Honey bee Engineering: Top ventilation and top entrances

Beekeepers have been discussing the subject of the top ventilation of hives for over a hundred years. This interest peaked in the 1940's and it was taken to be accepted practice, especially in the United States, to have top entrances or vents open in winter. The 1975 to the 2015 editions of "The Hive and the Honey Bee" [1–3] say that "Heat is not lost through the upper entrance" citing Edwin Anderson's 1943 experiments[4]. Yet we learn that honey bees seek nests with lower entrances when they can find them [5]. For such a behaviour to develop honey bees must surely have found some advantage?

After 100 years has everything been said? In this article, we will look at this from a different viewpoint, the engineering perspective, using the latest research from the world of ventilation engineering, to see if the honey bees may have found something that may have been overlooked. The discussion in this article is a simplification of the engineers work in this area applied to Anderson's experiment, which in it self is a simplification of hives and the heat from honey bees. Lets first look at Anderson's 1943 experiment.

Anderson's experiment

Using hives with only bottom entrances(figure 1a) and both top and bottom entrances (figure 1b) , he placed a 15Watt electric bulb in the bottom and a single thermometer. He reported that "The temperature in this hive with the top entrance remained about the same as the one with a bottom entrance only".

Did Anderson make a mistake? Did the others draw a wrong conclusion from his results? Are honey bees not concerned with heat when they choose a lower entrance?

This problem of a heat source in a box with a hole at the bottom and one the top has been well studied by engineers and they have performed experiments almost identical to Anderson's. The engineers using sophisticated instrumentation, described what happens in detail and have derived mathematical models to predict temperature and heat transfer [6,7]. Their studies show, that by relying on a single thermometer, it was impossible for Anderson to pick apart what is a very complex system of fluid mechanics and heat transfer. A system that depends, even at simplest level, on the size and shape of the top vent and bottom entrance, the way the heat moves through the walls and roof, and how air moves and mixes inside.

The heat pool

The work of the engineering researchers shows us that Anderson's hot electric bulb creates a jet of hot air that rises to the top of box and accumulates in a layer under the roof, a pool of heat (figure 2a). They observed that temperature of the pool is determined by how much heat is lost through the roof by conduction. They also found that the depth of the pool is reduced by hot air lost through the top opening (figure 2b). However, despite the vent, this pool of hot air is of almost uniform temperature, at a value unchanged by the addition of the vent.

Heat pool and the Anderson experiment

Anderson in 1943 was only using one thermometer. When he added the top entrance, this would have changed the depth of the heat pool, but not the temperature. He could not detect this depth change unless he was lucky enough to place the thermometer close enough to the surface of the pool so that the change in depth would pass across the thermometer when he added the top vent.

Which way does the heat go

We can definitely say all the heat the honey bee or light bulb generates must be escaping the hive if the hive is in an unchanging state, i.e. equilibrium, the resistance to that escape increases the temperature or changes the amount of mass heated. In a wooden hive with a thin roof the heat pool is shallow and relatively cool. The heat pool depth and temperature provides the buoyancy,(like a hot air balloon) to generate the air flow through the vent. So the flow through the vent in this type of hive is sluggish and the low temperature implies the amount of heat per unit flow is low as well. Thus not that much heat is lost through the vent and any draft is minimal. In addition, the low temperature and low velocities mean a low level of evaporation from any water on the walls or from the brood,. Now lets look at the opposite side of the coin.

Heat pool with added insulation with vents

When the hive is highly insulated (from packing or being made from polystyrene), the heat pool becomes hotter than the uninsulated, (figure 3a). Therefore the buoyancy under the roof is higher and as a consequence so is the air flow through the top vent. The proportion of heat lost through the top vent becomes dominant. The air flow through the top vent is high volume, hot and high velocity (figure 3b). With the top vent the depth of the heat pool is decreased but by greater extent than the uninsulated hive. The temperature at the top of the hive remains the same, top vent or no top vent.

Consequences of insulation with top vents for honeybees

The consequence for the honey bees is that any thermal advantage of the insulation can be negated and perhaps even reversed by the addition of a top vent. This high velocity flow through the top vent will move the previously slow or stagnant air (i.e. entrainment) and remove moisture from the internal structures such as larvae (forced evaporation). This not only dries parts of the hive it also cools the hive as evaporation of water needs energy (evaporative cooling). The honey bees now have the added problem of dehydration. Without the top vent, the air would be hot and humid, good for bees. With the top vent, the lower parts of the hive are cold and top parts hot and very low humidity, not good for bees [8]. Not surprisingly, researchers in the performance of colonies in insulated hives with added top vents have been rewarded with poor or inconclusive results for their labours [9,10]. In both cases of insulated and uninsulated hives the addition of top vents does not change the temperature at the top but changes how much of the volume of the hive is warmed.

How does moving the top vent downwards change things

The heat pool accumulates and the vent empties the pool but only does this from that region of the heat pool that is below the vent (figure 4a). This means there is less heat being transferred through the vent than when the vent was higher. As you move the vent even lower it will eventually not be in the heat pool and the heat loss will approximate to that without a vent (figure 4b).

Conclusions

Anderson’s statement, about the temperature he measured being unchanged was correct for the space next to the roof with the vent close to the top. However he could not know what was happening in in the rest of the box.

Although the statement that “no heat is lost through top vents” is technically incorrect, in hives that lose so much heat through the roof and walls that the heat pool is cool, the addition of vents may not make much difference. But in a hive that loses very little heat through the roof, the addition of top vents is very significant and can be detrimental.

Apis mellifera colonised northern Europe about 1 million years ago [11] and later, with our help, North America, by making its nests in tree hollows. These hollows are on average very highly insulating compared to our thin walled hives [12]. Thus a developing a preference for bottom entrances would have given them a definite survival advantage in making use of the insulation advantages of thick walled tree cavity without incurring the disadvantages.

Heat transfer and fluid mechanics in a cavity, building or a Honey bee nest are very complex; so complex that we should be making detailed and careful, measurements, experiments and simulations before we make assumptions about what is really going inside. In addition we should closely study the real experts in this field in the environment where they can express their expertise fully. The experts? Honey bees of course!

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With a background in engineering and physics, Derek finds the honey bee’s adaptations to exploit heat and mass transfer in cavities fascinating and so he has been researching this topic since 2011. He is now doing this in the context of study for a doctorate in “Differences in Heat Transfer between Man-made and Wild Honey bee Habitats using Computational Fluid Dynamics” at the School of Engineering at Leeds University in the united Kingdom.

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