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REDUCE ENERGY AND HEAT STRESS IN CLOSED RABBIT HOUSING UNDER EGYPTIAN DELTA ZONE CONDITIONS

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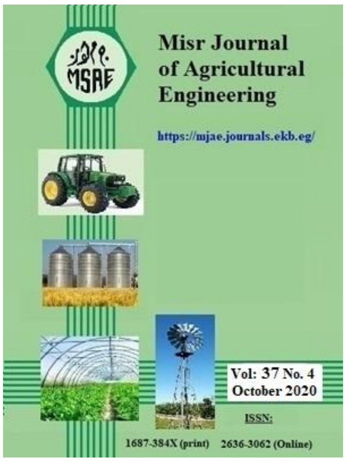


Keywords:
Rabbit, heat balance, heat stress, evaporative cooling

ABSTRACT

Many rabbit housing in Egypt were constructed without systematic design models from the viewpoint of sizing evaporative pad cooling system were determined by subtle mathematical models to solve this problem. Four commercial rabbit houses located at 30.95°N and 31.09°E and the pad fan evaporative cooling system were used to reduce the energy and side effects of heat stress on rabbit housing during summer 2017. Three different mathematical forms these forms were ASHRAE form (form 1); airflow depended upon the volume of the house (form 2), and heat balance (from 3). The house that operated with pad fan evaporative cooling and full pad area facing the fan had the best conditions for rabbits and the highest values of cooling performance. Therefore, the actual results for the previous house were the lowest indoor temperature was 26.85°C, the highest indoor relative humidity was 67.83 %, the highest saturation efficiency of cooling was 76.28%, the highest cooling potential was 7.25 °C and the highest value of the temperature-humidity index was 25.6 °C. Finally, when compared the obtained results from these houses with the results from calculation models, can found that these houses related nearly with the heat balance model.

1. INTRODUCTION

Heat stress is a big problem that is facing the rabbit housing, which caused many harmful effects on rabbit production and rabbit's live. Therefore, using the pad fan evaporative cooling system to solve this problem and reduced the side effects of heat stress on rabbit housing with providing the thermo-neutral zone by moist air conditions. In 2018, Egyptian production of rabbit's meat reached 62143 tonnes **(FAO, 2020).** Rabbits are a good source of cheap protein comparing with other kinds of animal protein. Environmental conditions, such as extreme temperatures (heat stress), significantly affect the overall performance of rabbits. A long season hot climate (from May to October) and short-season mild climate (from December to March) characterize the subtropical climate. Environmental conditions, such as extreme temperatures (heat stress), significantly affect the overall performance of rabbits. A long season hot climate (from May to October) and short-season mild climate (from December to March) characterize the subtropical climate. The use of evaporative cooling pads in rabbits housing can be considered a feasible solution to the problems caused by extreme heat conditions.

The heat load in the rabbit increases by exposure to a high environmental temperature and animals try to sustain homeothermy by using internal physiological means to help re-establish thermal balance. Rabbits use general body position, breathing rate, and peripheral temperature (especially ear temperature) as three means to increase heat loss. An animal must dissipate the excessive amount of metabolic heat produced into the surrounding environment to control body temperature. This heat regulation can be achieved through different heat losses such as physical, i.e., conduction, convection, radiation, and evaporation **(Aarnik et al., 2016 and Khalifa et al., 2018).** The rate of exchange depends on the ability of the environment to accept heat and vapor and also on the animal production status **(Maya-Soriano, 2012).**

Decreasing house temperature resulting in converts metabolizable energy (ME) directly into sensible heat, while at high internal house temperature; energy is lost is done by panting. **(Jimoh and Ewuola, 2016)** In critical summer conditions and mainly with fat animals, airflow should be increased at least 6-9 m^3 h^{-1} kg^{-1} l.w. case of fattening animals. **(Fabrizio et al., 2018)**. In heat stressed, both respiration rate and pulse rate are increased in rabbits **(Skriivanova et al., 2011**).

Rabbits are sensitive to heat stress, they have only a few active sweat glands, and the elimination of surplus body heat is difficult for them when the ambient temperature is higher than the optimum. It also suggested that, for rabbit husbandry, the optimal temperature humidity index is less than 27.8°C **(*Sakr et al* .,2019).** The optimum relative humidity is around 80 - 86% **(Kamal et a*l*., 2010).** Indoor temperature about 15-25°C is located in the thermoneutral zone for rabbits **(Cervera; Carmona¸2010**). The required indoor air temperature for rabbits is 15-25°C; the required relative air humidity is between 50 -70 %; the rate of minimum ventilation is 3 m^3 h^{-1} kg^{-1} body weight) and the maximum airspeed in the building on the level of animals: 0.3 m/s **(Bodnar *et al*., 2019)**.

At high ambient temperature (above 30°C), female rabbits' reproductive performance decrease and increases the mortality rate among the offspring. In males, increasing heat stress directly affects on the testicular function and semen characteristics. In general, rising indoor air temperature over the recommended range results in growth performance reduction **(*Hosny et al*.,2020).** For growing rabbits, the mean internal house temperature should not be lower than 15°C because rabbits preferred low temperatures than high temperatures. If internal house temperature reaches 35°C, they can no longer regulate their body temperature. Indoor relative humidity should not be higher by about 5% than that of the outside air relative humidity **(Hungarian, 2017).** The thermal environment for rabbits depends upon their age. The indoor temperature for young rabbits is 30-32°C and for older rabbits is 20-30°C. Increasing indoor air temperature over 30°C resulting in heat accumulation in the rabbit's body and rabbits, will collapse. Moreover, high temperatures will stop the female rabbits from breeding for 2-3 months giving rise to enormous economic loss **(Baumans and Vanloo,2013)**. Surface temperature measurements can be made without trouble and with high precision, especially on animal coats with low heat capacities **(Das et al.,2016).** Evaporative cooling techniques depend on mass and heat transfer between water and air (**Porumb *et al*., 2016).** Direct evaporative cooling systems are inexpensive and provide an attractive alternative to traditional summer air conditioning systems in hot and arid areas (**Khobragade and Kongre, 2016)**. (**Karaca *et al.*, 2016)** studied the relationship between the cooling effect and the pad water flow rate. Experiments were conducted at three different water flow rates (2 L min^{-1} m^{-2}; 4 L min^{-1} m^{-2} and 6 L min^{-1} m^{-2}) and two different pad air velocities (1.0 m s^{-1} and 1.5 m s^{-1}). The cooling effect and saturation efficiency values were the lowest at a water flow rate of 6 L min^{-1} m^{-2} while they were close to each other at 4 L min^{-1} m^{-2} and 2 L min^{-1} m^{-2} water flow rates.

(Asemola et al., 2017) observed that the rabbits which recorded with high ambient temperature may improve metabolic mechanisms for adaption to heat stress at a tolerable level.

(Frano-Salas *et al* .,2019) conduct a trial in rabbit farms using thermo-hygrometric and ventilation parameters. For ventilation, (longitudinal and transversal forced aeration were used besides using two different types of pads (cellulose or plastic) for the evaporative pad cooling system. The ventilation rate used in the experiment was a range from 6 to 9 m^3 h^{-1} kg live weight (l.w.), within the minimal values. Data showed that mean saturation efficiency was 90.5% with different values of external temperature and relative humidity when using an evaporative cellulose pad cooling system in house with transversal ventilation. In comparison, it was 61.4% in mean when using evaporative cooling with plastic pads, exceeded only with high temperatures and low relative humidity. Cooling systems were able to reduce, but not always to avoid, the danger of heat stress. Using a cooling system caused possible moderate stress conditions (THI>27.8,) even with efficient cooling pads. **(Darwesh, 2015)** estimated the performance of pad cooling systems in a poultry house for the Eastern area of Costal Delta, Egypt. His experiments were conducted from June to August. The average effectiveness for the pad cooling system was ranged between 75.6% to 79.5%, and the cooling effect ranged between7.7 °C to8.3 °C. (**El-Maghawry, 2018)** investigated the effect of using direct evaporative pad cooling system performance as a function of change in pad thickness (10 and 15 cm), water flow rate (3, 5, and 7 L min^{-1} m^{-2}), and rabbit stocking density with an approximate average (0.5 and 1.0 rabbit m^{-2}). The experimental results clarified that values of temperature reduction (7.3 and 6.8 °C), cooling efficiency (94.92 and 90.91 %), and temperature-humidity index (26.30 and 27.40 °C).

The surveying in rabbit housing showed that many houses depended upon natural ventilation and others depended upon pad evaporative cooling systems. In the rabbit, houses equipped with cooling systems are not designed according to engineering methods to provide a suitable temperature inside the house. So, the main objectives of this study were reduced energy and heat stress in the rabbit's housing by comparing three forms for seizing evaporative pad cooling system.

2. MATERIAL AND METHODS

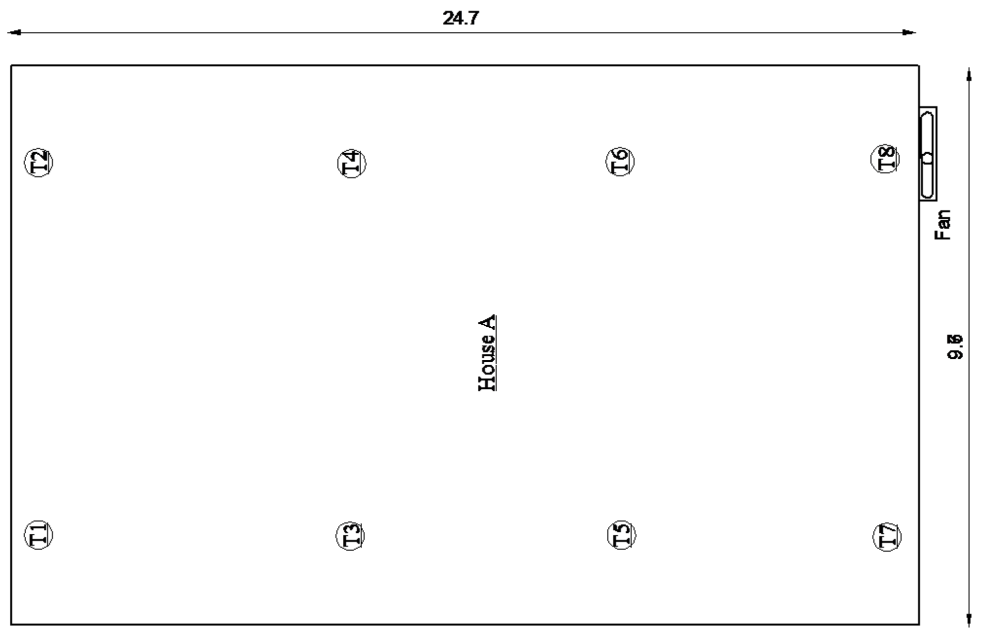
The experiment was conducted in a relatively hot summer season in August 2017 for evaluated the rabbit housing performance and judge the reliability of their housing designs relate to the exact models. It also determined the size and positions of evaporative pad cooling to reduce the energy consumption with pad cooling systems at minimum cooling conditions without any side effects on the rabbit. The experimental work was carried out in four commercial rabbit houses at 30.95°N and 31.09°E, respectively. Four identical rabbit's houses (A, B, C, and D) With a total complement of 3200 fatting New Zealand White (NZW) rabbits on each house in one living cycle. The identification of houses is house A: Control house mechanically ventilated without pad cooling, house B: pad cooling with 4.5m^2 pad area and facing fan, house C: pad cooling with 4.5 m^2 pad area and non-facing fan, and house D: pad cooling with complement pad area 9 m^2 and facing the fan. Three mathematical models were investigated to calculate the required pad area for the evaporative pad cooling system to cool the rabbit's houses.

2.1 Rabbits

A total number of 3200 fatting New Zealand White (NZW) rabbits with a total live weight of about 6400 kg were used in this work in each house.

2.2 Rabbits House

Four identical rabbit's houses in rectangular shape were used during the experimental work. Each house has geometric dimensions as follows; 24.7 m length, 9.6 m width; its roof is gable-even-span which inclined 20° from a horizontal plane, floor surface area, 237.12 m^2, and house volume, 723.216 m^3. It is orientated to North-South direction (i.e., the longitudinal direction is situated on North-South direction). The ceiling is made from asbestos, and the floor is made from 0.15 m reinforced concrete but, the house walls are constructed from 17 cm sand lime bricks and were blasted with 5cm of cement mortar as shown in Figure (1). The first house (A) is mechanically ventilated without an evaporative pad cooling the system and the other three houses (B, C, D) had an evaporative pad cooling system. House B, the ventilation fan is not facing the pad cooling area (4.5m^2), House C, the ventilation fan is facing the cooling pad area (4.5m^2), and House D, the full length of pad cooling, is used (9m^2). Each house was equipped with 800 cages and was fabricated from iron wire, distributed on eight rows of two floors throughout the house. Cages (50 cm long, 43 cm width, and 30 cm height) were equipped with a feeder and a nipple drinker.



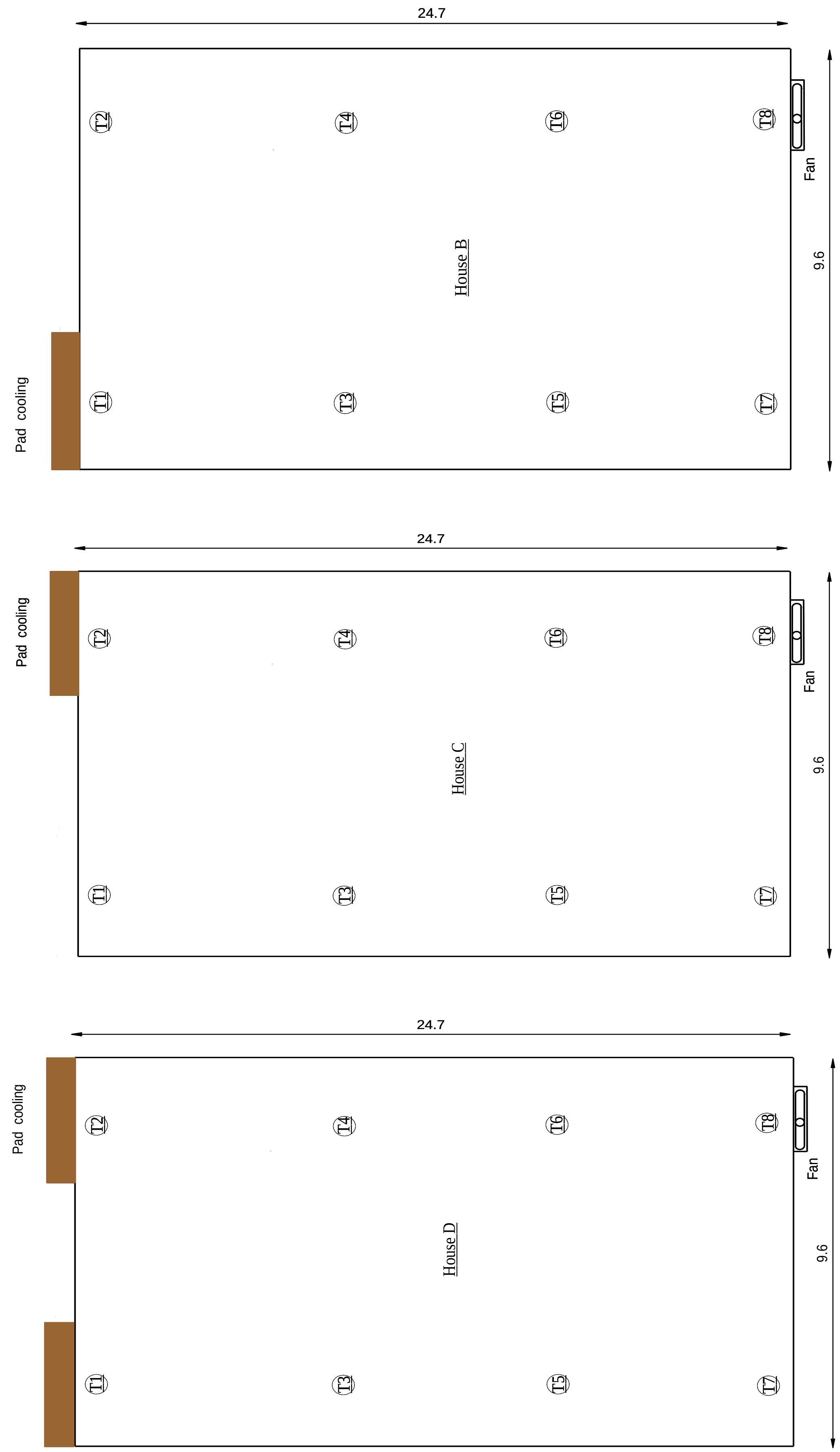


Fig.1. Rabbits' houses layout

2.3 Evaporative cooling system

The major components of this system are water supply, sump with a net volume of 500L, pump with 373 W in power, providing a water flow rate of 48 L/min, which adjusted by placed a valve in the line from the pump. The water flow rate was measured by using a measuring cup and a chronometer, perforated polyvinyl chloride (PVC) pipe (12.5 mm diameter) was suspended above the pads, A gutter collects evaporated water that drains from the bottom of each pad, and Ten corrugated cellulose pads, each having gross dimensions of 60 cm wide and 150 cm high function during the prevalent study. The total face area of cooling pads was 9 m^2 (6m long ×1.5 high), with 10 cm thick mounted vertically at the northern vertical wall. One axial flow suction fan, direct driven, 140 cm diameter, single-phase, and 42000 m^3 /h discharge installed on the other side of pad cooling (Southern wall). The airflow rate was determined and measured 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 adjusted mean pad face air velocity, air density, length of pad, and pad high, it can determine the air mass flow rate, as shown in Figure (2).

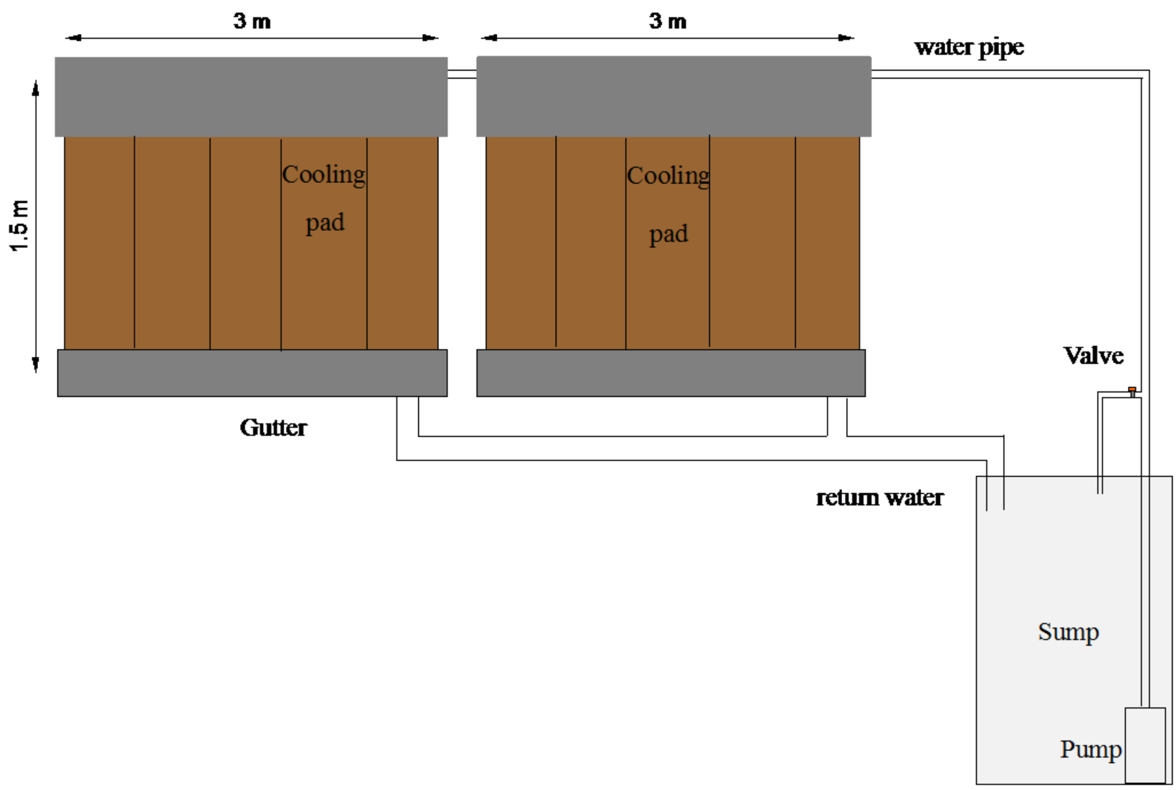


Fig.2. showing the evaporative pad cooling system

2.4 Mt 512 E-temperature controller

The indicator with a controlled temperature measured from -50 to 75 °C and a differential temperature of 0.1°C was used for reading and controlling temperature inside the rabbit's houses. The control system was used to control indoor air temperature at a set point of 27°C and was installed at 50 cm height. The sensor of the controller was set at the last third of the house near the ventilation fan. Therefore, if the house temperature increased over 27°C, the cooling system pump will be operated to reduce indoor air temperature to the setpoints. The thermostat stopped the pump before the fan go off so that the pad can dry out.

2.5 Data-logger devices

Five data-logger devices (16 channels) was used for collecting, recording, and reading from the different sensors (Thermstors LM 35 with a typical accuracy of ± (0.25°C at room temperature and ±0.75°C over a full -55 to + 150°C temperature range) installed at different positions inside and outside rabbits' houses. Inside the rabbits' houses, dry and wet bulb temperatures were measured at eight other locations along-side the house, including air temperature at the of pads (T_{pad}), at the center of the house (C_{enter}), and near fans (T_{fan}) then the temperature averages were taken in the calculation. Two sensors were used to measure dry and wet bulb temperature outside the house. Wet-bulb temperatures were measured by wrapped Thermistors in a wet cloth to get the wet- bulb (W_b) temperature. logger has a key-board and monitor. The time interval for data recording was 5 minutes with data acquisition every minute for integrated measurements. The calibration of all sensors and the data logger was successfully done at the beginning of the experimental work.

2.6 The psychometric chart program

The psychometric chart programmer was used to calculate relative humidity in front of the pad (Rh_{pad}), the center of the house (Rh_{center}), near the ventilation fans (RH_{fan}), and outside the houses (Rh_{out}) as depicted in Data-

2.7 Pades air velocity

A digital fan anemometer (model TFA) was used to measure mean pad face air velocity, measure the airflow rate from the axial fans, and mean air velocity in the rabbit's houses. The anemometer has a range of 0.1 to 30 m/s with an accuracy of ± 5% least significant digit.

2.7 Rabbit's body temperature

The rabbit's skin and fur were measured for every treatment using an infrared thermometer (model Mini Temp). It has a range of -18 to 400°C.

2.8 Evaporative pad cooling calculation

Evaporative pad cooling using three mathematical forms for determining the airflow rate requirements, number of fans required, pad face area, pad cooling length, water flow rate thought the cooling pads, gutter size, pump capacity, and sump siz*e* as showing in Table 1

Form 1

This model depends on the recommended airflow rate m^3 h^{-1} for every kg of living weight according to **(Alchalabi 2015**)

Form 2

This model depends upon air volume need to be removed according to house volume according to (**ASHARE,2005**)

Form 3

This model depends on the cooling load to be removed from the house by **(Field and Long .,2018.)**

Table 1. Evaporative pad cooling **calculation** using three **mathematical** forms

Items	Form 1	Form 2	Form 3
Required ventilation rate	$Q_a = \frac{N_a \times W_b \times Vr}{3600}$	$Q_{a1} = \frac{L \times W \times h}{60 \times \eta_c}$	$Q_m = \frac{Q_f \times \upsilon}{cp \times \Delta T}$
Fans number	$N_f = Q_a / F_c$	$N_{f1} = Q_{a1} / F_c$	$N_{f2} = Q_m / F_c$
Cooling pad area	$A = \frac{Q_a}{V_p}$	$A_1 = \frac{Q_{a1}}{V_p}$	$A_2 = \frac{Q_m}{V_p}$
Pad cooling length	$L_p = \frac{A}{h_p}$	$L_{p1} = \frac{A_1}{h_p}$	$L_{p2} = \frac{A_2}{h_p}$
Water flow rate	$W_r = 4.1 \times L_p$	$W_{r1} = 6 \times L_{p1}$	$W_{r2} = 7 \times \left[\frac{Q_m}{\upsilon} \times (W_c - W_a)\right]$
Gutter size	$G = 3 \times L_p$	-----------------	-----------------
Pump capacity (P.C)	------------------	$P.C = 7.4 \times L_{p1}$	-----------------
Sump size	$(V) = 19 \times L_p$	$(V_1) = 30 \times A_1$	-----------------

Nomenclature

A is Pad cooling area according to model 1 (m^2)
A_1 is pad cooling area according to model 2 (m^2)
A_2 is pad cooling area according to model 3 (m^2)
Cp is the specific heat of air (kJ. $Kg^{-1}{}_{dry\ air}$.°C^{-1}).
F_c is the fan capacity ($m^3\ s^{-1}$).
G is the gutter size according to model 1 (m).
h is the house height (m).
h_p is pad cooling height (m).
L is the house length (m)
L_p is pad cooling length according to model 1 (m)
L_{p1} is pad cooling length according to model 2 (m)
L_{p2} is pad cooling length according to model 3 (m)
N_a is the number of rabbits (dimensionless)
N_f is fan numbers according to model 1
N_{f1} is fan numbers according to model 2
N_{f2} is fan numbers according to model 3
Pc is pump capacity (L min^{-1})
Q_a is the required airflow rate according to model 1 ($m^3\ s^{-1}$)
Q_{a1} is the required airflow rate according to model 2 ($m^3\ s^{-1}$)
Q_m is the required airflow rate according to model 3 ($m^3\ s^{-1}$)

Q_f	is heating or cooling load (kW)
V_r	is the required ventilation rate ($m^3\ kg^{-1}\ h^{-1}$).
V_p	is airspeed permitted (1.25 m s^{-1})
V	is sump size according to model 1 (L)
V_1	is sump size according to model 2 (L)
W_b	is the mass of rabbits (kg)
W	is the house width (m)
W_r	is the water flow rate according to model 1 (L min^{-1}).
W_{r1}	is water flow rate according to model 2 (L/min).
W_{r2}	is water flow rate according to model 3 (L/min).
η_c	is saturation efficiency is 70% according to previous researcher reviews
υ	is air specific volume (m^3/kg)
ΔT	is the permissible increasing in house air temperature from the pad side to the fan side (3 °C)

2.9 Heat balance calculation inside the rabbit's house

The process of calculating the changes that occur in the environment inside a structure is called a heat balance **(Field and Long .,2018.)** Expressed mathematically, a heat balance is

$$\pm \text{Heat (kW)} = \text{Total heat gain } (H_g) - \text{total heat loss } (H_L)$$

For a summer heat balance, the heat gain is the sum of the animal heat, mechanical equipment heat, and heat flow as follows and illustrated in Figure (3)

$$\pm Heat_{summer} = (\text{Animal heat} + Heat \text{ flow} + \text{mechanical heat}) - (\text{ventilation})$$

Mechanical heat and Q_e is sensible heat used to evaporate water (kW) are too low so, it can be neglected so that the equation can be as follow

$$\pm Q_f = (Q_s + Q_B) - (Q_v)$$

Where Q_s is Sensible heat production in the house (kW), Q_f is heating or cooling load (kW), Q_B is building heat loss (kW), Q_v is ventilation heat loss (kW),

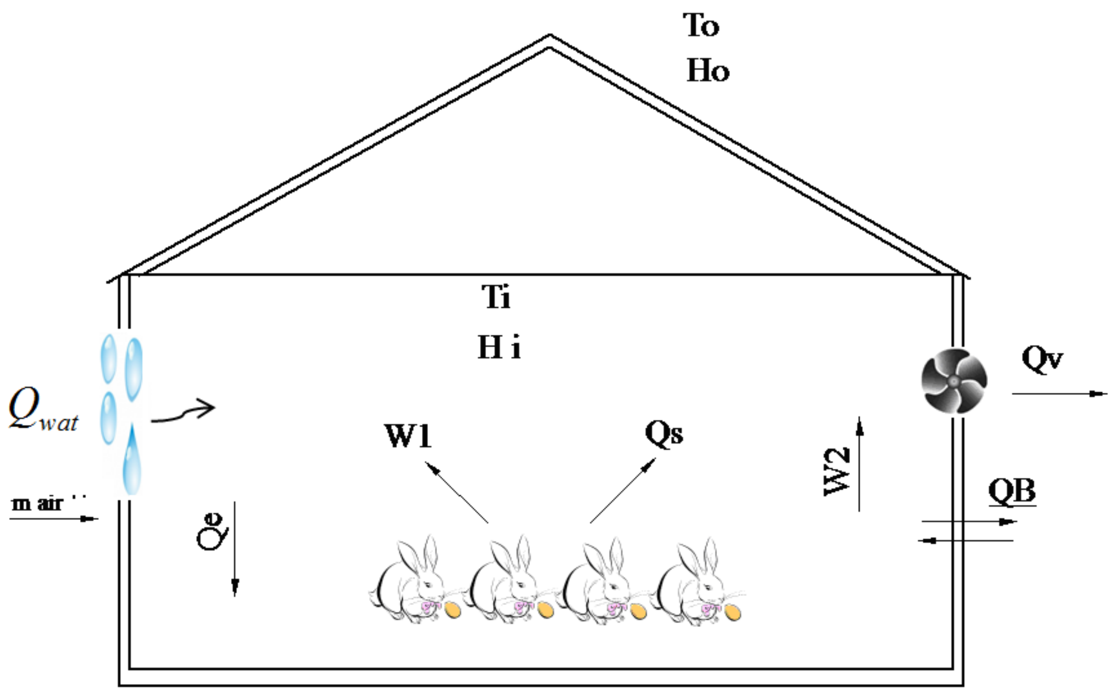


Figure3. Energy (thermal) equilibrium in rabbit's house

2.9.1 Sensible heat gain from the rabbits (Q_s)

To calculate the rate of sensible heat production (SHP) inside rabbit houses by using reviewed data as reported by **Lebas et al. (1997)** between ambient air temperature (°C) and release of sensible heat (W/kg).

Coefficient of multiple determination of the regression equation is (R^2) = 0.99804306 and its probability (P) = 0.00015.

$$SHP = -88 \times 10^{-7}.T_i^{\,3} + 316.66 \times 10^{-5}.T_i^{\,2} - 0.2165158.T_i^{\,2} + 5.7642857$$

$$Q_s = SHP \times W \times n$$

Where W is rabbits weight (kg), and n is rabbits number.

2.9.2 Building heat loss (Q_B)

The building heat loss through the building components was calculated according to **(ASHARE,2005)**

$$Q_B = Q_{siddwall} + Q_{gable} + Q_{roof} + Q_{perimeter}$$

$$Q_B = UA(T_i - T_o)$$

Where Q_B is overall heat flow(kW), U is the overall coefficient of heat transmission or thermal conductance (kW $m^{-2}.°C^{-1}$), A is the surface area of building parts (m^2), T_i, T_o are indoor and outdoor temperature (°C).

2.9.3 The overall heat transfer

The overall heat transfer of the house was determined using the following equations

U=1/R

R= ($1/h_1$ + L/K+$1/h_o$)

Where R is the overall resistance to heat transmission or insulation ($m^2.°C.\ kW^{-1}$),

$1/h_1$ is the convection resistance of the inner side of the house part ($m^2.°C\ .\ kW^{-1}$),

L is the thickness of the building part (m), K is thermal conductivity (kW .$m^{-1}.\ °\ C^{-1}$),

$1/h_o$ is the convection resistance of the outdoor part ($m^2.\ °C\ .kW^{-1}$).

2.9.4 Heat lost in the ventilation (Q_v)

The sensible heat lost in the ventilation air, (Q_v) was calculated using the following equation, which presented as follows :

$$Q_v = M \times Cp \times (T_i - T_o)$$

Where Q_v is sensible heat loss in ventilation air (kW), M is ventilation rate ($kg_{air}.s^{-1}$), and Cp is the specific heat of the air (kJ. $Kg^{-1}{}_{dry\ air}\ .°C^{-1}$).

2.9.5 Mass airflow rate (M)

Calculated based on temperature (M_t) and humidity (M_m) controlled and the most significant value taking in a calculation in ventilation heat lost

2.9.6 The ventilation rate for temperature control (M_T)

Mass airflow rate for temperature control (M_T) was determined as follows

$$M_T = \frac{Q_s - Q_B - Q_e}{Cp \times (T_i - T_o)}$$

Where M_T is the ventilation rate for temperature control (kg s^{-1}).

2.9.7 The ventilation rate for moisture control (M_m)

The rate of moisture loss should be equal to the rate of moisture produced so, the ventilation rate for moisture control was determined using the according to the equation as follows:-

$$M_m = \frac{(w_1 + w_2)}{(H_i - H_o)}$$

Where M_m is the amount of ventilation air for moisture control (kg $_{dry\ air}$. s^{-1}),w_1 is water vapor in the air from rabbits breathing (kg $_{water}$. s^{-1}), w_2 is vapor in the air from the litter (kg $_{water}$ .s^{-1}) and is included in (w_1), H_i is inside air moisture content (kg $_{water}$.kg^{-1} $_{dry\ air}$), and H_o is outside air moisture content (kg $_{water}$.kg^{-1} $_{dry\ air}$).

Moisture produced by rabbits' breathing was estimated using the following:-

$$w_1 = \frac{Q_L \times (N) \times W}{LHV}$$

Where QL is the latent heat production from rabbits ($kJ.kg^{-1}$), N is rabbits number, and LHV is the latent heat of water vaporization, 2450 kJ/kg water.

2.9.8 Latent heat production

Multiple regression was used by **Lebas et al. (1997)** that determinate the coefficients of multiple regression equation with R^2 = 0.99990177 and its Probability (p)= 0.01

$$Q_L = (1.13\times10^{-6}).T_{dbi}{}^5 - (1.06\times10^{-4}).T_{dbi}{}^4 + (3.73\times10^{-3}).T_{dbi}{}^3 - (0.05817).T_{dbi}{}^2 + (403.515\times10^{-3}).T_{dbi} - 0.42571$$

2.10 Performance of a cooling system

2.10.1 Cooling effect (CE)

The temperature reduction describes the cooling effect inside the rabbit house and easy criteria to evaluate the effectiveness of the cooling system

$$CE = (T_{db,o} - T_p)$$

Where $T_{db,o}$ is dry bulb temperature of the air entering the cooling system (°C),
T_p is dry bulb temperature of air exiting the cooling system (°C),
CE is cooling potential (°C).

2.10.2 Saturation efficiency (SE)

Saturation efficiency (SE) can be calculated as a temperature difference ratio using the following equation:-according to (**ASHARE 2005)**

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

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

2.10.3 Evaporative cooling performance (ECP)

Evaporative cooling performance (ECP) is a common term for measuring cooling capacity, and it can be calculated as a latent or sensible heat as follows:-

$$ECP = \frac{(Q)}{(V_s)} \times CE \times cp$$

Where ECP is Evaporative cooling performance, (kW).
Q is the ventilation rate ($m^3\ s^{-1}$).
Vs. is a specific volume of air ($m^3\ kg^{-1}$).

2.10.4 Unit Evaporative Cooling Performance (Unit ECP)

For measuring the absolute performance under base conditions that permit comparison, this unit describes the cooling effect delivered per hour per degree of cooling potential. It eliminates variables associated with local conditions as energy. It can be expressed as follow (Eq.39).

$$\text{Unit ECP} = \frac{(Q)}{(V_s)} \times SE \times cp$$

Where Unite ECP is Unit Evaporative cooling performance (kW/°C).

2.10.5 Ratio of cooling effect to airflow rate (CE/Q)

To judge the evaporative cooling system in reducing dry bulb temperature under different air flow rates and to permit comparisons on the base of airflow rate unity. The ratio of temperature reduction to airflow rate was suggested to cope with the variation in airflow rate among all treatments. It was computed using the following

$$CE/Q = (T_{db,o} - T_p)/\text{Q}$$

Where CE/Q is the ratio of temperature reduction to airflow rate ($°C.m^{-3}s^{-1}$).

2.11 Thermal environment and productivity of the rabbit

2.11.1 Heat energy removal

The rate of heat energy removal from the rabbit's houses can be calculated from the following

$$Q_r = m_r\,(h_{pad} - h_{ex})$$

Where Q_r is heat energy removal from the house by the cooling system (kWh), m_r is ventilation rate ($kg.s^{-1}$),h_{pad} is the enthalpy of air just leaving the cooling pads, and h_{ex} is the enthalpy of exhausting air in ($kJ.kg^{-1}$).

2.11.2 Moisture addition (W*)*

The total amount of moisture added to the saturated air after cooling by the evaporative process (W) in kg $h^{-1}$is computed based on the humidity ratio of air after (W_2) and before passing through the cooling pads (W_1) in (kg_w/ kg^{-1}) air, and the mass flow rate of cooled air (M_r) in ($kg_w\ h^{-1}$) by the following.

$$W = M_r\ (W_2 - W_1)$$

2.11.3 Temperature – humidity index (THI)

Temperature – humidity index (THI, units) as accurate and particle measure for evaluating the intensity and severity of heat stress (HS) under the environmental conditions. A value for THI below 27.8 was taken to signify an absence of heat stress, a range from 27.8 to 28.9 represents heat stress, while a value over 28.9 was considered to represent severe heat stress was calculated according to the following equation as proposed by **Marai et al. (2001**)

$$\text{THI} = \text{T}_{\text{db,i}} - [(0.31 - 0.31\,\text{RH,i})\,(\text{T}_{\text{db,i}} - 14.4)]$$

Where $T_{db,\,i}$ is Dry bulb temperature (°C), RH, i is indoor Relative humidity (%) /100.

2.11.4 Thermal environmental index for productivity (TEI_R)

Medeiros et al. (2005)

The nonlinear regression approach was used to derive a regression equation from calculating the environmental thermal index for the productivity of the rabbit (TEI_R). Values between 21 and 24 (comfortable) are associated to the maximum productivity; between 25 and 27 (moderately comfortable), between 28 and 30 (discomfort), between 31 and 34 (extremely discomfort), and for values above of 35 (dangerous).

$$\text{TEI}_{\text{R}} = 1.0903407 \times \text{T}_{\text{db,i}} - 0.0129632 \times \text{RH}_{\text{,i}} - 2.2703248 \times \text{u}$$

Where u is mean air velocity ($m\ s^{-1}$).

2.11.5 Physiological responses (T_{sp})

Medeiros (2001) Predicted surface temperature (T_{sp}) by a nonlinear regression equation,

$$T_{sp} = 1.21990371 \times T_{db,i} - 0.0406879 \times RH_i - 8.6782479 \times u - 0.1898457$$

3. RESULTS AND DISCUSSION

Designing models

One of the important agricultural structures is rabbit housing, which needs scientific design and a suitable environmental control design. From surveying, the researchers observed the few rabbit housing in Egypt. Also, they noticed little information about using a suitable environmental control system about these houses under control. Therefore, the present study employed four houses as a suitable orientation and built from popular building materials in the study area. One of these houses functioned as an experimental control, and others operated by pad-fan evaporative cooling. To evaluate the evaporative cooling systems in these houses were compared by three scientific, mathematical forms for pad-fan evaporative cooling design. Consequently, the basic knowledge to design the evaporative cooling system in the rabbit house is calculating the airflow rate inside the house for determining the dimensions of the pad cooling.

Table (2) indicated many parameters associated with the design pad-fan evaporative cooling system. These parameters were calculated by three models and compared the data from these models by experimental units. These parameters, such as airflow rate, number of fans, pad area, the pad length, water flow rate, gutter size, pump capacity, and sump size. The criteria for designing pad- fan evaporative cooling system in experimental units have a shortage from viewpoints of airflow rate, the number of fans, pad area, the pad length, as shown in Table (2). The previous parameters represent the most important design criteria of this cooling system. This shortage may cause undesirable inside air, unsuitable saturation efficiency, and low thermal requirements by the cooling system.

Meanwhile, the water flow rate value in experimental houses is acceptable to depend on form 2. The gutter and sump sizes in experimental houses were more extensive than the values estimated by three models. Also, this causing decreases in cooling system efficiency. In general, the form which nearly with the actual design was formed 3. This means that the pad area should increase to obtain the best performance.

Table2. Many parameter values by calculation models and available data in experimental houses.

Mathematical Form	**Airflow rate (Q) ($m^3\ h^{-1}$)**	**Fan numbers**	**Pad area, (m^2)**	**Pad length (m)**	**Water flow rate ($L\ min^{-1}$)**	**gutter size (L)**	**pump capacity ($L\ min^{-1}$)**	**sump size (L)**
Form 1	57600	1.37 ≈2	12.8	8.5	35	25.6	------	162.2
Form 2	61990	1.48≈2	13.77	9.18	55.1	-----	67.95	413
Form 3	48690	1.16≈2	10.82	7.22	20.42	----	-----	-----
Experimental	42000	1	9	6	48	43.2	-----	500

Psychometric conditions

The houses of rabbits which operated by fan-pad evaporative cooling systems subjecting to psychometric conditions that describing the relation between outside air and inside air after it moist throughout passing wetted pad.

Table 3 described that the psychometric conditions in houses understudied. This Table showed the outside air temperature and indoor air temperatures, moisture content additional in the houses resulting in evaporative pad cooling. Consequently, the increasing values of indoor relative humidity. Also, this Table indicated that the lowest inside air temperature in house D with the highest saturation efficiency. House D achieved these results because the pad area was higher than other houses; this means that the air stream length covering the complete housing and had the ability to reduce the air inside temperature. The contact time between moist air and inside air was suitable because of the moderate velocity of airflow rate in this house. While Table 4 explained the psychometric conditions of pad temperatures and temperature at a fan, which put ended building. The enthalpy after pad in house D had minimum value when compared with other houses. This means that the energy required for cooling in this house consumed low energy with high efficiency because the pad area was 9m^2.

Table3. Psychometric conditions in houses when using evaporative pad cooling system

House	Before pad				After pad			Saturation Efficiency (%)
	($T_{db,o}$) °C	($T_{wb,o}$) °C	(R_{Ho}) %	(W_o) kg_w/kg_{air}	($T_{db,i}$) °C	(R_{Hi})%	(W_i) kg_w/kg_{air}	
B	34.1	21.71	34	0.01137834	25.5	77	0.015825	69.41
C	34.1	21.71	34	0.01137834	25.4	80	0.0163581	70.22
D	34.1	21.71	34	0.01137834	24.65	82.5	0.01612596	76.28

Table 4. Psychometric conditions inside the house from pad to fan during the cooling process

House	Pad				Fan			
	T_p (°C)	Rh_p (%)	W_p (kg_w/kg_{air})	h_p (Kj)	T_F (°C)	Rh_f (%)	W_f (kg_w/kg_{air})	h_f (Kj)
B	25.5	77	0.015825	65.95	31.5	40	0.0115694	61.26
C	25.4	80	0.0163581	67.19	29.1	44	0.1108332	57.56
D	24.65	82.5	0.0161259	65.83	28.7	51	0.01258229	60.97

Temperature and relative humidity

Mean weekly outside air and inside air conditions shown in Fig. (4), using evaporative cooling in houses B, C, and D. Therefore, the air relative humidity values in these houses were higher than house A which operated without evaporative cooling. Also, the air inside the temperature in these houses lowers than house A. The outdoor and indoor air temperatures were nearly values in house A because there is no cooling in this house and natural heating load, where outdoor and indoor temperatures were 34.1°C and 34.3 °C, respectively. When compared results from in-between cooling houses, house D gave less mean indoor air temperature 26.85 °C and higher relative humidity 67.8 %. The obtained data of indoor air temperature was in the range of what was recommended by **(Cervera and Carmona,2010)** and **(Bodnar et al., 2019).** The mean indoor air relative humidity was suggested by **(Bodnar et al., 2019)** and under the suggested recommended range by **(Kamal et al., 2010).** This means that the full pad area can decrease the temperature inside the rabbit house. Moreover, this result meaning that the pads face area near to model 3, as shown Fig. 4. The worst performance in house B, which fan not facing the pad that means in this house, the system had not able to reduce the temperature inside it. House D consumed less energy to achieve this temperature and relative humidity

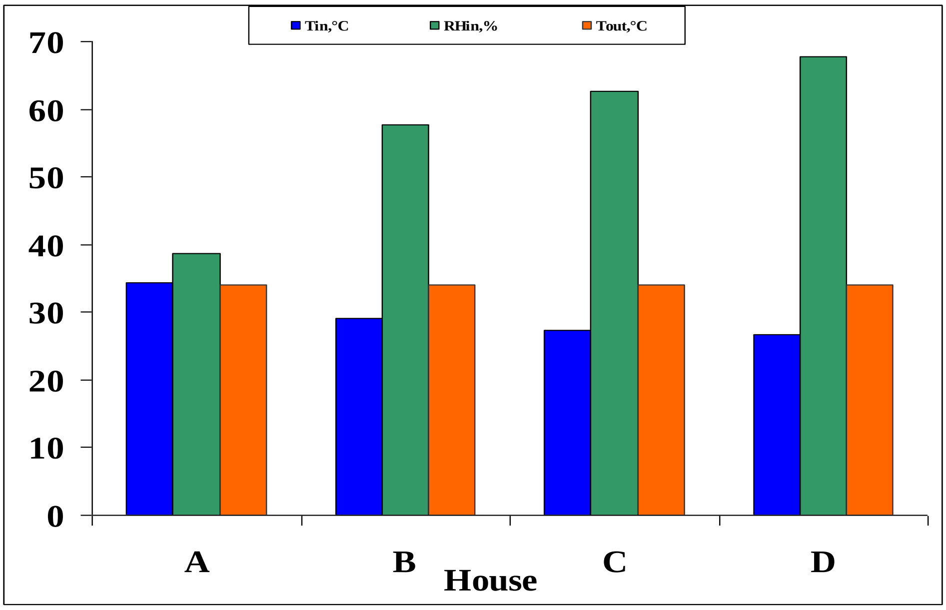


Fig. 4. Temperature and relative humidity

THI is an indicator of the thermal comfort level for animals in an enclosure. In other words, this indicator gives the temperature and relative humidity together that can provide the acceptable limit for circumstances environment. Also, THI indicates an animal response to temperature and humidity and the relative importance of the sensible and latent thermal components.

Fig. 5. Compared between houses from the viewpoint of THI values. The higher values of mean THI showed in house A. The threshold range of Temperature – humidity index blew 27.8 °C was taken to signify an absence of heat stress, a range from 27.8 to 28.9 °C represents heat stress, while a value over 28.9 °C was considered to represent severe heat stress according to **Marai et al. (2001).** Also, the THI value was in agreement with data found by **(El-Maghawry, 2018)** and **(Frano-Salas, 2019).** Therefore, houses B, C, and D in the safety limits. This means that the evaporative cooling system had effectiveness for improving the inside rabbit houses' environment. From Fig5, the results showed that houses C and D have low values of THI because the pad-fan evaporative cooling system can reduce heat stress more than the other two houses.

THI values lower (more comfortable), so that differences in energy and protein content of the ration did not affect the respiration rate. Meanwhile, heat stress causing energy and protein diets with higher levels increased respiration rate. This result was in agreement with what informed by **(Asemola et al., 2017).**

Evaporative pad cooling system performance

When compared between the houses which were employed in this present study. The highest values of these indicators showed in house D as tabulated in Table 5. Because house D has a $9m^2$ pad area that higher than other houses. Vice versa, the lowest values indicated at house B, as shown in Table 7. Because it has a 4.5 m^2 pad area and not facing the fan. From the viewpoint of ECP and unit, ECP indicated that The house B and C reduced the energy consumption for cooling systems because the pad area in these houses was lower than house D and the fan sizing was not enough for evaporating water from moist air.

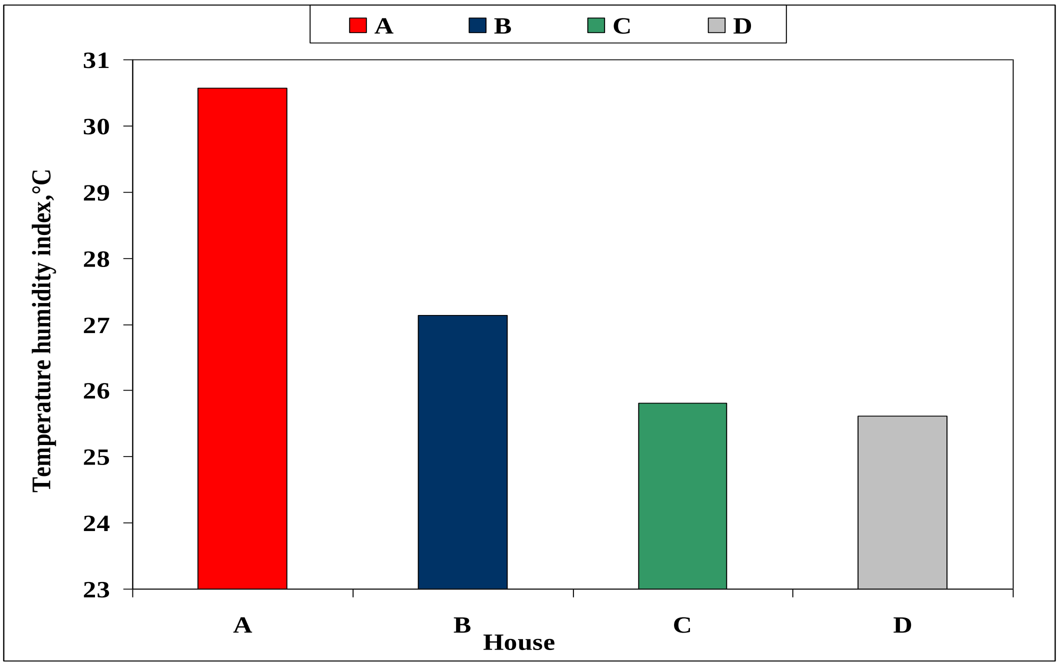


Fig. 5 Mean temperature-humidity index

Table 5. Performance of evaporative pad cooling systems

House	B	C	D
CE (°C)	8.6	8.7	9.45
S.E (%)	69.41	70.22	76.28
ECP (kW)	54.93	56.16	121.88
Unit ECP (kW °C^{-1})	443.28	453.25	983.63
CE/Q (°C s m^{-3})	1.53	1.55	0.84

The values of cooling effect (temperature reduction) were in the range of experimental results clarified by **(El-Maghawry, 2018).** The values of the saturation efficiency of the system were in the range found by (**Darwesh 2015)**.

Thermal environment and productivity for rabbit Physiological responses

Reveal to Table (6), some thermal environment, and productivity for rabbit physiological responses were introduced. These indicators, such as temperature-humidity index (THI), the thermal environmental index for productivity (TEI_R), predicted surface temperature (T_{sp}), heat energy removal (Q_r), moisture addition (W), sensible heat (Q_s), and latent heat (Q_L).

During the experimental period, as shown in Table (8), TEI_R was higher than THI in all treatments. The difference between THI and TEI_R was 4.85, 3.18, 2.36, and 1.61 for houses A, B, C, and D, respectively. The maximum mean value of TEI_R was 35.43 at house A. This value is above 35, according to **Medeiros *et al.* (2005),** for house A TEI_R value (dangerous). The minimum mean value of TEI_R was 27.22 for house D. Moreover, the value of TEL_R was (moderately comfortable). This indicated that the cooling system provides the best environment in house D. Comparing measured surface temperature (T_s) with predicated surface temperature

(T_{sp}) during the experimental period. The measured surface temperature (T_s) was lower than the predicted surface temperature (T_{sp}) for house A. The maximum mean value of (T_{sp}) and (T_s) were 33.94 °C and 33.4 °C for house A, respectively. While the minimum mean values of (T_{sp}) and (T_s) were 25.28 °C and 29.63 °C for house D, respectively.

The importance of a cooling system associated with the ability of this system to remove the energy. Therefore, the only way to cool any agricultural structure is to remove the heat energy from it. Also, heat removed from one medium is transferred to another medium, or process fluid. This meaning that efficient removal of heat is an economic requirement in the designed operation of a cooling system. From previous words can conclude that house D had the highest ability to remove heat energy compared with the other houses. Consequently, the highest moisture addition value in house D because it had higher heat removal energy and goaled higher cooling effect.

Based on the information available in the literature, it would be expected that SHP will and body weight. When the dry bulb increases and the wet bulb decreases, LHP reaches its maximum (3). At high air temperature and high RH combinations, animals and humans cannot exhaust the latent and sensible heat from heir body to the environments. Data should increase THI, accompanied by decreasing sensible heat from rabbits (Q_s) and increasing latent heat from rabbits (Q_L). The maximum mean value for sensible heat was found in house D, where the THI value was in its lowest value and latent heat also in its lowest value.

Latent heat (Panting) is a much higher energy cost pathway for heat loss than sensible heat loss, and it further affects blood acid-base balance and body water balance, thus adversely affecting the ability to maintain body temperature in a normothermic range. Any shift from evaporative to sensible heat loss may reduce maintenance energy and thus increase the amount of energy available for growth. Sensible heat loss can also prevent hyperthermia caused by dehydration, which results from severe panting. So increasing sensible heat and decreasing latent heat is helpful for rabbit production, as shown in house Table 6.

Table 6. Thermal environment and productivity for rabbit Physiological responses

House	A	B	C	D
THI, °C	30.58	27.15	25.81	25.61
TEI_R ,	35.43	30.33	28.17	27.22
T_{sp}, °C	33.94	30.09	27.07	24.28
T_s, °C	33.4	30.31	30.1	29.63
Q_r, kW.h		34.22	61.65	62.01
W , kg/h		106.36	115.15	219.89
Q_s,kW	11.13	12.48	13.13	13.30
Q_L,kW	15.66	9.85	8.87	8.65

4. CONCLUSION

The possibility of using a fan pad evaporative cooling system in rabbit housing to put these houses in a comfortable zone resulting in reduced heat stress. The previous study used three models to compute the appropriate pad cooling area that suitable the house and then compared the results of models with the actual designs in these commercial houses and exactly measured the deviation of these results when compared with these houses. The analysis of data and results of models indicated that the commercial rabbit housing which operated should modify the pad area, number of fan, and position of the fan facing the pad. Also, we should design any houses of rabbits based on the heat balance model to give the essential information to control the inside conditions for reducing energy requirements and providing the best conditions in the rabbit housing in Egypt. A grower man of rabbits should consider the design criteria of pad evaporative cooling system by scientific methods to reduce heat stress and energy inside rabbit housing. Therefore, using mathematical form 3 that depending on heat balance is preferred when designing a cooling system, as indicated in this study.

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تقليل الطاقة والإجهاد الحراري لمساكن الأرانب المغلقة تحت ظروف منطقة الدلتا المصرية

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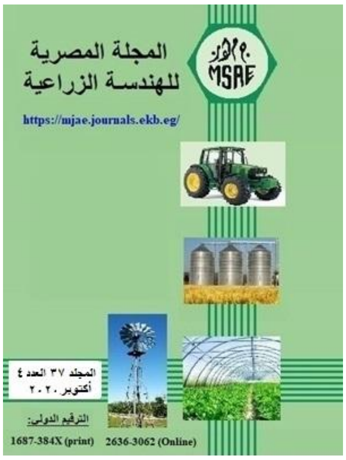
الملخص العربي

أجريت هذه الدراسة بهدف تقييم مساكن الارانب المزودة بنظام التبريد بالتبخير أو تلك الغير مزودة به في هذه المساكن على وضعها الحالي. وكذلك استخدام النماذج الرياضية لحساب مدي مقاربة النظم الموجودة للأسس العلمية التي كان يجب مراعاتها عند التصميم في البداية وهذه الأنظمة هي نظام رياضي يعتمد على حساب معدلات التهوية بناءً على وزن الجسم وآخر بناءً على حجم المسكن والنموذج الأخير يعتمد على معادلات الاتزان الحراري للمسكن والأرانب. ولذلك تم إجراء التجربة في أربعة مساكن متجاورة، بها أربع طرق مختلفة للتبريد. المسكن الأول تتم تهويته بالتهوية الميكانيكية فقط ويستخدم كمقارنة والمسكن الثاني يستخدم وسادة ذات مساحة ٤,٥م٢ ومواجه للمروحة والمسكن الثالث يستخدم وسادة ذات مساحة ٤,٥م٢ وغير مواجه للمروحة والمسكن الرابع وبه وسادة ذات مساحة ٩م٢ ومواجه للمروحة. وتم تقييم ثلاث نماذج رياضية تستخدم لحساب مساحة الوسادة المطلوبة وعدد المراوح وذلك في وكانت النتائج كالتالي أن المسكن المجهز بنظام التبريد بالتبخير مع استخدام كامل مساحة الوسادة أعطى أفضل ظروف داخلية من حيث درجة الحرارة والرطوبة النسبية حيث حقق استخدام نظام التبريد بالتبخير داخل هذا المسكن أفضل متوسط لدرجة حرارة وهي ٢٦,٨٥°م مع متوسط رطوبة نسبيه ٦٧,٨٣%. وكانت متوسط كفاءة نظام التبريد ٧٦,٢٨% وهذه النتيجة حققت متوسط دليل الحرارة - الرطوبة داخل المسكن ٢٥,٦°م. وعند المقارنة بين نتائج هذه المساكن مع نتائج النماذج الرياضية فكان استخدام النموذج الرياضي الذي يعتمد على اتزان الطاقة داخل وخارج المسكن هو الأقرب إلي النتائج المتحصل عليها من هذه المساكن. وتوصي الدراسة مربي الأرانب بضرورة الاعتماد على التصميم العلمي لنظم التبريد بالتبخير للحصول على مساحة وسادة مناسبة وكذلك الحصول على عدد مراوح مناسبة بالإضافة إلى تحديد موقع مناسب للمروحة في داخل المسكن. وبناءً على هذه الدراسة فإن أفضل مساحة للوسادة كانت ٩ م٢ ومقسومة على جزئين ويجب أن يواجه كل جزء في منتصفه مروحة للتعامل مع الهواء الرطب في المسكن موضع الدراسة.



الكلمات المفتاحية:
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