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Experimental Investigation and Performance Evaluation of a Solar Space Heating/Cooling and Ventilation System for a Poultry House in Egypt

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ABSTRACT

This research presents an experimental investigation of the space heating/cooling and ventilation system of the poultry houses in Egypt. High temperature and lack of proper environment, poultry production faced heat stress that reduced feed consumption, weight gain, and egg yield. This will lead to reducing production and consequently increased the price of poultry in the local market. The present work provided an experimental study to signify the effectiveness of the evaporative cooling system using several pads that made from low cost, and locally available materials. Designing a proper ventilation system is also introduced. The energy needed for heating and cooling purposes are provided by solar energy equipment. It can provide the system with the required electrical and thermal energy that derive the cooling/heating systems throughout the year. It was found that the system performance is affected by several parameters like type and thickness of pad materials, air temperature distribution inside the poultry house, meteorological conditions, temperatures of the hot water and cooling water. It was found that the highest ambient air temperature reduction is achieved by using pad materials of carton, linen, canvas, and rice straw respectively.

1. Introduction

Since poultry wealth is one of the components of animal production in Egypt, poultry has received considerable attention in recent decades to increase poultry production. Due to high temperature and lack of proper environment, poultry life is adversely affected, thus reducing production, which in turn increases the prices of poultry and products in the local market. Therefore, it is necessary to pay attention to this aspect to control the environment inside the poultry sheds by using the performance evaluation of the cooling system such as the evaporative cooling technique for poultry using solar energy. Solar energy can be used as a renewable source of energy; it can be used for cooling the poultry farm. It can provide the system with the required electrical and thermal energy that derive the cooling/heating systems throughout the year. Giabaklou and Ballinger [1] studied the effectiveness of a passive evaporative cooling system employing natural ventilation. The front faces of a building are provided with water guide filaments, where in water flows from the top to bottom by gravity. The incoming air gets cooled and goes inside the building. Such a system is found to reduce the temperature of incoming air by 9.9ºC, averaged over a day. Shukla et al [2] have done an experimental study in a cascade green house with inner thermal curtain. About 5-8ºC reduction in the temperature of greenhouse is reported during hot summer in Delhi. Energy saving aspects was attempted by Al-Azzawi and Almuhtadi [3] using of newly designed automated solar powered evaporative cooler. Naticchia et al [4] have used a new novel technique, water-evaporative wall, which reduces the conduction heat gain across the walls. The experiments have shown to reduce the summer overall heat load considerably. Tilahun [5] has investigated the feasibility and

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economic evaluation of low-cost evaporative cooling system in a fruit and vegetables storage.

The evaporative air cooler is able to decrease the air temperature more than 10°C and increase the relative humidity from 25.4 % to 91.1 %. Ten cm thickness cooling pad is used and the cooling efficiency obtained ranged between 55 % and 84 %. The power consumption recorded is 1.13 kWh for a fixed air flow rate of 4.3 kg/s. The energy efficiency ratio is found to be about 26.3 for mentioned air flow rate. Laknizi et al. [6] studied the performance of a direct evaporative cooling pad system under the climate conditions of six Moroccan cities. Their results showed that the rate of water consumption and the cooling capacity increase with increasing the thickness and frontal velocity while the rate of operability increases with increasing the thickness and decreasing the frontal velocity. They concluded that the system is suitable for the climatic conditions of Morocco. These results are also applicable to the residential sector.

2. Experimental setup

The presented design of the current poultry house space heating/cooling and ventilation system is shown in Figure 1. It consists of 4 loops, the first loop is the hot water loop which consists of solar flat plate collector, storage tank coupled with heat exchanger, hot water circulating pump, and heating coil inside the air handling unit (AHU) and connecting insulated tubes. The second loop is the chilled water loop which consists of author previous work solar activated carbon / methanol adsorption chiller [1], cooling coil inside the AHU, chilled water circulating pump, and connecting insulated tubes. The third loop is the evaporative air cooling loop which consists of cooling water tank, cooling water circulating pump, pad inside the AHU and connecting insulated tubes. The AHU consists of a metallic housing contained the chilled water coil, the heating water coil, the evaporative pad, and centrifugal fan. The fourth loop is the air loop which consists of AHU, insulated rectangular air duct, linear diffuser, the Poultry House (PH) and the exhaust fans.

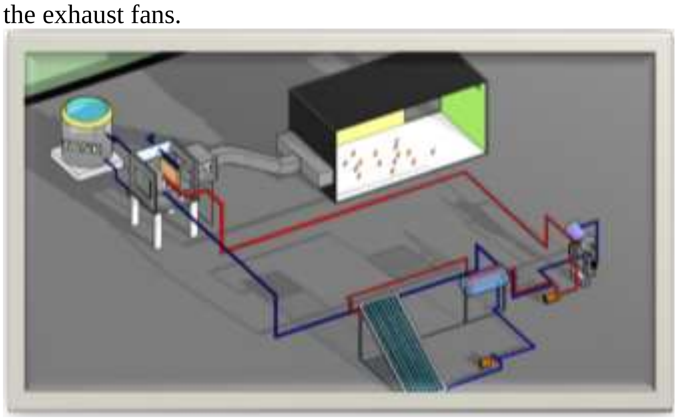

Figure 1: Layout of the space heating/cooling and ventilation system of the poultry house

The system was installed in Solar Energy Department, National Research Centre, Giza, Egypt. The poultry house's dimensions are 4 m length × 2.5 m width × 2 m height. It consists of four walls, roof and a concrete slab. Each wall consists of a sandwich panel galvanized steel. Each sheet has a thickness of 0.3 mm and between the two sheets of glass wool insulation with a thickness of 2.5 cm and its density type (24) was installed. Three ventilating fans are fixed in the eastern wall of the poultry house. The design of the Poultry house is shown in Figure 2. Figure 3 shows the AHU which is considered the main air processing unit. It consists of air filter, with a dimension of 70 cm ×50 cm and a thickness of 2.5 cm. The heating coil with a dimension of 70 cm ×50 cm and a thickness of 5 cm is used. It has also a discharge basin at the bottom and a water spray through nozzles. Three paths under the water spray nozzles with a dimension of 4 cm×95 cm were installed to allow the utilization of wet pads with different thickness (3cm, 6 cm, 9 cm). A centrifugal air supplier fan with a capacity of 2000 C.F.M was used. The AHU is manufactured using insulated galvanized steel sandwich panel with a dimension of 1 m x 1 m x 1 m. It is fixed on a metallic frame with 1 m height and each leg has a braked wheel to help the system moving if needed. Four pads were manufactured with different materials namely Cartons, Canvas, Rice-Straw, and Linen as shown in Figure 4. Three pads with different thickness are manufactured for each type i.e. 12 pads are manufactured to implement this experimental work.

The solar water heating system is designed to provide the required thermal energy to two systems; the first one is the solar water adsorbing refrigeration system using activated carbon and methanol while the second on the heating of the poultry house in winter using solar energy. The final view of the system is shown in Figure 5.

Figure 2: Design of the poultry house

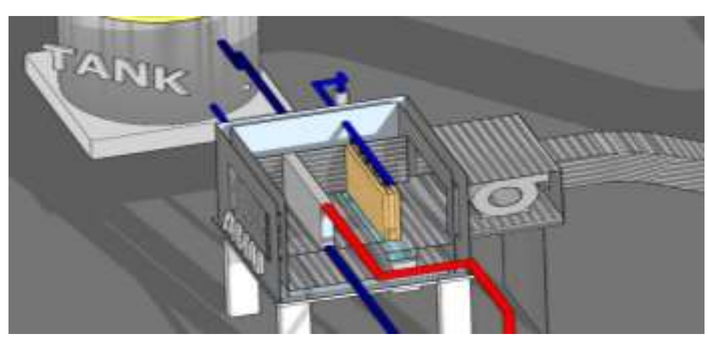

Figure 3: AHU design configuration

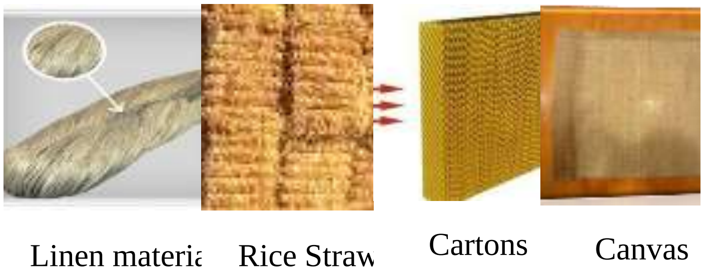

Figure 4: Types of pads materials

Figure 5: Photographic view of the space heating/cooling and ventilation system

Results and Discussion

Solar energy as a clean source of energy is used to cover the electric loads of the air handling unit centrifugal fan and circulating hot/cold water pump(s) and to cover the thermal energy needed for the system via solar flat plate collector. This thermal energy can be used to drive the space heating mode in winter and to drive the solar activated carbon methanol adsober chiller to provide space cooling in summer in addition to evaporative cooling system based on the humidity required inside the poultry house. Several parameters were studied to thermally evaluate the system performance like type and thickness of pad materials, air temperature distribution inside the poultry house, meteorological conditions, temperatures of the hot water and cooling water. Figure 6 represents the air temperature variation outlet from the AHU at different Pad materials with 3 cm thickness. It was clear that the type of pad materials is very effective parameter affect the air temperature variation outlet from the AHU with the same thickness (3 cm). It was found that the highest ambient air temperature (T_{amb}) reduction is achieved by using pad materials of carton, linen, canvas, and rice straw respectively.

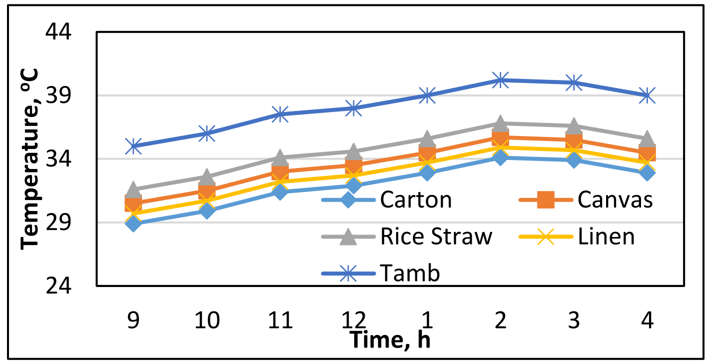

Figure 6: Air temperature variation outlet from the AHU at different pad materials with 3cm thickness

The effect of pad thickness on the air temperature variation outlet from the AHU for canvas, linen, rice straw and carton respectively is shown in Figures(7-10). For the all pad materials, it was found that increasing the pad thickness from 3cm to 6 cm and 9 cm provides larger temperature reduction with respect to ambient temperature.

The air temperature variation outlet from the AHU, inlet and outlet of poultry house (PH) with respect to ambient temperature is shown in Figures (11-14) for the Linen, Carton, Canvas and rice straw pad materials respectively with a thickness of 9 cm. From these figures it is clear that there is a remarkable temperature difference between the temperature outlet from the AHU and that outlet from the linear diffuser (inlet to poultry house). This is due to some thermal losses and possible leakage in the air paths. It is found also that there is a temperature reduction between the cooled air inside the evaporative cooling system and the ambient temperature of 9 ºC, 8ºC, 7ºC, and 6ºC for the Carton, Linen, Canvas and rice straw pad materials respectively.

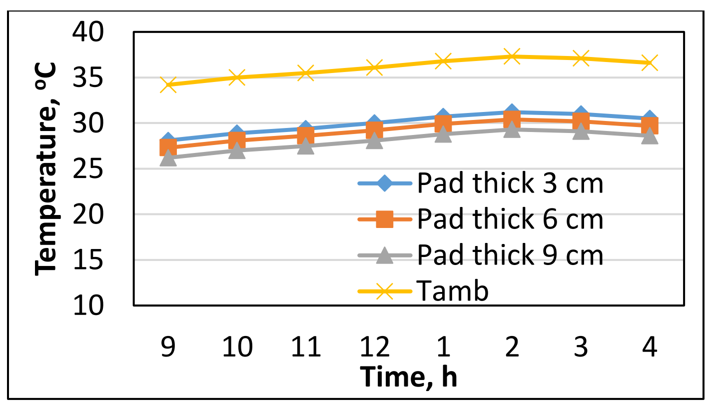

Figure 7: Air temperature variation outlet from AHU with different Canvas pad thicknesses

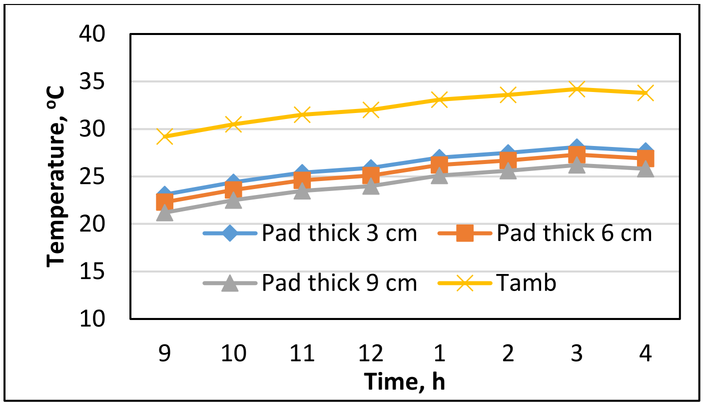

Figure 8: Air temperature variation outlet from AHU with different Linen material pad thicknesses

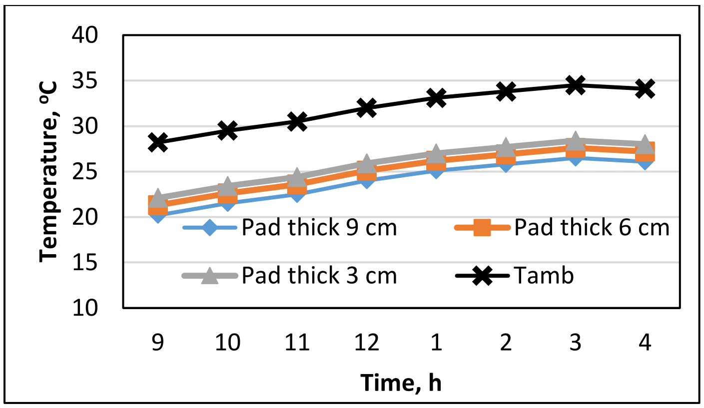

Figure 9: Air temperature variation outlet from AHU with different Rice straw pad thicknesses

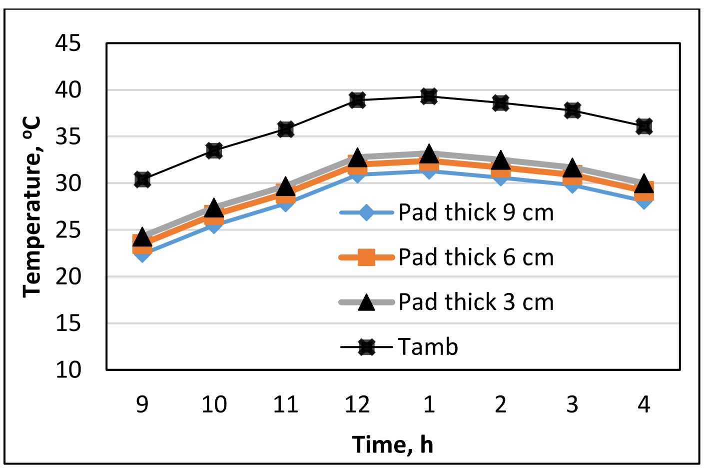

Figure 10: Air temperature variation outlet from AHU with different Carton pad thicknesses.

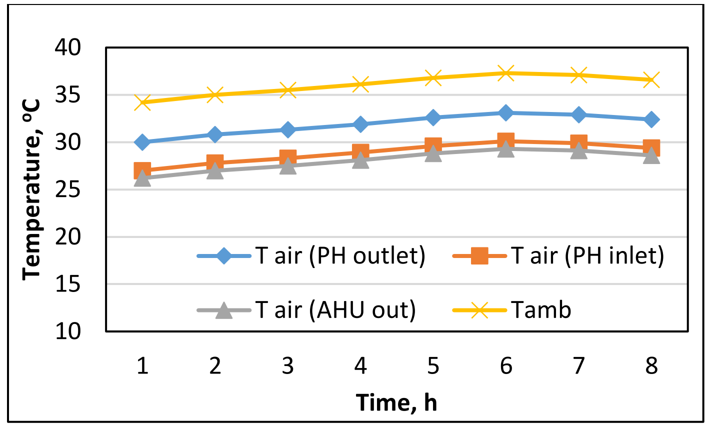

Figure 11: Air temperature variation outlet from the AHU, inlet and outlet of PH with respect to ambient temperature at Canvas pad thickness 9 cm.

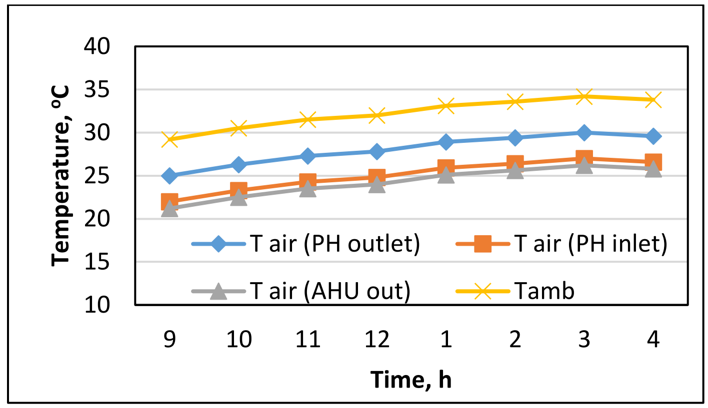

Figure 12: Air temperature variation outlet from the AHU, inlet and outlet of PH with respect to ambient temperature at Linen material pad thickness 9 cm

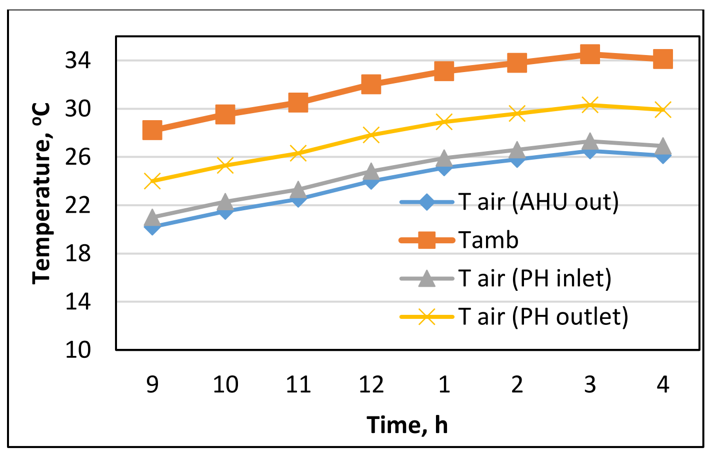

Figure 13: Air temperature variation outlet from the AHU, inlet and outlet of PH with respect to ambient temperature at Rice Straw pad thickness 9 cm.

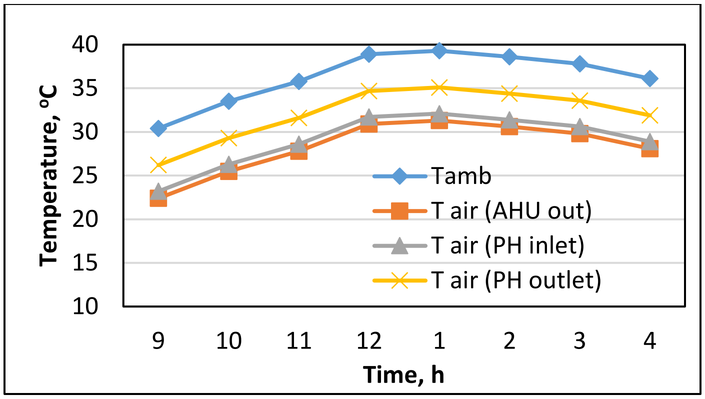

Figure 14: Air temperature variation outlet from the, inlet and outlet of PH with respect to ambient temperature at Carton pad thickness 9 cm.

Due to the evaporative air cooling system, the incoming air contact the wet surface of the pad materials and the wetted thin film started to evaporate. The evaporation process absorbed amount of thermal energy from the cooling water that caused a temperature reduction of the cooling water. It is observed that high temperature reduction occurred with larger pad thickness. The water temperature variation of the evaporative air cooling system with different pad thicknesses inside the AHU with respect to water inlet temperature is shown in Figures (15-18) for the Linen, Carton, Canvas and rice straw pad materials respectively. For all the pad materials, it is found that there is a considerable temperature reduction between the water inlet to the AHU and the water outlet from the AHU for the pad thickness of 3 cm, 6 cm, 9 cm respectively. Consequently, the water temperature Variation outlet from the evaporative air cooling system at different Pad materials with 9cm thickness is shown in Figures 19. It is clear that the temperature reduction was observed as 5.5ºC, 4.5ºC, 4ºC, and 3ºC by using carton, linen, canvas, and rice straw pad materials respectively.

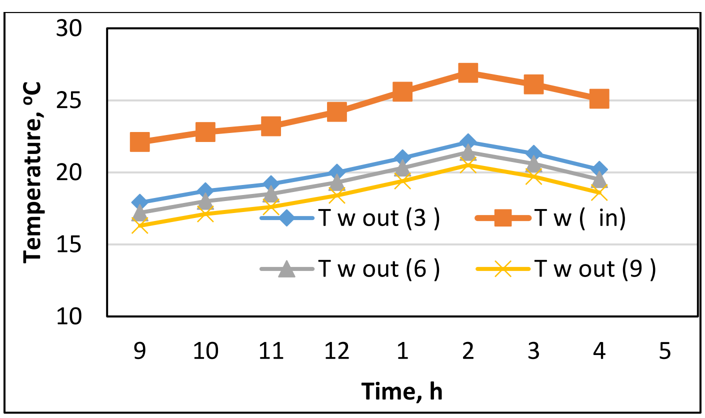

Figure 15: Water temperature variation of the evaporative air cooling system with different Carton pad thicknesses.

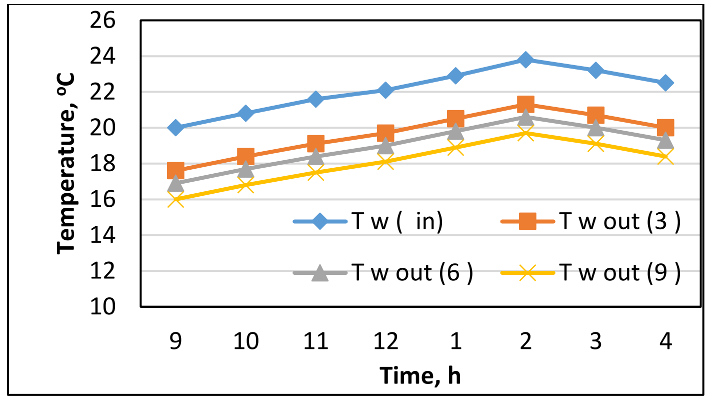

Figure 16: Water temperature variation of the evaporative air cooling system with different Linen material pad thicknesses.

Several experiments were run to measure the air temperature variation inside the Poultry house in three vertical levels with respect to ambient temperature for the studied pad materials at thickness of 9 cm Figures (20-23) represent the air temperature variation inside the Poultry house in three levels with respect to ambient temperature using carton, linen, canvas, and rice straw pad materials respectively. It is clear that the air temperatures inside the poultry house in the three vertical studied levels are very close to each other which mean that the air circulation inside the poultry house is well designed.

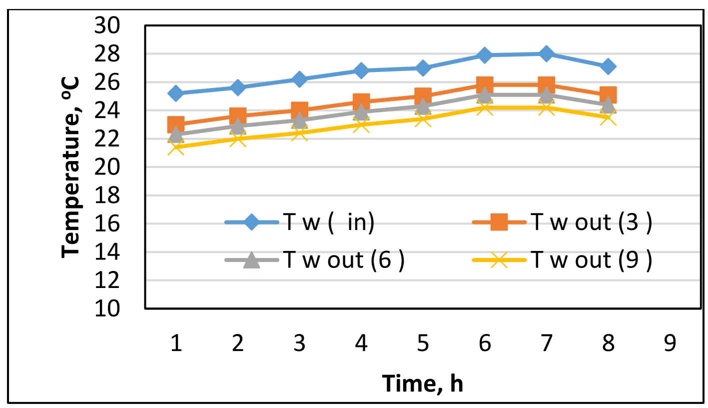

Figure 17: Water temperature variation of the evaporative air cooling system with different Canvas Pad thicknesses.

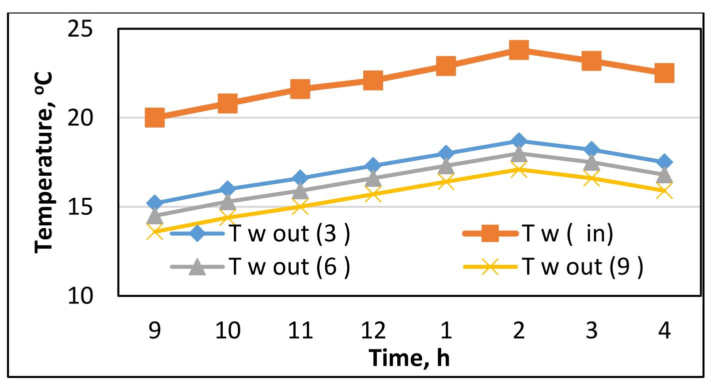

Figure 18: Water temperature variation of the evaporative air cooling system with different Rice straw pad thicknesses.

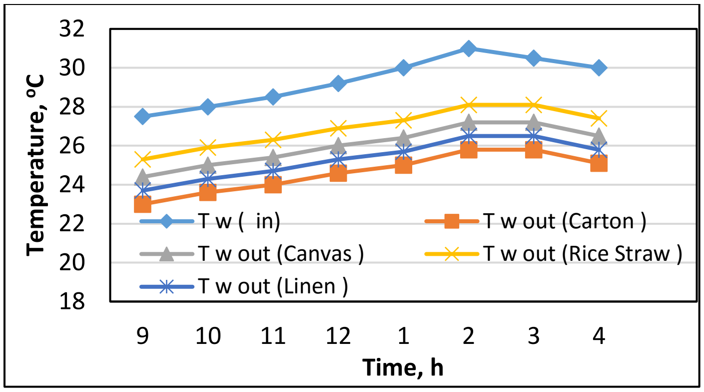

Figure 19: Water temperature Variation outlet from the evaporative air cooling system at different pad materials with 9cm thickness.

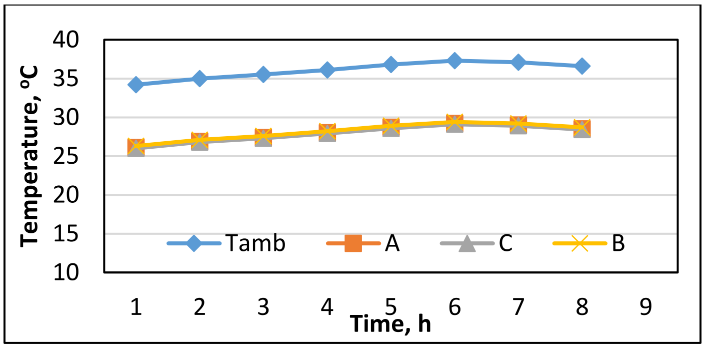

Figure 20: Air temperature variation inside the PH in three levels with respect to ambient temperature at Canvas pad thickness 9 cm.

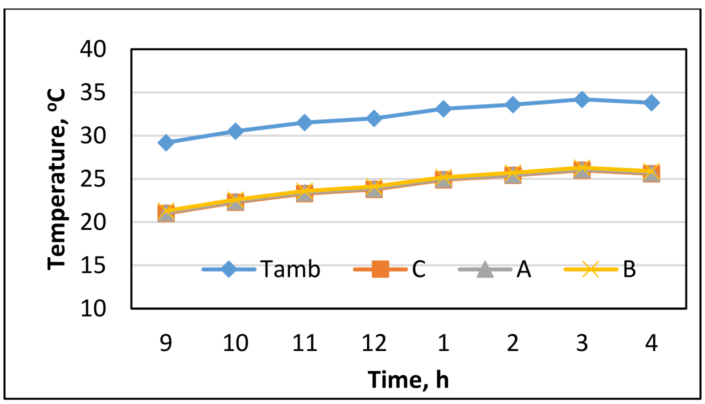

Figure 21: Air temperature variation inside the PH in three levels with respect to ambient temperature at Linen material pad thickness 9 cm.

The average air temperature inside the poultry house is represented with respect to the ambient temperature for the four studied pad materials; carton, linen, canvas, and rice straw respectively as shown in Figure 24. It can be concluded that the highest temperature reduction inside the poultry house was achieved by using carton, linen, canvas, and rice straw pad materials respectively.

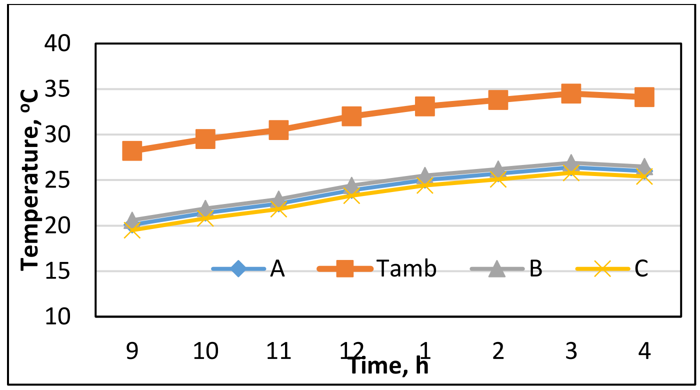

Figure 22: Air temperature variation inside the PH in three levels with respect to ambient temperature at Rice straw pad thickness 9 cm

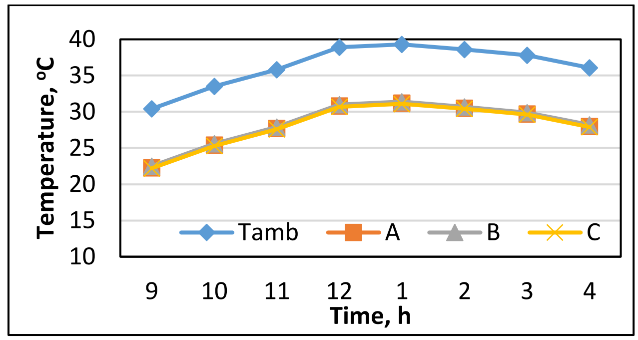

Figure 23: Air temperature variation inside the PH in three levels with respect to ambient temperature at Carton pad thickness 9 cm.

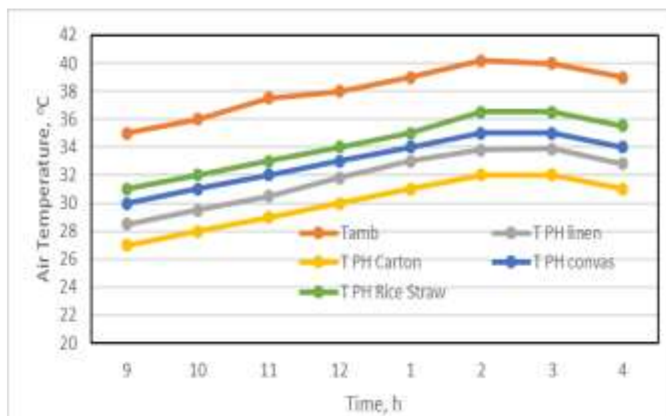

Figure 24: Air temperature variation inside poultry house with respect to ambient temperature at pad thickness 3 cm.

Conclusions

Some concluded remarks can be summarized as follows:

- Low cost, locally available evaporative cooling pad materials like carton, linen, canvas, and rice straw materials are utilized.
- It was found that the system performance is affected by several parameters like type and thickness of pad materials, air temperature distribution inside the poultry house, meteorological conditions, temperatures of the

hot water and cooling water. It is found that the highest ambient air temperature reduction is achieved by using pad materials of carton, linen, canvas, and rice straw respectively.

- For all pad materials, it was found that increasing the pad thickness from 3cm to 6 cm and 9 cm provides larger temperature reduction with respect to ambient temperature.
- It is found also that there is a temperature reduction between the cooled air inside the evaporative cooling system and the ambient temperature of 9ºC, 8ºC, 7ºC, and 6ºC for the Carton, Linen, Canvas and rice straw pad materials respectively.
- For all pad materials, it is found that there is a considerable temperature reduction between the water inlet to the AHU and the water outlet from the AHU for the pad thickness of 3 cm, 6 cm, 9 cm respectively. It is found that the temperature reduction was observed as 5.5ºC, 4.5ºC, 4ºC, and 3ºC by using carton, linen, canvas, and rice straw pad materials respectively.
- Finally, it can be concluded that the highest temperature reduction inside the poultry house was achieved by using carton, linen, canvas, and rice straw pad materials respectively.

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