Remote Control of the Temperature-Humidity and Climate in the Beehives with Solar-Powered Thermoelectric System

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Abstract: In this study, a temperature- and humidity-controlled system fed by solar energy has been developed to ensure the optimal living standards within the hives for bees. All energy necessary for the entire system has been obtained from the solar radiation stored in gel accumulators. Temperature and humidity data have been received constantly with wireless sensor networks and analyzed so as to determine whether they are within the ranges of optimum values through the software following their transmission to a central system. By using a thermoelectric system, appropriate heating and cooling processes have been conducted in order to keep the temperature within the hive at the optimum level. Furthermore, the beekeeper has been informed via an automatic message sent to his mobile phone to enable him to take emergency measures in case of any adverse situation related to temperature or humidity. In this way, while the loss of bees has been reduced to minimum with the creation of a suitable ambient for the well-being of the bees, maximum increase has been observed in the honey yield.

Keywords: Beehive climate, Solar energy, Remote control, Temperature control, Thermoelectric

1. INTRODUCTION

A honeybee colony displays various characteristics in different periods of the year depending on the environmental factors as well as its own internal dynamic. As a result, a conscious breeder should keep the records of the previous seasons and years completely and properly so as to know the needs of the colony (Sammataro and Avitabile 1998, Ok and Okan 2011). Temperature and humidity within the hive are important for all bees. In the 1700s, François Huber stated in his work "The Encyclopaedia Britannica" that the optimal temperature for brood rearing of bees is approximately 30° C. He also stated that an average of 150 worker bees is estimated to die during the colony controls made by opening the hives. Thus, unnecessary examinations of the hives should be avoided.

Cause of the most of the colony deaths is that best consume too much honey to heat the hive because of the cold weather and as a result they go hungry and as for the bees in the colonies with less bee frames, bees cannot feed themselves because honey within the hive freezes due to the cold. As for the summer months, bees stop whatever they are doing right that time and attempt to cool the hive as it is an urgent task to cool the hive during that season because of the hot weather. Moreover, when there is an excessive amount of humidity within the hive, this can lead to such diseases as septicaemia (blood poisoning) and this, in turn, cause colony losses. In such cases, urgent actions become compulsory. However, beekeepers can be late to realize these cases.

As they are social insects, a honeybee colony can survive when the temperature of the external environment is between -20 and +48 ºC and even -40 and +60 ºC. However, they show the best performance at the temperatures between +21 and +35ºC. When the temperature falls below +14ºC, the honeybee starts not leaving the hive and forming a ball (winter cluster). When the temperature falls below +6 ºC, the hive has the appearance of an exact ball (Pirker 1980). It is known that each bee can produce a heat of 0.1 calorie per minute at 10ºC. But bees are creatures that cannot make changes in their body temperatures. As a consequence, they cannot maintain a balance between the temperature within the hive and their body temperatures.

In today’s world, technology is used widely and frequently and its areas of usage are on the increase in parallel with the fact that it also still develops. As in the case of all fields, technology continues to be used effectively in agriculture (Dumitrascu 2007). Temperature and humidity within the hives can be controlled with technological techniques (Shao and Xin 2008, Tani and Cugnasca 2007, Es’kov and Toboev 2009, Fehler et al. 2007, Erdogan et al. 2009). Thermoelectric energy can be used to prevent the temperature changes in the hive and to create the appropriate temperature/humidity ambient. Moreover, analysis of the data obtained from the agricultural practices through wireless networks is also becoming more and more common (Pulli and Zheng 2005). As for the literature, it has been observed that various techniques have been used for the heating and cooling of the colony and the hive and a yield analysis has been conducted (Gould and Gould 1995, Wineman et al. 2003).

Es’kov and Toboev (2009) determined the temperature of different parts of bee bodies related to external air temperature and localization of bees in the colony using the thermal imaging method. A feedback between external air temperature and heating of bee bodies was revealed. The thoracic part of the body had a relatively high temperature irrespective of the localization of bees in the colony.

Kronenberg and Heler (1982) stated that a high amount of heat is produced to balance the temperature of the brood area at low temperatures (10 ºC), but in high temperatures (40 ºC), metabolic rate decreases in spite of the fact that involuntary movements increase. In this study, it has been observed that honeybees turn into clusters when the temperature falls from 30 ºC to 10 ºC and that involuntary movements and fanning movements increase while they accelerate their metabolisms depending on the severity of the cold. Starks et al. (2000) observed that honeybees raise the temperature of the brood area regularly to increase the brood activities and protect themselves against predators. They have also stated that when Ascosphaera apis which is the pathogen of chalk brood contaminates to the colony at the temperatures below 30 ºC, honeybees realize this and raise the temperature before the broods get sick.

Tani and Cugnasca (2007) developed and applied a Smart Transducer Interface Module (STIM) to a beehive monitoring system based on a LonWorks control network. This monitoring system is part of a ongoing research on the behaviour of bees, pollinators that provide essential ecological services and have a major impact on environmental sustainability. The STIM contains a digital temperature and humidity sensor used to monitor the condition inside the beehive. Its hardware is based on a PIC 18F252, an off-the-shelf, low-cost microcontroller by Microchip. A NCAP to the LonWorks network was also developed, which allowed the STIM to be seamlessly connected to the existing system. The use of a TAC Xenta 511 module, a LonWorks device with web server functionality, allowed the beehive's humidity and temperature, measured by the STIM, to be remotely monitored through the internet.

In Meitalovs et al. (2009), temperature sensors have been located under a cover over the brood and temperature data have been recorded every 15 minutes for a whole year. At the end of the study, a low brood development has been observed in the winter months and an increasing brood area development has been observed during the spring months and the biggest correlation has been found out between temperature and season. The most important effect of the temperature values has occurred in the late spring when food storage and brood activities are intensive, as well as in the summer months and late autumn when the winter clusters start to form. Temperature has showed the slightest effect in the winter months when no brood activity occurred.

Mardan and Kevan (2002) observed that capped brood deforms above 36 ºC, loss of worker bees increases and water consumption within the hive also increases dramatically above 38 ºC. In a study carried out as regards to the regulation of the humidity rate of the brood by the honeybees, honeybees work rather effectively for the regulation of the biophysical structure of the brood in line with the colony needs is observed (Human et al. 2006). This study pointed out that the worker bees are effective on the in-hive humidity rate, but some difficulties are experienced in balancing the humidity rate of the brood and in-hive humidity amount is influenced significantly by the outside air conditions, so worker bees can only balance the in-hive humidity amount at the half-optimum level.

In Tautz et al. (2003), honeybee pupas have been located in the incubators in order to investigate the possible results of the temperature regulation for a high-quality breeding of the adults according to the environmental factors. During the development phase, temperature has been stabilized at 32 ºC - 34.5 ºC and 36 ºC. This area of temperature has been naturally formed within the hives. It has been observed that bees show different reactions in different temperatures. Cetin (2004) has stated that providing the most suitable environmental conditions is necessary so as to be able to get efficiency and be successful in the beekeeping sector which is strictly interrelated with the climate factor and the ambient temperature. It has also been observed that measures taken within the beeyards or hives minimize the negative impacts of the ambient temperature. In Aydin (2005), factors that have been investigated are the preparation of the bees for the winter months, keeping them strong enough for the following season, disease control and struggle as well as the evaluation of the activities that will be performed in the hive in the autumn months as regards to colony management. In particular, control of Varroa, cleaning and relationship of in-hive regulations with environmental factors (heat, precipitation and humidity), importance of the profilactic methods against honeybee diseases pests have been emphasized.

In the first section of this study where urgent actions have been taken in the emergency situations by the control of in-hive temperature and humidity parameters, thermoelectric heating and cooling system has been mounted into the hive. In the second section, solar panels and gel accumulators have been used to feed the system with electric energy generated from solar power. In the third section, temperature and humidity sensors have been added into the hive. Data received from the temperature and humidity sensors by establishing the wireless sensor network system have been sent to GSM-supported central system. The software to process these data has been developed in the central system. This software ensured that the beekeeper is warned via GSM in case of any adverse situation.

2. MATERIAL AND METHODS

In general, proposed system is composed of four basic units. These are photovoltaic panel and battery unit, thermoelectric cooling/heating unit, temperature and humidity control unit with microcontroller and the GSM module. Block diagram including these four basic units is indicated in the Fig. 1.

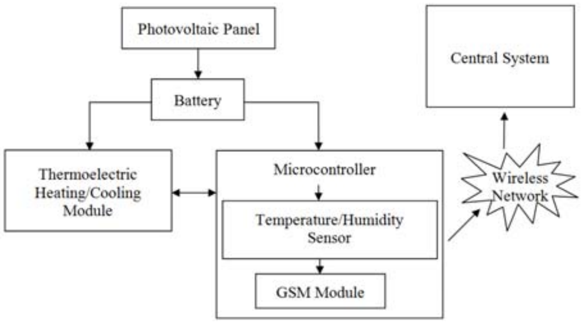

Fig. 1. General diagram of the system which controls the in-hive temperature and humidity parameters

2.1 In-hive Temperature and Humidity Control

In-hive temperature should be kept between the optimum value ranges for the bees. Furthermore, it should be avoided from the humid ambient which will disturb the bees. To this end, in-hive temperature and humidity values can be obtained through the sensors. Internal temperature of the hives of the bee colonies has been adjusted to minimum 21 ºC and maximum 35 ºC. At the same time, these temperature values have been determined after being tested in the test colonies at the beginning of the study. For this purpose, in-hive temperature has been controlled with a sensor located on the upper sticks of the frames within the hive. As it has been observed that worker bees start to crowd into the brood when the internal temperature falls below 21 ºC, this temperature has been determined as the lower limit of the internal temperature. But when the in-hive temperature raises over 35 ºC, worker bees start to flap their wings so as to ventilate the hive by going out of the hive and being lined in front of the flight hole of the hive and as a result, 35 ºC has been determined to be the upper limit or the internal temperature when thermoelectric cooling system will start to operate. PIC16F876 microcontroller has been used to perceive and process the in-hive temperature and relative humidity values (Cano et al. 2007).

2.2 In-hive Heating and Cooling

Temperature should be kept between certain degrees to create the optimum ambient for the bees within the hive. Therefore, thermoelectric heating and cooling system has been used in the hive. Thermoelectric heating/cooling is the formation of a temperature difference in the tips of the wire when electricity is supplied to the system which is a combination of the tips of two different metals (Bell 2008). In these systems, semiconductor materials are used. They operate quietly as they have no moving parts. Thermoelectric modules are generally manufactured by mixing N and P type material pairs. In the thermoelectric structure, electricity moves along the lower and upper layers of each N and P type material. Electrons which move as a result of the supplied electricity current cause heating in a surface while they cause cooling in the other surface (Fig. 2). This is called as peltier effect (Rowe 1995). When the direct current flows over the circuit made out of two different semiconductor materials that are combined, heat is absorbed at the junction with Joule heating and heat releases from the other junction. Amount of the released heat depends on the direct current flowing through the circuit.

$$QP= \pi I \quad (1)$$

QP: Heat amount transferred per unit time (W),

I: Direct current flowing over the circuit (A),

π: Peltier invariant is (V).

$$\pi= \alpha T \quad (2)$$

α: Seebeck coefficient (V/0C),

T: Absolute temperature.

$$QP= \alpha T I \quad (3)$$

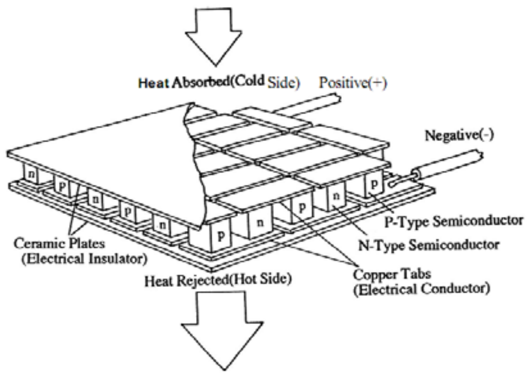

Fig. 2. Peltier effect in the thermoelectric systems

2.3 Transfer of the In-hive Temperature and Humidity Data through Wireless Network

As it is known, devices measuring the parameters such as temperature and humidity have a rather wide usage area in the industrial practices. Today, temperature and humidity sensors can make considerably sensitive measurements by being integrated into digital systems (Wang et al. 2006).

Data obtained from the sensors is transmitted to the central system through the wireless network to make the peltier module work with the aims of keeping the in-hive temperature under control and, if it is necessary, heating or cooling the hive. To this end, a solar-powered wireless sensor network has been incorporated into the system. Two radio modems serving as a receiver and a transmitter have been utilized so as to forward the data to a distant point. Preferred radio modems provide communication by using RS232 or RS485 interface. At the same time, the device can provide wireless communication with a center or each other via radio signals (Wang et al. 2006). Devices used in the study operate in 2.4 GHz Ism band. Device can communicate at a speed of 19200 baud in the air and its speed can be as high as 57600 baud provided that RS232 interface is used. The modem with integrated antenna can transmit data as far as 100-500 m within the city and as far as 2 km in the open field. GSM-based SMS system has also been developed to warn the beekeepers in emergencies as well as these temperature and humidity data sent to the central system. The central system contains a processor unit where data analysis will be carried out on the mini-mainboard, wireless network interface and the interface essential for the communication. System has a storage unit where all the data received from the hives can be stored. Thus, it becomes possible to access all the data whenever it is desired and to analyse them.

2.4 GSM Communication Module

Sensors and thermoelectric module are used to be able to keep the in-hive temperature that is necessary for the well-being of the bees within the optimum ranges. GSM module has been integrated into the central system in order to inform the beekeeper to take urgent measures in cases when the in-hive temperature cannot be kept within the desired temperature values and in-hive humidity rate is unusual (Fig. 3). In cases of emergencies, the beekeeper is informed with the GSM module. Furthermore, temperature and humidity data of a present moment can be obtained through the GSM module only with a request sent to the GSM module to learn the in-hive temperature and humidity situations whenever it is deemed necessary (Jiang et al. 2008).

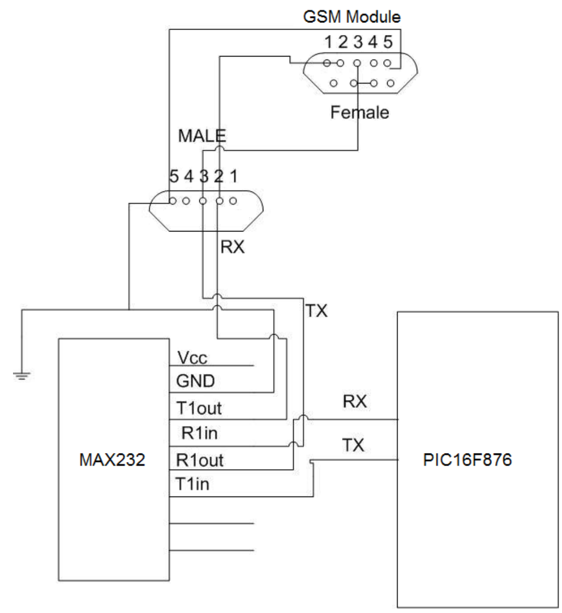

Fig. 3. GSM module connection scheme

2.5 Energy Feed of the System

In this study, solar power has been used to meet the energy need of the system developed for the temperature and humidity control of the beehives. It is really important for the system to be operated by the solar power especially in the fields where no other alternative form of energy was used (Bratcu et al. 2008, Sun et al. 2009). Generating electricity out of solar power is a method used alternatively in the circumstances where any other energy supply is available. Consequently, energy generated from the sun is stored and can be used if it becomes necessary. Recently, solar power has become a topic on which many researchers have been conducted.

Photovoltaic batteries are semi-conductor substances which convert the solar power reflecting to their surfaces directly into electric energy. In general, a photovoltaic battery whose shape can be square, rectangular or circle has an area of 100 cm2 and its thickness is between 0.2-0.4 mm. Photovoltaic batteries operate on the basis of photovoltaic principle, i.e., electric voltage occurs at their ends when sunlight falls onto them. Source of the electric energy supplied by the battery is the solar power falling onto its surface. Solar power can be converted into electric energy by a productivity rate ranging from 5% to 20% depending on the structure of the photovoltaic battery (Gxasheka et al., 2005).

In this study, solar energy is used for energy need of this system in view of beekeeping field conditions.

3. EXPERIMENTAL RESULTS

In today's world where electronic technology develops rapidly, microprocessors and microcontrollers are used in every field and can make more precise operations when compared to analogue systems. Within the framework of these developments, many industrial applications are adapted to the microprocessor based systems and this provides speed and high precision in the control and measurement operations.

Measurements of the ambient temperature and humidity within the hive have been realised with the SHT11 sensor (Barbiarz et al. 2009). SHT11 is the temperature and relative humidity sensor with digital outputs of the Sensirion Company. Results of the measurements are transmitted digitally to the microcontroller over two cables via serial communication unit. It can perform a temperature measurement with a ± 0.5 °C error between the temperatures of -40 °C and +128 °C, a relative humidity measurement with a ± % 3.5 error.

If the in-hive temperature is lower than the setted temperature value (21 °C), ambient temperature is raised by operating the thermoelectric heater. It is also ensured that the heater inactivates when the desired temperature is reached. As a result, ambient temperature can be stabilized at the level (±0.40 °C) of the sensitivity of the sensor. Besides, humidity data have also been obtained through the measurement of the ambient humidity data by the same sensor.

In the study, 3 TEC1-12703T125 thermoelectric modules have been used for each hive. Values specified by the manufacturer for this component is indicated in the Table 1 (Han et al. 2010). This module having the dimensions of 40×40×5.4 mm is composed of 127 pairs, maximum value of voltage is 15.2 Volt, maximum current is 3 Amper and it has a cooling power of 29.7 Watt in the maximum temperature difference. Voltage and current values correspond to 50% of the maximum values in the optimum operating conditions. It has been observed that module can keep the beehives at the desired temperatures thanks to these characteristics. It has been ensured that heat obtained via peltiers is distributed into the hive in a homogeneous way through heat pipes. Wires are grounded by being covered with thin metal plates in order to eliminate the negative impact of the magnetic area that heat pipes can cause on the bees.

Table 1. Parameters of thermoelectric module

Model	TEC1-12703T125
Couples	127
U_{max}	15.2
I_{max}	3
ΔT_{max}	67
Q_{max}	29.7
LxWxH(mm)	40×40×5.4
R(Ω)	4.260

In this study, electricity needed for the data transfer system via wireless network, in-hive cooling and heating and the GSM module is supplied by the solar power as shown in Fig. 4 and Fig. 5. Solar panels of 135W and 40W have been used respectively for the central system and in-hive systems. 8 gel accumulators have been utilized so as to store the electricity obtained from the solar panels. When these gel accumulators are insufficient, circuit voltage has been used for the electricity need of the system.

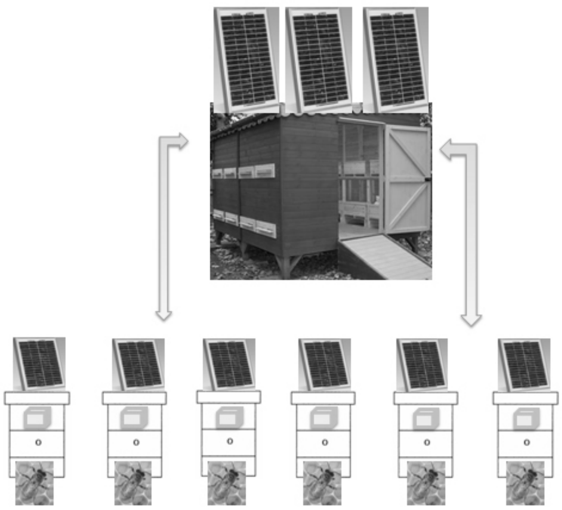

Fig. 4. Data transfer to the wireless network through the temperature and humidity sensors with the in-hive cooling and heating system

System, as a whole, operates automatically. Different external temperature and radiation values have been observed throughout the year. Temperature and humidity values have been measured per minute during the experiment. It has been seen that in-hive temperature is balanced within about 40 minutes. Measurements obtained at the end of the experiment are indicated in the Fig. 6.

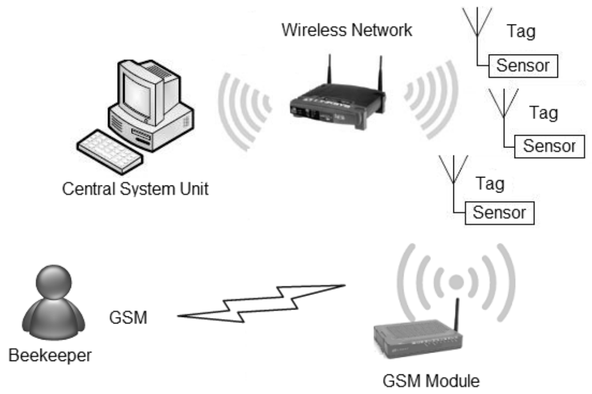

Fig. 5. Central system unit processing the data received from the sensors and the GSM module

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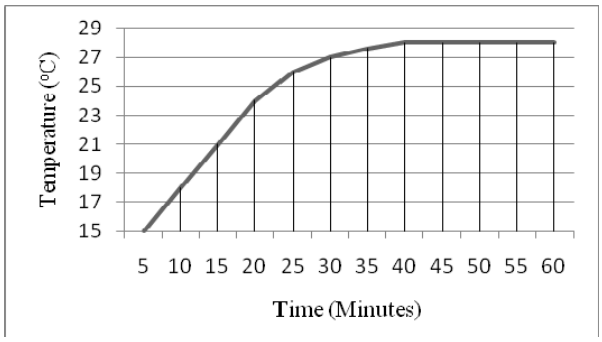

Fig. 6. Changes in the temperatures with time in the thermoelectric cooler

The optimum humidity is nearly is 55%. The average maximum and minimum humidity in climated hives is recorded as 70% and 21%, respectively.

4. CONCLUSIONS

It is known that worker bees firstly consume honey to raise the temperature of the brood and later produce heat by staying immobile in the closed brood area or contracting its abdomen rapidly. It has been detected that brood production increases provided that the hives are heated with the thermoelectric system fed by solar power. Furthermore, it has been observed that the numbers of bees that embark flying have increased. In addition, the number of the bees which perform heating and ventilation operations reduces to the minimum level during the brood phase. So, this study examines a linear relationship between the daily honey yield and the daily increase in the hive weight and the number of the bees that embark flying on the daily basis.

Measurements of the in-hive temperature and humidity values have been carried out with a sensor by using a SHT11 integrated system in this study conducted to enhance the in-hive comfort. All process variable data reaching to the PIC microcontroller reach as a binary information that the microcontroller can process directly without needing a A/D transformer as this sensor's output is digital. Use of the components manufactured by using solid semi conductor technology as the temperature and humidity sensing elements both increases the reliability of the sensor and ensures that the stability of the sensors remain at the optimum level when long-term operation is taken into consideration.

In this system, control is performed by using PIC microcontroller so it offers the opportunity to carry out the change possibly occurring in the control operation through the software. This opportunity provides us with the advantage of control flexibility as well as the economical advantage when compared to the systems in which changes in the system control are realized through hardwares.

Moreover, with this system, beekeepers that are away from their colonies can have a chance of remote control of their bees. In this way, the beekeeper can always be informed with the developed system in cases of adverse conditions. The system enables the people engaging in the beekeeping activities in the regions with very hot and cold climates to be able to control their colonies automatically.

Consequently, there are little technologies researches about internal hive comfort for honeybees. In this study, significant differences were found on microclimate beehive monitoring system according to traditional systems. It is observed that the internal temperature and humidity and ventilation of the hive played very important role on honey bee behaviours.

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