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The Assessment of Pad-Fan Evaporative Cooling System in Broiler Housing

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ABSTRACT

An investigation was executed to study the impact of using different thicknesses for pad cooling and various airflow rates on the cooling system effectiveness inside the house of broilers and on its performance in the summer of 2019, Egypt (latitude angle of 30.42°N and longitude angle of 30.59°E). The trial was done using 20, 30, 40, and 50 m^3/s. airflow rates, As well as using ten and fifteen cm pad thickness. The experimental work results' pointed to using a pad cooling system with fifteen cm pad thickness with 20, 30, 40, and 50 m^3/s airflow rates increase the temperature cooling effect by 25.54, 30.89, 13.36, and 44.63 % comparing with using ten cm pad thickness for the same previous flow rates, respectively. Cooling efficiency increased by 24.73, 29.5, 12.17, and 44.46% when using a cooling system with fifteen cm pad thickness comparing with using a cooling system with ten cm pad thickness for 20, 30, 40, and 50 m^3/s airflow rates, respectively. The average value of pad water consumption decreased by 57 % when using a fifteen cm pad cooling system compared to a 10 cm pad cooling system. The lowest mean value for T.H.I. was 25.4°C at an airflow rate of 50 m^3/s for fifteen cm pad thickness. Reared birds in the house with fifteen cm pad cooling thickness were not stressed, according to T.H.I. Value and thus lead to increasing the production Efficiency factor by 17.91% comparing with using a ten cm pad cooling system.

keywords: airflow rate, pad thickness, and temperature-humidity index

INTRODUCTION

There is considerable attention in animal production of meat nowadays to cover the demand of the population for the animal protein. Broilers are the cheapest protein sources comparing with other protein sources, such as (cheap, beef, and buffalo). Thus because broilers have a high feed conversion efficiency to meat also, a capital cycle shorting period. The total national production of chicken's meat was 1066627 tones. In 2018, according to (F.A.O. 2020). Increasing national broiler meat production depends not only on health protection but also on better environmental conditions in the winter and summer season. Environmental control includes maintaining correct indoor air temperature, suit air relative humidity, permitted air gaseous emission, and suit ventilation rate required for excessive heat and moisture dissipation is mandatory. At hot climate conditions, the inner dry bulb temperature of the broiler house may reach very high values. This situation causes heat stress at the produced birds. Heat stress happened when indoor dry bulb temperature and relative humidity reach a high level. The suitable percentage for air relative humidity inside broiler houses is between 50-70 % for the first three weeks of broiler age, and for the rest of the broiler, life should be 40 to 60% (Fairchild, 2012). Heat stress reduces the quantity of heat dissipates from the broilers' body, increasing core body temperature for birds. Raising 4 °C in core body temperature leads to a bird's death. Heat stress reduces feed intake, rate of growth, and immune function (Quinteiro-Filho *et al*., 2010). Reducing heat stress in broiler houses can be achieved using tunnel ventilation, with evaporative pad cooling systems (Daghir,2007).

Tunnel ventilation systems are employed to moderate seasonal temperature fluctuations and are particularly useful during hot weather. In general, the air is drawn at a velocity of 2.50 m/s through the house length removing heat, moisture, and dust. The airflow produces a wind-chill effect, reducing air temperature by 5-7 °C. House air should be exchange within one minute to provide sufficient indoor temperature ranged between 28-29°C (Cobb Broiler Management Guide, 2018). Maintaining interior air temperature at 29°C, which is the upper limit of the thermal comfort zone, is mandatory (Osório *et al*., 2009).

For heat removable, the most suitable airflow rate is 7-9 m^3 /kg bird per hour in an insulated building (Alchalabi, 2015). If the dry bulb temperature of interior air exceeds 28 °C, the fan–pad cooling system should maintain morel cooling for growing chicks. (Laknizia *et al*.,2019). (Abdollah *et al*.,2011) showed increasing pad's velocity and also pad's thickness, increasing pressure drop, and more water will evaporate, thus decreasing the cooling efficiency system and increase the indoor relative humidity. It also concluded that using a cooling system with a fifteen cm pad thickness and 1.8 ms^{-1} and pad's velocity increase the system saturation efficiency.

Rajesh Maurya *et al.* (2014) concluded that cooling system efficiency would increase if pad thickness rises because of increasing the contact surface area. Increasing the pad's velocity leads to less water contacting time for

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evaporation, which decreases saturation efficiency. Increases of mass airflow rates raise the cooling effect and lower the interior air relative humidity. Rising air mass flow rates reduce cooling system efficiency (Kulkarni and Rajput, 2011). At high pad air velocities, temperature reduction and cooling efficiency values of system decrease, but this situation is only valid if the airflow character of the atmosphere (laminar, turbulence) is typical while passing the pad. When the flow character changes, this relationship becomes invalid. Because the air velocity crossing the pad affects both the air trajectory crossing the pad and contacting time with a wet surface, at low air velocities, airflow has a laminar character. Laminar character airflow means that little amount of air in contact with the damp pad surface, in a particular thickness, find the opportunity to get moistened. Therefore, the cooling effect of air crossing the pad and the cooling efficiency decreased. Increasing air velocity means that air layers were broken and turning the flow from laminar into turbulence. As a result, the opportunity for water evaporation from the pad surface rises. In other words, increasing the pad's air velocity increase both the cooling effect and cooling system efficiency (Yıldiz *et al*., 2010). Da_gtekin *et al*. (2011) concluded that no relation model describes the relation between cooling effect, cooling efficiency, and pad's thickness. Increasing mass airflow rate increases evaporative cooling performance (ECP), and it was between 1.1 to 6.72 kWh for different materials (Khobragade and Kongre,2016).

Kocatürk and Yildiz (2006) evaluated the performance of fan - pad cooling system using three pad's air velocity (0.5, 1.0, and 2.0 ms^{-1}) at a water flow rate of (4 L $min^{-1}m^{-2}$) from June to September in the Mediterranean region climate conditions. They found that the cooling efficiency and cooling potential ranged between 77 to 84% and 6.7 and 5.6°C, respectively, and the water evaporation rate varied between 0.078 and 0.210 L min^{-1} m^{-2}. Cruz *et al*. (2006) used four different pad's air velocity 1.6, 3.2, 4.8, and 5.6 $ms^{-1,}$ respectively, and four temperature ranges. Air velocity of 3.2 ms^{-1} and indoor dry bulb temperatures of 32 to 34°C gives the highest value of cooling efficiency (80% and more).

T.H.I. Equations explain the interrelation between dry bulb and wet bulb temperature inside the broiler house. T.H.I. Value is an indicator of physiological parameters such as (pulse rate and respiration rate) and heat production. Even though T.H.I. Take into consideration dry and wet bulb temperature; it ignores the great importance of air velocity, a necessary method to dissipate from excessive heat production in new poultry production houses like tunnel-ventilated houses. Broilers dependent upon losing extreme heat in the form of sensible heat to preserve its body temperature stable, and this can be achieved by rising air movement. The Temperature-humidity-velocity index (THVI) describes the effects of those parameters on the C.B.T. of broilers under acute heat stress (Tao and Xin, 2003). Increasing interior air temperature and T.H.I. The value above the limited upper level tends to reduced body weight and feed conversion efficiency (Sohail *et al*., 2012). Joseph *et al*. (2012) recommended that for broiler, the T.H.I. should be between 20°C and 26°C, where additional cooling is mandatory to prevent performance declines.

From the previous introduction, many researchers evaluated fan – pad cooling system performance using different parameters; some consider the effect of using different pad thicknesses on cooling system performance, and others studied varying airflow rates, and they concluded that increasing pad thickness tends to increase cooling efficiency.

Increasing the pad's air velocity decreases cooling efficiency also increases air mass flow rate, increases the cooling effect of air, and reduces air relative humidity. Therefore, the objectives of this research were to assess the relationship between air flow rates and pad thickness on evaporative cooling performance and performance broiler chickens at the market size.

MATERIALS AND METHODS

Materials

An investigation work executed in two similar broiler houses in one living cycle in Egypt (30.42°N, 30.59°E). The experiments were born in the relatively hot summer of 2019.

1. Broiler house

Broiler houses dimensions were 38 m in length, fifteen m in width, and 3.1 m in height and had a floor surface area of 570 m^2 and a volume of 1767 m^3. The house has an East-West orientation (Figure 1). The ceiling and the floor were made from fifteen cm of reinforced concrete, and the house walls were made of 12-cm red bricks and were blasted with 5 cm of cement mortar. The houses were provided with a hand-feeding system arranged on the interior surface. It was also equipped with four rows of a Nibble drinking system for broiler drinking.

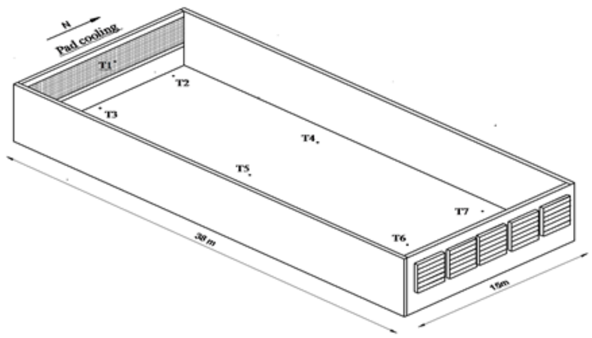

Fig .1. Schematic diagram for broiler houses with evaporative pad cooling system, dry and wet bulb temperature sensors arrangement inside the houses

2. Broiler

A total number of 5800 birds with 26-days age - Hybrid Ross birds with a mass of 1.25 kg were reared until the end of the living cycle at the age of 36.

All the broilers were reared in the same place until the age of 26-days age then the broilers were weighted then divided into two groups. Each group of about 5800 birds reared in the identical separated house until the end of the living cycle

3. Fan – pad cooling system

Two fan pad cooling systems different in thickness of pad (ten and fifteen cm) were used in the experiment.

All houses were provided with a fan – pad cooling system. Pads were distributed at the end of the western wall, and ventilation fans were placed on the eastern border. The cooling system consisted of a pad, water line supply, 350 W water pump, perforated polyvinyl chloride (P.V.C.) (10-mm diameter) distribution pipe, gutter, one tank with a volume of 500 L each, and a bleed-off line (Fig 2).

Twenty-five corrugated cellulose pads, each one is 0.6 cm in width and 1.5 m in height, were used. The total area of the cooling pads was 22.5 m^2 (fifteen m in length and 1.5 m in size). Five axial-flow, direct-driven suction fans with diameters of 126 cm, three phases, and 36750 m^3 h^{-1} discharge were used to maintain the required air mass flow rate during hot periods under 2.5 mm of static pressure. An electric motor operated fans with a belt pulley by attaching an electronic tap changer to each fan motors, permitting the required air velocity to be easily achieved. The mass air flow rate can be quantified by multiplying the adjusted average pad air velocity, air density, length of the pad, and pad height.

Methods:

Experimental work was done in two similar broiler houses during the summer of 2019, with a total complement of 5800 broilers in each place with 26 ages using tunnel ventilation with fan- pad cooling system to investigate the effect of two different pad thicknesses (ten and fifteen cm) and four different mass airflow rates (20, 30, 40, and 50 m^3 /s) on the efficiency indicators of the selected pad cooling system in the form of cooling effect, saturation efficiency, heat energy removal, water consumption on evaporation, Evaporative cooling performance, Ratio of temperature reduction to airflow rate (ΔT/Q), T.H.I and THVI and on broilers performance.

The water pump withdraws water from the water tank through a filter and then pumps it through a perforated distribution pipe above the pads. A gutter under the places was used to hold the water draining from the pads. The collected water can be recycled as long as salt or minerals do not accumulate on pads. A valve was used to adjust the water flow rate through the distribution pipe. Pads' water flow rate was constant during the experiment, and it was about 3.11 L. min $^{-1}$ $m^{-2,}$ and for all treatments, as shown in Fig (2). The pads' water flow rate was measured using a measuring cylinder and a chronometer.

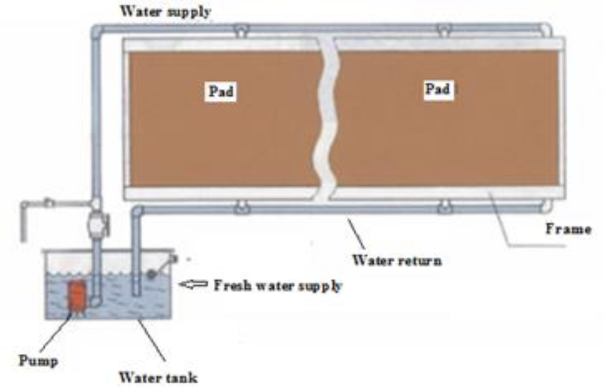

Fig .2. Schematic diagram evaporative pad cooling system, components

A Mt 512 E-temperature controller and indicator with temperature control range between −50 to 75°C was used to read and control the temperature inside the laying hen houses. The calibration of the sensor was successfully completed at the beginning of the experiments.

The control system was used to keep the indoor air temperature at a set point of 28°C, and it was installed at 0.25 m in height with a differential temperature of 0.1°C. This represents the maximum temperature of comfort during the last two weeks of rearing in which the birds are sensitive to the heat. As a result, reducing the cooling load may be achieved if the ventilation rate increases to take advantage of the lower temperature of the outside air.

The sensor of the controller was set at the last third of the house near the ventilation fan. Therefore, if the house temperature increases over 28°C, the cooling system pump reduces the indoor air temperature to the preset points. The thermostat stopped the pump before all of the fans stopped working so that the pad could dry.

1. Measurements

Temperature measurements and relative humidity

Two data-logger devices (16 channels) were used for collecting, recording, and reading from the different sensors (L.M. thermistors with an accuracy of ± (1/4°C) at room temperature and ±3/4°C over a full −55 to + 150°C temperature range) and were placed at various positions indoor and outdoor the broiler houses. Inside the house, dry bulb ($T_{i,db}$) and wet bulb ($T_{i, wb}$) temperature were measured at six various positions along-side of the building, including pads' water (T_p), house center (T_c), and near the fans (T_f); average temperatures were then calculated. Figure 1 shows the positions where the temperature was measured. Two sensors were used to measure dry ($T_{o,db}$) and wet-bulb ($T_{o,wb}$) temperatures outside the house. Wet-bulb temperature ($T_{o,wb}$) was measured by thermistors wrapped in wet clothes. The psychometric chart program was used to calculate pads' relative humidity (Rh_p), a center of the house (Rh_c), relative humidity near the ventilation fans (RH_f), and outside the building (Rh_o) (Fig 1).

The data logger was connected with a keyboard and a monitor. The computer programs Lap Jack and Profilap were employed. The Lap Jack program was used to run the data logger on the computer, and the Profilap program was used to convert the reading from analog to digital. The time interval for the data recording was 5 minutes, and data were acquired every minute for integrated measurements. All the sensors and data loggers were calibrated before experiments staring.

Air velocity

A digital fan anemometer (model UNI-UT363) was used to determine to mean pad face air velocity, mass airflow rate from the axial fans, and average air velocity inside houses. The anemometer had a range of 0.1 to 30 m s^{-1} and accuracy of ± 2%.

The mean pad's air velocity was measured for each pad thickness at different mass airflow rates at 30 points across the pad face area. The mean value of the measured points was then calculated. The axial fans were calibrated by determining air velocity exiting from the fan outlet at nine different points within the cross-sectional area of the fan. Air velocity exiting from the fan outlet was determined by calculating the mean value of nine measurements. The airflow rate at the fan outlet was then calculated by multiplying the mean air velocity by the cross-sectional area of the fan. The airflow rate was adjusted by attaching an electronic tap changer to each one of the fan motors; it is possible to obtain the desired air velocity quickly. By multiplying the adjusted mean pad's air velocity, air density, length of pad, and pad high, it can determine the air mass flow rate.

1-Performance of cooling system

1-Cooling effect

The cooling effect can be expressed as temperature reduction and was estimated using Equation (1).

$$\Delta T = (T_{db,o} - T_p) \quad (1)$$

Where ΔT is the cooling effect, (°C); $T_{db,o}$ is the outside air dry-bulb temperature (°C), and T_p is the dry-bulb temperature (°C) of air just leaving the pad.

2- Saturation efficiency (S.E.)

Saturation efficiency is defined as the ratio between the actual dry-bulb temperature reduction (i.e., cooling effect) and the theoretical maximum at 100% saturation (ASHARE, 2005). It is calculated as a percentage from the following Equation (2).

$$S.E = \frac{(T_{db,o} - T_p)}{(T_{db,o} - T_{wb,o})} \quad (2)$$

Where S.E is the Saturation efficiency (%), $T_{wb,o}$ is wet bulb temperature of the outside air, °C, and ($T_{db,o}$ - $T_{wb,o}$) is the wet-bulb depression, °C.

3- Heat energy removal

The rate of heat energy removal from the broilers houses can be calculated from the following Equation:

$$Q_r = m_r (h_{pad} - hex) \quad (3)$$

Where Q_r is heat energy removal from the house by the cooling system,kW.h, m_r, is ventilation rate kg/s, h_{pad}, is the enthalpy of air just leaving the cooling pads, and hex, is the enthalpy of exhausting air in kJ/kg.

4- Pad water consumption

Water consumption in the evaporation process was calculated by Equation (4).

$$m_e = M \times (w_{out} - w_{in}) \quad (4)$$

Where m_e is the water consumption (kg h^{-1}), M the air mass flow rate (kg h^{-1}), W_{out} is the humidity ratio of air before pads (kg $_{water}$. kg^{-1} $_{dry\ air}$), and W_{in} is the humidity ratio of air after pads (kg$_{water}$. kg^{-1} $_{dry\ air}$).

5- Evaporative cooling performance (ECP) (Cooling Energy)

Evaporative cooling performance (ECP) is a common term for measuring cooling energy, and it can be calculated as latent or sensible heat.

The cooling energy is calculated by the temperature difference at the inlet and the outlet according to Equation (5) (Laknizia *et al.*, 2019).

$$ECP = m \times cp \times \Delta T \quad (5)$$

Where ECP is the cooling energy (kWh), m is the air mass flow rate (kgs^{-1}), and cp is the specific heat of the air (kJ kg^{-1}.°C^{-1}).

$$m = \rho \times V \times L \times H \quad (6)$$

Where ρ is the density of air, V is the mean pad air velocity (m s^{-1}), L is the width of the pad cooling (m), and H is the height of the pad cooling (m).

6-Ratio of temperature reduction to airflow rate (ΔT/Q)

It was computed using the following Equation:

$$\Delta T / Q = (T_{db,o} - T_p) / Q \quad (7)$$

Where $\Delta T/Q$ Is the ratio of temperature reduction to airflow rate, °C.s/m^3.

7-Temperature – humidity index (T.H.I.)

The temperature-humidity index for broilers (T.H.I.) was calculated using the following Equation according to (Tao and Xin, 2003)

$$THI = 0.85T_{dbi} + 0.15T_{wbi} \quad (8)$$

Where $T_{i,db}$ is Indoor air-dry bulb temperature, °C and $T_{i,\ wb}$ is Indoor air wet bulb temperature, °C.

The threshold range of T.H.I. was calculated depending on the comfort (thermo-neutral) zone for broilers in which dry bulb temperature ranged from 21°C to 25°C and air relative humidity ranged from 60% to 70 %. This is the comfort zone for broilers at marketing size. The threshold values of T.H.I. was found to be ranged from 20.1°C to 24.5 °C.

8-Temperature – humidity- velocity index (THVI)

The temperature-humidity velocity index calculated using the following Equation (Tao and Xin 2003).

$$THVI = (0.85T_{dbi} + 0.15T_{wbi}) \times V^{-0.058} \quad (9)$$

Where THVI is Temperature – humidity- velocity index (°C) and V is Air velocity, m/s.

They also established several stages of thermal comfort values such as normal ≤70, alert from 70 to 75, danger values are those from 76 to 81, and emergency values were ≥82, based on variations in the bird's body temperature

2-Broiler performance:

1-Feed conversion efficiency (F.C.E)

Broiler feed conversion efficiency was calculated using the following Equation (Ross Management Guide, 2014):

$$FCE = \frac{W_b}{F_c} \times 100 \quad (10)$$

Where F.C.E is feed conversion efficiency, %,Wb is broiler body mass, kg, and Fc = broiler feed consumption, kg

2-Feed conversion ratio (F.C.R)

Broiler feed conversion ratio was determined using the following relation according to Arbor Acers Management Guide (2014):-

$$FCR = \frac{F_c}{W_b} \quad (11)$$

Where F.C.R is the feed conversion ratio per kg, F_c is Total broiler feed consumption, kg and W_b is Total broiler body mass, kg

3-Production Efficiency Factor (P.E.F)

The production efficiency factor was determined using the following relation according to (Arbor Acers Management Guide, 2014) as follows:

$$P.E.F = \frac{\text{mean live weight x percentage of lived}}{\text{feeding time x feeding conversion ratio}} \text{ x } 100 \quad (12)$$

RESULTS AND DISCUSSION

1-Dry bulb temperature and relative humidity

Fig (3) and Fig (4) illustrated the recorded air temperatures (T) and relative humilities (R.H.) throughout the operating period for both pad thickness (ten and fifteen cm) at different airflow rates. Generally, Indoor air temperature was lower than the outside one, and the inside relative humidity was higher than the outside one. The reduction in inside indoor air temperature which observed inside the structures was due to the use of an evaporative pad cooling system in which the air stream to be cooled comes directly in contact with the wetted pad, and evaporates some water by exploiting heat for evaporation from surroundings and carrying some moisture through an adiabatic process. Indoor air temperature in case of using a pad thickness of fifteen cm (T_i 15 cm) was lower than the indoor air temperature at a pad thickness of ten cm (T_i 10 cm) for all airflow rates (20, 30, 40, and 50 m^3 /s). Increasing the airflow rate from 20 to 50 m^3/s for both pad thickness ten and fifteen cm contributes to decreasing indoor temperature. The lowest value recorded for reducing indoor temperature was recorded at a flow rate of 50 m^3/s at fifteen cm pad thickness. The observed increase in relative humidity inside structures was due to the use of an evaporative pad cooling system. In general, the house which using evaporative cooling with 10 cm pad thickness had the highest values of relative humidity comparing with the house, which had an evaporative cooling system with fifteen cm pad thickness under different airflow rates (20,30,40 and 50 m^3 /s). At airflow rates of (20,30,40 and 50 m^3 /s)when using 10 cm pad thickness, the mean values of relative humidity were (80.14,79.89,81.91 and 79.06 %, respectively. Meanwhile, using fifteen cm pad thickness under the range of airflow rates were (75.33, 73.44,74, and 67.6%), respectively.

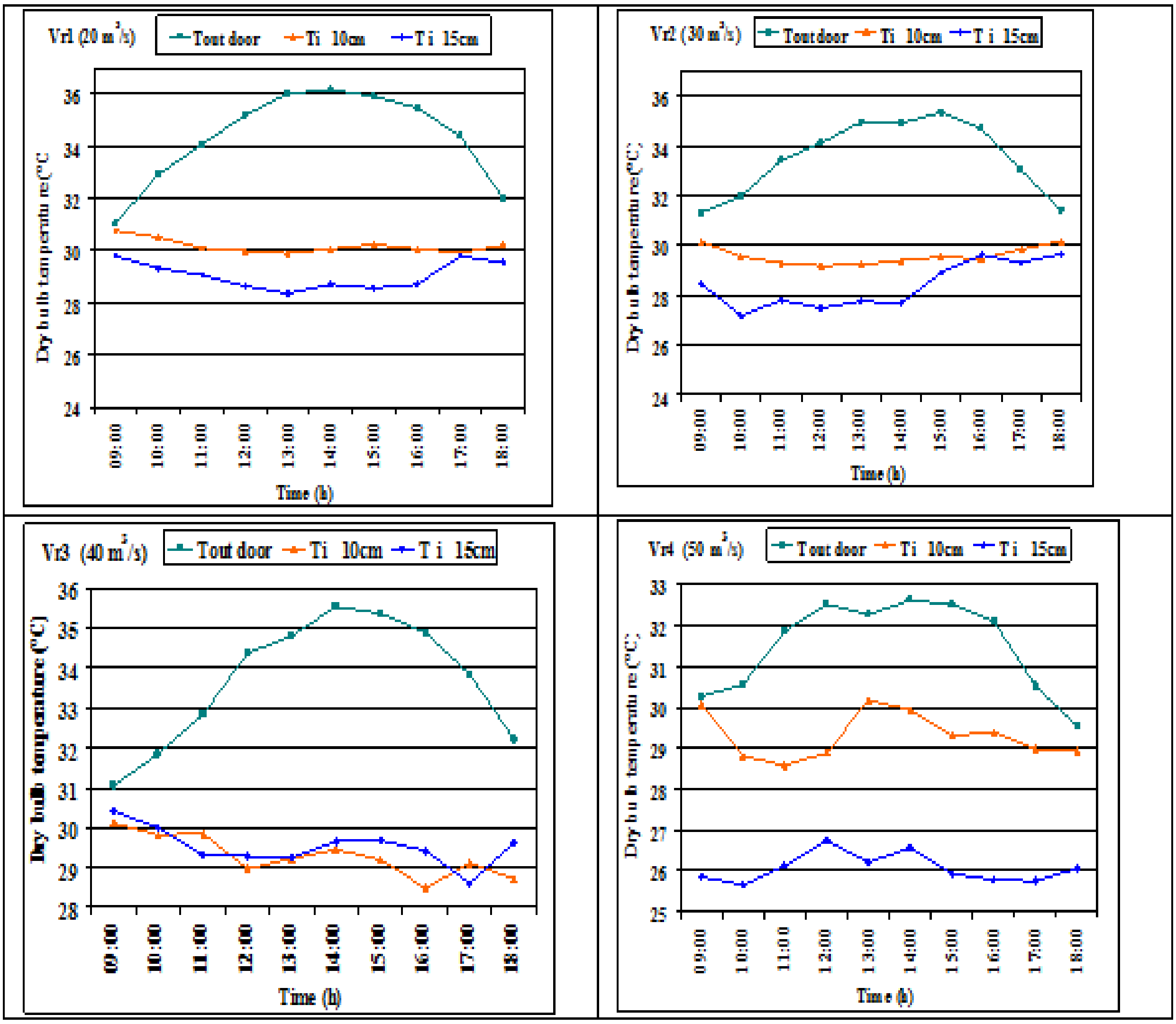

Fig .3. Effect of airflow rate on indoor temperature under two pad thicknesses

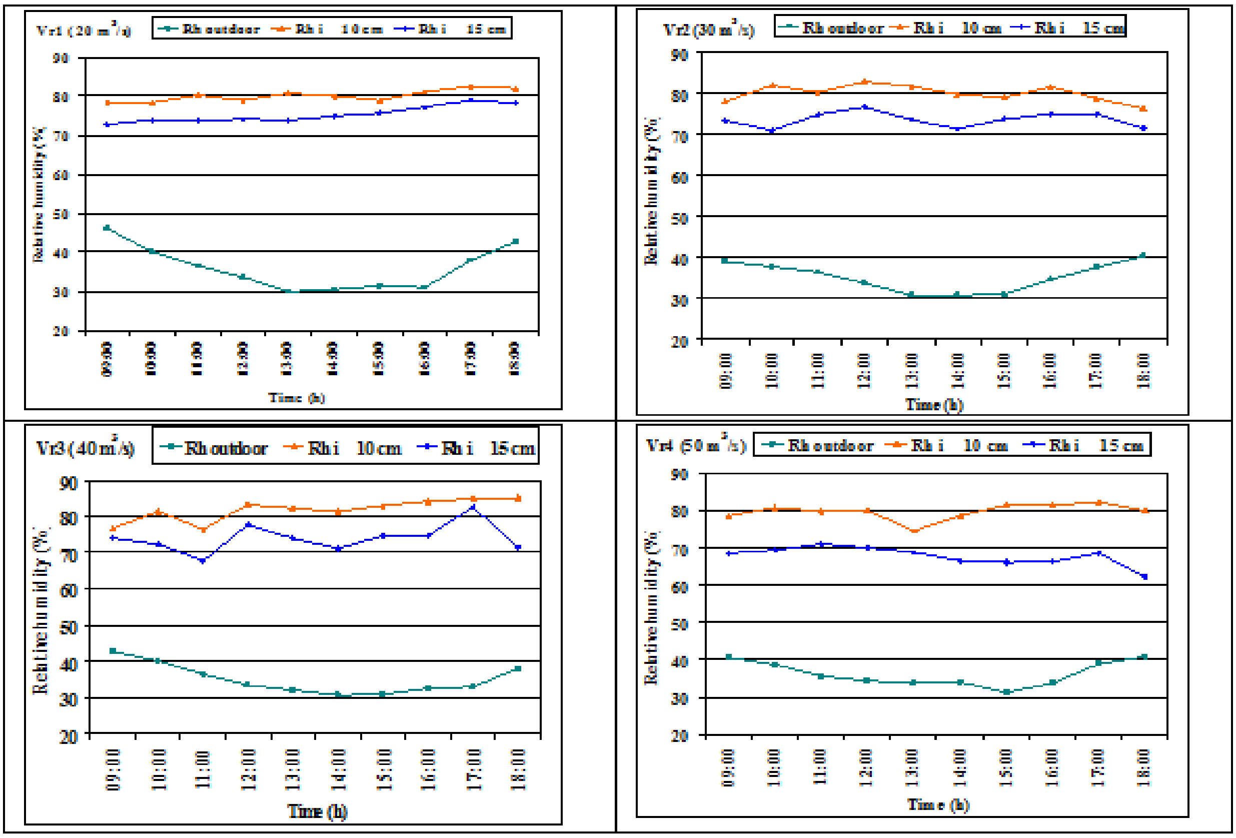

Fig .4. Effect of airflow rate on relative humidity under two pad thicknesses.

Table (1) illustrated the temperature mean, relative humidity, and standard deviation (S.D.) during the operating period for both pad thickness and four different airflow rates. The minimum mean value of the indoor temperature of about 29.3 °C (S.D. =0.92) was found when using a pad thickness of 10 cm and an airflow rate of 40 m^3/s. For pad thickness of fifteen cm, the minimum means the value of the indoor temperature of about 28.38 °C (S.D. =0.27) at 30 m^3/s air flow rate. Corresponding, the outside temperature was 33.7°C (SD=0.305) and 33.5°C (SD = 0.185) for both pad thickness, respectively. Minimum mean values of indoor air temperatures for both pads thickness were in the range which suggested to be inside broilers houses by (Cobb Broiler Management Guide, 2018) and (Osório *et al*., 2009).

Lower standard deviation values indicated in the Table (1) and belonging to fifteen cm pad thickness confirms the previously mentioned result of the better environmental control level in cooling air temperature using fifteen cm pad thickness.

Table (1) shows the mean air relative humidity and standard deviation (S.D.) during the operating period for both pad thickness at various airflow rates. The minimum mean value of about 79.61 % (S.D. =6.8%) was found when using a 10 cm pad thickness at 50 m^3/s air flow rate. For pad thickness of fifteen cm, the minimum mean value of about 67.61% (S.D. =1.7%) at 50 m^3/s air flow rate. Corresponding, the outside relative humidity was 36.1% (SD = 0.39) for both pad thickness. The obtained data were in agreement with that published by (Fairchild, 2012)

Lower standard deviation values indicated in the Table (1) and belonging to fifteen cm pad thickness confirms the previously mentioned result of the better environmental control level in cooling air temperature using fifteen cm pad thickness at all pad face air velocities. Proper controlling of temperature and relative humidity of air at an acceptable level can be achieved using a fifteen cm pad thickness.

Table 1. showed temperature mean, relative humidity, and standard deviation (S.D.) during the operating period for both pad thickness and four different airflow rates

Pad thickness (cm)	Airflow rate, m^3/s	T_{dbo}, °C	SD of T_{dbo},°C	T_{dbi} , °C	SD of T_{dbi} ,°C	RH_o %	SD of RH_o,%	RH_i %	SD of RH_i,°C
10 cm	20	34.32	0.76	30.17	1.54	35.99	0.3	80.15	7.17
	30	33.51	0.19	29.58	1.12	35.17	0.28	79.89	6.99
	40	33.68	0.31	29.3	0.91	34.99	0.41	81.92	8.431
	50	31.49	1.25	29.32	0.93	36.1	0.39	79.60	6.79
15 cm	20	34.32	0.76	29.05	0.74	35.99	0.3	75.34	3.771
	30	33.51	0.19	28.38	0.27	35.17	0.28	73.45	2.44
	40	33.68	0.30	29.53	1.08	34.99	0.41	74.03	2.85
	50	31.49	1.25	26.07	1.37	36.1	0.39	67.61	1.69

2- Cooling effect

Temperature reduction (ΔT) was determined to describe the cooling potential of the investigated system. Fig (5) shows temperature reduction throughout the operating period for ten cm and fifteen cm pad thickness at various airflow rates. Recorded outside temperature T_{dbo} was indicated for comparison as well. Comparing between ten cm and fifteen cm pad thickness revealed that, values of cooling effect in the case of fifteen cm pad thickness was higher than that for ten cm pad thickness for the same airflow rate. The maximum cooling effect was 11.7 °C when using a cooling pad with fifteen cm pad thickness and 9.5°C when using pad cooling with ten cm at airflow rates of 20 m^3/s. This maximum ΔT occurred with an outside temperature of about 36.fifteen°C at hours 14:00.

In general, as it is illustrated in Fig (5), the higher the outdoor temperature correspond to lower relative humidity, is the higher is the temperature reduction. In conclusion, the pad thickness and airflow rate have a significant effect on temperature reduction.

Table (2) indicates mean temperature reduction (ΔT) and standard division (S.D.) during the operating period for both pad thickness at various airflow rates. Mean values of about 7.8°C and 9.8°C were found as maximum air temperature reduction for ten and fifteen cm pad thickness, respectively. For fifteen cm pad thickness, the maximum mean value of the cooling effect was 11.7 °C at 20 m^3/s air flow rate. Increasing airflow rate from 20 to 40 m^3/s results in a decrease in temperature reduction to 8.83°C. The obtained data were in agreement with that published by Rajesh Maurya *et al*. (2014). The same trend was noticed for ten cm of pad thickness. It can be observed that the higher the thickness is, the higher the pad face air velocity is required to get more temperature reduction. There was not a fixed trend between pad thickness and airflow rate. This is due to the contradiction effect of the higher kinetic energy corresponds to the highest air flow rate (highest pad face air velocity) and the contact time between air and water films on the pad materials. Increasing airflow rate (pad face air velocity) passing through the pad media leads to break the films between pad materials and consequently increasing the water vapor transfer to the air stream, which in turn increases temperature reduction. On the other hand, increasing pad face air velocity decrease contact time between air and water films. This provided a good chance for air to carry on more water, depending on its thermal specifications.

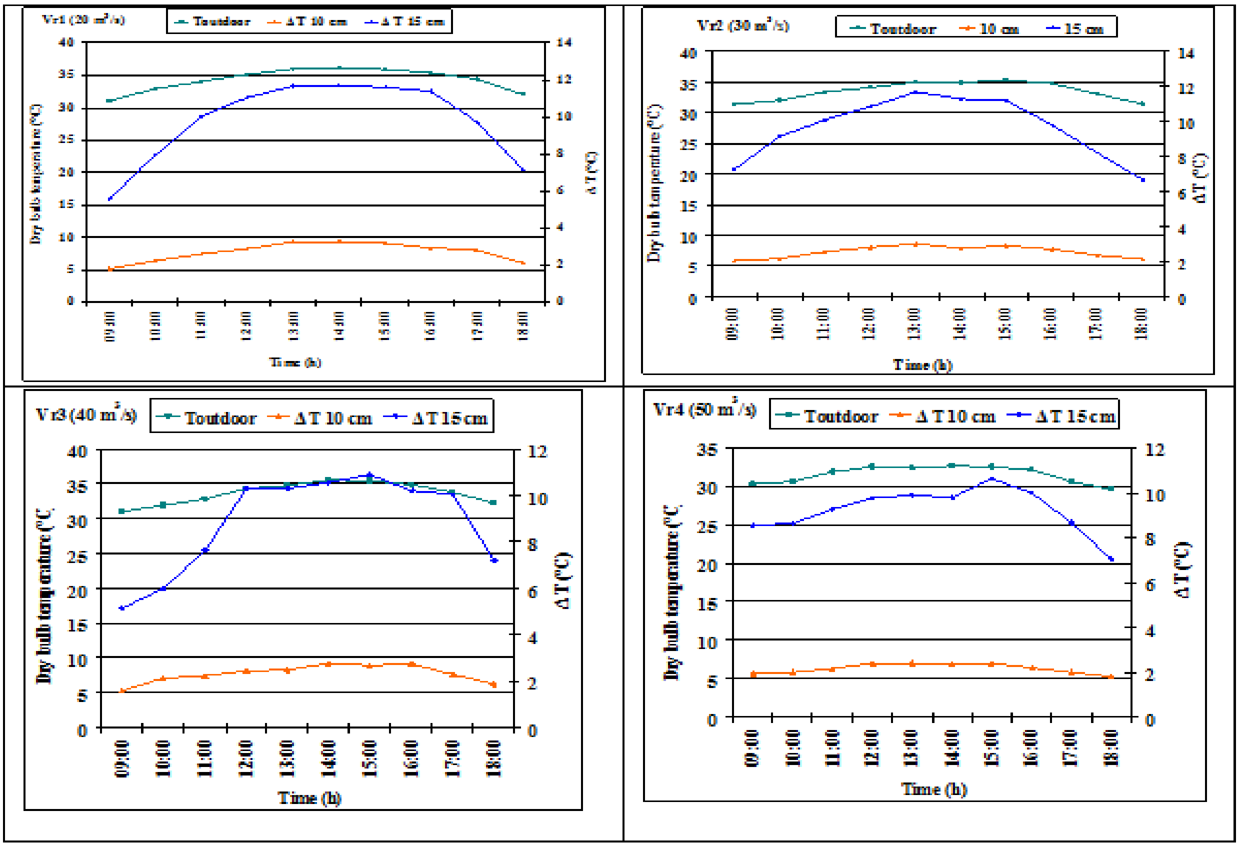

Fig .5. Effect of airflow rate on cooling effect under two pad thicknesses

Table 2. the measured data and calculated values of the average cooling potential and saturation efficiency at different pad thicknesses and various airflow rate

Pad thickness (cm)	Airflow rate,m^3/s	T_{dbo},°C	SD of T_{dbo},°C	RH_o %	SD of RH_o,%	ΔT,°C	SD of ΔT,°C
10 cm	20	34.32	0.76	35.99	0.3	7.8	0.39
	30	33.51	0.19	35.17	0.28	7.35	0.71
	40	33.68	0.31	34.99	0.41	7.79	0.4
	50	31.49	1.25	36.1	0.39	6.37	1.4
15 cm	20	34.32	0.76	35.99	0.3	9.8	1.1
	30	33.51	0.19	35.17	0.28	9.61	0.90
	40	33.68	0.30	34.99	0.41	8.83	0.35
	50	31.49	1.25	36.1	0.39	9.22	0.62

3-Saturation efficiency (S.E %)

Table (3) indicates the saturation efficiency average during the operating period for both pad thickness and different airflow rates. The higher values of S.E. for ten cm pad were 65.05 % at 20 m^3/s air flow rate when the outside temperature was 34.32 °C and outside air relative humidity was 35.99 %. These data were in agreement with published by (Kulkarni and Rajput, 2011).

The higher values of S.E. for fifteen cm pad were 82.44 % at 50 m^3/s air flow rate when the outside temperature was 31.49 °C and outside air relative humidity was 36.1 %. These data were in agreement with published by (Kocatürk and Yildiz,2006)

Table 3. Effect of airflow rate on saturation efficiency under two pad thicknesses

Pad thickness (cm)	Airflow rate (m^3/s)	$T_{db,o}$, °C	RH_o %	S.E (%)
10 cm	20	34.32	35.99	65.05
	30	33.51	35.17	61.5
	40	33.68	34.99	64.81
	50	31.49	36.1	57.07
15 cm	20	34.32	35.99	81.14
	30	33.51	35.17	79.84
	40	33.68	34.99	72.7
	50	31.49	36.1	82.44

Saturation efficiency is a function of both air-water contact time and pad face air velocity up to the maximum level. Increasing air velocity through a given pad thickness decreases the contact time. The improved efficiency with increased air velocity was reverse of what one might except because with higher velocity, the opportunity for evaporation or contact time is reduced.

Increasing the velocity thought a given pad thickness decreases the contact time. The improvement in efficiency with contact time is readily apparent, and in practice, it can be controlled by varying the velocity. The influence of variations in velocity with a given air-water contact time has been given slightly since, other than to caution against excessive velocities. As pad face air velocity increases, the thickness of the film decreases, resulting in increased heat transfer and evaporation rates and a corresponding increase in saturation efficiency. Increasing the air velocity reduces the contact time, which can be restored by increasing pad thickness.

Four multiple regression equations were developed to describe the relationship between saturation efficiency (S.E.) and outdoor temperature ($T_{db,o}$), outdoor relative humidity (RH_o), and pad thickness (d) for the four airflow rates. Multiple regression analysis revealed that the saturation efficiency for the four airflow rates was strongly affected by the outdoor temperature, outdoor relative humidity, and pad temperature. The multiple regression equations obtained were-

$$SE(20m^3/s) = 4.27\,T_{dbo} + 0.43\,RH_o + 3.22\,d - 128.99 \qquad R^2 = 0.73$$

$$SE(30m^3/s) = 2.69\,T_{dbo} - 0.045\,RH_o + 3.8\,d - 64.76 \qquad R^2 = 0.6$$

$$SE(40m^3/s) = 4.98\,T_{dbo} + 1.28\,RH_o + 2.78\,d - 175.46 \qquad R^2 = 0.74$$

$$SE(50m^3/s) = 1.64\,T_{dbo} + 0.26\,RH_o + 5.076\,d - 55 \qquad R^2 = 0.86$$

The combined correlation coefficients (r) for these parameters together were 0.854, 0.774, 0.860, and 0.927 for the four different airflow rates, respectively.

4-Heat energy removal

The heat energy removal from the broiler's houses varied from treatment to another during the experimental period, as revealed in Fig. (6). The most generous amount of heat energy removal was achieved with an airflow rate of 50 m^3/s for both pad thickness ten a fifteen cm (compared with other airflow rates. But, comparing heat energy removal for the same airflow rate under different pad thickness, pad thickness of fifteen cm had the highest value of heat energy removal (1093.7 kW.h). Heat energy removal is a function of air mass flow rate, enthalpy of air just leaving the cooling pads, and enthalpy of exhausting air from the house by ventilation fans. Increasing airflow rate or the difference between both enthalpies values or increasing both at the same time, means more heat energy removal. So, rising airflow rates from 20 m^3/s to 50 m^3/s contribute to increasing heat energy removal. Also, using fifteen m pad thickness plays a role in decreasing temperature reduction (decreasing temperature in front of the pad), which means lower enthalpy. For a reason above, the difference between air just leaving the cooling pads and enthalpy of exhausting air from the house by ventilation fans increased when using fifteen cm pad thickness. For a reason above, 50 m^3/s air flow rate at fifteen cm pad thickness had the most massive value of heat energy removal from broiler houses.

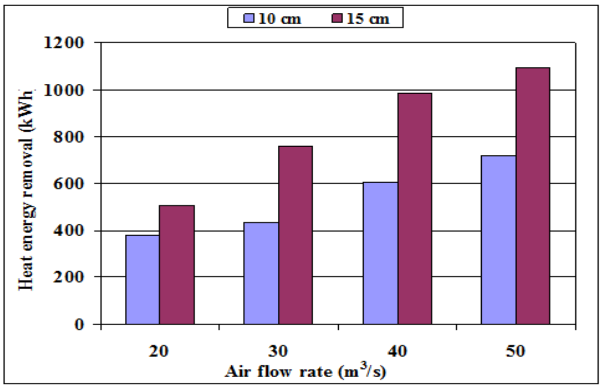

Fig .6. Effect of airflow rates on heat energy removal at different pad thickness

5- Pad water consumption

Pad water consumption for other treatments was determined and illustrated in Fig (7). Data showed that, with increasing airflow rate from 20 m^3/s to 50 m^3/s, pad water consumption increased from 1172 kg/h to 1847.3 kg/h for ten cm pad thickness. For fifteen cm pad thickness, pad water consumption increased from 582.84 kg/h to 711.51 kg/h with increasing airflow rate from 20 m^3/s to 50 m^3/s except at 30 m^3/s, pad water consumption decreased to be 543.35 kg/h. Data also showed increasing pad thickness from ten cm to fifteen cm tends to reduced pad water consumption. Increasing pad water consumption contributes to improving indoor air relative humidity in case of using ten cm pad thickness, as shown previously in Fig (4).

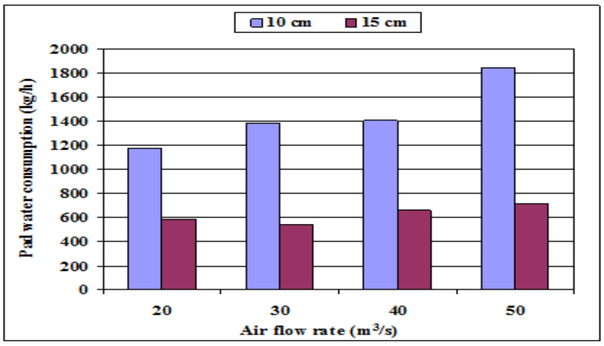

Fig .7. Effect of airflow rate on pad water consumption at two pad thickness

6-Evaporative cooling performance (cooling energy)

Fig (8) illustrates evaporative cooler performance for both pad thickness ten and fifteen cm under different airflow rates. ECP for fifteen cm pad thickness was higher than ECP for ten cm pad thickness. Also, increasing airflow rates lead to an increase in ECP value. These data were in agreement with published by (Khobragade and Kongre, 2016). The mean value of ECP for ten cm pad thickness ranged between 194.42 to 364.18 kWh for 20 m^3/s to 50 m^3/s, respectively. The mean value ECP for fifteen cm pad thickness ranged between 243.31 to 526.87 kWh for 20 m^3/s to 50 m^3/s, respectively.

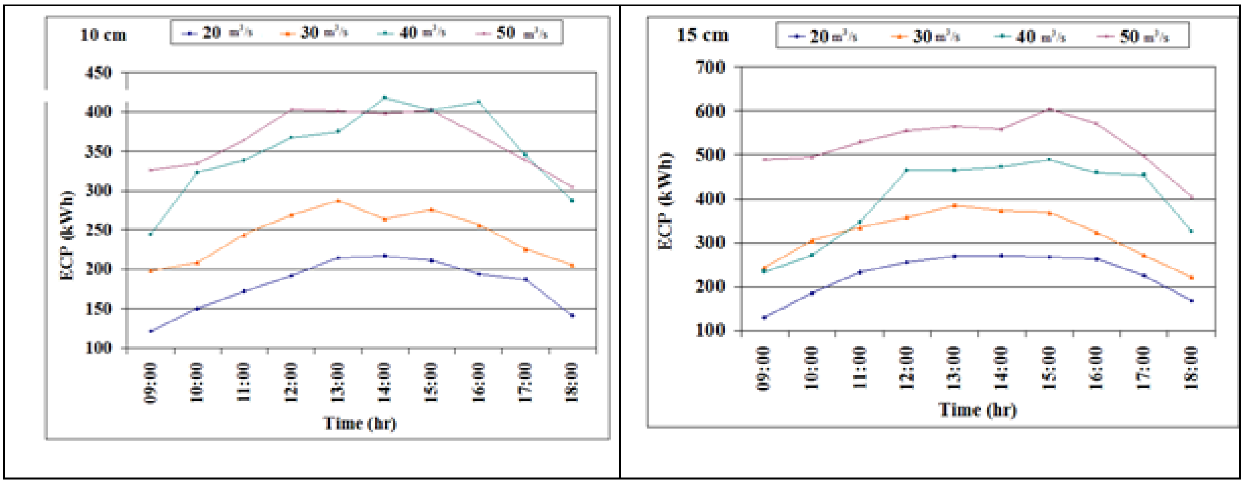

Fig .8. Evaporative cooling performance different airflow rates for both pad thicknesses.

7. The ratio of temperature reduction to airflow rate (T/Q)

Because of the variation in air flow rate applied in each treatment as previously mentioned, it was considered to determine the temperature reduction per unite of airflow rate. This procedure may provide a better criterion for comparison between the studied factors. The ratio of temperature reduction to airflow rate (T/Q) throughout the operating period for both pad thickness at different airflow rate are illustrated in Fig (9). In general, the unite of airflow rate has more capability to reduce the temperature in case of a fifteen cm pad thickness of more than ten cm pad thickness at a various air flow rate. For ten cm pad thickness, the mean highest value was 0.38 °C.s/m^3 at 20 m^3/s air flow rate. For fifteen cm pad thickness, the mean highest amount of (T/Q) was 0.48 °C.s/m^3 at 20 m^3/s air flow rate. As mentioned before, the variation in air flow rate resistance due to the variation in pad thickness plays an essential rule in this phenomenon.

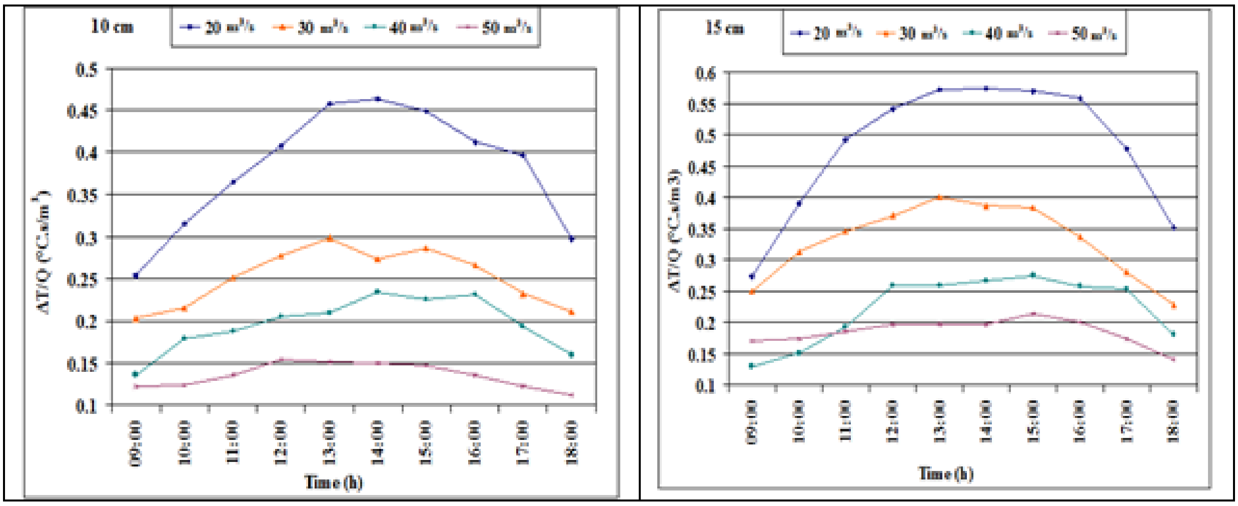

Fig .9. Temperature reduction to airflow rate for different airflow rates for both pad thickness

8. Temperature humidity index

Temperature humidity index (T.H.I.) as an essential factor to judge such an evaporative cooling system in reducing heat stress was determined for both pad thickness (ten and fifteen cm) under different airflow rates during the operating period as shown in Fig (10). The permitted value of T.H.I. is ranged from 20.1 to 24.5ºC. According to the T.H.I. Values are calculated inside the house of broilers, and the mean value of T.H.I decreased from 29.74 ºC to 28.87 ºC with increasing airflow from 20 m^3/s to 50 m^3/s at ten cm pad thickness. The same trend was found at fifteen cm pad thickness, the mean value of T.H.I decreased from 28.51 ºC to 25.4 ºC with increasing airflow from 20 m^3/s to 50 m^3/s. Only one exception was found when using a 40 m^3/s air flow rate, T.H.I. The value increased to be 28.95 ºC. Comparing the temperature-humidity index for broilers with the maximum threshold value reveals that the T.H.I. is out of range in all treatments, which means undesirable effects. But, on the other hand, the evaporative pad cooling still has the virtual advantage in reducing the T.H.I. of the none cooled (outside) air when passing through the investigated pad materials and different airflow rates. Data also showed that using fifteen cm pad thickness decreased T.H.I. Values more than using a ten cm pad thickness. Increasing T.H.I. from 24.5 ºC to 27.4 ºC resulting in heat stress occurred. These values were in the range of what was recommended by Joseph *et al.* (2012). As a result of previously reason, feed conversion efficiency decreased, and meat production decreased as a result.

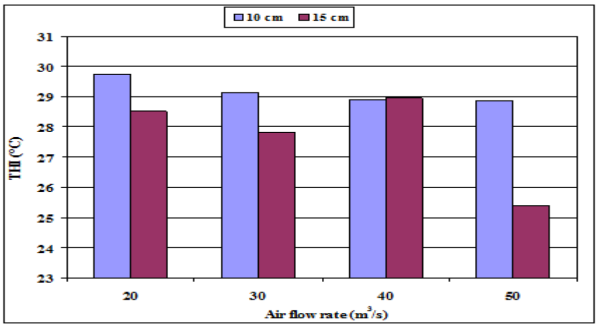

Fig .10. Temperature humidity index for different airflow rates for both pad thicknesses.

9. Temperature humidity velocity index

Temperature humidity velocity index (THVI) is an essential factor that reveals the relative importance of indoor dry bulb, wet bulb temperature, and air velocity inside a broiler house to judge on cooling system effect on birds when using different airflow rates with two pad thickness as shown in Fig (11). The mean value of (THVI) for all airflow rates in case of using a ten cm pad thickness was higher than using fifteen cm pad thickness. Mean values of (THVI) when using ten cm pad thickness were 29.84 ºC,28.93 ºC,28.62 ºC, and 28.28 ºC for 20 m^3 /s,30 m^3 /s,40 m^3 /s, and 50 m^3 /s airflow rates, respectively. But when using fifteen cm pad thickness, the mean values of (THVI) were 28.74 ºC,27.95 ºC,28.82 ºC, and 25.01 ºC for 20 m^3 /s,30 m^3 /s,40 m^3 /s, and 50 m^3 /s airflow rates, respectively.

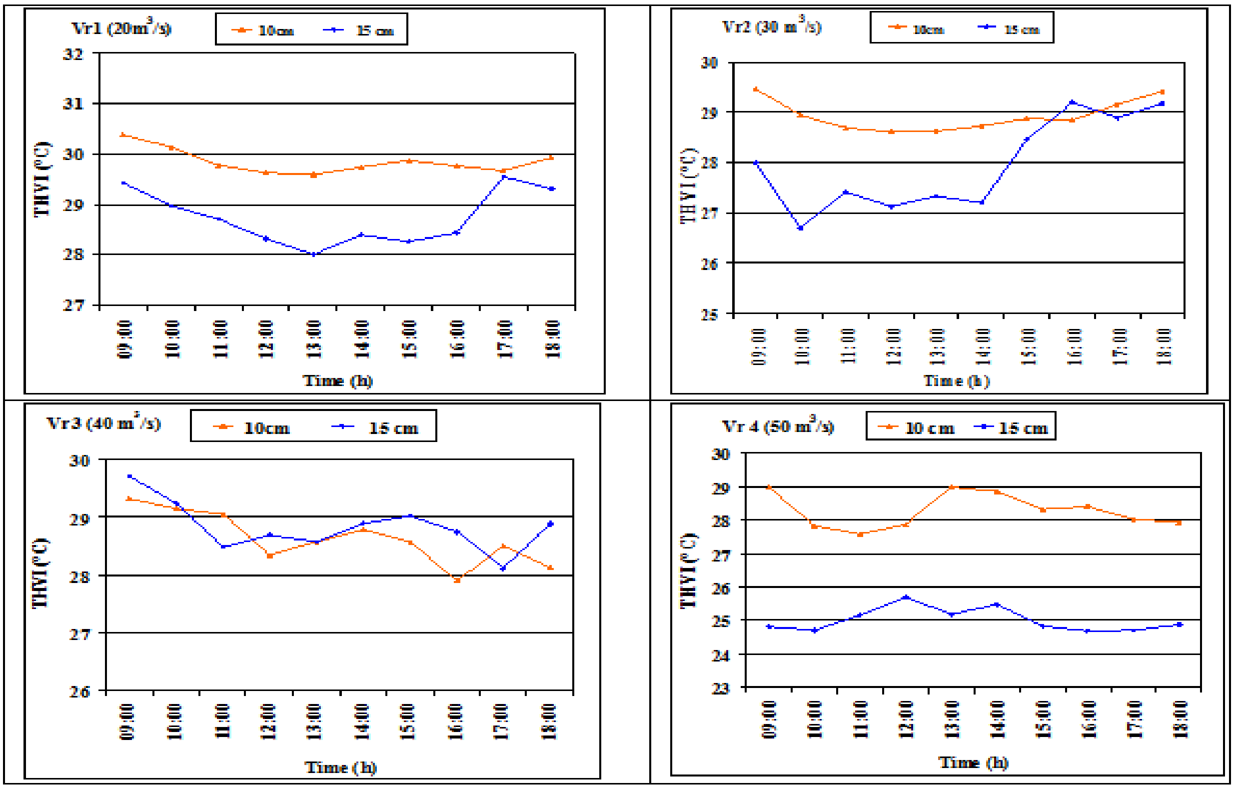

Fig .11. Effect of airflow rate on temperature humidity velocity index under two pad thicknesses.

Broiler performance

Due to the microclimatic conditions of broilers house were at and around the optimal level throughout the experimental period, the conversion feed rate under comfortable indoor conditions was at a high level resulting in increasing the body weight of broilers from 1.25 kg to 2.04 kg and from 1.25 kg to 2.22 kg for both pad thickness (10 and fifteen cm), respectively., as listed in Table (4).

Increasing evaporative cooling efficiency plays a vital role in lowering indoor air temperature inside the house, using evaporative pad cooling with fifteen cm pad thickness. Providing optimal environmental conditions inside the broiler house from indoor air temperature, indoor relative humidity (lower litter moisture content), and reasonable airflow rate, positively affected the growth and development of broiler within the living cycle of the experiment. Using evaporative pad cooling with a pad thickness of fifteen cm contributes to increasing total live mean weight by 0.9429 ton at the end of the live cycle comparing with the house cooled by cm evaporative pad cooling system. Also, other performance indicators such as feed conversion efficiency and an efficiency rate of production were increased from 69.2 % to 75.4 % and from 384.91 % to 453.87 % when using fifteen cm pad thickness comparing with 10 cm pad thickness.

Table 4. Broiler performance for both pad thickness

Pad thickness (cm)	Mean live weight (kg)	F.C.R	F.C.E (%)	E.R.P (%)
15 cm	2.22	1.33	75.4	453.87
10 cm	2.04	1.45	69.2	384.91

CONCLUSION

Experimental work was carried out during the summer of 2019 on two identical closed commercial broilers houses each was occupied with a total complement of 5800 birds for meat production. Four different air flow rate passing through the evaporative cooling system functioned with both houses (ten cm and fifteen cm pad thickness) during the summer season. Based on the obtained results during the experimental work, the evaporative cooling system was able to keep the mean indoor air temperature lower than 30°C in all circumstances. The following conclusions were drawn:-

1- The maximum mean value of indoor air temperature of about 30.17 °C was found when using a pad thickness of 10 cm at an airflow rate of 20 m^3/s, while the minimum mean value of indoor air temperature of about 28.38 °C was found at 30 m^3/s air flow rate for pad thickness of fifteen cm

2- For all treatments of both pad thickness of the evaporative cooling system, it was found an increase in air relative humidity, which is considered the main disadvantage of the system. The minimum mean value of indoor relative humidity was 67.61 % at 50 m^3/s air rate for fifteen cm pad thickness. The maximum mean value was 81.92 % at 40 m^3/s air flow rate for ten cm pad thickness.

3-Temperature reduction for all fifteen cm pad thickness air flow rate treatments was higher than that for ten cm pad thickness air flow rate treatments. It ranges from 8.83 ºC to 9.8 ºC for all cm fifteen cm pad thickness air flow rate treatments, while in ten pad thickness air flow rate treatments, it ranged from 6.37 ºC to 7.8 ºC.

4- The highest mean value of the saturation efficiency was 82.44 % and occurred with fifteen cm pad thickness at an airflow rate of 50 m^3/s. The lowest mean value of saturation efficiency was 57.07% and was found with a ten cm pad thickness at an airflow rate of 50 m^3/s.

5- For pad thickness of fifteen cm, the highest mean value of Evaporative cooling performance was 1039.7 kWh at an airflow rate of 50 m^3/s and for pad thickness of ten cm was 719.92 kWh, also at 50 m^3/s air flow rate.

6- Pad water consumption was as its height value of 1847.4 kg/h at an airflow rate of 50 m^3/s at pad thickness of ten cm while using fifteen cm pad thickness for evaporative pad cooling system, the highest value was 711.5 kg/h at the same airflow rate. The lowest value of pad water consumption was 543.4 kg/h at an airflow rate of 30 m^3/s for an evaporative pad cooling system with a pad thickness of fifteen cm.

7- The highest mean value of the ratio temperature reduction to airflow rate was 0.48 °C.s/m^3 and occurred with fifteen cm pad thickness at an airflow rate of 20 m^3/s. The lowest mean value of 0.13°C.s/m^3 was found with a ten cm pad thickness at an airflow rate of 50 m^3/s.

8-The lowest mean value for T.H.I. was 25.4°C at an airflow rate of 50 m^3/s for fifteen cm pad thickness, while the highest mean value of T.H.I. was 27.73 at 20 m^3/s air flow rate at ten cm evaporative cooling pad thickness.

9-Birds that reared in house with fifteen cm evaporative pad cooling thickness were not stressed according to T.H.I. Value, thus, translated into increasing feed conversion efficiency by about 8.91 % and the total meat production by 8.82 % comparing with birds, which reared in house with ten cm evaporative pad cooling thickness. 17.91%

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تقدير معايير نظام وسادة – مروحة للتبريد بالتبخير فى مساكن دجاج التسمين

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أجريت هذه الدراسة في صيف 2019 بقرية بابل مركز تلا بمحافظة المنوفية وإحداثيات الموقع هي (30,67° شمالا و 30,98°) في مسكنين لإنتاج دجاج التسمين وتوجيه المسكن شرق – غرب . بغرض دراسة أثر استخدام أربع معدلات من مرورا لهواء من خلال نظام التبريد (20، 30،40و 50 م^3/ث) وذلك مع استخدام سمكيين مختلفين لوسادة التبريد (10 و 15 سم) على أداء نظام التبريد بالتبخيرى و كذلك أداء دجاج التسمين متمثلا في الإنتاج . تم قياس درجة الحرارة الجافة والرطبة أمام الوسادة وكذلك في جميع أرجاء المسكن وأيضا خارج المسكن كذلك تم قياس سرعة الهواء أمام الوسادة وكذلك داخل المسكن وكانت أهم النتائج المتحصل عليها هي كتالي :- عند استخدام نظام التبريد التبخيرى وسمك الوسادة 10سم ومعدل تهويه 20م^3/ث كان أعلى درجة حرارة داخل المسكن 30,17 م وسجلت أقل درجة حرارة وهى 28.38 م° عند استخدام معدل تهوية 30 م^3/ث عند وسادة ذات سمك 15سم.عند استخدام معدل تهويه 50 م^3/ث ووسادة بسمك 15 سم كانت الرطوبة النسبية 61.67 % وهو أقل معدل للرطوبة النسبية للهواء داخل المسكن وعند استخدام معدل تهوية 40 م^3/ ث ووسادة بسمك 10سم كانت الرطوبة النسبية 81.92 % وهو أعلى معدل سجل للرطوبة النسبية داخل المسكن.كانت أعلى قيمة لخفض في درجة الحرارة يتراوح بين 8.83 الى9.8 م° وذلك عند استخدام نظام التبريد ذو وسادة بسمك 15سم. عند استخدام نظام التبريد بوسادة ذات سمك 15سم ومعدل تهوية 50 م^3/ث سجلت أعلى كفاءة لنظام التبريد وهى 82.44% وعند استخدام نفس معدل التهوية مع نظام تبريد ذو وسادة بسمك 10سم سجلت أقل قيمة لنظام التبريد وهى 57.07%. أقل قيمة لدليل الحرارة والرطوبة كانت 25.4 م° عند استخدام معدل تهويه 50 م^3/ث ووسادة تبريد ذات سمك 15سم .