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PERFORMANCE EVALUATION OF POULTRY HOUSES UNDER DIFFERENT EVAPORATIVE COOLING SYSTEMS

Soliman G. Abd El-Rahman*, M.A. El-Shazly, K.I. Wasfy and A.A.A. Abd El-Atty

Agric. Eng. Dept., Fac. Agric., Zagazig Univ., Egypt

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ABSTRACT: Poultry production occupied a major role in the agriculture industry worldwide. Poultry housing design plays a vital role in determination of the internal climatic conditions for optimum health, growth and productive performance of the poultries. The present investigation aimed to evaluate the performance of different evaporative cooling systems with environmental control of poultry houses. The effect of two different evaporative cooling systems (direct and indirect) under three water flow rates of 2, 4 and 6 l/min.m^2 on poultry houses performance was evaluated in terms of temperature reduction, relative humidity, evaporative cooling efficiency, poultry weight, consumed energy and cost. Experimental results revealed that using direct evaporative cooling system with 4 l/min.m^2 water flow rate and indirect evaporative cooling system with 2 l/min.m^2 water flow rate provided sufficient conditions of temperature reduction (9.59 and 7.28^{o}C), relative humidity (63.88 and 61.21%), cooling efficiency (75.67 and 83.67 %), poultry weight (2.4 and 2.3 kg) and consumed energy (1.2 and 6 kW.day) with net return (7.54 and 5.80 LE/kg), in that order. Based on previously mentioned results, it is recommended to use direct evaporative cooling system for poultry houses as it minimizes both energy and cost requirements compared to the indirect evaporative cooling system, therefore it was found to be suitable for small rural farmers.

Key words: Poultry houses, evaporative cooling systems, water flow rate, environmental control, evaporative cooling efficiency, consumed energy, cost analysis.

INTRODUCTION

Population and economic growth in developing countries are creating a global demand for food of animal protein. Broiler chickens remain the fastest source of providing protein for human consumption worldwide because of their rapid growth, ability to utilize feed efficiently and quick turn-over rate according to **Jiya *et al.* (2014)**.

Heat stress can be a major problem, so adequate internal climate of poultry houses is necessary. High temperature and radiation grades not only negatively affect production performance, but also prevent immune function **(Mashaly *et al.*, 2004)**. **Dagtekin *et al.* (2009)** stated that pad evaporative cooling systems may provide a solution for controlling the high temperatures that can negatively affect poultry houses. Average evaporative cooling efficiency was determined as 69.2% on July 18th, 70.1% on July 19th, 69.4% on July 25th, 70.8% on July 29th and 72.0% on August 3rd. The temperature decrease in pad exit during the experiment was determined as 6.1, 7.3, 4.4, 5.0 and 5.9^{o}C, respectively. **Renaudeau *et al.* (2012)** indicated that the health condition of poultries is highly dependent on the temperature inside the house. In hot conditions, appropriate steps should be taken to avoid the heat stress. Ventilation represents a strong tool for improving climate and air quality in poultry houses if the benefits of weather conditions can be maximized. **Barzegar *et al.* (2012)** showed that the cellulosic pad made out of Kraft paper with 2.5 mm flute size has the highest performance (92%) at 1.8 m/sec. air velocity in comparison

* **Corresponding author: Tel. :** +201020880628
E-mail address: s_gad1244@yahoo.com

with the other cellulosic pads. **Petek *et al.* (2012)** compared the cooling performance between the traditional (control) and two stages evaporative pad cooling system (experiment) for poultry houses during extreme summer conditions. Results indicated that two stages pad cooling system gave lower air temperature and relative humidity than those of the traditional system. The body weight gain was significantly influenced by the cooling system, in addition, the use of two stages, pad cooling system is more efficient method to alleviate heat stress and thus, improve the growth performance comparing with traditional system. **Lucas and Marcos (2013)** stated that controlling the environmental conditions is crucial to successful poultry production and welfare. Heat stress is one of the most important environmental problems challenging poultry production worldwide. The heat stresses affect the poultry growth, production, quality and safety. **Darwesh (2015)** revealed that using evaporative cooling system was able and sufficient to maintain internal air temperature of the poultry house at the required level. The results clarified that the average daily cooling efficiency values during June, July and August were determined by 77.4%, 75.6% and 79.5%, respectively. **Troxell *et al.* (2015)** noted that temperature is important in the poultry growth cycle. Poultry are homoeothermic, meaning they produce and dissipate heat to maintain a relatively constant temperature. Body temperature is a function of the poultry metabolism and is of importance in all heat transfer processes. Adult chickens body temperature varies between 39 and 40^{o}C. Poultry house indoor temperature has an immediate impact on poultry, depending on how well it is monitored and controlled. **Karaca *et al.* (2016)** found that cooling efficiency and the reduction temperature of the air passing through the pad were lower at water flow rate of 6 l/min.m^2. The most adequate water flow rate for the experimental conditions was considered 4 l/min.m^2. **Porumb *et al.* (2016)** mentioned that the evaporative cooling is conducted using heat and mass transfer (water and air as the working fluids). There are two types of evaporative cooling systems; direct evaporative cooling (DEC) and indirect evaporative cooling (IEC). The first type (DEC) is induced by the passage of an air flow and thus, decreasing the air temperature. When the water evaporates into the air to be cooled, simultaneously humidifies it. While, the second type (IEC) is carried out by cooling the air and kept it separated from the evaporation process, therefore it is not humidified. **Bishoyi and Sudhakar (2017)** stated that cooling pads play a major role in cooling efficiency and energy performance of the evaporative air coolers. This paper presents the experimental results of a direct evaporative cooler with two different cooling pads based on actual weather data. The results showed that the energy efficiency ratio and cooling capacity of an air cooler with Honeycomb cooling pad is better than the Aspen cooling pad of the same surface area. **Wang *et al.* (2019)** designed a new ventilation (NV) system to mitigate the air temperature variations and improve the uniformity in poultry houses. The evaporative cooling pads were installed on both sidewalls and the exhaust fans were located on a gable wall in the NV system. The results showed that the NV system provided a cooler air environment than the wet-pad evaporative cooling (TV) system, and the maximum fluctuation in average air temperature was reduced to 1^{o}C *vs*. 6.1^{o}C in TV system. Based on temperature humidity heat stress index (THI), the NV system reduced the heat stress time across the building compared to the TV system. The egg production was higher in the NV system house than in the TV system house (20.3% *vs* 18.9%) and the average bird's mass in NV system house was 21 g higher than in TV system house.

An adequate environment within poultry houses is a very important requirement for success in the poultry industry. When the literature was reviewed, there was no clear comparison study on the effectiveness of the two evaporative cooling systems on the poultry house. So, the present investigation focuses on studying the poultry houses behaviour under environmentally controlled direct and indirect evaporative cooling systems with different water flow rates and determining the suitable conditions for improving the poultry production. This determination is also based on the economic estimation of the poultry houses that operated by any of cooling systems under study.

MATERIALS AND METHODS

The experiments were executed in experimental poultry house during the summer of 2018 at San

El Hagar (Latitude: 30°10′ 32° 15′ and longitude), Sharkia Governorate, Egypt.

Materials

Poultry

Copp chicks were used for breeding under the present study. Chicks were delivered at the age of one day. Chicks were breeded on floor surface with using 3 kg/m^2 of sawdust as a layer under them.

Poultry Houses

The house was constructed from bricks with capacity of 100 poultries to be suited for the average bird density of 10 bird/m^2 according to **(Mendes *et al.,* 2004; Arbor Acres, 2007; Škrbić *et al.,* 2009)**. As shown in Fig. 1 the poultry house dimensions were 2.5 x 4 x 3 m and orientated in north-south direction. It was equipped with heating system, evaporative cooling system, and lighting to be under full environmental control and provide appropriate conditions inside the house. This poultry house was operated using electricity as a power source.

Heating Unit

The heating conditions were provided inside the poultry house using electric heater. The used heater was three candles, Jac type, NGH-3025 model and 1500 W power.

Evaporative Cooling System

The major parameters affecting the thermal poultry comfort are temperature and relative humidity, which can be handled by evaporative cooling systems. The evaporative cooling (EC) technology is based on heat and mass transfer between air and cooling water. Two evaporative cooling systems of direct evaporative cooling (DEC) and indirect evaporative cooling (IEC) were used under all experiments for cooling atmosphere inside the poultry house in the hot summer months. The direct cooling pad and indirect apparatus were positioned on the south wall of the building as shown in Fig. 2.

In DEC as shown in Fig. 3, water was pumped by pump power of 100 W with 60 l volume to the pipes, which positioned above cooling pad. The cooling pad was constructed from local materials of cardboard with dimensions of 60×50 cm and 10 cm thickness. These pipes were perforated and the water was fall on the pad as a droplets. The pads were wetted from the pipes that were positioned above them. Excess and falling water from the pad was collected in pipes and returned again to the tank. When the outdoor hot air was passed through the pad, the air temperature was decreased and be humidified. The humidifier added water to the incoming air stream to be cooled inside the poultry house.

Regarding to IEC system as shown in Fig. 3, water was pumped using pump power of 500 W with 60 l volume, that placed inside the house and it was equipped with a fan of 90W power. This system was carried out by cooling the air and kept it separated from the evaporation process, therefore it was not humidified.

The poultry house was supplied with fan, 50 cm in diameter with maximum air capacities 45 m^3/min with average air velocity of 3.1 m/sec. The used fan specifications were 3165-00 model, 300 rpm rotational speed and operated by motor power of 90 W. The fan was positioned on north wall at an opposite direction of air inlet place that was taken into consideration when designing the house. Every poultry live weight needs 4 m^3/hr., air flow rate per each kg according to **Alloui *et al.* (2013)**.Ventilation control was achieved by adjusting the air inlets and the fans (by switching fans on or off). The system was equipped with a set of operating timers to be operated at specific intervals and stopped period every 2 min.

Methods

Experimental Setup

Experiments were conducted under the following conditions of:

- Two different evaporative cooling systems of direct evaporative cooling (DEC) and indirect evaporative cooling (IEC).
- Three different water flow rates of 2, 4 and 6 l/min per m^2 of pad surface.

Measurements

The following indicators were taken into consideration for evaluating the performance of poultry house as:

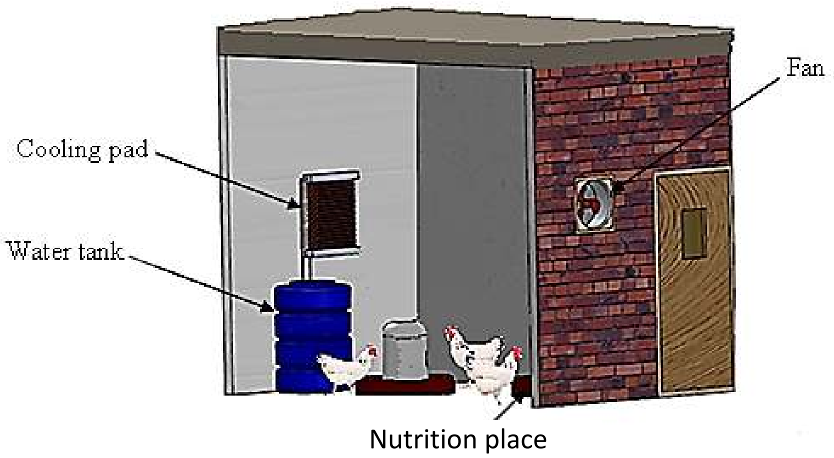
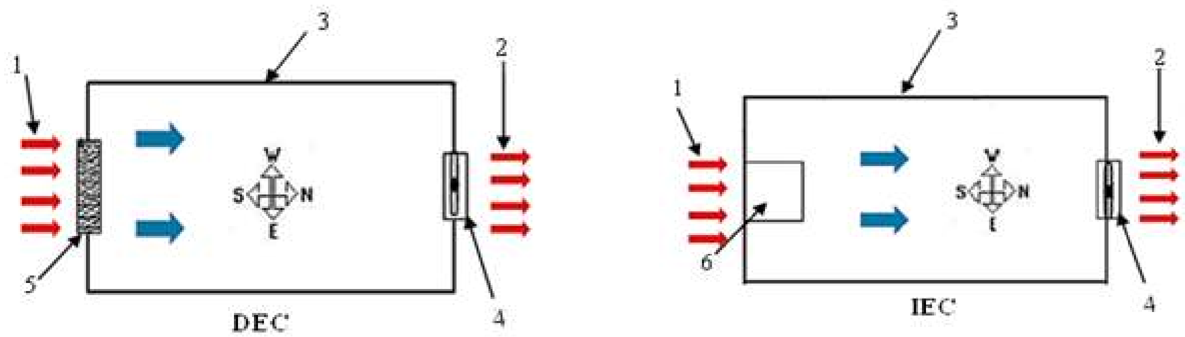


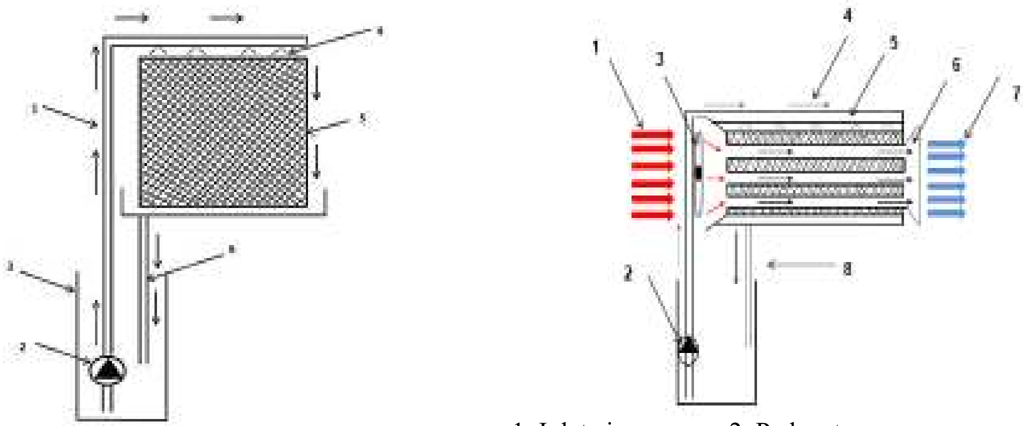
Fig. 1. Pictorial representation of the used poultry house



1. Inlet air (hot air), 2. Outlet air, 3. Poultry house,
4. Dynamic ventilation Fan, 5. Cooling pad, 6. Indirect ventilation device.

Fig. 2. A schematic diagram of two evaporative cooling systems in the poultry house

DEC **IEC**



DEC:
1. Water inlet pipe 2. Pad water pump
3. Pad water tank 4.Water droplets
5. Cooling pad 6. Water return pipe

IEC:
1. Inlet air 2. Pad water pump
3. Air Fan 4. Water pipe
5. Water droplet 6. Air outlet path
7. Outlet air 8. Return water pipe

Fig. 3. Evaporative cooling systems

Temperature (T) and relative humidity (RH)

Internal and ambient temperatures of air were measured with hour intervals during experiments. TM-40 X series (Tenmars Electronics Company) was used to measure temperature with an accuracy ± 1^{o}C, humidity with an accuracy ± 3.5% and the air speed with an accuracy ± 3%. Added to that, inlet and outlet water temperatures were measured by 0.85 mm diameter of copper – constantan thermocouples. All thermocouples were calibrated and connected directly to a digital millimeter.

Temperature reduction (ΔT)

The temperature difference between outside the house (T_{ao}) and inside the house (T_{ai}) was used to describe the performance of evaporative cooling systems. Temperature reduction (ΔT) was calculated using the following equation:

$$\Delta T = T_{ao} - T_{ai}$$

Where:

T_{ao}: Outlet dry-bulb temperature of the air stream (°C) and T_{ai}: Inlet dry-bulb temperature of the air stream (°C).

Evaporative cooling efficiency ($\eta_{cooling}$)

The cooling efficiency ($\eta_{cooling}$) was determined according to **Ashrae (2005)** and **Zhao *et al.* (2008)** by the following equation:

$$\eta_{cooling} = \frac{T_{ao} - T_{ai}}{T_{ao} - T_{wb}}$$

Where:

T_{wb}: The outlet wet-bulb temperature of the air (°C).

Poultry weight

Poultry weight as growth performance was recorded every day throughout the growth period (5 weeks).

Consumed energy

Electric meter was connected with experimental system to measure the consumed electrical energy. This electric meter was obtained from engineering industries company, Egypt.

Production cost

The total production costs (LE/kg) were assessed for different evaporative cooling systems and calculated according to the conventional method of estimating both fixed and variable costs.

The net return (LE/kg) was calculated using the following equation:

Net return = Total return - Production cost

RESULTS AND DISCUSSION

The obtained results will be discussed under the following heads:

The Climatic Conditions of the Experimental Region

Solar radiation and ambient temperature were represented with respect to time of day in Fig. 4 as climatic conditions of the experimental region. Selected day on 8th June 2018 was taken as a model of climatic conditions for other experimental days, which approximately took the same behavior like this mentioned day. Recorded results from 6.0 am to 18.0 pm explained that the solar radiation was gradually increased from the beginning morning hours at 6.0 am to be reached to the highest values of 1119.17 W/m^2 at 13.0 pm, and then decreased. Ambient temperature was varied from 27.47 to 29.23^{o}C.

Temperature Reduction

Fig. 5 show the effect of different water flow rates on temperature reduction under different evaporative cooling systems. Obtained results clarified that the behavior of temperature reduction was increased gradually through the time of day up to 13.00 pm and then decreased. This behavior was referred to the effect of climate conditions.

By the use of direct evaporative cooling (DEC), obtained results revealed that temperature reduction was increased by increasing water flow rate from 2 to 4 l/min.m^2, while the lowest values were obtained under 6 l/min.m^2 water flow rate. The maximum values were 10, 11.5 and 8.8^{o}C under water flow rates of 2, 4 and 6 l/min.m^2, respectively at 13.00 pm. The most adequate water flow rate for the experimental conditions was considered 4 l/min.m^2 according to **Karaca *et al.* (2016).** The decrease in temperature reduction at 6 l/min.m^2

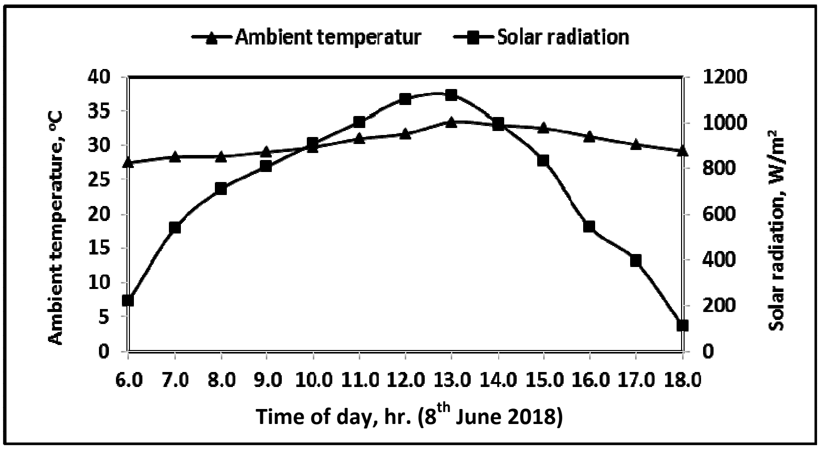


Fig. 4. Climatic conditions of the experimental region dated on 8th June 2018

DEC IEC

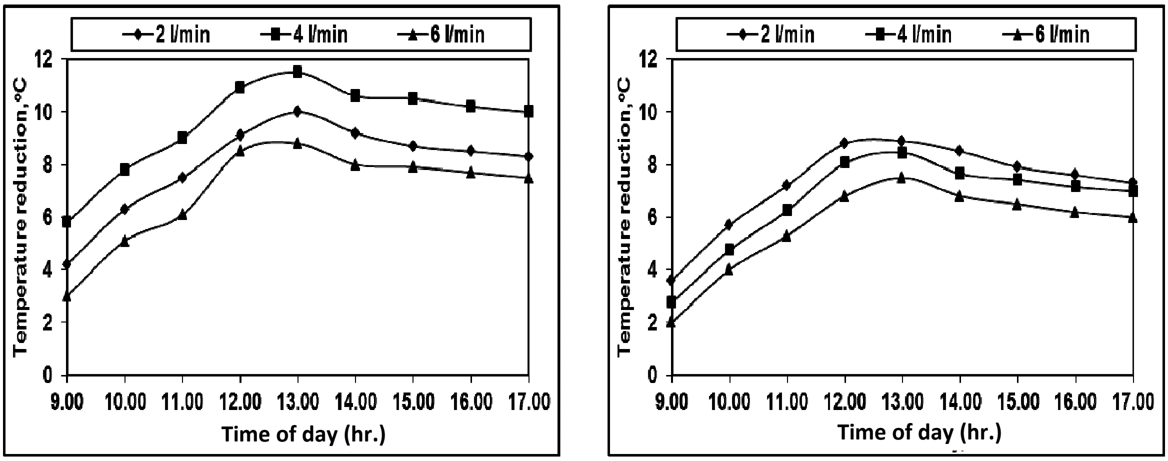


Fig. 5. Temperature reduction versus time of day under different water flow rates and evaporative cooling systems

was attributed to that excessive water flow causes the wavy surfaces at the pad covered with water, increases the resistance of the airflow, thereby decreases pad porosity, resulting in smoother surface with reduction in total surface area, and thus decreases the temperature reduction according to **Albright (1989) and Yıldız *et al.* (2010)**.

With regard to using indirect evaporative cooling system (IEC), it was seen that increasing water flow rates from 2 to 6 l/min.m^2 gave inverse results of temperature reduction. Based on theory of IEC and experimental results, more water streams did not increase the temperature reduction, but caused a hindrance to the secondary air flow rate. The air flow is very important to avoid the cooling pad rot. The highest reduction was 8.9, 8.45 and 7.5°C for water flow rates of 2, 4 and 6 l/min.m^2, respectively at 13.00 pm, these results agreed with those of **Herrero (2009)**, who recommended that the water flow rate did not exceed 3 l/min by the use of IEC.

It was evidence from experimental results that IEC gave the minimum reduction in temperature than DEC, this may be due to reduce the outlet dry-bulb temperature of the air stream by the use of IEC.

Relative Humidity (RH)

Obtained results from Fig. 6 illustrate that relative humidity (RH) was increased gradually versus time of day up to their maximum values at 13.00 pm, due to climate conditions, and then decreased. The highest values of RH at 13.00 pm were 64.5, 66.5 and 67.4% for DEC, while they valued as 63.2, 65 and 66.7% for IEC under 2, 4 and 6 l/min.m^2, in that order.

At 13.00 pm showed the maximum effect of the evaporative cooling systems because the poultries are exposed to the maximum values of heat stress. Direct evaporative cooling system (DEC) gave the highest values of RH than indirect evaporative cooling system (IEC). DEC adds moisture to the air, and so increases the air humidity. On the other hand, IEC system provides only sensible cooling to the process air without any moisture addition.

Added to that, increasing water flow rates from 2 to 6 l/min.m^2, the temperature was decreased and thus, RH was increased.

Evaporative Cooling Efficiency

The effect of evaporative cooling systems with different water flow rates on evaporative cooling efficiency was illustrated in Fig. 7.

Concerning the effect of water flow rate on the cooling efficiency under DEC, results represented that increasing water flow rate from 2 to 4 l/min.m^2, increased cooling efficiency from 74 to 78% at 13.00 pm and any further increase in water flow rate from 4 up to 6 l/min.m^2, the cooling efficiency was decreased from 78 to 70%. The average obtained values of cooling efficiency were in line with **Darwesh (2015).** The increase in cooling efficiency by increasing water flow rate from 2 to 4 l/min.m^2 may be attributed to the amount of the water flow rate, which was enough to wet the pad area completely until the pads are suitably moist and thereby, the cooling efficiency is increased, this results is in agreement with **Gunhan *et al.* (2007)**. However, the continuous increasing in water flow rate from 4 to 6 l/minm^2 leads to increase the relative humidity, reduce the surface area exhibition to the air from the inlet, the temperature decrease of the air passing through the pad and thus, cooling effectiveness value decrease, these results are compatible with **Albright (1989) and Yildiz *et al.* (2010)**.

With respect to the effect of water flow rate on the cooling efficiency under DEC, it was cleared that increasing water flow rates from 2 to 6 l/min.m^2 tends to decrease the cooling efficiency from 85 to79 % at 13.00 time of day. This increase of water flow rate, decreased the quantity of air, so affect the cooling efficiency, this is in line with **Al-Sulaiman (2002)**.

IEC gave the highest values and more efficient than DEC. This may be due to the decrement in relative humidity level in the system that worked with IEC, added to the temperature reduction between air outlet dry and wet-bulb temperature by applying psychometric chart of air properties and therefore, the efficiency of IEC was increased compared to DEC. These results are in agreement with **Zhao *et al.* (2008) and Porumb *et al.* (2016)**. In addition to using DEC, the mineral matter accumulates on the pad (calcification) and the characteristics of the pads deteriorate. This causes reductions in the efficiency of the system over the time according to **Albright (1989), Koca *et al.* (1991), ASAE (1994) and Yıldız *et al.* (2010)**.

Poultry Weight

Relating to the effect of evaporative cooling systems with water flow rates on the final poultry weight, obtained results in Fig. 8 clarified that the poultry weight values at the end of experimental period were 2.3, 2.4 and 2 kg for DEC, while values were 2.3, 2.2 and 1.9 kg for IEC under 2, 4 and 6 l/min.m^2, respectively. The optimum water flow rate was 4 l/min.m^2 for DEC, while was 2 l/min.m^2 for IEC. Excessive water flow rate decreases the temperature reduction, which caused overheating and heat stress and affects the poultry weight.

There is no clear effect on using evaporative cooling systems on the final poultry weight. But the variation of poultry weight may be attributed to the exposure to heat stress, which reduces the feed intake and thereby, affects the production performance adversely.

Consumed Energy

Related to the consumed energy for the two used evaporative cooling systems as shown in Fig. 9, results clarified that IEC consumed more energy comparing with DEC, due to the variation in the components of two systems. IEC

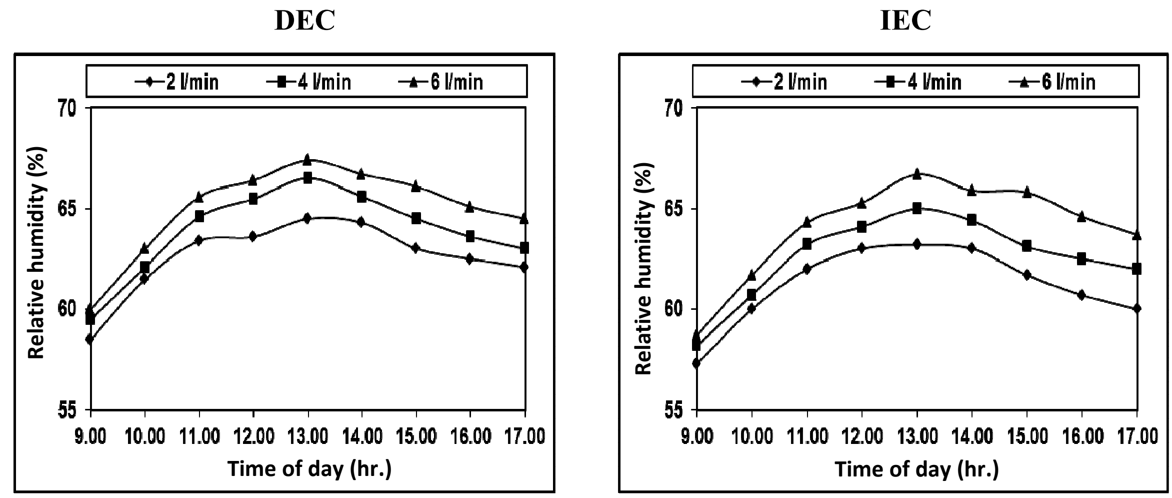


Fig. 6. Relative humidity under different water flow rates with evaporative cooling systems

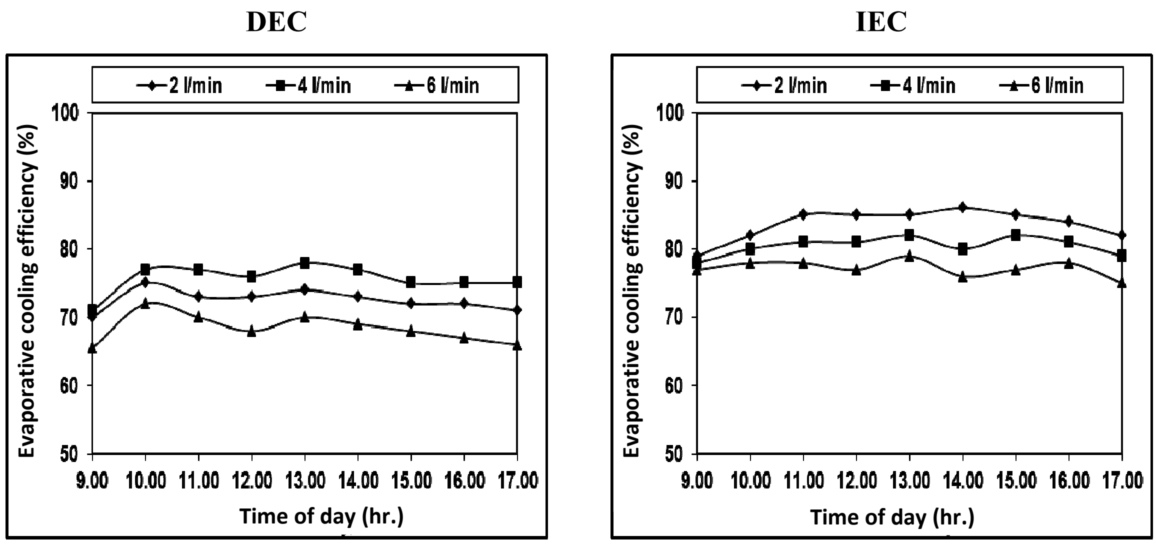


Fig. 7. Effect of water flow rate under different evaporative cooling systems on evaporative cooling efficiency

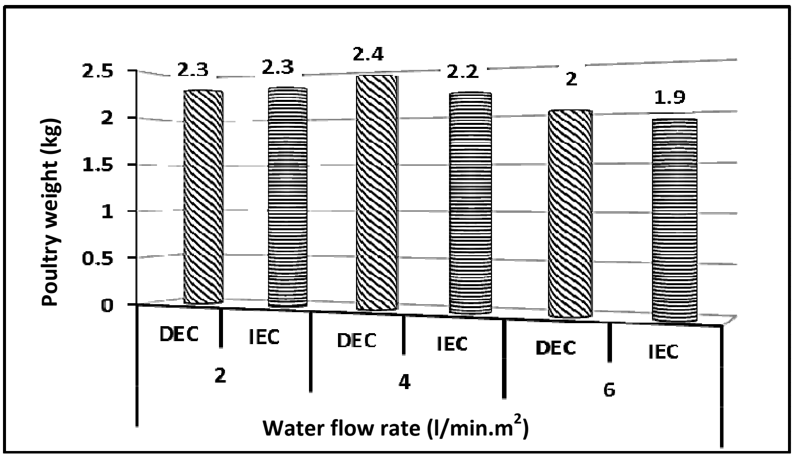


Fig. 8. Variation in poultry weight under different evaporative cooling systems

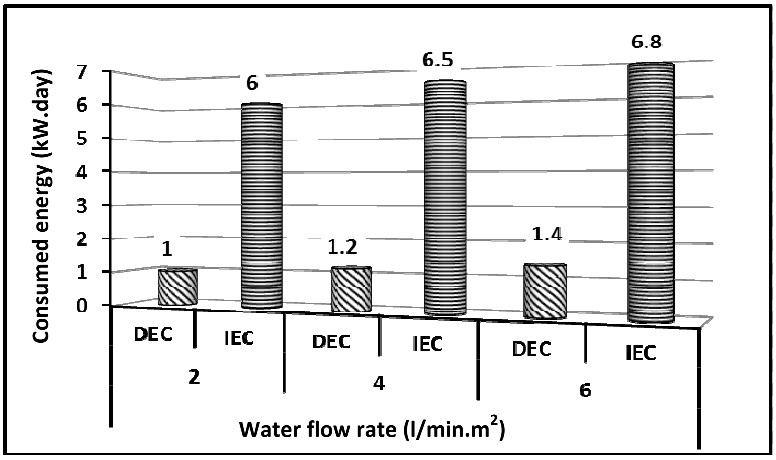


Fig. 9. Consumed energy of evaporative cooling systems

consumed energy for operating pad water pump and air fan that responsible for pulling the air and pushing it into pipes.

On contrary with using DEC characterized by simplicity in installation and components, added to the most widespread form of evaporative air conditioning.

The total consumed energy values were 1, 1.2 and 1.4 kW.day for DEC, while it valued 6, 6.5 and 6.8 kW.day for IEC under 2, 4 and 6 l/min.m^2, respectively.

It was noticed that increasing water flow rates, more consumed energy for water pumping and thus, the total daily consumed energy were increased.

Cost Production

Cost production was illustrated in Table 1 to evaluate the effect of different evaporative cooling systems with water flow rates economically.

From obtained experimental results, it was revealed that DEC is inexpensive than IEC, this is in agreement with **Khobragade and Kongre (2016)**.

By the use of DEC with 4 l/min.m^2 water flow rate gave the minimum production cost of 17.50 LE/kg, the highest total return of 25.04 LE/kg, and thus the total return cost of 7.54 LE/kg. While using IEC at 2 l/min.m^2 water flow rate achieved the lowest production cost of 19.60 LE/kg with the highest total and net return of 25.40 and 5.80 LE/kg, respectively.

Conclusions

The present study aimed to evaluate the performance of different evaporative cooling systems under different water flow rates of poultry houses.

Obtained results revealed that:

- Evaporative cooling system can be used for reducing heat stress inside the poultry houses with energy efficient system.
- Direct evaporative cooling system with 4 l/min.m^2 water flow rate gave sufficient conditions of temperature reduction (9.59°C), relative humidity (63.88%), cooling efficiency (75.67%), poultry weight (2.4 kg) and consumed energy (1.2 kW.day) with net return (7.54 LE/kg).
- Indirect evaporative cooling system with 2 l/min.m^2 water flow rate provided suitable conditions of temperature reduction (7.28°C), relative humidity (61.21%), cooling efficiency (83.67%), poultry weight (2.3 kg) and consumed energy (6 kW.day) with net return (5.80 LE/kg).
- It is recommended to use direct evaporative cooling for poultry houses, as it decreases both energy consumption and production cost compared to the indirect evaporative cooling system, and therefore suitable for small rural farmers.

Table 1. Cost estimation of the poultry house under different evaporative cooling systems

Cost estimation	Evaporative cooling systems					
	DEC			IEC		
	Water flow rate, l/min.m^2			Water flow rate, l/min.m^2		
	2	4	6	2	4	6
Production cost, LE/kg	17.90	17.50	20.00	19.60	20.30	23.10
Total return, LE/kg	24.80	25.04	21.50	25.40	25.09	24.00
Net return, LE/kg	6.90	7.54	1.50	5.80	4.79	0.90

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تقـييـــم أداء مـــزارع الـــدواجــــن تــحـــت أنظـــــمــــة التبــريــد التبخـــيـــري المختلــفـــة

سليمان جاد عبدالرحمن- محمود عبدالرحمن الشاذلى- كمال ابراهيم وصفى- علاء عوني أحمد عبدالعاطي

قسم الهندسة الزراعية – كلية الزراعة – جامعة الزقازيق – مصر

تعتبر صناعة الدواجن من أهم الصناعات الرائدة على مستوى العالم التي تعطى عوائد اقتصادية عالية، حيث أنها تعتبر مصدر هام للبروتين الحيواني، تصميم عنابر الدواجن له دور كبير في تحديد الظروف الملائمة داخل هذه العنابر وأثرها على الإنتاجية، تهدف هذه الدراسة الى تقييم أداء عنابر الدواجن باستخدام نظم التبريد التبخيري المختلفة، حيث تم دراسة تأثير استخدام نظامين للتبريد التبخيري (المباشر وغير المباشر) تحت معدلات مختلفة للمياه ٢ ، ٤ و ٦ لتر/دقيقة لكل متر مربع، وقد تم دراسة تأثيرها على مستوى الانخفاض في درجة الحرارة، الرطوبة النسبية، كفاءة عملية التبريد التبخيرى، الوزن، استهلاك الطاقة، كذلك تكاليف الانتاج وصافى العائد، وقد توصلت النتائج إلى استخدام نظام التبريد التبخيري المباشر بمعدل تصرف للمياه ٤ لتر/دقيقة أعطى انخفاض في درجة الحرارة (٩,٥٩ ^{o}م)، الرطوبة نسبية (٦٣,٨٨%) وكانت كفاءة التبريد (٧٥,٦٧%)، الوزن (٢,٤ كجم)، الطاقة المستهلكة (١,٢ كيلو وات.يوم) وصافى العائد (٧,٥٤ جنيه/كيلو)، استخدام نظام التبريد التبخيري غير المباشر بمعدل تصرف للمياه ٢ لتر/دقيقة أدى الى الحصول على قدر كافي من الانخفاض في درجة الحرارة (٧,٢٨ ^{o}م) والرطوبة نسبية (٦١,٢١%)، كفاءة التبريد (٨٣,٦٧%)، الوزن (٢,٣ كجم) والطاقة مستهلكة (٦ كيلو وات.يوم) وصافى العائد (٥,٨٠ جنيه/كيلو)، يوصى باستخدام نظام التبريد التبخيري المباشر فى مزارع الدواجن حيث انه أعطى انتاجية عالية واقل استهلاك للطاقة والتكاليف مقارنة بالنظام غير المباشر تحت ظروف التشغيل المناسبة بمعدل تدفق للمياه بمقدار ٤ لتر/دقيقة لكل متر مربع من البادة.

المحكمـــــون:

١- أ.د. جمال الدين محمد نصر أستاذ الهندسة الزراعية – كلية الزراعة – جامعة المنصورة.

٢- أ.د. محمد محمد مراد حسن أستاذ الهندسة الزراعية المتفرغ – كلية الزراعة – جامعة الزقازيق.