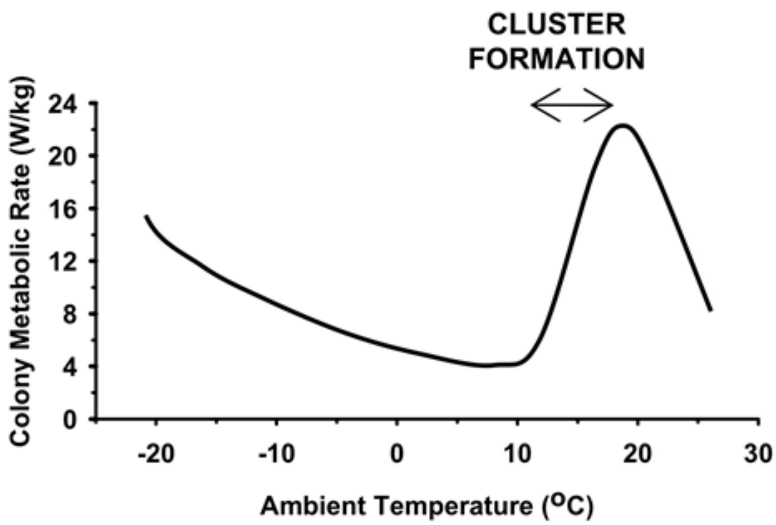

Figure 1. Colony metabolic rate as a function of ambient temperature (Southwick, redrawn from Seeley) From Canadian Association of Professional Apiculturists (Melathopoulos, 2013)

It can be extrapolated that an increase in insulation and preservation of warm air in the hive would lower the stress on the cluster from heat exchange into the environment. In an experiment by Derek Mitchell, he found the heat transfer rate is up to seven times greater in standard hives which measure .75 inches thick compared to natural tree nests averaging 5 inches thick (2015). We agree with Mitchell's assessment surmising that bee behaviors thought to be commonplace may be coping mechanisms for poor nests caused by human intervention. However, several concerns are often voiced by beekeepers when presented with a configuration lacking in upper ventilation. We will address those problems and solutions next.

Humidity and Dew point

Specific humidity is a measure (grains/volume) of actual water in the air. The maximum amount of water before condensation takes place is temperature (dry bulb) dependent. If we follow the horizontal line for a specific humidity with a temperature drop, we end at a dew point temperature where condensation will form on a surface at this temperature.

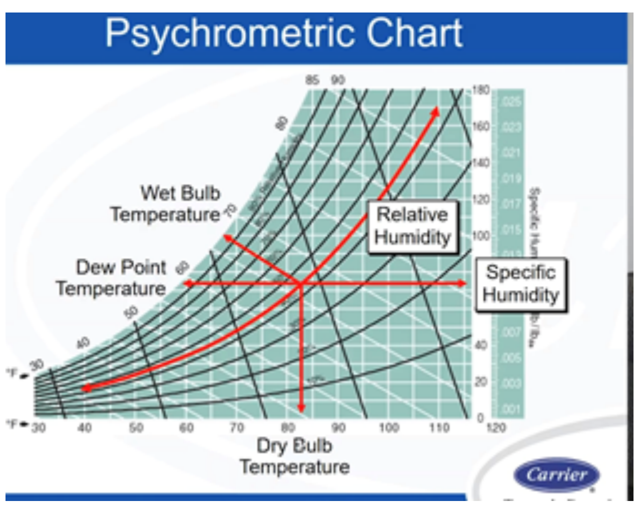

Figure 2. Adapted from http://www.handsdownsoftware.com/CARRIER-Chart.PD

The relative humidity changes with a constant amount of water in the air (specific humidity). With a bee hive's constant volume, the same amount of water vapor combined with a sudden change in temperature results in a large swing in relative humidity. In addition to outside humidity, bees create humidity within the hive when performing certain tasks like converting nectar to honey, bringing in water and their own metabolism. Each time the outside ambient dew point intersects with the dew point in the hive, complete saturation of air humidity is reached causing condensation to occur on the coldest surface in the hive (Mitchell, 2019).

Is humidity something that needs to be ventilated out the top of the hive? In nature, bees have survived in hollow trees for millennia with thick walls and usually only a small entrance hole on the lower third of the cavity. There is limited opportunity for ventilation due to this. In an experiment by Sachs et.al in 2017, they discovered humidity is conveyed from the center of the bee cluster to the outside walls of the hive. The humidity is absorbed by the surrounding wood and transported outside through vapor diffusion or it condenses on the walls and runs off towards the bottom. In hollow trees, this natural dehumidification results in almost no heat loss. The heat rises back up to the cluster.

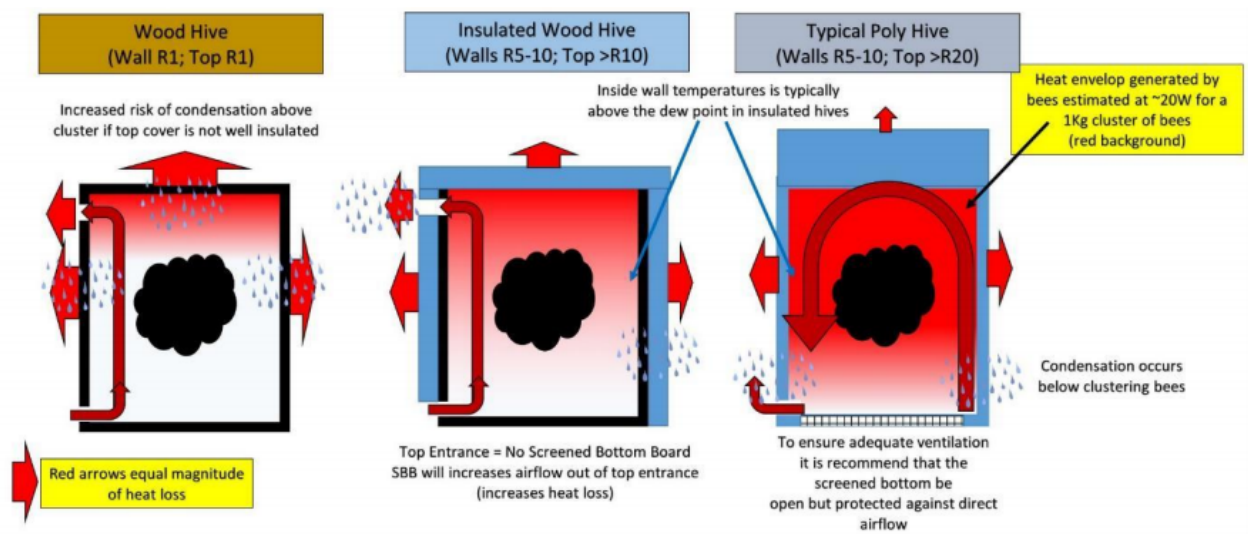

Figure 3. How Insulation Works (Tardif, 2020).

Dewpoint is the temperature at which air will have reached maximum moisture retention. When the ambient temperature lowers to the dewpoint, condensation results. Therefore, increasing insulation would lower the dew point temperature reducing the chance of condensation on internal hive surfaces. A modern polystyrene hive has an insulation value of R7 compared to the <R1 of a ¾ inch wooden hive (BetterBee, n.d.). Inner and telescoping covers in the polystyrene hives are typically twice the insulation value of the sides (<R20) to ensure the ceiling is not the coldest place in the hive so condensation will take place safely on hive walls. The result is an environment closely mimicking that of a hollow tree.

Finally, higher nest temperatures and humidity have been linked to reductions in disease and parasites (Mitchell, 2015). Kraus and Velthuis (1997) discovered at 79–85 % Relative Humidity on average, only 2 % of the mites produced offspring, whereas with 59–68 % RH on average, 53 % of the mites produced offspring. The benefits of insulation are higher levels of humidity in the nest, increased survival of smaller colonies and lower Varroa destructor breeding success (Mitchell, 2015).

Oxygen and CO_2

Air exchange brings in oxygen and removes water and CO_2 thermoregulation byproducts. CO_2 is heavier than O_2 and exits through the hive entrance or screened bottom board. An estimate of water released by breathing is .68 kg for every 1 kg of honey consumed. Some of this water vapor is used to feed brood, and dilute honey as a winter water source. (Melathopoulos, 2013)

Hive compositions address air exchange in two basic ways: creating ventilation through hive upper boxes--common on traditional wooden hives--or screened bottom boards on polystyrene hives. Polystyrene hives utilize natural airflows of warmer air rising and cold air falling create a current of air exiting the lower entrance and screen bottom board. Top vented wooden hives rely on hot air to remove moisture. Both strategies are effective in removing moisture; the difference being internal temperature and humidity. An estimate of water released by breathing is .68 kg for every 1 kg of honey consumed. Some of this water vapor is used to feed brood, and dilute honey as a winter water source. (Melathopoulos, 2013)

Resources

Arguably, the major drawback to upper ventilation is it removes heat which results in the loss of energy. An estimate of the stored energy in 1 Kg of honey is 330 Watts (Taultz, 2009). Excessive air exchange will force bees to consume winter stores at a higher rate. Compounding this problem further, consumption of stores is not consistent throughout winter months: .42 Kg/wk in December vs .84 Kg/wk in March. (Melathopoulos, 2013) As temperatures increase starting in February, the cluster breaks to perform cleansing flights and possibly start a small amount of brood, increasing the resource consumption. This can cause a disproportionate amount of water production. With the often-rapid drops in ambient temperature common in northern climates it makes humidity control so critical. The bees have few behavioral strategies other than trying to get back into the cluster. Unfortunately, the clustering process can take 3 days (Owens, 1972). Equipment choices to help manage condensation and conserve heat are tested during these weather extremes.

As an alternative to hive walls composed of insulation like polystyrene, beekeepers in northern climates often add additional insulation or protection to reduce temperature and humidity fluctuations inside the hive. Data indicates a gain of nearly 5ºF inside a hive with manufactured hive wraps. Based on assuming 20 percent of energy saved was converted to heat, this gives a 4.4 pound honey gain (BeeCosy, n.d.). Our experimental data indicates 10 ºF higher temperatures in polystyrene hives with no upper ventilation than non-polystyrene, upper ventilated hives, potentially increasing the honey gain even greater.

Following is a small-scale experiment conducted by Tollerson in the winter of 2020 to identify if the above assumptions are correct.

Method

Participants and Materials

1. Subject 1 - Two deep boxes of bees and honey in a polystyrene (Poly) hive with no upper ventilation. A super above containing 3 inches of candy and an extra 2-inch blue board insulation insert and Poly inner cover and telescoping cover. The tray under the screened bottom was removed to avoid an ice dam forming under the bees as water condensed in the hive and ran down the sides. The hive was placed on top of a piece of 2-inch-thick blue board insulation to stop drafts from blowing up into the screened bottom. Entrance was left to the 4-inch-long by 0.5-inch-high opening. Ceiling insulation estimate above bees: approximately 25 R-value. Side wall: 7 R-value.
2. Subject 2 - Two medium boxes of bees and honey in a Poly with no upper ventilation. All other details identical to Subject 1.
3. Subject 3 - Two deep boxes of bees and honey in a wooden hive wrapped in 2-inch blue board insulation on the hive bodies only. A super placed above with an insect screen bottom holding compacted pine wood shavings. Above that a 3-inch deep empty attic with (8) 1-inch holes drilled for ventilation. Then a wood inner cover and telescoping cover. Ceiling insulation estimate above bees approximately 13 R-value. Side wall of nest walls: 11 R-value. Insulation of upper quilt and ventilation boxes: <1 R-value.
4. Subject 4 - Layens style built with 2-inch-thick cedar walls. No outside insulation. A blanket of 2-inch-thick raw sheep's wool laid on top of the top bars under the lid. (8) half inch ventilation holes drilled in the sides of the lid. Ceiling insulation estimated at 8 R-value. Side walls approximately 2 R-value.
5. A control each replicating Subject 2, 3, and 4 had frames with foundation only inside, respectively.

Design

Subjects 1,3, and 4 all had similar population size and honey poundage going into the winter. Subject 2 was slightly smaller. Subjects 1,2,3,4 had August mite counts of 1.3%, 0.6%, 5.6%, and 2.2% respectively. All hives were sheltered from east, west, and north winds.

Procedure

All hives were measured every 5 minutes for temperature (F), humidity and dew point (F) from January 2020 through April of 2020. Remote sensors were placed directly on the top bars of the frames in the highest box and in the middle relative from all 4 walls. All data was collected on a memory card.

Results

Temperature Fluctuations

The controls (Figure 4) demonstrated less temperature fluctuations in the (Poly) hives. The Poly hives also maintained an average of ten degrees higher temperatures in the hive. Both Poly and Wood insulated hives demonstrated less temperature fluctuations than the non-insulated Layens hive.

In the live colonies, Poly Subjects 1 and 2 both consistently maintained 10-20 degree higher temperatures than the Wood Subject 3 (Figure 5). Poly Subject 2 recorded at higher temperatures because the bees clustered somewhat closer to the temperature sensor (6 inches away) than the other three subjects (10 inches away). So it was omitted from the graphic.

Heat Loss

The heat loss from the ventilation and quilt boxes can be seen in the wood Subject 3 in a FLIR image (Figure 6b). The difference between the surfaces of the insulation on the brood boxes at -15.4 ^{o}F and the ventilation holes on the upper boxes is over 18 degrees higher. By comparison, Figure 6a shows reduced heat losses on the Poly subjects. The few bright areas are from absorption of heat from the sun on the surface of the hive earlier in the day rather than internal heat loss at seams and openings.

Humidity and Dew point

The relative humidity (RH) showed the highest humidity in the Poly Subject 1 hive (Figure 7). However, the Subject 1 range falls within the preferred range (79-85%) outlined by the Kraus and Velthuis (1997) experiment. What is to be considered of more detriment to the colony is each time the ambient cold air lowers to intersect with the dew point in the hive. The Poly Subject 2 dew point rarely intersected the ambient air temperature, meaning no condensation was forming in the hive throughout the time period (Figure 8a). However, the wooden subject 3 shows multiple dew point and ambient temperature intersections indicating condensation formation (Figure 8b).

Outcomes

The longest living colony was Poly Subject 2 which perished April 14 after an extreme temperature drop at night. Since it was a smaller colony to begin the winter it was not able to cover the brood and get back in the cluster. The second longest to survive was Poly Subject 1 perishing on February 10. Followed by Wood Subject 3 perishing on February 5. Finally, the shortest survival length was the Layens Subject 4 perishing January 25. All autopsies showed dry bees with plenty of food stores but caught out of the cluster in a cold kill.

Discussion

Beehive ventilation is always necessary to ensure bees have an acceptable environment. But the placement of this ventilation in the floor of the hive instead of the upper portion of the hive may prove to maintain more optimal humidity and temperature for the colony. This combined with greater insulation like that in polystyrene hive bodies may lower the oxidative stress of the bees and increase survival rates based on the data recorded. The experiment would benefit from being repeated with at least 10 subjects of each configuration with similar colony size and recorded weights.

Increased insulation above the bees eliminates the concern of condensation dripping on to the bee cluster and forms instead on the colder hive walls. We believe our research and data collection shows not only that upper ventilation is not necessary for survival, the internal environment favors lower ventilation. With a better understanding of winter humidity and extended cold exposure to the honeybee cluster, beekeepers are better informed when selecting a hive design or when modifying their hive equipment based on their location especially when considering summer and winter conditions.

For polystyrene hives, a recommended winter setup leaves the screen bottom boards open to allow for condensation to safely flow out through the screen bottom board and allow for ventilation transfer. The hives are recommended to be set on top of a piece of blue board insulation to block wind drafts from blowing up into the screen bottom. Any upper entrances are unnecessary and have the potential to let warmth escape as demonstrated by the FLIR image 5b.

Author Note

We would like to thank contributing author, Etienne Tardif, for his help with organizing and interpreting the data for the experiment. We would also like to thank Scott Debnam and Dr. Thomas Seeley for their mentorship and help during the planning process of the experiment. This paper was submitted as the final project for the online Master Beekeeping Course at the *University of Montana*, class of 2020. The authors can be contacted at atollerson@gmail.com or mgary654@gmail.com

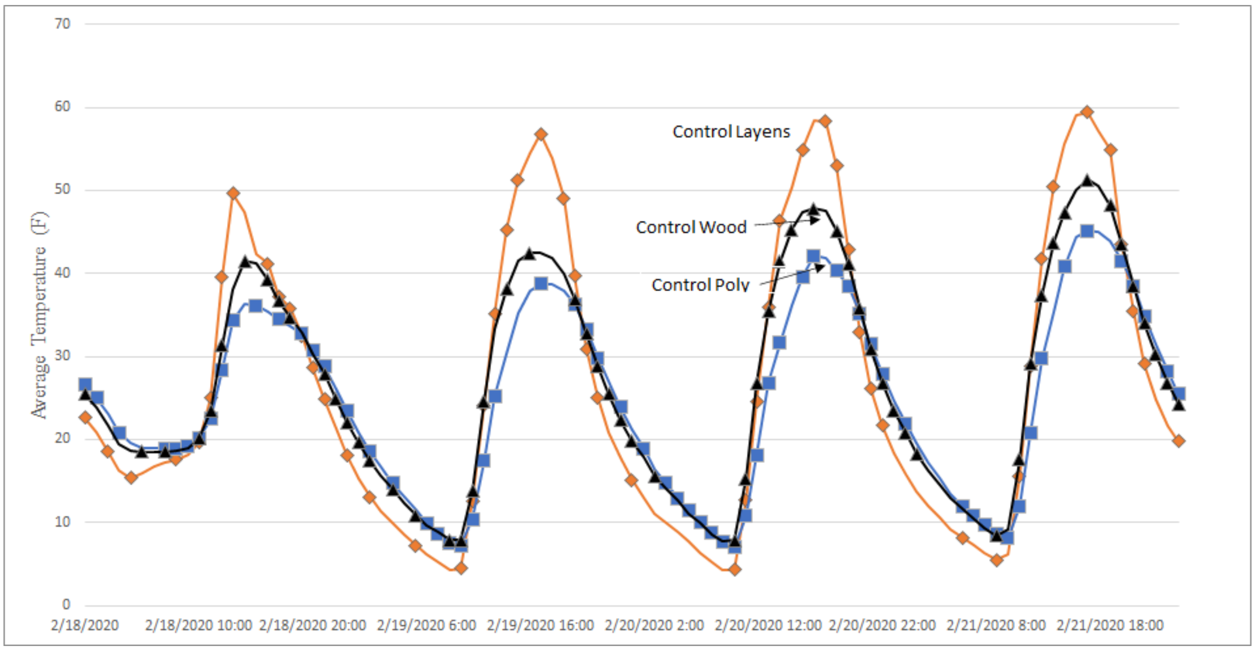

Figure 4. Fluctuations of temperature in empty Control Hives.

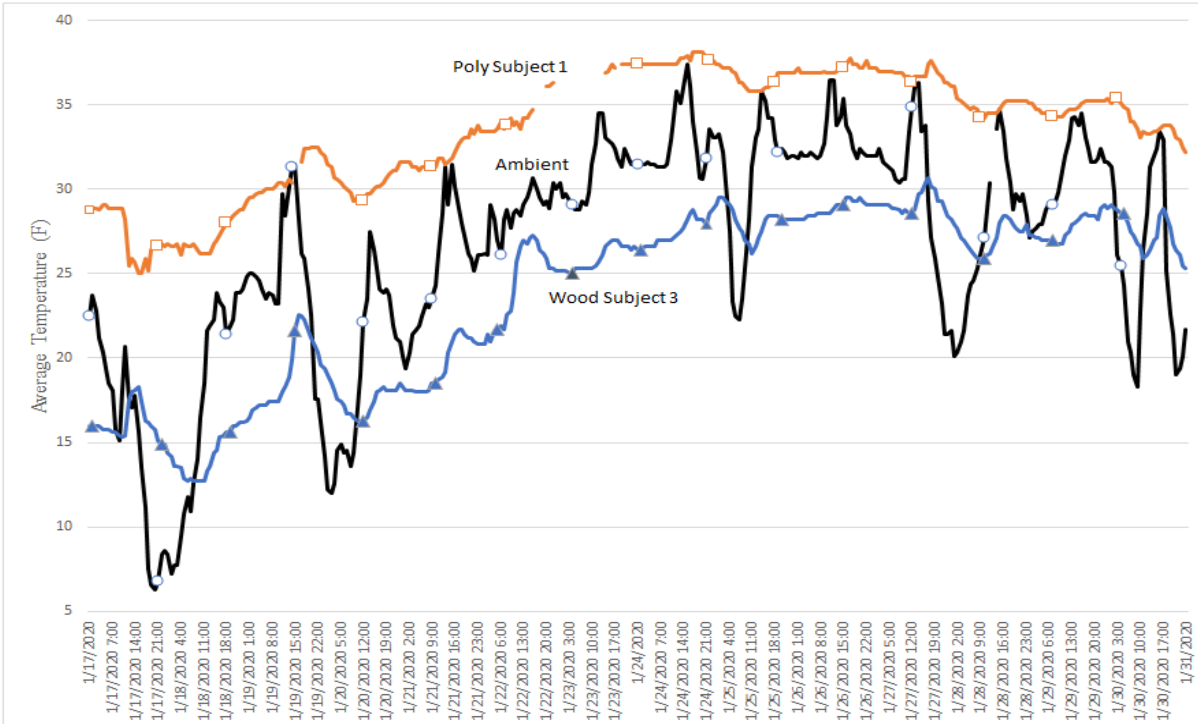

Figure 5. Comparison of Temperatures in two live colony types.

Figure 6a. Infrared image of Subject 1-3. Low heat loss from the Poly subjects on the left. High heat loss from the upper box of Subject 3 on the right. Bright heat register areas on front are from sun absorption earlier that day, not loss from the hive.

Figure 6b. Infrared image of wood Subject 3 with upper ventilation box. Warmest surface temperature at visible ventilation holes of the upper box recorded at 3 °F for a difference of 18.4 degrees heat loss out the op.

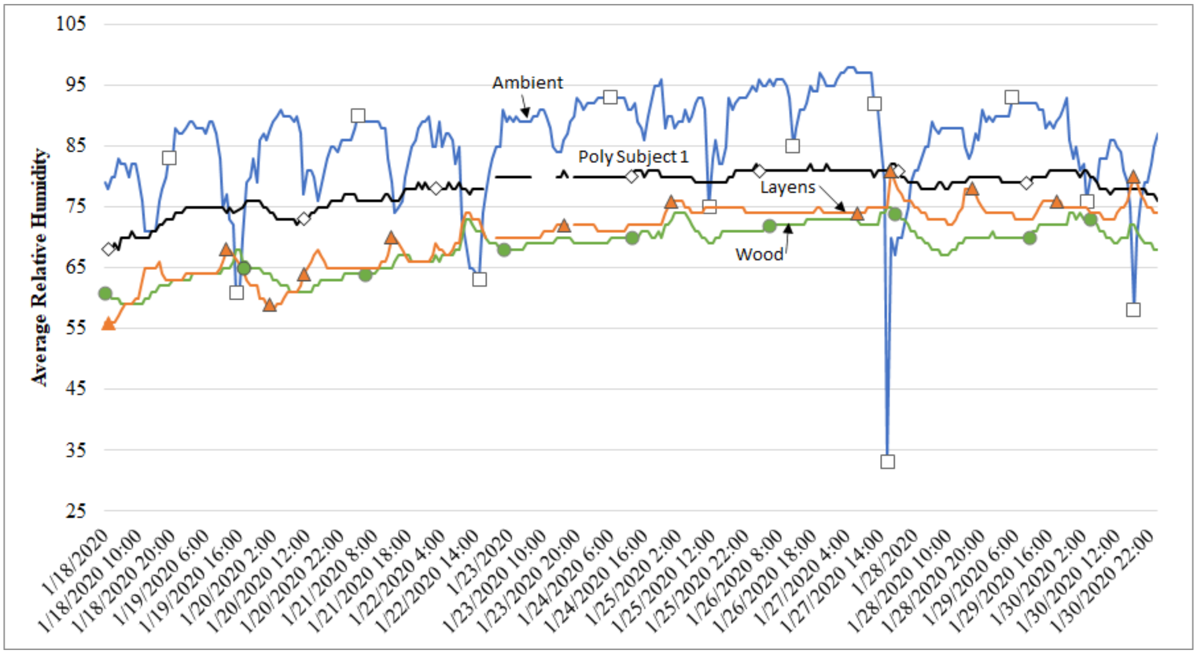

Figure 7. Comparison of Relative Humidity levels. The relative humidity is higher in the Poly because the average temperature is 10 degrees warmer than the Wooden hives. As temperature increases, relative humidity increases.

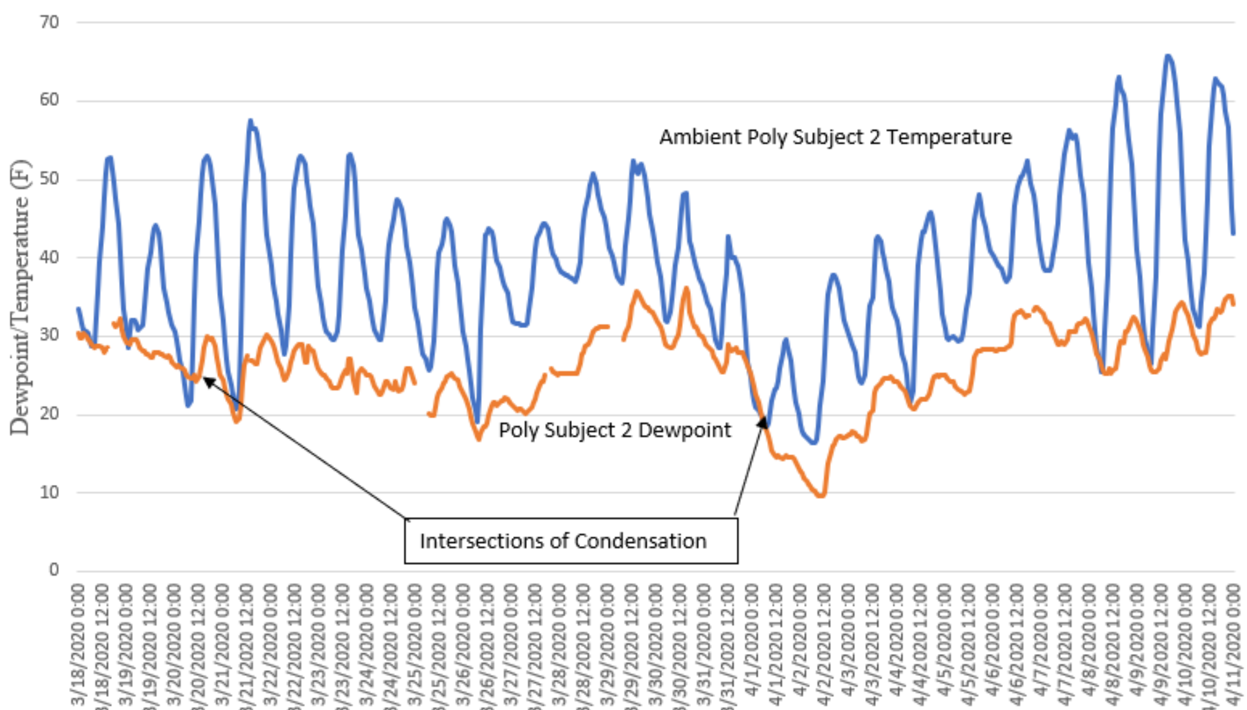

Figure 8a. Dewpoint of Poly Subject 2 compared to Ambient Temperature of the subject. Low occurrence of full intersections

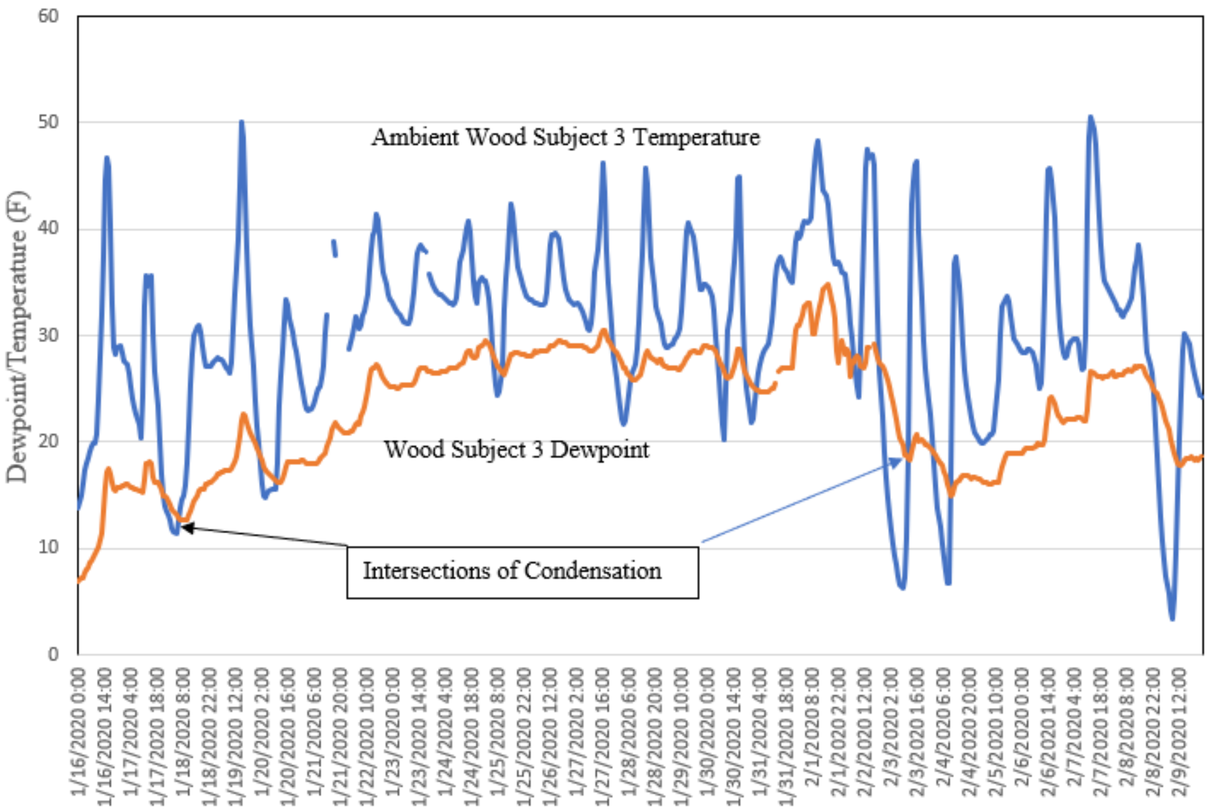

Figure 8b. Dewpoint of Wood Subject 3 compared to Ambient Temperature of the subject. High occurrence of full intersections

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