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Warming Beehives with Solar Energy Stored in Water

Mohamed Ali Ibrahim AL-RAJHI*
Ministry of Agricultural, Agricultural Engineering Research Institute, Department of Mechanization of Livestock and Fish Production, Dokki-Giza, EGYPT

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ORCID ID
orcid.org/0000-0001-5212-5401
*Corresponding Author: moh.elrajhi@yahoo.com

Abstract: This study presents the possibility of utilizing a passive solar system in sunny places, which collects solar energy by using a polyethylene sheet to trap the long-wave thermal radiation and store it in water for warming the internal environment of beehives and its effect on nest temperatures, honey area, pollen area, sealed brood area, and the number of occupied frames. A total of six Langstroth hives containing honeybee colonies of equal strength from the species of hybrid Carniolan are divided into two groups as follows: a control group (untreated hive), and modified beehives that have been treated with the solar energy storage system. The solar energy storage system consists of an insulated wooden drawer located under the beehive's bottom board, containing sealed water bags, and is covered with a polyethylene sheet. Solar energy stored in water is used to reduce the variation of inside air temperatures between daylight and nighttime. The highest values of the honey area, pollen area, sealed brood area, and the number of occupied frames (916 cm^2, 842 cm^2, 3688 cm^2, and 9 frames, respectively) were obtained for the modified beehives at the end of March, while the lowest values (98 cm^2, 219 cm^2, 911 cm^2, and 3 frames, respectively) were recorded for the control groups of beehives at the middle of January. In modified beehives treated with a solar energy storage system, there was a significant rise in hive temperature, honey area, pollen area, sealed brood area, and bee population. So, it is recommended to use the new modification for warming beehives.

Keywords: Honeybee colonies, warming, modification, solar energy

1. Introduction

Solar radiation is defined as the solar flux that arrives at the solar collector without being scattered during its journey through the atmosphere. This radiation comes from the geometrical disc of the sun. The atmosphere provides a diffuse component of scattered light through Raleigh scattering, dust, and aerosol scattering (Duffie and Beckman, 1980). Clouds scatter sunlight as well, adding to the total scattered flux, but this scattering is not strictly diffuse in nature. The sunlight is scattered by the ground surfaces, adding to the total flux arriving at the tilted solar collector. Scattered solar radiation cannot be focused by any optical system, but it does contribute flux to flat plates and other non-focusing solar collectors. A passive solar system acts as a collector of solar heat. This heat is then stored in water (Butler, 1985). A passive solar heating system was used by Ben-Amor et al. (1990) for heating greenhouses by using EVA (Ethylene-vinyl acetate) plastic tubes (320 mm in diameter) filled with water and capturing solar energy during the daylight and distributing it back during the night. Yahia (2006) studied and investigated the possibility of utilizing a passive solar energy system for warming the environment of the cucumber crop. Solar energy is free, available in large quantities during daylight and environmentally clean, so its utilization can be more attractive. Hamdan (1998) mentioned that for many solar energy applications, water is used as a storage medium. The energy storage capacity of water is given by Duffie and Beckman (1980) as follows: $Q = m. Cp. \Delta T$, Watt (where, Q= total heat capacity, watt; m= mass of water in the storage unit, kg; Cp= specific heat of water, 4200 $Jkg^{-1}°K$; ΔT= temperature range during an operating cycle, °K). Overcoming the winter season is crucial for beekeeping, as the temperature is an important factor affecting the larval and pupil development of insects (Nylin and Gotthard, 1998). Maintaining a range of temperature from 32 to 36 °C inside colonies is important for honeybees (Becher et al., 2010). The internal temperatures are related to the external temperature, as discussed by Rice (2013). Constant temperature is crucial for the typical growth and development of the brood. Deviation can occur when the ambient air temperature changes and affects the developmental period of honeybee's immature stages and emergence rate (Tautz et al., 2003). In addition, the ambient temperature has a significant impact on foraging activity, as low temperatures below 10 °C can prevent flight activity (Joshi and Joshi, 2010). Stabentheiner et al. (2003) used infrared technology to measure the temperature of bees' bodies and showed that some workers made heat by shivering (activating their wing muscles). In low-temperate and subtropical conditions, only strong bee colonies can produce high honey yields (Hauser and Lensky, 1994). Worker bees contribute to the regulation of brood nest temperature by creating heat while sitting motionless on brood cell caps (Kleinhenz et al., 2003). Increasing levels of metabolism (ie, honey consumption for heat production) are indeed associated with exposure to cold temperatures. The adult bees begin to generate their own heat by consuming carbohydrates (in the form of stored honey), and as a result, they go hungry. In some cases, they are unable to eat the honey since the honey in the hive has frozen. Colony losses are frequently caused by starvation. They cluster and starve as a result of eating the honey that has been stored. If bees are short of honey, a syrup made of two parts of granulated sugar and one part of water should be offered to them (Edwards-Murphy et al., 2016) which increases the production cost. Workers spend more energy and time on thermoregulation than on brood care (feeding, and building brood cells) at low temperatures, which results in a reduction in brood production (Vogt, 1986). Furthermore, it has been demonstrated that the number of brood cells is reduced during cold seasons compared to hot periods (Borges and Blochtein, 2006). There have been many attempts to improve the inner temperature of the bee colonies to reduce the loss of honeybee colonies in winter (Braga et al., 2019). Morse (1999) mentioned that wintering hives in the cellar was a common practice. When the hives are outside, they consume 22.3 kg of honey, but when they are placed in a cellar, they only consume 6.8 to 13.2 kg. Detroy et al. (1982) studied the effect of hive insulation on heat conservation inside the hive, reducing honey consumption by about 21-25%. There have been many attempts to reduce the loss of honeybee colonies in winter, by improving the conditions of the temperature inside the bee colonies, such as Erdogan et al. (2009). For example, Morse (1999) advised keeping bee colonies in dark-painted hives and exposing them to full sunlight during the winter in the Northern United States, but he presented no experimental data to support his recommendation. Honeybees' performance in cold weather has been improved by some common beehive adjustments. Heated and heated-fan beehives (Erdogan et al., 2009), beehives with a device to control the temperature during the winter season (Vollet-Neto et al., 2011; El-Sheikh et al., 2021), and beehives with an automatic system and complex control architecture to improve the honeybee wintering process are some examples of these cold-based modifications (Zacepins and Stalidzans, 2012). Paul (1979) made a passive solar energy collector for overwintering honey bees, which is a cumbersome, tent-like affair in which the hive is housed. Altun (2012) developed a solar-powered device to regulate temperature and humidity within beehives in order to provide the best environment for the bees.

There is a few research about the warming of beehives under Egyptian conditions. Therefore, the objectives of the present study were to warm weak bee colonies to keep their hive temperature values between suitable temperature ranges without harming the bees by using a passive solar energy system that minimizes winter losses using a cheap material such as water. Water bags work as collectors and storage materials during daylight and re-use during the night. The newly adapted beehives have been constructed and tested to minimize wintertime losses and enhance colony performance by decreasing both colony food consumption and mortality. It also aimed to evaluate the queen's status in brood production and population development.

2. Materials and Methods

The present work was started from 1 December until 30 March at a specific location at 31°10'13" N, 31°47'56" E (Meet Salseel city, El-Daqahlia Governorate, Egypt). The average maximum and minimum temperatures were 18.7 and 11 degrees Celsius for the winter. During the winter tests, the average outside temperature was 14.6 ºC.

A solar energy storage system was used to warm Langstroth beehives (outside measurements: 53x43x25 cm and wall thickness: 2 cm) in winter. The Langstroth hives, otherwise known as movable frame hives, are one of the types of hives designed for rearing honeybees. The Langstroth beehive is the most widely used hive in the world (Ojeleye, 1999). The solar energy storage system was set up as a drawer under the beehive bottom board after removing the half-inner side of its bottom board. The bottom half of the board was closed with a wire screen to prevent foreign insects from entering the hive. The solar energy storage system dimensions were 48.5 cm long, 41.8 cm wide, and 18 cm deep. A beehive containing a body and an attached solar system fixed under it, which comprises sealed water bags, is illustrated in Figure 1. The sides and bottom of the drawer were constructed of two layers of plywood (0.3 cm thick), and the space between the two layers was insulated with two layers of foam equaling 1.4 cm. The heat storage stability was achieved by the application of the foam layer as a thickening agent. The top of each drawer was covered with a polyethylene sheet, which had its inner side opened (2.5x48.5 cm), to allow hot air extension. The polyethylene sheet also decreases radioactive heat losses by preventing part of the long-wave radiation from leaving its surface. The tight polyethylene sheet absorbs the IR radiation and radiates back part of it into the enclosure. The water bags located in the wooden box (drawer) were made of clear plastic, well-tied, and contained 0.02 m^3 of water. It absorbs solar energy and emits it into the upper reaches of the beehive body. The heat energy was transferred from the hot water (heated by solar energy during daylight) into the interior ambient air by means of convection and radiative. The use of water for thermal storage provides the following advantages: Water is not toxic, non-flammable, inexpensive, and acts as a storage medium. Drawers were horizontally opened toward the hottest part of the sky (south direction) at sunrise in order to maximize the solar radiation flux incident on them during the winter months. The drawer was insulated and coated in black to increase absorptivity. At sunset, drawers were moved back (closed) to their original positions under the frames of honeybees. The winter hive entrance was open and the summer one was closed. A piece of sackcloth was placed over the frames to prevent any foreign insects from interning the hive and absorbing water resulting from the evaporation process of the hive and causing problems, such as lowering the temperature of the colony and the spread of fungi, viruses, and bacteria. Also, to ensure temperature isolation at the hive, the top of the hive was covered with insulating material. A total of 6 Langstroth enclosure beehives with removable tops contained honey bees (hybrid Carniolan) that had been established 8 months prior to the onset of the experiment and were placed 40 cm from the ground on a sunny site in the bee yard, with their entrance facing south in order to protect the hive from the prevailing rain and wind. They were equivalent in strength, food supplies (honey-pollen), the queen's age (around 8 months old), and the number of combs covered with bees from both sides (around 6 combs). We monitored Nosema Apis and Varroa every twelve days and treated them whenever necessary.

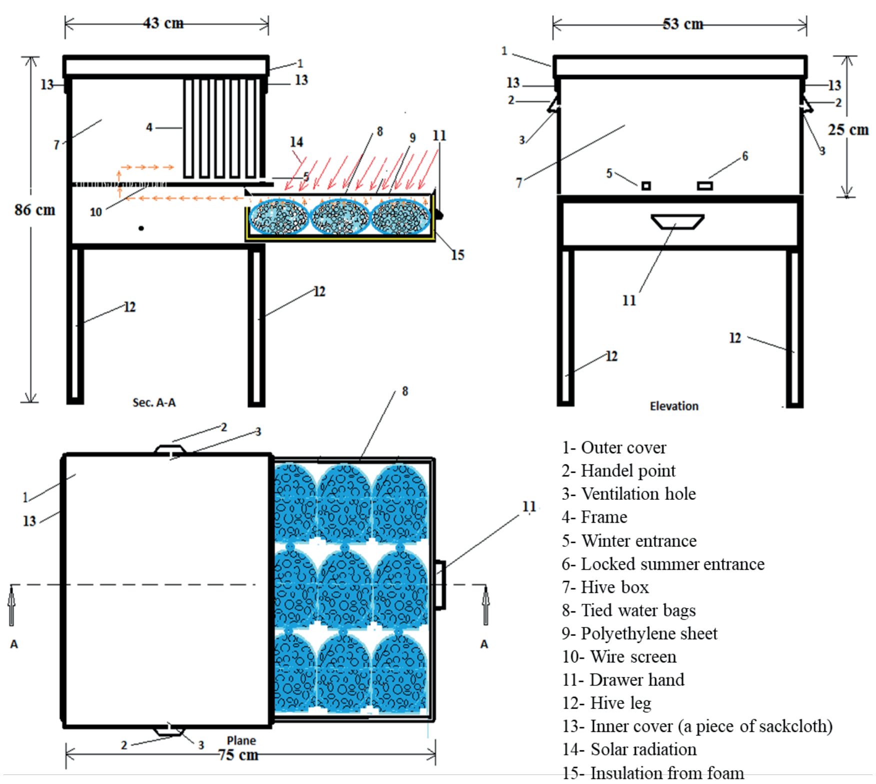

Figure 1. Schematic diagram of a solar energy storage system

Beehives were divided into two groups as follows: (G_1), the colony in the untreated hive (control group), and (G_2), beehives treated with a solar energy system, and each group consisted of three hives. There were two small holes located under the handling point to permit some undirected air movement and allow moisture, which rises to the top of the hive, to escape. Bee entrances and vents were provided in the cover. Throughout the winter season, the number of combs covered with bees on both sides was counted every twelve days to check for empty new combs. Two thousand mature bees, which cover a comb from both sides, were estimated to represent the population of bees (Hauser and Lensky, 1994).

The ambient temperature around beehives, as well as the temperature inside the hive (inside the nest and outside the nest), was measured using a data logger. All the new photos of sealed brood, honey, and pollen cells were taken after shaking the bees off. The nearest areas (square centimeters) of capped brood, pollen cells, and honey were determined by considering four cells per square centimeter of the comb. Throughout the winter season, this investigation was carried out every 12 days.

3. Results

The minimum temperature in the climate region ranged from 10.7 °C in January to 14.9 °C in March, while the maximum temperature was in the range of 18.8 °C in January to 22.8 °C in March. The average temperatures at night in December, January, February, and March were 15.4, 13.4, 15, and 16.8 °C, respectively, while the average temperatures during the day were 17.9, 15.9, 17.5 and 19.7 °C, respectively. The minimum estimate of mean rainfall was 0.00 mm in February and March, and the extreme value was 32.0 mm in January. The overall average wind velocities during December, January, February, and March were 3.2, 3.4, 3.5, and 4.1 m sec^{-1}, respectively. The overall average relative humidity, % during December, January, February, and March was 75, 76, 74, and 67%, respectively, as illustrated in Table 1.

Figure 2 shows the average ambient temperature around beehives, both outside the nest and inside the nest, for the studied colonies during daylight. From Figure 2, the least and highest ambient temperatures were 10.44 °C at 3 am and 21 °C at 2 pm, respectively. The average value of the ambient temperature was 14.89±3.01 °C during the daytime, so the ambient average temperature was less than about 6.43 °C nest. The lowest and highest temperatures outside the nest for the control hive were 16.48 °C at 5 am and 22.5 °C at 3 pm, respectively. The average temperature for the control hive was 19.17±1.02 °C during the daytime, so the control hive's average temperature was about 4.28 °C higher than the ambient temperature. The minimum and maximum temperatures outside the nest for the modified hive were 18.1 °C at 5 am and 23.9 °C at 6 pm. The average temperature for the modified hive was 21.32±0.07 °C during the daytime, so the modified hive's average temperature was about 6.44 °C higher than the ambient temperature. As shown in Figure 2, the temperature inside the nest ranged from 30.1 to 32.1 °C and from 33.7 to 34.9 °C using the control and modified hives, respectively. The average regulated temperature in the control and modified hives was 32.02±0.48 and 33.27±0.61 °C, respectively.

Figure 3 illustrates the relationship between honey area, cm^2, and investigation date in beehives based on a test employing a control and modified solar energy storage system. At the end of it, the mean honey area, cm^2, increased from 789 cm^2 for control hives to 916 cm^2 for modified solar energy stored hives. Honey areas for control hives declined from 143 cm^2 on the first day of the experiment (12 December, 2021) to 98 cm^2 towards the middle of January (17 January, 2022), then began to

Table 1. The mean temperatures, wind speed, rainfall, and possible sunshine duration during the 4 months of study

Parameter	Tested months			
	December	January	February	March
Mean maximum temperature, °C	20.8	18.8	20.2	22.8
Mean minimum temperature, °C	12.9	10.7	12.6	14.9
Mean temperature, °C	16.6	14.9	16.2	18.4
Mean temperature at night time, °C	15.4	13.4	15.0	16.8
Mean temperature at day time, °C	17.9	15.9	17.5	19.7
Wind speed 2m, m sec^{-1}	3.2	3.4	3.5	4.1
Rain fall, mm	0.4	32.0	0.0	0.0
Possible sunshine duration, hr	10.0	10.2	11.2	11.8
Relative humidity, %	75.0	76.0	74.0	67.0

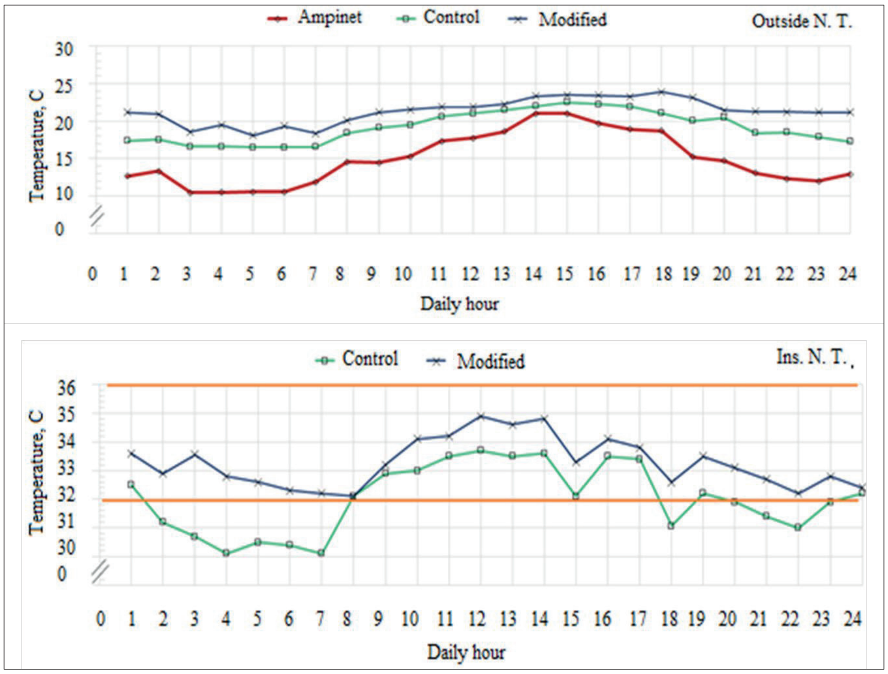

Figure 2. The average ambient temperature around the beehive, as well as temperatures outside and inside the nest

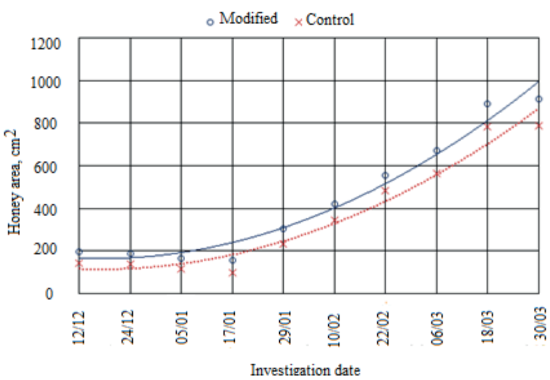

Figure 3. Effect of warming by heat stored in water bags on honey area

increase from 234 cm^2 at the end of January (29 January, 2022) to 789 cm^2 at the end of the trial (30 March 2022). This is owing to the effect of changes in ambient temperature throughout the trial, as indicated in Table 2. At all times during the experiment, the warmer environment created by the modified solar energy storage system in hives reduced mean honey consumption by about 28.60% compared to the control hives. The quadratic equation, as illustrated in the following equations (1 and 2), is the most accurate fit-curve for the relationship between honey area "HA" and investigation dates at the control and modified solar energy storage systems. The coefficient of determination "R^2" was about 0.971 and 0.963 for the control and the modified solar energy storage systems, respectively.

$HA = 0.071x^2 - 0.6939x + 115.50 \rightarrow (1)$ in the control hive

$HA = 0.078x^2 - 0.7205x + 164.73 \rightarrow (2)$ in the modified hive

Table 2. The mean values of the measured honey areas

Investigation date	Honey area (cm^2)			P-value
	Modified Mean	Control Mean	Increment (%)	
12 Dec.	195	143	36.36	**
24 Dec.	187	140	33.57	**
05 Jan.	167	117	42.73	**
17 Jan.	155	98	58.16	**
29 Jan.	303	234	29.49	**
10 Feb.	419	343	22.16	**
22 Feb.	555	485	14.43	**
06 Mar.	671	563	19.18	**
18 Mar.	890	782	13.81	**
30 Mar.	916	789	16.10	**
Mean	445.8	369.4		
R^2	0.963	0.971		

**: P-value<0.001

From Figure 4, the minimum and maximum pollen area values were 219 and 676 cm^2 when using the control hive, and they were 392 and 842 cm^2 when using a modified solar energy storage system. After 36 days, pollen areas fell from 331 to 219 cm^2 at control hives and from 481 to 392 cm^2 at the modified solar energy storage system.

The data illustrated in Table 3 showed a highly significant increase in pollen areas over time ($P<0.001$) and the modified solar energy storage system was responsible for the most variation in pollen areas (PA). The coefficient of determination "R^2" was about 0.926 and 0.918 for the control and the modified solar energy storage system, respectively, according to the quadratic equations (3 and 4).

$PA= 0.0896x^2 - 6.0304x + 492.15 \rightarrow (3)$ in the control hive

$PA= 0.0940x^2 - 6.6508x + 340.33 \rightarrow (4)$ in the control hive

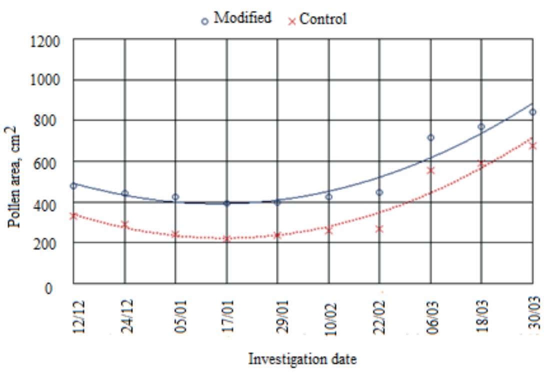

Figure 4. Effect of warming by heat stored in water on pollen area

Table 3. The mean values of the measured pollen areas

Investigation date	Pollen area (cm^2)			P-value
	Modified	Control	Increment	
	Mean	Mean	(%)	
12 Dec.	481	331	45.32	**
24 Dec.	442	292	51.37	**
05 Jan.	424	243	74.49	**
17 Jan.	392	219	79.00	**
29 Jan.	397	235	68.94	**
10 Feb.	427	258	65.50	**
22 Feb.	449	269	66.91	**
06 Mar.	716	555	29.01	**
18 Mar.	771	590	30.68	**
30 Mar.	842	676	24.56	**
Mean	534.1	366.8		
R^2	0.953	0.960		

**: P-value<0.001

Figure 5 shows the correlation between the sealed brood areas and the investigation dates. The data showed that for the control and modified solar energy storage systems, the average sealed brood areas were 1881.5 and 2039.6 cm^2, respectively. The lowest and highest sealed brood areas (SA) at control hives were 911 and 3591 cm^2, respectively, while the lowest and highest sealed brood areas at modified solar energy storage systems were 1170 and 3688 cm^2, respectively (Table 4).

The coefficient of determination "R^2" for the control and modified solar energy storage systems was around 0.960 and 0.953, respectively, according to the quadratic equations (5 and 6).

$SA= 0.3555x^2 - 14.741x + 1376.7 \rightarrow (5)$ in the control hive

$SA= 0.3777x^2 - 17.031x + 1251.3 \rightarrow (6)$ in the control hive

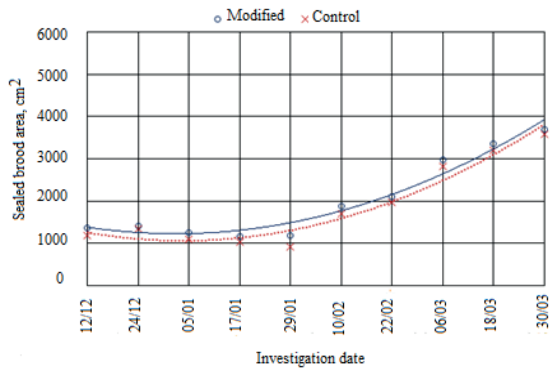

Figure 5. Effect of warming by heat stored in water on sealed brood area

Table 4. The mean of the measured sealed brood areas

Investigation date	Sealed brood (cm^2)			P-value
	Modified	Control	Increment	
	Mean	Mean	(%)	
12 Dec.	1357	1183	14.71	**
24 Dec.	1412	1332	6.01	**
05 Jan.	1248	1085	15.02	**
17 Jan.	1170	1022	14.48	**
29 Jan.	1190	911	30.63	**
10 Feb.	1880	1704	10.33	**
22 Feb.	2099	1969	6.60	**
06 Mar.	2983	2823	5.67	**
18 Mar.	3369	3195	5.45	**
30 Mar.	3688	3591	2.70	**
Mean	2039.6	1881.5		
R^2	0.953	0.960		

**: P-value<0.001

Figure 6 shows how the number of occupied frames increases as the test period lengthens. The figure represents the drop in data received from control hives from the first day to 48 days, from 6 to 3 occupied frames during the test period, before increasing to 7 occupied frames at 108 days at the end of the test period. Because of this, the corresponding number while utilising the modified solar energy storage system is directly related to the test period, which increased from 7 to 9 occupied frames from the first test day to the 108th test day. Meanwhile, the mean values for control and modified solar energy storage systems were 5.1 and 6.4, respectively.

Data illustrated in Table 5 showed the relationship between the number of occupied frames "No" and investigation dates at the control and modified solar energy storage systems. The equations (7 and 8) show that the coefficient of determination "R^2" was about 0.857 and 0.854 for the control and the modified solar energy storage systems, respectively. There was a highly significant increase in the number of occupied frames over time (P<0.001).

No= $0.0009x^2 - 0.0732x + 6.5727 \rightarrow$ (7) in the control hive

No= $0.0009x^2 - 0.0826x + 5.6727 \rightarrow$ (8) in the control hive

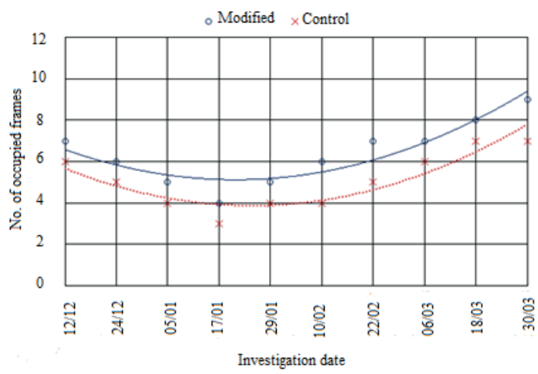

Figure 6. Effect of warming by heat stored in water on the number of occupied frames

Table 5. The mean values of the measured number of occupied frames

Investigation date	Number of occupied frames			P-value
	Modified Mean	Control Mean	Increment (%)	
12 Dec.	7	6	16.67	**
24 Dec.	6	5	20.00	**
05 Jan.	5	4	25.00	**
17 Jan.	4	3	33.33	**
29 Jan.	5	4	25.00	**
10 Feb.	6	4	50.00	**
22 Feb.	7	5	40.00	**
06 Mar.	7	6	16.67	**
18 Mar.	8	7	14.29	**
30 Mar.	9	7	28.57	**
Mean	6.4	5.1		
R^2	0.854	0.857		

**: P-value<0.001

4. Discussion and Conclusion

Flight activity can be hampered by temperatures below 10 °C (Joshi and Joshi, 2010). Out of 1294 hours of possible sunshine duration during the study, the ambient temperature was higher than 10 °C. In general, foraging activities of field bees were quite favorable during the winter of 2021-2022 and there were no wintertime losses due to dysentery (dysentery is caused by the retention of faeces that would typically be expelled during cleansing flights outside the hive). In general, foragers' activity is stopped when wind speeds exceed nine m sec^{-1} (Hoopingarner and Waller, 1992), but the wind speed never approached this value during the study.

The findings indicated that the modified hive was able to maintain a temperature at the state with the lowest standard deviation, especially when using solar energy stored in water. Honeybee workers in controlled beehives expend more energy than those in modified beehives in order to perform successful thermoregulation. The present results were in agreement with those of Altun (2012), who developed a mechanism to keep the temperature in beehives within an optimum range and discovered a decrease in the number of bees that undertake heating operations. The presence of solar energy stored in tied water bags caused the internal temperature of the modified beehives to rise.

The high temperatures near the brood region may have enhanced several tasks of the workers, including honey crop ripening. There was a significant increase in honey areas over time (P<0.001) and the modified solar energy storage system was responsible for the most variation in honey areas.

The pollen area continually increased after 36 days, until the experiment ended after 108 days. This trend could be attributable to the impact of changes in ambient temperature during the experiment. The modified solar energy storage system increased the average pollen area by about 53.58% when compared to the control hive, due to the higher energy stored in water, which enhances the colony's performance and decreases pollen consumption. This finding is compatible with Dodoloğlu and Genç (2002) findings.

The data showed that the modified solar energy storage system towered over the control ones, and there was a highly significant increase in pollen areas over time (P<0.001). The modified solar energy storage system raised the average sealed brood area by 14.48 % over the control hive after 48 days from the beginning of the test. Because workers expend more energy and time on thermoregulation than on brood care (feeding, and creating brood cells), the rate of brood cell production slows or even stops during periods of low ambient temperature, resulting in a reduction in brood production by the colony. The rate of brood cell production decreased significantly when the temperature of the environment dropped, which is in line with previous findings (Velthuis et al., 2000; Borges and Blochtein, 2006). The decrease in brood cell production during cold periods could be due to the queen's sensitivity to low temperatures (Velthuis et al., 2000); workers' sensitivity to low temperatures; or changes in tasks by workers, such as switching from brood cell construction to thermoregulation (Engels et al., 1995).

The data obtained on sealed brood areas using the modified solar energy storage system increased by about 26.24% compared to using control hives. These findings suggest that by raising nest temperatures as a result of a modified solar energy storage system, fewer workers are required for thermoregulation, allowing more bees to focus on brood cell production. In general, brood area growth activity was higher when the modified solar energy storage system was used than when the other control group was used. This result is comparable to Genc et al. (1999) findings.

When compared to control hives, the improved solar energy storage system in sunny places provided the best results in terms of hive temperature management, maximum areas of (honey, pollen, and sealed brood); and the maximum number of occupied frames. The findings of the present study could strongly suggest that it is important to have a good understanding of how to use the new method for winter beehives during the winter season, so it is recommended for the middle (with 30-100 beehives) and small beekeepers to deal with honeybee colonies. Also, it is recommended to use the bottom drawer as an internal feeder to which the sugar syrup is added during the remainder of the year to maximize the benefits of the improved system.

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Declaration of Conflicts of Interest

No conflict of interest has been declared by the author.

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