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Original article

The Effect of Months of the Year, Recorded by a Smart Bee Device, on the Temperature and Relative Humidity of Beehives and Broods

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Abstract

Threats from different origins are affecting agriculture in general and beekeeping in particular. Climate change, diseases, the use of pesticides, insecticides, thefts and genetic erosion due to random crossing of exotic and native strains. Internet of Things (IoT) devices have found many applications to reduce these threats, including the honeybees sector. They consist of embedded sensing, computing, and communication devices, connected to the Internet through specific lightweight messaging protocols. A “SmartBee+ Device”, developed by Beekeeper Tech (www.smartbeekeeper.com) was used and honeybees information have been gathered during three years period 2020-2021, from over 100 in-field beehives. Each beehive was set up at a different location in Tunisia, France and New Zealand. A SmartBee+ device connects to one beehive and operates in several modes: the Monitoring mode, the Transhumance mode, the Tracking mode, and the hibernate mode. Two embedded sensors and two external sensors measured the hive’s main parameters: The inner beehive's temperature and relative humidity and the Brood's temperature and its relative Humidity. In addition, the hive's location is recorded with a GPS module. A total of 51444 and 50671 temperature and relative humidity records from the hives and 8756 records of the temperature and relative humidity at the brood level were used in this study, analyzed and results presented and discussed. Main results showed how honeybees workers mitigate the heat burden at the brood level by increasing their temperature till 7°C in winter and decreasing the brood temperature by 8 °C in summer hot months. Breeding values of queens, based on their endothermic mechanism trait, can be predicted to improve their ability to cope with extreme temperatures and select well-adapted strains. These improvements will affect positively the majority of small beehives keepers in the world by reducing the loss of their colonies.

Keywords: Honeybee, Iot, Temperature, Relative Humidity, Hives.

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INTRODUCTION

Since ancient times, beekeepers around the world have continued to value a diversity of bee breeds. In addition to their production of honey and its derivatives with known virtues, bees as pollinators contribute to natural balance, food security, and sustainable development. The majority of honeybees are European strains of *Apis mellifera*, which is, also, indigenous to Africa and the Middle East [1]. It is estimated that more than 20,000 species of bees exist worldwide [2].Today there are more than 94 million beehives in the world. They were 80 million units in 2010. They cover traditional and modern farms and harbor multiple honey flavors linked to a very rich and varied traditional knowledge. The top honey producers in the world are Asia, followed by Europe, North America and Central America. World trade is dominated by China as the leading exporter of honey and Europe as the leading importer [3]. North Africa was not only the "granary" of Rome but also its "honey tank". All countries have entered a competition for its control through product diversification, productivity, profitability and scientific and technological innovation. This global phenomenon is taking place at a time when threats from different origins are affecting agriculture in general and beekeeping in particular. Climate change results in prolonged droughts or floods when it rains, diseases, the use of pesticides and insecticides and thefts. The low productivity of developing countries' native animal genetic resources, including honeybees, is not only a result of poor management, lack of feeding resources or climate change. It is, also, due to the absence of reliable specific Breeding Strategies. Unfortunately, animal breeding experts are not involved in the decision-making when livestock policies are developed and the science of animal genetics is usually confused with Artificial Insemination. The objectives of this study were to ;1) describe developed sensors for beehives and colonies and 2) to show the effect of months of the year on the temperatures and humidity parameters measured at beehives and colony levels.

MATERIAL and METHODS

Beehives recording system setup

The beehives recording system is based on Internet of Things (IoT) devices. They consist of embedded sensing, computing, and communication devices, connected to the Internet through specific lightweight messaging protocols. IoT devices have found many applications, including agriculture, Smart grid and energy saving, Wearable technology, Health Care, and Smart Cities Many bee monitoring systems are reported in the literature [4]. It is clear, however, that almost all the scientific experiments and papers were made using a very limited number of connected Beehives, during a short period. Also, there is no research yet made regarding the bee brood behavior. Data, in this work, have been gathered during three years period 2020-2021, from over 100 in-field beehives. Each beehive was set up at a different location in Tunisia, France and New Zealand. A "SmartBee+ Device", developed by Beekeeper Tech (www.smartbeekeeper.com) was used to record temperature and humidity information. Two embedded sensors and two external sensors (Figure 1) measured the hive's main parameters: The inner beehive's temperature and relative humidity and the Brood's temperature and its relative Humidity. In addition, the hive's location is recorded with a GPS module.

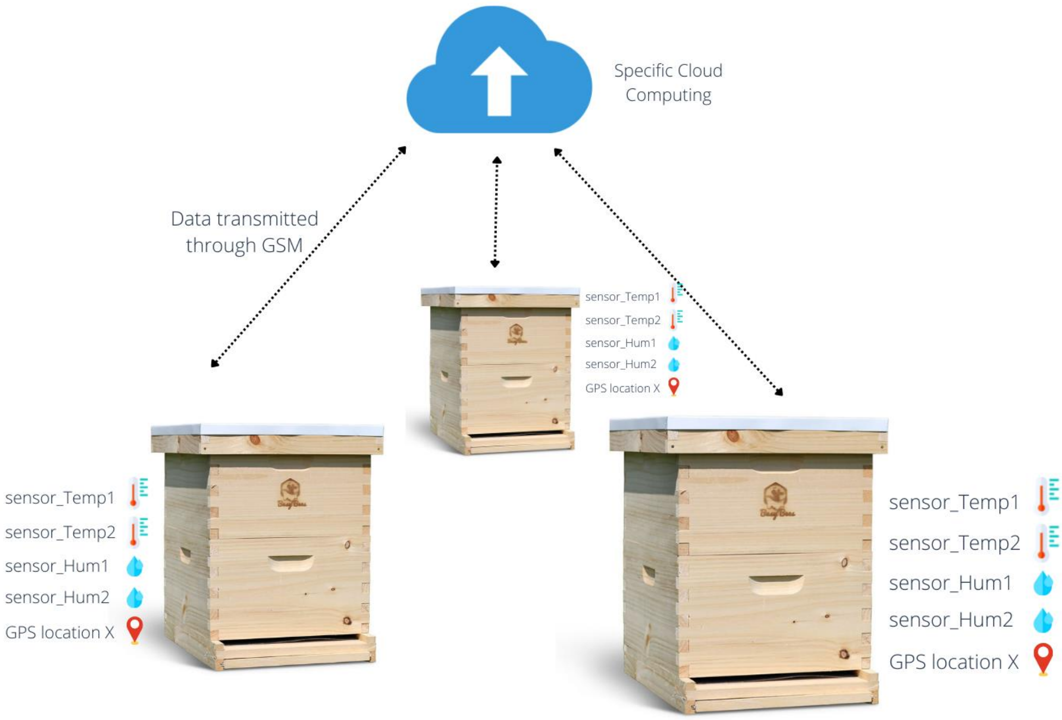

Figure 1. Data transfers from the hives to the cloud.

The SmartBee+ Device was used to support a variety of sensors network architecture as shown in figure (2). The device uses the 2G Network to relay results to Amazon Web Services (AWS), which is the world's most comprehensive and broadly adopted cloud platform. A SmartBee+ device connects to one beehive and operates in several modes: the Monitoring mode, the Transhumance mode, the Tracking mode, and the hibernate mode. The Monitoring mode is the standard mode where the device reads and records the beehives' measurements with a predefined frequency, initially set up to 4 times per day, every 6 hours. When the 4 readings are successfully done, all the data will be transmitted to the cloud in 30 seconds. Between readings, the hibernate mode will be automatically activated to ensure an ultra power saving. All the device's functionalities are shut down except the motion sensor. When this sensor is triggered intentionally, the Tracking mode is automatically activated and the GPS is activated for 10 minutes. If the sensor still detects a movement, the tracking mode will rest. The Transhumance mode is used to program a hibernation for a specific period of time. As energy performance is a critical parameter for in-hive devices. SmartBee+ uses an Ultra-low-power STM32L151RET6 microcontroller and it's powered by a Lithium 5000mAh battery. In a standard mode, the lifetime battery is around 8 months without charging. Since the most available network, worldwide, is the 2G/3G/4G Network, the device uses the 2G network for maximum reliability in rural areas. The communication protocol selected is the *MQTT*

(Message Queuing Telemetry Transport) which is an OASIS standard messaging protocol for the Internet of Things (IoT) and It is designed as an extremely lightweight publish/subscribe messaging. Data gathered with the SmartBee+ Device are transmitted using MQTT protocol to the AWS IoT portal which is a managed cloud service that lets connected devices easily and securely interact with cloud applications. Most of the SmartBee+ Computing processing is made using AWS Lambda, which is a serverless, event-driven compute service that lets you run code for virtually any type of application or backend service without provisioning or managing servers. Once the data is processed, it will be stored in the Amazon *DynamoDB* database which is a fully managed, serverless, key-value NoSQL database. This serverless architecture is the most secure and scalable, and low-cost clouding architecture, designed by Amazon for IoT applications.

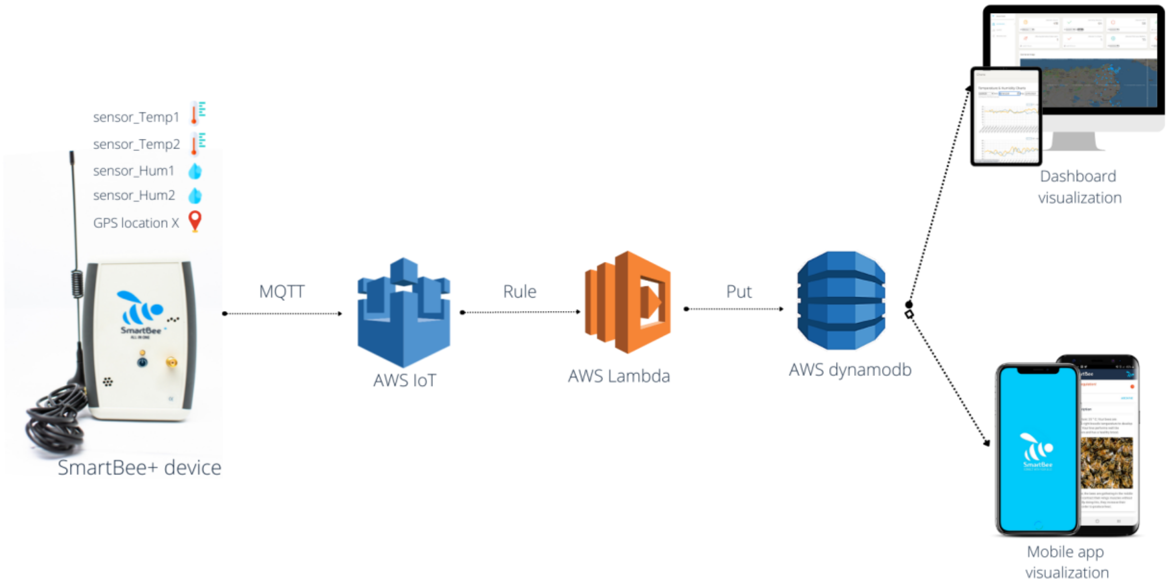

Figure 2. The Transmission and Clouding architectures

Data analyses

Temperatures and Relative Humidity (RH) information, within beehives and at the brood level, were recorded through SmartBee+ devices during the period 2020-2022. A total of 51444 and 50671 temperature and relative humidity records from the hives and 8756 records of the temperature and relative humidity at the brood level were used in this study. Proc Univariate of SAS first checked the distribution of the temperature and relative humidity variables. All distributions presented two peaks, meaning a normal distribution with two modes. When data from hives established in Tunisia were analyzed separately from data from France and New Zealand, the normal distribution with one peak was found. This distribution situation may indicate that the original data included two groups of hives or bees. A total of 78 beehives and 38 beekeepers remained in the edited final database with 42738, 42240, 6507 records for within hives temperature, relative humidity, and brood temperature and relative humidity, respectively. Proc Means of SAS were used to compute means and variation of all measured variables. The linear model (1) was used to estimate the effect of the beekeeper management, the month effect and time of recording on temperature and humidity variables within hives.

$$y_{ijkl} = \mu + uyd_i + m_j + t_k + e_{ijkl} \quad (1)$$

Where y_{ijkl} is the temperature and the relative humidity within the hive; μ the population mean; uyd_i is the effect of the beekeeper-the year-the day class which translates " the beekeeper management" on measured variables; m_j is the effect of the month; t_k is the effect of the time when the record is taken and e_{ijkl} is the residual error. All factors in the model were fixed effects, except the residual error which was random. Model (2) was used to estimate the effect of the beekeeper management, the month effect and time of recording on temperature and humidity variables at the brood level. Model (2) used the temperature and the relative humidity within the hive as covariates.

$$y_{ijkl} = \mu + uyd_i + m_j + t_k + b1 * T + b2 * H + e_{ijkl} \quad (2)$$

RESULTS and DISCUSSION

Sources of variation of temperatures and RHs

Sources of variation are in table (1). It shows that both temperature and relative humidity measured within the hives or at the brood level were highly influenced by the management of beekeepers, the month effect and the time when the observation was recorded (p <0.01).

Table 1. Sources of variation of temperature end relative humidity

Source of variation	Hive temperature (T1)	Brood temperature (T2)	Hive Relative humidity (H1)	Brood Relative humidity (H2)
User-year-day	**	**	**	**
Month	**	**	**	**
Time	**	**	**	**
Error df	41463	6184	40965	5852
R^2 (%)	75	81	55	69
Model used	1	2	1	2

** p < 0.01

Average temperatures were 23.58 degrees Celcius (sd 7.69) and 28.44 degree Celcius (sd 7.34) within the hives and at the brood level, respectively. The relative humidity however was higher at the brood level. Average relative humidity was 69.69 % (sd 14.9) and 73.65 % (sd 15.3) in the hive and at the brood level, respectively. Raw means and variation of temperatures and RHs, by groups of months, were reported in Table (2). Winter group includes January-February, March and November and December. Summer group includes Months from 6 to 9 and Spring group includes April, May and October. This grouping was based on the month effect translated by its least square solution derived by model (2). On average, mean temperature at the brood level were 27.54 °C +-8.26, 31.17 °C +- 3.64 and 28.25 °C +- 6.24 in winter, summer and spring, respectively. In beehives, temperatures were lower in winter and spring compared to brood temperatures. The RH was lower in summer in both beehives and at the brood level. It was 63.28+-12.99 and 61.72 +- 17.82, respectively.

Table 2. Means and variation of temperature and RH by season

Season (months)	Winter (1-3 +11-12)		Summer (6-9)		Spring 4-5 and 10	
Variable	Mean	SD	Mean	SD	Mean	SD
Hives						
Temperature	17.21	5.93	30.08	4.02	22.59	5.26
RH	75.86	14.12	63.28	12.99	71.17	14.59
Brood						
Temperature	27.54	8.27	31.17	3.64	28.25	6.24
RH	79.26	10.87	61.72	17.82	67.89	14.94
THI						
% of hives records	38.83		41.09		20.08	

Effect of month of the year on honeybees' behavior

The effect of month of the year on measured temperatures and relative humidity in hives and at the brood level is shown in figure (3). These are Least Squares Solutions reflecting the clean effect of the month on temperatures and relative humidity in beehives and in the brood. The figure showed that from November to March, temperatures in the studied hives were relatively low. The coldest month was December with 23.58 °C +-3.87. There were approximately 6 °C difference between March and December, with higher temperature toward March. Then, the temperature increases from April to reach its maximum in July and August and starts decreasing again. There were 17 °C difference between the temperature of December and summer months when temperatures reached more than 40 °C. Research shows that regardless of the ambient temperature, the in-hive microclimate of a beehive at the central brood area must be kept at the average optimum temperature of 32 °C–36 °C for the colony to survive [5]. Therefore, to survive both cold winters and hot summers, just like human buildings, *Apis Mellifera* will employ several heating and cooling strategies to thermoregulation of their hives at the optimum temperature. At the brood level, figure

(3) showed that there were 8 ° C difference during January until March in favor of the brood temperature, which was warmer. Honeybee workers are mitigating the cold either by increasing the density on the brood net or with increased endothermic mechanism [5]. From April to October, the brood temperature was cooler with 7°C difference compared to the hive temperature. A colony of a beehive typically consists of a single queen bee; 10,000–60,000 female worker and 1000–2000 male bees (drones) in the summer with the 'only' task of mating with a virgin queen from a foreign colony [5].

The trend of RH in beehives has been always higher than the one recorded at the brood level. Its highest values were recorded in December and January (70 % +- 10 %). These values decreased until July and August to be 50% and increased again. At the brood level, there were two periods where the RH was low. They were during January-March and July-August with 40 % and 30% less than the RH recorded in December. The average RH at the brood level was 73.5 +- 5.8 °C. This biological behavior showed how honeybees are playing key roles in making the colony comfortable. They make the brood warm when temperature is cold in the hive especially during cold months January-March. They provide cooler environment during hot months between May and October.

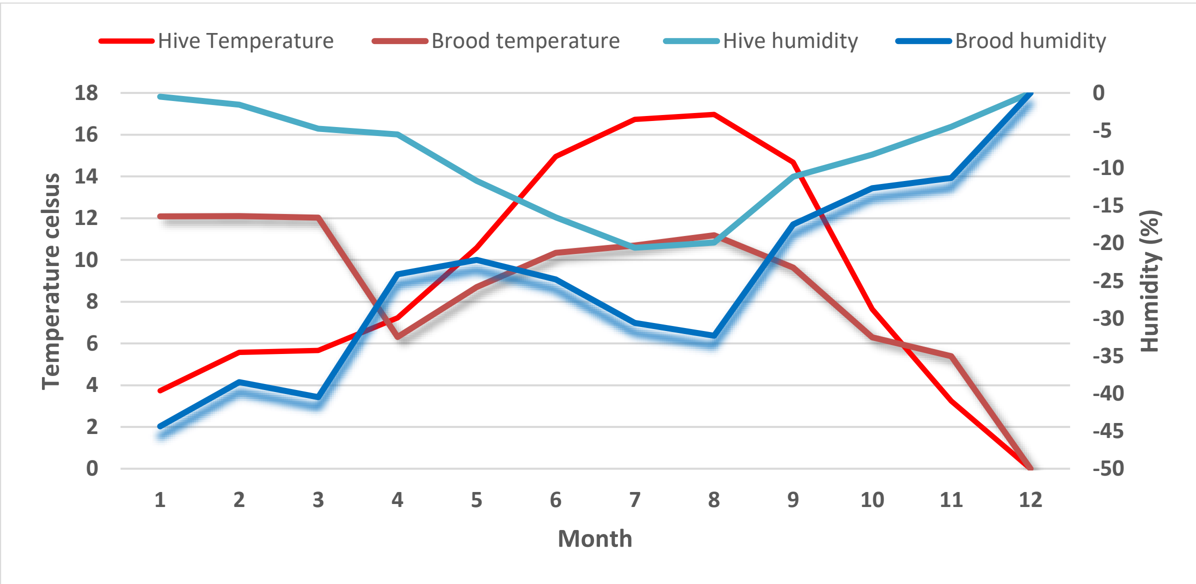

Figure 3. The effect of month of the year on the temperature and relative humidity in beehives and at the brood level.

The described behavior of the studied honeybees showed how their biological thermoregulation mechanisms were used to adapt to their environment during the year. This study is specific in its kind because it was based in real precise data from smart devices of connected hives. There is no real doubt that the future of honeybees will rely more and more on precise and accurate information recording to better manage them and use them in a sustainable way.

Temperature Humidity Index (THI)

A standard minimum THI, computed based on the lower comfortable temperature (33 °C) and the lower comfortable RH (90 %), and a standard maximum THI, computed based on the upper comfortable temperature (36 °C) and the upper comfortable RH (55 %), were used to check how the connected hives offered a comfortable environment to honeybees. The THI equation reported by [7] was used to estimate the lower and upper THI thresholds of bees comfortable range. These thresholds were defined as THImin and THImax as seen in (3 and 4).

$$THImin = 1.8*33 – (1-0.90)*(33-14.3) + 32 \quad (3)$$
$$THImax = 1.8*36 – (1-0.95)* (36-14.3) + 32 \quad (4)$$

There were 3.41 % and 2.96 % of bees in the comfortable range of temperature and humidity in hives and at the brood level, respectively. The large number of bees (97%) were below the lower limits and 1% beyond the upper limits of both standard THIs. These information translate the need for searching practical ideas to implement in order to mitigate weather changing effects on beehives and approach to recommended comfortable conditions for honeybees.

CONCLUSIONS

This study showed, based on temperatures and relative humidity precise data recorded by specific sensors, how honeybees adapt to their environment through their biological mechanisms to cool or warm up their respective colonies. Honeybees, at the brood level to mitigate weather conditions in their respective hives, used thermoregulation adjustment mechanisms. During cold months from January to March, they manage to increase their temperature and lower the relative humidity at the brood level. During hot months, from April to October, they lower both their temperature and relative humidity. A little proportion of bees, however, were kept in a comfortable range of temperature and relative humidity. The use of smart devices to monitor these variables are in much need. Breeding values of queens, based on their endothermic mechanism trait, can be predicted to improve their ability to cope with extreme temperatures and select well-adapted strains.

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