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Differential thermal regulation of the growth of the bee colonies in the early spring period

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Abstract. This paper addresses the issue of the control of activity and growth of the bee colonies (brooding) in the early spring period. The bees are brooding up already in the late winter, and the intensity of brooding in this period is determined by daytime temperatures and sunshine hours that increase the temperature of the inner hive space. The objective is to design and verify a technology that would ensure the conditions for the optimal brooding in the early spring period and thus the numerically strong bee colonies. The experimental part was based on the temperature regulation in the inner hive space. A preset temperature was maintained inside the hive by an electric heating system with regulation. A differential thermal regulation which enabled the optimal growth of the bee colonies in accordance with the phenophases was chosen for verification. To verify the proposed method, two groups of the bee colonies were assembled. One group of the bee colonies had a heating system with regulation installed inside the hive. The second group of the bee colonies was in the hives without the heating system installed. The dependence of the brood area on time was monitored for the evaluation of both groups of the bee colonies. It was proven that the differential thermal regulation enables the optimal growth of the bee colonies in the early spring period in accordance with the phenophases. The brood area increased evenly for the group of the bee colonies with a regulated temperature of the hive space, reaching a larger area.

Key words: bee colonies development, brood area, hive thermal regulation.

INTRODUCTION

This paper addresses the issue of the control of activity and growth of the bee colonies (brooding) in the early spring period in commercial beekeeping. For commercial beekeeping, the early spring development is a prerequisite for gaining numerically strong bee colonies and efficient beekeeping with high production capability. The objective is to design and verify a technology that will ensure the conditions for the optimal brooding in the early spring period and thus the numerically strong bee colonies in the main production period. The optimal brooding conditions were simulated by the regulation of the temperature inside the hive. The experiment was focused on the locations with less appropriate climate conditions (low number of sunshine hours in the early spring period and altitude above 500 metres).

Intensive agriculture is increasingly dependent on commercial beekeeping. Beekeeping ensures honey production and pollination of agricultural crops by commercially provided service (Williams, 1994). It is estimated that in case of cross–pollination plants the bees participate in 80–90% increase in yield (Aizen et al., 2009). For agricultural crops such as winter rape, fruit orchards or clovers, yields are increased by 30–50% by bee pollination in comparison with the self–pollination (Klein et al., 2007). The effectiveness of commercial beekeeping is thus determined by the seasonal yield of honey and the ability to maximally pollinate agricultural plants (Gallai et al., 2009). In both cases, the effectiveness of the beekeeping is directly impacted by the number of bees that ensure nectar collection and thus pollination of plants.

In the main production period, a strong bee colony has more than 50–60 thousand bees (Jaffé et al., 2010). In order to achieve this population density, the optimal development (brooding) in the early spring period is necessary (Seeley, 1985). Brooding is the ability to lay eggs by the queen. In the early spring period, the development of bee colonies is influenced by several factors. Intense brooding capacity is affected by the health condition of the queen and the bee colony, supply of pollen, honey, and climate conditions (Herbert & Simanuki, 1978). In a broader sense, the intensity of the early spring development depends on the successful overwintering of the bee colony and on the climate conditions during the early spring (Eckert et al., 1994). Climate conditions are a significant factor influencing bee colony development during the early spring period. The bees are brooding up already at the end of the winter and the intensity of brooding during this period is determined by daytime temperatures and sunshine hours, which increase the temperature of the inner hive space.

Overwintering of bees and its influence on the early spring development

Overwintering is a perfectly developed physiological ability of bees. Successful overwintering is not impacted directly by the climate conditions. The basic factors influencing the success of overwintering are the bee colony's health conditions and sufficient food supplies. Climate conditions only influence the activity of winter cluster (its expansion and shrinkage depending on ambient temperature) and have a direct impact on the consumption of food supplies (Matilla & Otis, 2006). At stable nonfluctuating temperatures, the bee colony is calm (inactive) and the consumption of supplies low (Kronenberg & Heller, 1982). On the contrary, with significant temperature fluctuations or during a long above average temperature winter period, bee activity is increased and leads to higher consumption of supplies (Jones et al., 2004).

In commercial and hobby beekeeping, a technology of brooding in the insulated hives is expanded. The insulated hives eliminate (offset) the impact of climate changes on the hive temperature. From this point of view, the technology of the beekeeping in the insulated hives has an impact on the overall consumption of the supplies in the winter (Stabentheiner et al., 2010). It has therefore an economic importance. On the contrary, in the early spring and spring period, the insulated hives prevent the increase of the daily temperature inside the hive and has a direct impact on the slower development of the bee colonies in the early spring period (Severson & Erickson, 1990).

Climate conditions and their impact on the early spring development

The life cycle of the bee colonies and their activity in each season is closely related to plant phenophases and climate conditions. Climate conditions and hence plant phenophases do not occur every year the same way. Plant phenophases may show a certain shift in time against the calendar period (Gordo & Sanz, 2006). Even in areas between which there is no great distance, there may be major differences due to, for example, altitude or differences between the open country and the urban area. Central Europe is characterized by great climate diversity. During the spring development, cold and above average hot periods can occur. Vegetation responds to fluctuation between cold and hot periods by slowing or accelerating its development, but nectar production in its amount remains usually the same. Only the phenophases of the flower change. The bee colonies can easily cope with the fluctuations in cold and hot periods during the early spring period, but the cold periods reduce the activity of brooding and thus such bee colonies enter into the main production period (to main brooding) with the lower population density (Todd & Reed, 1970). Such bee colonies have lower production capacity.

MATERIALS AND METHODS

The experimental part of the work was based on the measurement of the activity of the early spring development of the bee colonies in dependence on the changing temperature inside the hive. To verify the procedure whether it is possible to influence the early spring development of the bee colonies, ten bee colonies were monitored. The bee colonies were divided into two groups of five bee colonies. The first group of five bee colonies (group A) was in the hives without the heating system and the natural development was retained throughout the experiment. The second group of five bee colonies (group B) was equipped with the heating system inside the hives. The heating system has increased the temperature of the inner hive space by a set value. The difference in the early spring development was continuously monitored in both groups of bee colonies by the measurement of the brood area. The whole experiment ran from 23 January 2017 to 31 March 2017. The experiment included bee colonies with an equal quantity and comparable supply of glycid and pollen. The term 'glycid' supply means the sum of the original winter supply and the honey added by the insertion of the honeycombs at the beginning of the experiment.

Construction of hives and their location

All bee colonies (group A and B) were in constructively identical hives. The hives were double–spaced, not insulated all–wooden construction with an insulated cap. The size of the frames 240 x 390 mm. The hives were located in the area with the altitude 520 metres. They were located in an open agricultural landscape. The position of the hives was set so that the front side headed south into the open landscape (i.e. all day sunshine exposure of the hive) and from behind they were protected against the northwest winds by the forest. All hives were fitted with two temperature sensors. The location of the sensors was the same for all hives (one sensor near the inner side wall and the other near the inner back wall) so that they were out of reach of the winter cluster. Both sensors were located about 200 mm under the insulated cap. The sensor on the side wall was located between the first and second frames, i.e. about 40 mm from the inner wall, the second sensor was located also about 40 mm from the inner back wall. In the group B bee colonies, the heating system connected to a programmable control unit was installed. The heating system was placed on the bottom board of the hive.

Heating system and programmable control unit of thermal regulation

The diagram of the heating system connection and the programmable control unit is shown in Fig. 1. The heat source was an electric heating system (1) located on the bottom board (2) of each hive of the group B (3). In the hives of the group A (4), the heating system was not installed. The heating system (1) consisted of two commercially produced heating plates Solar TF03 of size 320 x 1,236 mm connected consecutively. The total heating area then had a dimension of 320 x 272 mm. The rated output of the heating system was 2 x 36 W. The heating system (1) was supplied with pulse voltage via the programmable control unit (5). A 24 V safe voltage source was used for power supply (6). The heating system of this design has been chosen with regard to both construction and operational simplicity (easy manipulation, maintenance, low purchase costs, no need for adjustment of the hive for use). Switching on the heating system was ensured by the Siemens Desigo PXC36 programmable control unit (5). Siemens Desigo PXC36 is the freely programmable control unit designed for controlling and regulation of the technical equipment of buildings (heating, ventilation and air conditioning of buildings). Temperature sensors Siemens QAP22 (7) were used as temperature sensors in both inner and outdoor hive spaces. The sensor for the measurement of the outdoor temperature was placed in a sealed plastic box (wind protection) located under the hives (sunshine protection).

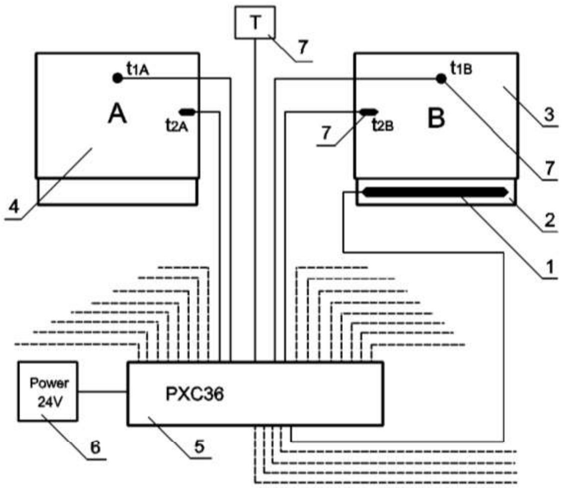

Figure 1. Diagram of the heating system connection and the programmable control unit: 1–heating system; 2–bottom board of the hive; 3–hive of the group B; 4–hive of the group A; 5–programmable control unit; 6–power supply; 7–temperature sensors.

Adjustment of the programmable control unit and measurement methodology

The setting of the programmable control unit was accomplished so that the heating system installed in the group B bee colonies simulated by its thermal power and time switch the thermal power of the solar radiation, which would fall on the walls of the hive during sunny day. This setting should ensure the basic condition for successful verification of the proposed procedure. The heat supplied by the heating system into the hive must increase the activity of the bee colony, encourage the brooding, but at the same time there must be no discrepancy between the increased activity of the bees and the phenophases of vegetation in the given locality.

The solar radiation simulation was determined by the operating time and heat power of the heating system and was performed only during the early spring period from 23 January 2017 to 31 March 2017 for the group B bee colonies. The programmable control unit switched on the heating system daily between 9 am and 3 pm. The temperature at which the inner hive space was warmed up during this time interval was set to be 5 °C higher than the average temperature of the same hive at night between 9 pm and 3 am. At the same time, the heating system was put out of operation once the inner hive space temperature reached 10 °C. The average night temperature was evaluated by the programmable control unit on the basis of the values measured by the temperature sensors located inside the hive. With this setting of the programmable control unit, it was ensured with an acceptable error that the bee colony was exposed to the natural climate conditions in the given locality for a substantial part of the day (between 3 pm and 9 am). The temperatures at which the inner hive space was warmed up between 9 am and 3 pm followed the changes in the outdoor climate conditions, their development during the whole early spring period and corresponded to the phenophases of the surrounding vegetation.

Methodology for the monitoring of the early spring bees development

Bee colonies activity was evaluated by the size of the brood area on the honeycombs. A commonly used measurement method so–called frame grid was used to evaluate the brood area. By the frame grid, the brood area is measured in dm^2, therefore this unit is used in the following text. The measurement was performed irregularly with an interval of approximately 14 days. The irregularity of the measurement interval was due to two reasons: the requirement for optimal climate conditions for measurement (windless sunny day, outdoor temperature at least 8 °C) and the requirement for minimal disturbance to the bee colony.

RESULTS AND DISCUSSION

The suitable climate conditions to conduct an early spring control of the bee colonies overwintering occurred on 23 January 2017. All monitored bee colonies were checked for glycid and pollen supply, their health conditions were assessed subjectively, and the initial values of the brood areas were recorded, see Table 1. In the hives from the group B bee colonies, the heating system was put into operation and the programmable control unit was set up. In the following period, the brood area was measured at approximately 14 day interval (whenever appropriate climate conditions for the opening of the hives occurred). The brood area was measured in all five bee colonies from the group A (A1 to A5) as well as the group B (B1 to B5). The measured values are recorded in Table 1. The programmable control unit continuously recorded the average outdoor temperatures, the average temperatures of the inner hive space of the group A and B bee colonies, and the maximum temperatures of the inner hive space of the group A and B bee colonies.

The growth of the brood area in the monitored period is shown in Fig. 2. To create a chart, the average brood areas in the monitored period were used, see Table 1. The exponential trendline was used to plot the dependence of the growth of the brood area on time as it most closely reflected such dependence. Correlation reliability for dependencies was above 0.95.

The brood area grew faster in the group B bee colonies during the monitored period, where the daily temperatures of the inner hive space were increased by 5 °C compared to the average night temperatures of the inner hive space. As shown in Fig. 2, at the end of the monitored period the total brood area of the group B bee colonies reached approximately double the values of the group A bee colonies, where the daily temperatures of the inner hive space were not increased by the heating system. Thus, the plotted course on dependency of the both groups of bee colonies indicate that the growth of the brood area is temperature–dependent.

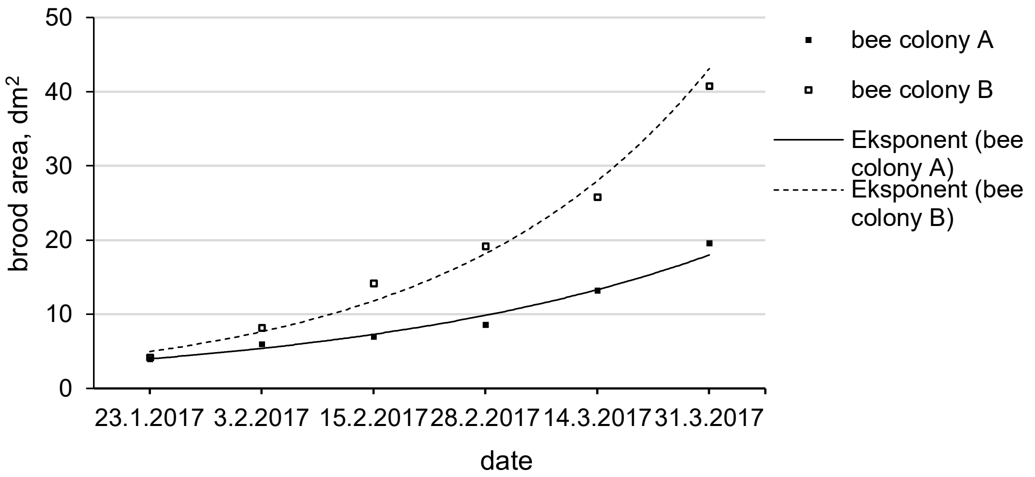

Figure 2. The brood area in the monitored period.

Table 1. The brood area of each bee colony in the monitored period

	Brood area, dm^2					
	23.1. 2017	3.2. 2017	15.2. 2017	28.2. 2017	14.3. 2017	31.3. 2017
Bee colony A1	3	6	7	9	12	20
Bee colony A2	4	7	8	9	13	19
Bee colony A3	5	6	7	9	13	18
Bee colony A4	4	6	7	8	14	21
Bee colony A5	4	5	6	8	14	20
The average brood area of the group A bee colonies, dm^2	**4**	**6**	**7**	**8,6**	**13,2**	**19,6**
Bee colony B1	5	7	13	18	28	44
Bee colony B2	4	9	14	19	26	40
Bee colony B3	5	8	15	20	25	36
Bee colony B4	3	8	14	18	26	42
Bee colony B5	4	9	15	21	24	42
The average brood area of the group B bee colonies, dm^2	**4.2**	**8.2**	**14.2**	**19.2**	**25.8**	**40.8**

During the experiment the condition of equal glycid and pollen supply was fulfilled. At the same time, all monitored bee colonies were numerically balanced and were in the equal health conditions based on the subjective assessment. The only objective variable was the hive temperature. The temperatures at which the inner hive space of the group B bee colonies were warmed up were not constant throughout the experiment, but reflected the changes of the outdoor temperatures. As outdoor temperatures gradually increased during the upcoming spring, the temperatures in the hives increased as well. Once the temperature of the inner hive space reached 10 °C, the heating system was disconnected. After disconnecting the heating system, the higher temperatures of the inner hive space could only be achieved in a natural way (as a result of external climate conditions). These climate conditions affected both groups of the monitored bee colonies the same way, i.e. the temperature above 10 °C was in this case also in the inner hive space of the group A bee colonies. This condition occurred during some warm days at the end of the monitored period (March).

Nevertheless, for the group A bee colonies, the size of the brood area was delayed behind the group B bee colonies. It can be estimated that the brood area depends not only on the temperatures reached but also on the length of the period with balanced optimal temperatures for the growth of the brood area. Although the programmable control unit in the group B bee colonies in the second half of March regularly switched off the heating system (higher temperatures above 10 °C were reached naturally) and thus the conditions were equal for both groups of the bee colonies (A and B), the group B bee colonies showed almost twice larger brood area.

In Fig. 3 the temperatures that were measured during the bee colonies' monitoring are plotted. The measured average outdoor temperatures, the average temperatures of the inner hive space for both groups of the monitored bee colonies (A and B) and the maximum inner hive space temperatures for both groups of the bee colonies are plotted. The average outdoor temperatures as well as the average temperatures in the inner hive space were calculated using the method of the hourly measurement. Measured temperatures (average outdoor, average inner hive space and maximum inner hive space) for each day of the monitored period represent a considerably large set of data. Therefore, measured temperatures are not listed in a separate table, but are only plotted as the points in Fig. 3. The average outdoor temperatures are plotted as a stacked line precisely displaying temperature fluctuations in the monitored period. The average and maximum inner hive space temperatures are for greater clarity plotted as a trendline. The exponential course of the trendline with a correlation greater than 0.95 was used for the plot.

From the plotted average temperatures of the inner hive spaces for all bee colonies of the group A and group B is clear that they have a similar course but different values of average temperatures in the monitored period. The average temperatures of the inner hive spaces in the group B bee colonies (equipped with the heating system) were on average 0.9 °C higher. It can be concluded that in the absence of the 0.9 °C measured average temperature difference, the group B bee colonies was exposed to similar climate conditions as the group A bee colonies (without the heating system) during the monitored period and developed in accordance with the phenophases of the surrounding vegetation. This assumption is based on a similar course of the average temperatures of the inner hive space of the both groups of bee colonies. Thus, the heating system had little impact on the average inner hive space temperature and had no influence on the achieved temperature course. The difference in the average inner hive space temperatures of an average value of 0.9 °C is unlikely to significantly affect the activity of bees and the growth of the brood area during this period. However, as shown in Fig. 2, all of the group B bee colonies monitored showed the growth in the brood area. The reason for this growth will not be average inner hive space temperatures but fluctuation in daytime and nighttime temperatures. This would correspond to the course of the measured maximal temperatures of the inner hive space.

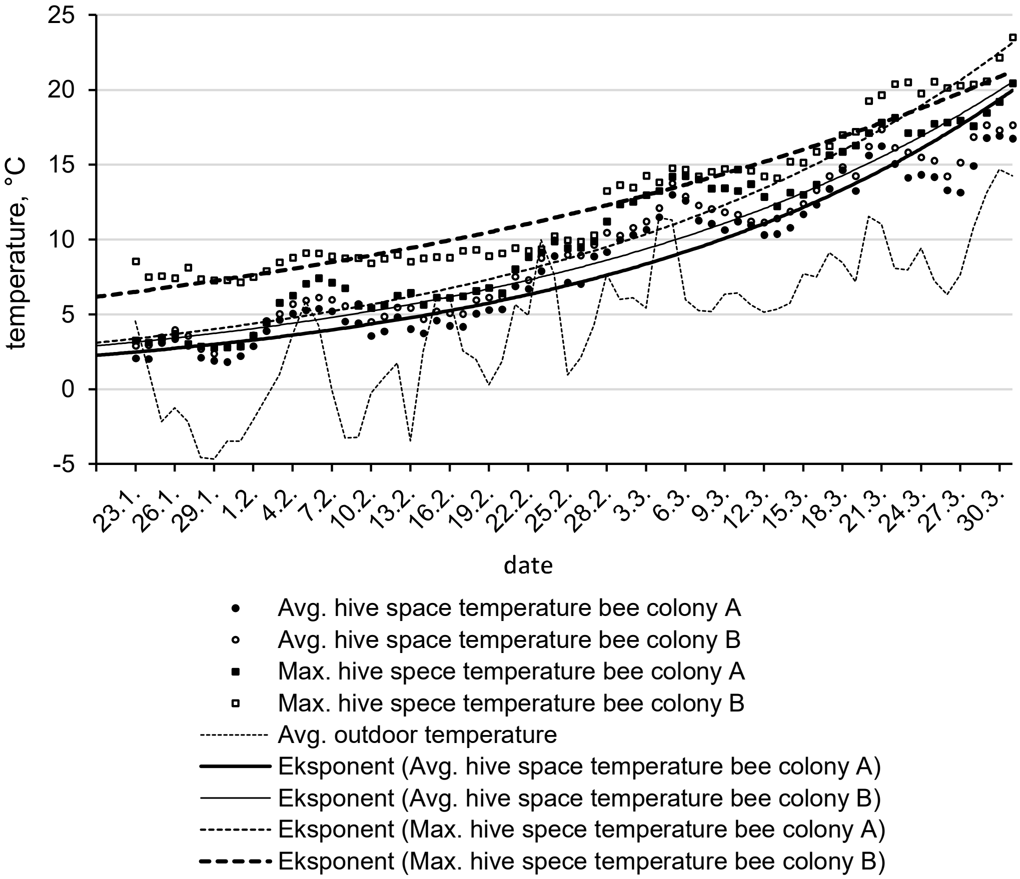

Figure 3. Temperatures measured in the inner and outdoor hive space.

The maximum temperatures' course of the inner hive space is also plotted in Fig. 3. At the beginning of the monitored period (January, February), the differences in the maximum temperatures were reached by the heating system setup and in the group B bee colonies reached values higher up to 5 °C. At the end of the monitored period (March), as with the average inner temperatures, the difference gradually decreased. It was again a result of the rising outdoor temperatures, which were the signal to disconnect the heating system. It can be assumed that the difference in the maximum achieved temperatures within the inner hive spaces between the bee colonies of both groups is the factor that influences the activity of the bee colonies and affects the growth of the brood area.

CONCLUSIONS

The result of the experiment is the design of differential thermal regulation technology of bee activities. The design of the technology is based on the increase of the daily temperatures of the inner hive space to simulate the climate conditions of sunny days (thermal power of solar radiation). During the early spring period, the outdoor temperature varies greatly in sunny days. This is manifested by the great difference between daytime and nighttime temperatures. Simulating the effect of solar radiation by raising the temperature in the hives means increasing the temperature of the inner hive space during the day, but allowing natural climate conditions to occur at night. The bees are considered to be thermosensitive organisms. It can be assumed that they will actively respond to the maximum daily temperatures that simulate solar radiation. The proposed technology, its technical design and experimental verification confirm this assumption.

The realization of the experiment confirmed that the early spring bee development, as measured by the growth of the brood area, is temperature dependent. By the differential regulation of the temperature of the inner hive space was at the end of the monitored period for the group B bee colonies (with a heating system) achieved about twice the size of the brood area in comparison to the group A bee colonies, where the daily temperatures of the inner hive space were not increased by the heating system. From a detailed analysis of the measured temperatures of the inner hive spaces of the two monitored groups of bee colonies (A and B), it is obvious that the average hive temperatures have a similar course in the monitored period, but different values of the average temperatures reached. The difference in average temperatures in the inner hive spaces was about 0.9 °C. Such a small difference is unlikely to significantly affect the activity of the bees and the growth of the brood area during the early spring period. The reason for increased activity of bee colonies and the growth of the brood area will not be the average temperatures of the inner hive space but fluctuations in daytime and nighttime temperatures. This would correspond to the course of the measured maximum daytime temperatures of the inner hive space, where the differences between the group A and B bee colonies were about 5 °C. It can be assumed that the difference in the maximum achieved temperatures within the inner hive spaces between the bee colonies of the two groups is the factor that influences the activity of the bees and affects the growth of the brood area.

Based on the proven results, the technology of differential thermal regulation of bee activity can generally be considered as an operationally efficient technology. The technical design of the proposed technology is structurally simple and has demonstrated high technical and technological reliability under operating conditions.

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