RESEARCH

Preamble

By Jeff Murray August 19, 2021

When I first started working with observation hives there seemed to be very little discussion of thermal regulation, nor an understanding of small hives. Since each super had only one frame in it, and that just touching it indicated that the bees on it were generating heat, I felt it was worth looking into. I had to learn how an ordinary hive maintained its heat during the cold months, as well as how it cooled itself in the warm ones, to then compare it to a much smaller population in the observation hive. It turned out to be quite an experience to realize what an extraordinary evolutionary accomplishment the ability of the northern honey bees to survive the cold.

Honey bees (Apis mellifera) first appeared in south east Asia, in a tropical environment where they set up their colonies, outside on the branch of a tree, for example. To exploit resources in a totally different environment, they had to adapt, and find a way to survive the cold. How and why did they move to an enclosure, in a colder climate, and how long did it take them to do this? I do not know. Perhaps the fact that they had to move from an open space to simply an enclosure, could explain another feature. Contrary to many other social insects, termites, ants, and wasps, they were not capable of increasing the size of their space. Since they had no control over it, their only solution to the problem of overpopulation is to reduce it by separating out a large percentage of bees in the form of a swarm to find a new space. Swarming, therefore, is directly related to how large the space was that that particular population occupied. As the population increased beyond the capacity of any space, they were obliged to send more than half of it to a new location to relieve that congestion in their original location. Hence the phenomenon specific to all honeybees: swarming. Thus I understood my own misconception. I thought that simply because a hive was small, it would never swarm. When I started working with observation hives, I realized that it was not the size of the population that mattered, but how that population occupied the space it had chosen. This principle applies equally to large Langstroth hives as well as to small observation hives.

Another issue with observation hives is the very specific shape the space has to have to allow viewers to see what is happening in the hive and the implication that shape has on both thermal regulation and swarming. For thermal regulation for warmth, the normal technique of feral and commercial hives was achieved by forming a "cluster". The bees would fill a group of adjoining combs, which, if viewed as a separate entity, would come to closely resemble a sphere of bees. Obviously, this would not be possible in a narrow observation hive. So how to compensate for the inability to form a "cluster"? The answer, we discovered, was by using insulation on each one of the separate frames, on both sides of the individual supers, on top of the glass sides. Initially that allowed the observation hive to survive the winter, even when the queen had to stop laying because the insulated area was not able to reach the requisite laying temperature of 35°C. Then after publishing this article, we were able to have the queen lay in mid-February, because through insulation, we maintained the requisite temperature at the right time. First it happened with a different type of hive that we had installed at the National Audubon Society's Boston Nature Center. This hive consisted of a large two-sided glass box that could contain four frames, visible from both sides. In this instance we were able to cover at least two brood frames with two inches of foam rubber insulation continuously on both sides, so there was no interruption of coverage between the two frames of brood. The second time it happened was in my house with our regular modal system where each frame was placed in one super, with glass on each side so you could observe the whole hive, when you removed the insulation from the supers. There I applied three inch thick pieces of insulation to the glass. I also put insulation on the wooden pieces at the bottom and the top of each super, thus insulating what had remained exposed to the cold before. I know now that I should have documented all this carefully. I regret that I did not. However I am confident that if the experiment is repeated one can achieve the same results. I also found, after I had written this paper, that in an observation hive, the bees were also very adept at cooling themselves, when it got too hot. Specifically, it was only when the room in which the observation hive was located reached a temperature of 90°F that one had to remove the two inches of foam rubber insulation covering a brood frame. I felt confident enough, even with the partial results, when I published this paper in 2012, to refer to this system as a permanent observation hive. I had shown that by controlling the temperature, it allowed the hive to keep going even through the winter, even if the queen interrupted laying for a few months, and in the summer, by cooling it, that an observation hive could function in the same way as any other hive.

Regarding swarming, since an observation hive occupies a relatively small space, it was soon likely to swarm if that space was not increased appropriately. That's why two-frame observation hives that are often sold, cannot last very long. We have found that in an observation hive, under normal care, usually reaches five frames. Occasionally they can reach six, but never more than that. I suspect that this is because, with this way of distributing the frames, it takes the queen too long to move from brood frame to brood frame and therefore limits her production.

The permanent observation hive

[Editor's note: this article was published in a slightly abbreviated form in The New Zealand BeeKeeper *in April and May 2012.]*

By Jeff Murray

This article focuses on how thermoregulation defines the architecture of honey bee colonies and how it applies to observation hives.

Observation hives have often been considered temporary, and used primarily for the purpose of scientific experiments or commercial displays. Even when established as a more permanent exhibit, most often they have been operated as the satellite of a regular Langstroth hive from which frames are taken or put back.

My experience has been different. I have been able to keep them, sometimes for years, wintering over with just two frames at a time with a queen and a few hundred bees. How is this possible? The answer, I believe, can be found in the principles of honeybee thermoregulation.

I have no formal training as a biologist. I started out in the usual way as a hobbyist beekeeper. Quite by chance, after seeing an observation hive in a museum, I decided I had to have one in my house for the benefit of my children. I have been working with observation hives, on and off, for about 30 years now. The last 10 years have been the most rewarding because I have been able to set up first one, and then two, such hives in the Boston public schools. Without this experience, especially the help of the teachers and my friends, this paper could never have been written.

Luckily for me, I blundered upon observation hives without knowing their reputation for being fragile and temporary—if I had known, I might not have been working with them at all. Instead, I set about first learning how to make them work and then-trying to figure out why they worked at all.

I also started reading extensively about bees, and subscribing to a trade magazine (the *American Bee Journal*), to try to understand how a hive functions in general, and how observation hives do in particular.

Early on, I felt heat loss was going to be a problem in cold weather, with all the cold conducting glass exposed to a cold room where I kept my first one. At first I had the notion that by surrounding the glass with a heating element, as you might protect some pipes from freezing, I could find the ideal temperature for the hive.

I quickly realized that the bees were so good at adjusting to their thermal environment that all I had to do was offset the conductivity of the glass by placing foam insulation on it, and they would take care of the rest. Gradually I realized what a great resource an observation hive could be and wondered why there were so few used in schools, or anywhere.

I. Thermoregulation

Thermoregulation, the ability of these social insects to maintain a constant temperature between 33–36°C in the brood nest despite a very wide spectrum of ambient temperatures, is one of the great evolutionary accomplishments of the honey bee (*Apis mellifera*). So crucial is the perception of temperature change to bees that an individual worker is able to pick up changes to within 0.25°C using receptors located on her antennae (Mathis & Tarpy, 2007).

Thermal homeostasis is a state of equilibrium between different interrelated elements of the honey bee colony to maintain a constant temperature in the brood nest between 33–36°C. How this happens in cold and hot weather for all hives and how it applies to observation hives in particular is the subject of this paper.

There is a continuum of changing density of bees within a given space as the temperature increases from cold to hot. At the cold end, they totally surround the warm core of the cluster with the outermost surface of bees getting as close to each other as physically possible, heads facing in, in an outer layer of protective insulation. In the middle of the temperature range they stay close to each other so they can maintain the brood-rearing temperature. As the temperature gets warmer, they get further and further apart, until some of them actually move out of the hive altogether.

A. Population and thermoregulation in the winter cluster

To survive in winter, bees form a ‘cluster’. They must occupy an area of empty comb so that the whole volume—including the empty cells and the bee space between them—is packed with bees, directly under and distinct from their stores of honey.

As Edward Southwick points out, “the clustering phenomenon itself precipitously reduces surface area for heat exchange from the sum of the surface area of individual bees down to the outermost surface area of the cluster.” What he means is that the outside insulating ‘skin’ of the cluster, formed of bees packed as close as possible with only their abdomens showing, reduces the size of the surface presented for heat exchange between the cluster and the cold interior temperature of the hive T(h). By exposing their rear, instead of their whole body, to the cold, they have considerably reduced the surface exposure (Southwick, 1983; Appendix 1). On the continuum of closeness in relation to temperature, this is at the bottom of the scale.

In earlier research, Charles Owens conducted an experiment during five consecutive winters in Madison, Wisconsin. By placing 192 heat-sensing thermocouples in each one of several hives, parallel and perpendicular to their fronts, he was able to map out the shape, comportment, and distribution of the population at each temperature level (what he calls an “isotherm”) inside the cluster.

Between the measured temperatures, he isolated a specific population of bees and observed their behavior in the cluster as they moved or became less dense. He then compared three different types of hives, each modification being defined as a “treatment”.

One of the significant facts in the article is that if the temperature inside the hive T(h) was modified either by insulation (the “packed” treatment), or by a heating element (the “tape” treatment), the size and shape of the cluster would grow larger, particularly between the first two isotherms (Owens, 1971).

Owens also contends that, to survive, a colony must be “strong” rather than “weak” so as to be able to reach food outside the cluster. I interpret “strong” to mean a large population, and “weak” to mean a smaller one (see footnotes 1, 2). This suggests that at a given temperature, a colony must have a critical mass of bees to insure that the core of the center remains at brood rearing level; otherwise they cannot counter the heat loss caused by the ambient temperature, even with the protection of the hive, the insulating shell between the first two “isotherms”, and the requisite food (Owens, 1971).

Has the size of this critical population been quantified? In *The ABC and XYZ of Bee Culture*, Morse puts an actual number of 12,000 to 15,000 bees (4 or 5 pounds or 1.814 to 2.268 kilograms) for such a population (Morse, 1990, p. 475). Most of this research is site specific without saying so explicitly. It would be interesting to find out (if it has not been done already) whether, for example, in a warmer climate where, the winters were very mild, the size of the cluster and the stores of honey would vary.

Heat generation is an essential feature of the cluster. While it was always assumed that the warm interior was a source of heat only because of the oxidation through the digestion of honey, in 2002 Anton Stabentheimer, Pressl, Papst, Hrassnigg, and Crailsheim et al., using new infrared technology, were able to measure the temperature of the individual parts of bees' bodies, and show that there were also some workers who actually made heat (thermogenesis) by “shivering” (activating their wing muscles) (Stabentheimer et al., 2003).

Finally, another factor is a source of fuel (honey) to maintain temperature by digestion. The hive must accumulate enough food to feed itself during the period that nectar is not available to survive. Seeley mentions a volume of 40L as the preferred choice of scout bees searching for a new home site if they want to store enough honey for this purpose (Seeley, 2010, p. 56).

So far, then, the three factors involved in the bees' strategy to deal with the cold are:

1. being inside a protective structure (natural or artificial)
2. heat generation by a large enough population to overcome the cold hive temperature T(h), as it is affected by the ambient temperature T(a), and
3. enough food to allow this to happen.

B. The sphere: how the shape of the volume affects thermoregulation

But there is an additional, fourth, factor: the shape the colony takes during the winter cluster. It usually coincides with the shape of the brood area. (There are some exceptions: clusters that are separate from brood areas, as referred to by Taber & Owens, 1970.)

To describe the shape of the cluster, the brood area is a good place to start. Many readers are familiar with the brood pattern in a Langstroth hive's deep supers. The center frames usually have the largest circumference of brood. The further away from the center, in either direction, the greater the reduction of the brood circumference pattern on the frames—until it practically disappears to nothing on the very last ones. If somehow you could take an X-ray of only the bees, it would tend to look more and more like a sphere.

Southwick (1983) speaks of the shape used to reduce heat exchange surface as the “spherical cluster”. Tabor and Owens, in their experiment with small colonies, where bees were allowed to build their own combs in an empty cube, postulate after statistical analysis that the “ideal shape for embryo colonies of bees is a sphere” (Tabor & Owens, 1970).

Here is the full quote:

> The hypothesis, tested by the analysis of variance, is therefore advanced that *the ideal shape for embryo colonies of bees is a sphere.* For such a shape, the correlation of weight to height*, height to length, and width to height should be positive and significant for all population groups. In our test, of the twelve correlations (omitted because of length), seven were positive and five were negative, but only one difference was significant at the five per cent level of confidence.* (Tabor & Owens, 1970, p. 630) [emphases mine]. (See Appendix 3.)

In other words, the sphere is the form that the bees prefer for the brood nest, and by extension the cluster. (Even though, as it often happens, they do not quite get to this perfect shape.)

Why a sphere? For thermal reasons, I believe. We have already seen from Southwick (1983) that the outer layer of bees, by coalescing tightly together, offers the least space for heat exchange between warm and cold locations in the hive. In a sphere, all the bees on the outer shell of the cluster are equidistant from the warm center, and by the same token, the center is equally insulated from the cold. This does not mean that the cluster does not move around or take somewhat different shapes, but the thermal character of the sphere still applies.

To give an idea of the implications of different cluster shapes on heat conservation or heat loss, take, for example, a tetrahedron: a pyramid made up of four equilateral triangular sides. If the cluster had that shape, the bees at each one of the points of the pyramid would be colder than all the bees in the center of the pyramid. They would be more and more exposed to the outside cold as they moved further and further toward the tip of the points, and away from the interior. The interior would, at the same time, be exposed to three ‘cold spots’ where the points join the center of the pyramid.

To generalize: the more the shape of a cluster is spherical, the more it can conserve heat, and conversely, the less spherical, the more it loses. In an irregular polyhedron this would even be more so. This means that the cavities chosen as home sites must allow for a more or less spherical cluster; otherwise, the advantage of a large population that Owens has described and Morse has quantified will be lost.

So, not only the size of the population, but also the shape it takes in the winter cluster, is crucial for successful thermoregulation. Architecture does matter!

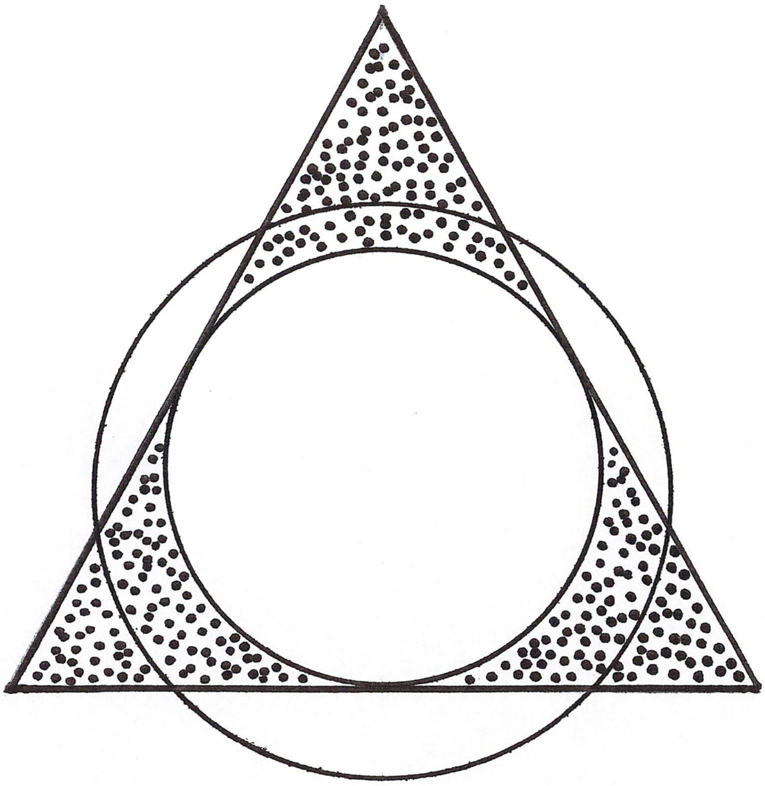

Figure 1. This figure represents a cross section of a tetrahedron pyramid cut perpendicularly from the apex to the base. The outer circumference represents a cross section at the center of the sphere of approximately equal volume to that of the tetrahedron. For example, if the side of tetrahedron is 5, then the volume will be 16.263015; if the radius of the sphere is 1.96875, then the volume will be 16.235689, approximately the same size volume. In the tetrahedron, you can see certain areas that are more exposed than the sphere of the same volume.

The inner circumference represents a cross section of the center of a sphere inside the tetrahedron where all points are equidistant from the center. The shaded areas show locations where a cluster of this shape would be most vulnerable to the cold.

C. Ambient temperature [T(a)] and temperature within the hive [T(h)]

In discussing thermoregulation, there are two different temperatures to keep in mind: ambient temperature or T(a), the temperature outside the hive, and T(h), the temperature inside the hive.

We have seen that bees at different temperature levels of the cluster (which Owens calls "isotherms")—particularly bees between the outer layer at the surface of the cluster at 44°F (6.66°C) and the next measured layer of 60°F (15.5°C)—react differently to Owens's different treatments. When he modified the interior temperature, T(h), by adding insulation (packed treatment), or electrical heating tape (tape treatment), the shape of the cluster expanded. (Bear in mind, as Owens has demonstrated, that the cluster is often moving around in the hive.)

Another example of the effect of modifying the T(h) is in Morse's description of hives in cellar wintering, a technique that was often used at the turn of the past century. While only one of the variables of the equation, food consumption, is measured, the hive temperature, T(h) increased, when they are moved to a relatively warmer place. When the hives are outside they consume 49 pounds (22.3 kilograms) of honey during the season, but when they are placed in a cellar they only consume 15 to 29 pounds (6.8 to 13.2 kilograms) (Morse, 1990, p. 473; see also footnote 3).

Even with his different treatments, Owens was modifying the T(h) in a relatively small range (the winter temperatures of Madison, Wisconsin). What would happen if the modifications were more extreme: as in observation hives kept in a warm 68°F (20°C) room, or in a cooler setting with foam insulation on the glass, both set ups having an opening to the cold outside; where the temperature was raised significantly above cluster forming temperature of 57°F (14°C), or if brood was present, where the necessary thermal level is easily maintained? These are precisely the kind of modifications that we have used in the last 10 years. (More on the results in the second part of this article).

Before closing the subject of temperature, let us consider the special importance of ambient temperature, or T(a). T(a), gives all colonies essential cues from the environment. First, whether it is too cold to fly below 54°F (12.22°C) (Morse, 1990, p. 178). Second, and more importantly, when to start preparing for winter the queen will stop laying, bees will move closer together, and more nectar will be stored around the brood area). Third, as the nursing needs diminish when the queen stops laying, the ingested protein that the workers take in is turned into an egg yolk-like substance, vitellogenin, instead of being used to generate royal jelly. This will prepare the surviving bees to live through the long winter.

Another essential environmental cue, not related to temperature, is the amount of light coming through the hive opening. The days are longer after the winter solstice, triggering increased brood rearing by the queen (Morse, 1990, p. 473; see also footnote 4).

Now let us look at how thermal homeostasis plays out in cold and hot weather.

D. The thermal homeostasis equation in cold weather

We first present the equation, which defines thermal homeostasis in cold weather for all hives. We can express this as follows:

$P(SV)+ F / T(h) =$ Thermal Homeostasis (in cold weather)

where P is Population, SV is Spherical Volume, F is food supply, and T(h) is temperature inside the hive.

This relationship assumes:

1. population as a critical mass able to generate enough heat to overcome the cold temperature in the hive
2. volume, more or less in the shape of a sphere to assure the most efficient use of the heat generation in the cluster, and
3. enough food as a fuel to allow this action to take place.

Since all these variables need to increase as the temperature gets lower, we can say that the three variables: population, spherical shape, and food supply need to be larger as the T(h) gets smaller. We can say that they are inversely proportional to each other.

Two frames freestanding on a table with the bees inside. Photo: Jeff Murray.

II. Hot weather

A. Standard strategies

As it gets warmer, and the temperature of cluster forming (57°F, or approximately 14°C) is reached and passed, the bees will still stay close together to ensure that the brood stays at a constant temperature of 33°C to 36°C (Morse, p. 471). Mathis and Tarpy (2007) found that "the upper limit for unaffected brood development is between 38°C and 39°C (100°F and 102°F)"; above that, the bees will adopt a series of countermeasures that are increasingly effective in cooling the hive.

There are at least three countermeasures that bees will take to counter a rising T(a). First, because bees generate heat simply by digesting honey, when the T(a) rises they will begin to move apart to dilute the effect of close assembly. When overheating threatens, they may, on their own, move out in great numbers in front of the hive and form a "beard". (Alternatively, the beekeeper can lower the T(h) by adding supers.) With any increase in temperature the bees will "start to fan their wings thereby cooling the hive interior through forced convection … If these measures prove inadequate, they will spread water, especially within the brood nest, for evaporative cooling." Therefore, "they can accomplish the extraordinary feat of maintaining a near constant brood nest temperature near 35°C (95°F) while outdoor temperatures … [can range] up to 50°C (122° F)" (Mathis & Tarpy, 2007).

Of these three countermeasures, the third one is the most effective. It is the one that is the least possible in an observation hive, so in discussing thermal homeostasis in warm weather for all hives the discussion will be confined to that.

B. The thermal homeostasis equation in warm weather

One equation that describes thermal homeostasis in warm weather can be written as:

(NWD(SV) + VT) (T[h])= Thermal Homeostasis;

where

NWD = number of water deposits
VT = ventilation
SV = Spherical Volume and
T(h)= temperature inside the hive.

In this equation, NWD(SV) and VT vary directly with T(h). As T(h) increases in number, so too do NWD(SV) and VT.

There are similar implications that apply both to the water evaporation strategy to counter heat and to the cluster's heating and insulation efforts in dealing with the cold. Both strategies are based on the spherical form of the brood nest, but while the latter depends on the size and shape of the population, the former depends on the number of evaporation units, in the form of deposited droplets of water in the brood comb, and on sufficient fanning to produce evaporation.

As the colony must produce a critical mass of cooling effects to offset the increasing heat inside the hive, the T(h). Here again also, it seems that the size and shape of the brood nest come into play. In his book "The Wisdom of the Hive"(1995) pg 212, Seeley mentions that the cooling activity takes place especially in the brood nest, which we found to resemble a sphere. I suspect, without corroboration, that as in the case of the cluster, it may be that the cooling requirements are such that the area of water deposit may go beyond the parameters of the brood chamber. The same principle is involved here: to achieve a critical mass for the purpose of either heating or cooling. A larger population can occupy more than the brood chamber, if it is available, to meet the challenge. In cooling, a critical mass of evaporation sites encompassing more than the brood chamber can counter a rising temperature.

III. Small colonies

Tom Seeley's wonderful book *Honeybee Democracy* (Seeley 2010) was a revelation to me because, in it, he discusses small colonies. It was a way to think outside the 'Langstroth' box. Picking up where Martin Lindauer left off, he returned to the study of wild hives. In upper New York State, Seeley found and cut down numerous feral colonies that had settled in hollow sections of trees. He was surprised to find that their populations were smaller than those of commercial hives he had most often been dealing with. By carefully measuring the volume of these tree hollows, he realized that 40L was the preferred choice of the scout bees searching for a site.

Although Seeley concluded that the preference for a space with that volume is related to the need of the bees to accumulate enough honey to survive the winter, I believe that it is also related to the need of the bees to have sufficient room for the critical mass of population to form a spherical cluster of adequate size. For example there could, theoretically, be a 40 L cavity with the right amount of honey, and the right population, but if it was spread out very thinly over a long stretch, not allowing a spherical shape, the cluster could not maintain the right thermal homeostasis. For the same reason, in warm weather, if the bees were unable to concentrate the water deposits in a spherical brood area, the cooling effects would be diminished.

How, then, do these two thermal homeostasis equations affect the observation hive? In both cases observation hives, because of space limitations, are lacking in crucial variables needed for homeostasis. In cold weather they prevent the concentration of a sufficient population in the form of a sphere to generate the necessary heat. In hot weather, also because of space limitations, they preclude the concentration of a sufficiently large number of water deposits to cool the hive.

Normally, if left alone, such hives would not survive seasonal temperature extremes. However, the beekeeper has an option to offset these problems: intervening in the in-hive temperature T(h).

A. Observation hives homeostasis in cold weather

As we have seen, the equation for homeostasis in cold weather is:

Homeostasis = P (SV) +F/T(h)

If P+SV and F are inversely proportional to T(h), then the higher the number for T(h) the smaller the sum of P(SV) and F need to be. Therefore, the more the beekeeper can intervene to raise T(h), the less important it is to the hive's survival to have a large population in a spherical cluster with a large food supply. And the less the need for a large, spherically clustered and well-fed population, the more viable an observation hive becomes. In other words, an observation hive is viable in cold weather even if the T(a) is very cold, as long as the beekeeper can sufficiently elevate the T(h).

I have found this to be true again and again. Year after year I have been able to winter over a very diminished hive, sometimes with a frame with one queen and just 200 bees. It had received all the outside cues. The queen stops laying, the bees that surround her live a long time (as evidenced by the very few bodies found on the bottom board), and brood rearing starts in late February to mid March. By June we usually have three, sometimes four, fully populated frames ready for the summer season.

This is as big as these hives get. The stabilizing structure has been removed. The entrance is hardly visible on the bottom.

B. Observation hives homeostasis in warm weather

In warm weather, the main danger for an observation hive is the colony absconding because of its inability to use the most efficient form of cooling: the third and last strategy, cooling by evaporation. In one instance in June 2004, without my being informed, contractors sanded the floor in the classroom where a hive was located. They left all the shades up in a south-facing room, while at the same time closing the bank of large windows and the door. The hive was in the full sun in a hot room. I do not know what temperature was reached, but when I returned the next day, all the bees were gone.

Besides this example, I have seen others that were less dramatic, but where, after the heating event, there were just a few bees left without a queen.

How does this play out with the formula? As we have seen, the equation for homeostasis in warm weather is:

Homeostasis = (NWD(SV) + VT) (T(h).

Since NWD(SV) + VT vary directly with T(h), the more T(h) is reduced, the smaller NWD(SV) +VT need to be, to the point where neither is necessary to maintain the required T(h) until they can take on a very limited shape or disappear altogether.

So, in the same way as in cold-weather homeostasis, if we modify the temperature of the hive, the T(h), we can achieve thermal homeostasis in hot weather. In warm weather, since the temperature varies directly with the cooling, the T(h) needs to be reduced.

In June 2009, Jenerra Williams, one of the teachers at the Mission Hill School in Boston, on a hot 80°F (27°C) day decided to aim a fan right at the brood nest of the observation hive in her classroom. This was a revelation to me. I realized that it was the way to modify the T(h) in an observation hive, by taking advantage of the natural conductivity of the glass to cool off the hive. One clear indication of success was that once the fan was on, the bees got closer together again on the frame to adjust and ensure the proper temperature for the brood.

Sometimes, if we get to the hive after the temperature T(h) has risen beyond 100°F to 102°F (38°C to 39°C) and there is too much frenetic movement inside, we will spray water on the glass of the brood frames, thus replicating the bees' own technique by evaporating the water on the surface of the glass. The T(h) then drops dramatically and the bees slow down.

To summarize: if we modify T(h) by bringing down the temperature when we place a fan directly in front of the frame(s) with the brood, then NWD(SV) +VT do not need to be so extensive, and the size and shape of the cluster can be altered so as to be viable in an observation hive. While an observation hive is subject to the same stresses in hot weather as other hives, because the T(h) can be made much lower, the observation hive can still continue to function as a very small viable colony even if the volume of water deposits and the ventilation have been greatly reduced.

IV. Conclusion. The observation hive as a permanent colony.

Thermoregulation affects the architecture of honeybee colonies. My own understanding of that fact enabled me to explain how, contrary to usual practice, my observation hives could last as long as they did.

It is true that we (the teachers I work with, and my friends) have not worked out all the details. In many respects, the way we use this technique is a bit like hammering a tack with a sledgehammer. For example, we do not know how much insulation to use. If a room is maintained at a constant temperature of 72°F (22.3°C), even with the cold, outside air coming in through the tube, do we need any insulation at all?

This is a close-up of the tube going to the outside, with a protective, see-through box over it. Photo: Jeff Murray.

In all our locations the room was not heated or was heated only during the day. Then again, we faced situations where the hive had to be set over a radiator and in fact was overheated in the middle of the winter. Were we maintaining the hive at a continuous in-hive temperature T(h) by using the insulation as a way to keep out the heat of the room, instead of insulating it from the cold? Alternatively, in warm weather, could it be that by constant cooling of the hive, we interfered with the collection and storing of nectar and pollen?

These are questions for further study. Right now, we have only a partial answer, but one which is just enough to achieve the goal of maintaining a small colony alive through temperature extremes.

By carefully controlling the T(h), a beekeeper can maintain an observation hive as a perfectly viable colony. It is true that managing one involves somewhat different tasks than a regular Langstroth hive, but these tasks are different, not more complicated. Although I have started and maintained many over the years using the principles of thermoregulation, scientific practice requires replication: that is, that others perform the same experiment separately to see if the same results occur.

I wrote a "how to" article on the subject of observation hives in the *American Bee Journal* in November 2009 (Murray ABJ, 2009, p. 1075) in which I made many recommendations, among them a method to add or take off the glass 'supers' without getting a single bee in the room, which makes it safe to use in a class or at home.

Incidentally, I note that in the 30 years that I have managed observation hives, I have always kept them in a lighted room, either from a window or artificial light from a bulb, always shielding them from direct sunlight. I have never seen any evidence that exposure to light stops the hive from functioning normally. It is true that bees are extremely phototropic, and that if you suddenly raise a window shade they will all, in one collective movement, move towards the source of light. But, after a while, once the source is a constant part of their environment, they will soon resume normal behavior.

In closing, even though we occasionally interfere with the hive by feeding, insulating, or cooling it, an observation hive is the closest we will ever get to see---in such great detail, and so continuously---a wild animal functioning in its natural environment. When, long ago, I first saw the bees dancing before my eyes in the Observation Hive of the Boston Museum of Science, it was so extraordinary to me that I wanted to find a way to make that experience available, everyday, to my children. I went about building one and putting it in my home. As the years went by, I came to realize that everyone would benefit if they simply had the opportunity to witness, in a familiar setting, one of Nature's great dramas, one that we are so seldom allowed to see. Starting and maintaining many small colonies is in itself a worthwhile pursuit when we are losing so many hives to so many different threats.

Now that you know that an observation hive can be viable year-round, why not set up one of your own? If anyone in New Zealand wants to replicate our experience, we are in the process of setting up a website: classroomhives.com that will have a lot of concrete information. We use a prefabricated observation hive from the Kelley Company of Clarkson, Kentucky, but instead of having to import an expensive item from abroad, it might make more sense to have someone from New Zealand make the same kind of hive on location. It is simply several boxes with 1/8-inch glass on each side, deep Langstroth frames, with the appropriate bee space, and a clear one-inch I.D. (interior diameter) tube leading to the outside.

I would welcome any requests for information on how to set up one of these hives. I can be reached at: jnj.murray@verizon.net.

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Working with bees is always a reminder that it is the collective effort that makes things work. I would like to mention my collaborators: Jenerra Williams for having been willing to take on this unchartered project for 10 years; Amina Michel Lord for her many contributions: documenting in the school newspaper the hive's activities and facilitating the work around it; Benadette Manning and Michele Goe for their work in making the hives officially a reality to the Boston School Administration; Benadette again for teaching me through her Trigonometry class, the mathematical issues relating to the hive; Noah Wilson-Rich for our many conversations about apiculture and his sound advice; and Dave Slaney, Lesley Cohen, Nancy Fithian and Stefan Economou, my editors, who had so much to do with making this article readable and clear.

Footnotes

1. " … The cluster moved sideways and down into the center body then it returned to its original location. Apparently it moved to obtain honey. This demonstrates how a strong colony can move its stores under low temperature conditions. Weaker colonies might starve with honey in the frame next to the cluster, because the bees are unable to generate enough heat to let the cluster spread over additional comb."

2. "The 5-year tests of the check colonies showed that stronger colonies changed cluster location and size more than did weaker colonies. Weak clusters could not generate sufficient heat to move even during mild winter temperatures in Wisconsin."

3. Morse (p. 473) states, "Colonies were exclusively in single Langstroth supers. Both 8 and 10 frame supers were satisfactory. A colony in a single super needed 45 pounds of honey from the end of the fall season until the start of the active season in the spring. However, if the colonies were wintered over in a cellar and removed in late March, they needed only 15 to 29 pounds of honey during the time they were

actually in the cellar."

4. Morse (p.473) states, "… The information we do have suggests that bees removed from the cellar in late March had little or no brood. This also implies that winter brood rearing is stimulated by an increasing day length after the winter solstice".

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Appendix 1

Edward Southwick writes, "The clustering phenomenon itself precipitously reduces surface area for heat exchange from the sum of the surface areas of individual bees down to the outermost surface area of the cluster. Simplifying he shape of the single bee to a cylinder, to 1.4 cm in length and 0.4 in diameter, would yield a surface area of about 1.76 cm^2. A colony of 20,000 individuals not tightly packed would have a total assumed surface area for heat exchange of about 35,186cm^2. Individuals in the central area of even a loose colony would not be exposed to air temperature as cool as those at the extremity. However, tight clustering could reduce the effective area of heat exchange to a minimum 4189cm^2 (for a spherical cluster with a diameter of 20cm) a reduction of 88%. Heat loss is minimized at colder ambient temperature by reduction in cluster size".

Appendix 2

Steven Taber and Charles Owens write, "Embryo colonies of honeybees of several populations were started in separate 1·2-m^3 wooden boxes in the spring of 1966 and 1967 at Tucson, Arizona, for no longer than 24 days. Each separate unit contained a laying queen. The wooden boxes were constructed of 1·9-cm plywood and designed so any side could be swung open to examine the bees. A 1·9 x 10·2-cm entrance into the box was made in the middle of one side, and two 2·5-cm holes were drilled to one side of the entrance, one above and one below, to provide more ventilation and ports for bee flight. The entrances to the boxes were faced in various directions so we could determine the effect of port direction on comb orientation. Also, a round platform was mounted above the floor of the box on a vertical pole placed in the center of the box to furnish additional clustering sites. No inducements were added (i.e. pieces of comb) to encourage the bees to cluster. After 24 days, the bees in each colony were killed and counted. This period was selected based on an assumed life span of 40 days so only the work of the original bees would be measured.

The colonies formed by the bees in this study are representative of initial development of colonies in nature with some queen less some in multiple clusters, and some that build comb in what will prove to be unsatisfactory or impossible conditions. The statistical analysis of the dimensions of thirty-two colonies suggested that these dimensions are relatively consistent. The hypothesis, tested by the analysis of variance, is therefore advanced that *the ideal shape for embryo colonies of bees is a sphere.* For such a shape, the correlation of weight to height, height to length, and width to height should be positive and significant for all population groups. In our test, of the twelve correlations (omitted because of length), seven were positive and five were negative, but only one difference was significant at the five per cent level of confidence."

Appendix 3

Christopher Mathis and David Tarpy write, "Like most organisms, honey bees have a smaller range of heat tolerance above their optimum temperature (35°C)(95°F) than they do below. In fact, the upper limit for unaffected brood development and adult activity is between 38°C and 39°C (100°F and 102°F). Consequently, cooling the hive during the summer is of primary importance to the welfare of the colony. Nonetheless, recent thermal imaging research by Human et. al. (2006) has shown that a colony can maintain brood nest temperatures at a near constant 35°C (95°F) while outdoor temperatures ranged from 3.7°C (38°F) to 30.7°C (87°F), and they can even do so indefinitely at ambient temperatures of 50°C (122°F)! A honeybee colony can achieve this extraordinary consistency primarily by active ventilation and evaporative cooling.

> When overheating threatens, the bees move farther apart on the combs and start to fan their wings, thereby cooling the hive interior through forced convection. If these measures prove inadequate, and then they will spread water, especially within the brood nest, for evaporative cooling. Water is spread in small puddles depressions on the capped cells containing pupae, as thin layers over the roofs of open cells containing eggs and larvae, or as hanging droplets in these cells. Water may also be rapidly evaporated through "tongue-lashing" whereby bees hang over brood cells and steadily extend their tongues back and forth. Each time a bee does this it expresses a drop of water from its mouth and pulls the droplet between mandibles and tongue into a thin film that has a large surface for evaporation. These various ways of using water for nest cooling can be referred to as "water spreading". (Seeley, 1995 pp. 212–213)

As previously stated, worker bees forage for four items necessary for hive survival: plant nectars (which are converted into honey), pollen (a protein source), propolis (a construction adhesive and sterilizer), and water. Water, either collected by itself or in the form of dilute nectar, plays a key role in summertime hive thermal management.

As outdoor temperatures rise beyond hive comfort desires, workers will ventilate hot air from the hive through active fanning. Bees throughout the hive will take up fanning positions to move air across the honey stores (to dry the water out of the honey) as well as to control brood nest temperatures. Bees will reposition themselves during these ventilation periods to dry out or cool specific areas of the hive. These ventilation paths move air across the hive as well as up through the hive.

Honey bees collect water for two reasons—thermoregulation of the brood nest and nutrition of immature bees. Worker bees will change jobs during periods of extremely hot weather in response to a need for additional water and hive cooling. As temperatures continue to rise, the colony will begin to increase water intake (usually by pollen foragers switching to water collection). They may take stored or just collected water to spray in the hive as they fan, causing evaporation of the water and resultant hive cooling.

One final means of (passively) reducing hive temperature is by removing internal heat sources; that is, the adult bees themselves. Increased hive temperature will cause the adult workers to either move to less crowded regions of the nest, or even outside of the hive. Indeed, bees will often form a ‘beard’ below the entrance of the hive, particularly when they do not have temporary access to a fresh water source (such as during the night) or when the ambient relative humidity is high (so that evaporative cooling is less effective)”.