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Development of analytical model for predicting environmental operating parameters of poultry house with fan and pad evaporative cooling system in different climatic zones of Sudan

Fadlalla MAH and Hassan IM

Department of Agricultural Engineering, Collage of Agricultural Studies,
Sudan University of Science and Technology, Sudan

Corresponding author: hassantal@gmail.com

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ABSTRACT

Aim: The study was conducted to develop, validate and apply a steady state analytical model based on mass balance principle to predict optimum temperature distribution of a commercial poultry house equipped with fan and pad cooling system in five climate zones of Sudan**.**

Materials and Methods: The model considers poultry house as a heat exchanger to simulate heat and mass transfer under poultry house structural characteristics, external and internal climatic conditions, pad efficiency, ventilation rate and poultry biological characteristics The temperature and humidity of incoming air, the operational characteristics of exhaust fans and the temperature drop occurring in the along the house length, insulation material, and roof and wall characteristics were specified to set up the model. The main model outcome was the prediction of the optimum air temperature distribution inside the poultry house. These air temperatures were validated by experimental measurements obtained at a height level of 1.2 m above the ground in the middle of poultry house.

Results: The correlation coefficient (R^2) between computational results and experimental data was at the order of 0.77 for the analytical model, with average percentage error of 7.6%. The analytical model proved to be a useful evaluation tool, for air flow in the poultry house showing that fan and pad evaporative cooling system could be effectively parameterized in numerical terms, in order to improve system's efficiency. Sensitivity analysis was made by quantifying the effects of changing model inputs of outside temperature and its changes, relative humidity (RH), and air seepage by 20% increment and decrement on some model outputs (internal mean temperature, RH and fan discharge).

Conclusion: It was concluded that the difference between inside and outside air temperature was strongly related to the ventilation rate as well as to the incoming solar radiation.

Keywords: Heat exchanger, temperature gradients, poultry house ,environmental operating parameter, fan and pad cooling.

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Introduction

One of the greatest concerns in poultry production is maintaining body temperatures at permitted levels which do not surpass the upper limit of the thermal comfort range which should not exceed 29 °C, where the optimal temperature is 25 °C (Albright, 1990; Osório et al, 2009). Heat stress with high temperature combined with high humidity causes suffering and mortality in the birds, and reduces production that adversely affects the profit from the enterprise.

Under normal conditions, chickens do a good job of cooling themselves with physiological and behavioral mechanisms but these mechanisms fail at high temperatures. In barn air temperatures that cause heat stress and mortality are considerably below broiler body temperature. Broiler surface temperatures typically range from 95 – 100°F, with skin temperatures warmer than feathers. Air temperatures in this range can virtually stop heat loss from the broiler and accelerate heat prostration. For this reason, an important goal for hot weather ventilation systems is to keep air temperatures below 95°F.Some studies have been performed with the objective of producing models to predict chicken behavior function of temperature, and humidity variables (Gates et al, 1995; Kristensen et al, 2000; Severo et al, 2003), Such models intend to determine the proper design aspects of cooling and ventilation systems for minimizing production losses during hot weather. However, in these models optimum environmental operating parameters are not specified directly and assumed to be indirectly maintained from design elements.

Evaporative systems for cooling barn have been developed to provide the desired growing conditions in the barn during the hot period of the year. The principle underlying direct evaporative cooling is the easy conversion of sensible to latent heat while unsaturated air is cooled by exposure to free and colder water, both thermal isolated from other influences. Various studies on evaporative cooling systems applied to horticulture, mainly fog and pad and fan systems, were already published, and among others, those by Montero et al. (1981, 1990) and Giacomelli et al. (1985). Kittas et al. (2003) presented and validated a model to predict temperature gradients in a large evaporative cooled greenhouse; and finally Fuchs et al. (2006) developed a numerical model based on energy balance equation which solved numerically.

Evaporative cooling pads are currently the most effective and efficient systems for cooling broiler houses (Montero et al., 1981; Kittas et al., 2001). They are used in poultry and dairy houses for reducing heat stress on animals (Gates et al., 1995; Ali et al., 1996; Arbel et al., 1999; Zabeltitz, 2002 and Chen, 2003) and storage structure for fruits and vegetables (Helson and Wilmot, 1991 and Umbarker et al., 1991). Kittas et al. (2001) observed that a fan-pad cooling system during summer in a commercial greenhouse producing cut roses and a half–shaded plastic roof reached 80% efficiency and succeeded in maintaining greenhouse temperatures that were cooler (up to 10oC lower) than outside. It has been reported by several researchers that evaporative cooling improved milk production and fertility for cows during summertime climates (Ali, 1996). Also, use of evaporative cooling minimized the heat stress birds were exposed to during growth New pads, or those in good condition, generally have high efficiencies (70 – 90%); and when sized, installed, and maintained properly, can provide more cooling effect than fogging without the risk of wetting the broiler house interior. Re-circulating-type pads use a plumbing system including a sump, a pump to re-circulate the water through the pads, and exhaust fans at one end of the greenhouse. Fogging pads are a variation in which the pad is wetted by fogging nozzle spray instead of a Re-circulating water delivery system. If all vents and doors are closed when the fans operate, air is pulled through the wetted pads and water evaporates. As each gallon of water is evaporated, 8,100 BTUs of heat energy are absorbed from the air by the water during the change from liquid to vapor. Removing energy from the air lowers the temperature of the air being introduced into the greenhouse.

The air will be at its lowest temperature immediately after passing through the pads. As the air moves across the house to the fans, the air picks up heat from solar radiation, animal, and soil, and the temperature of the air gradually increases. The resulting temperature increase as air moves down the greenhouse produces a temperature gradient across the length of the greenhouse, with the pad side being coolest and the fan side warmest. Evaporative cooling effectiveness depends upon several factors including width and density of pads and pad material used (Kittas et al., 2003). Temperature difference between the inside and outside of the broiler house is determined by the solar and broiler heat added and the rate at which air in the house is exchanged by the ventilation system. The greater the amount of heat added to the air, the higher the temperature of the air within the house. The faster the air in the house is exchanged, the closer the house temperature will be to the outside temperature. Evaporative cooling is used to maintain temperatures within the comfort zone when outside temperatures approach or exceed the upper limit of the comfort zone.

To design or to operate a ventilation system in hot weather, calculation of the heat gain through the building and heat production by the broilers is needed. Heat flows into the house through the walls and roof and, to a lesser extent, through the floor, due to conduction and to heating by the sun. Heat also enters the house through the ventilation air and is added from the broilers themselves. Heat flows out of the house through the exiting ventilation air. When designing or operating a hot weather ventilation system, the acceptable difference between inside and outside temperature must be defined. At first though, the choice might be to maintain inside house temperature within a degree or two of the outside temperature. Although this would be 'ideal,' it is not practical or necessary in many situations. When ventilation fans in the poultry buildings are insufficient for diminishing internal temperatures below 29 °C, secondary or artificial modification are used, such as changing the thermal properties of the roofing material (Silva et al., 1990 and Tinôco et al., 2001) or changing specifications of building and insulation materials of walls and roof or by incorporating evaporative cooling systems by installation porous plates or cooling pads, or by misting (Sartor et al., 2001) Due to the importance of understanding distribution parameters such as temperature inside poultry buildings, some simple models have been proposed which provide the average temperature inside the installation, but not distribution throughout the building (Timmons et al., 1988; Olgun et al., 2007) The barn provides a suitable environment for the intensive production of various crops. They are designed and operated to control solar radiation, temperature, and humidity and carbon dioxide levels in the aerial environment. The availability of solar radiation and its daily and yearly distribution has a tremendous influence on productivity and quality of plant growth and also on comfort living. The greenhouse air temperature mainly depends on the distribution of solar radiation after transmission through the greenhouse cover which in turn depends on shape and size of greenhouse, motion of the sun and weather conditions. Greenhouse's design, orientation and type of glazing will affect the amount of light transmitted into the structure (Giacomelli et al., 1995). The design, selection and operation of a controlled environment barn depends upon the climatic conditions of each zone and plants requirement. Sudan has five climatic zones on the basis of rainfall, relative humidity, ambient air temperature and in solation. These zones are, desert (Dongola), Semi-desert (Khartoum), dry (Wad Medani), Semi-dry (Sinnar) and Semi-wet (Damazin) (Adam 2002).

The aim of this study was to develop, validate and apply a simplified steady state mathematical model to predict temperature distribution as optimum operating parameters in a commercial poultry house equipped with fan and pad cooling system for each one of the five climate zones of Sudan.

Materials and Methods

Collected Data

House Data: The experiments were carried out at the poultry house of Collage of Agricultural Studies in the department of animal production-Sudan University of Science and Technology in Khartoum (Table 1). The experimental barn is with a 60 m length, 12 m width, 1.2m Height, and laying to the east. In the house the roof heat transfer factor and wall heat transfer factor was 1.6 m^2 c/w and number of bird is 20000, and each with a 2 kg average bird weight. The house saturation efficiency was 83%, temp difference was 4 c, and out and air temperature was 45c, It was considered that radiation absorption was 0.4, sun radiation was 1010 w, kPa, the relative humidity was 10 %, wet bulb region temp was 22 c, pressure 101.325 kPa, warm air leakage rate to the barn 20%, and specific heat is 1.0.

Climate Zones Data: Annual meteorological data averaged over 30 year records for cities representing the five Sudan climate zones was obtained from Sudan Meteorological Department and depicted.

Table 1: Measured mean annual meteorological data averaged over 30 year records for cities representing the five Sudan climate zones

City	Longitude (deg)	Latitude (deg)	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad. MJ/m²/day	ETo. mm/day
Dongola	19.1461° N	30.4703° E	26	43.2	48	294	11.1	26.6	9.88
Khartoum	15.5007° N	32.5599° E	27	41.8	56	259	10.7	25.8	8.43
Wad Madani	14.3931° N	33.5392° E	24.5	41.3	71	268	10.7	25.8	8.41
Sinnar	13.0317° N	33.9750° E	18.2	41.6	86	164	11.3	26.9	7.26
Damazin	11.7855° N	34.3421° E	24.8	40.1	80	190	10.3	24.2	6.81

Development of Analytical Model: The barn is considered as heat exchanger and based on the theoretical approach outlined by Abd Allah (2002), Willits, (2003) and Ali (1996). The analytical model was used to calculate the temperature distribution in the barn environment under steady-state conditions. The model was build and coded in Excel sheet. The model functional relations as follows:

Input Data:

Inputs		
Length	60	m
Width	12	m
Height	3	m
Roof heat transfer factor	1.6	M2c/w
Number of wall side	2	
Number of an exterior	20000	
Weight of bird	2	Kg
Saturation Efficiency	83	%
Frame wall height	2	m
concert wall height	1	m
perimeter	36	m
Number of windows	8	
windows Area	3	m2
Door area	6	m3
Doors Number	3	
Number of aspects	2	
Pressure	101.325	kPa
Specific volume	0.91	M3/kg
Wet bulb temp	22	C
Air temperature	45	C
Out temperature	45	C
relative humidity	10	%
Sun radiation	1010	W
Temp difference	4	C
radiation absorption	0.4	
Wall heat transfer factor	1.6	M2c/w
Laboratories membrane roof	30	w/m^2C
Specific heat	1	
Warm air leakage rate to the barn	20	%
Live the initials	Layin gheat	
Building temp c	28	C
MP gH2o	3.8	gH2o/Kg-h
GHL W	3.2	W/kg

Data Processing:

Determine air cooling		
Degree temperature cooling air	tc=ta-η*to-twb)	C
Temperature balancing		
Average temperature inside the barn	Tav=tc+Δt\2	C
perceived temperature,	qs=No*m*Mp	KW
The air temperature abroad from the Hangar	Te=tc+Δt	C
Roof Area	Ar=L*w	M2
temperature sun air	Tsa=to+Iα/h	C
Temperature traveling through the roof	Q'cd=Ar/Rr*(tsa-te)	KW
Area of the walls	Aw=(L*H,2+(W*H)*2	M
Temperature traveling Through wall	Q''cd=Aw/RW*(ta-tav)	KW
Temperature traveling through the ceiling and walls	Qcd=q'cd+q''cd	KW
Heat load macroeconomic soccer to the	qhl=qs+qcd	KW
Rate of flow of cooling air inside the barn	Q=qhl/(cp*Δt*(1/Vo)	m3/s
Budget moisture		
Stem water who enters into the fold in the air cooling	Wc=Q*wc/Vo	Kg/s
Air steam emitted from poultry	Wp=((N*Wt*Mp)/(1000))/3600	Kg/s
Stem water which goes out in the air from the Hangar	We=Wc+Wp	Kg/s
Humidity conditioned upon his departure from the Hangar	we=We*Q/Vo	Kg/kg
Average relative humidity	φav=φc+φe/2	%
Warm air leaks mixed with cooling air Account		
Rate of the air flow through the hangar	Qpd=Qf-Qfl	m3/s
Rate The leakage of hot air inside the barn	Qfl=(0.2*Qf)	m3/s
Block cooling air	mc=Qpd/Ve	kg/s
Air bloc leakage	mfl=Qfl/Vo	kg
Humidity content mix air	w'c=wc*mc+wo*wfl/m'c	kg/kg
The air temperature when suction Fans	t'e=t'c+qhl*Vo/cp*Q	c

Results and Discussion

1- Model Building:

The mathematical model is established in Excel sheet for the poultry house environmental conditions and adapted for the territories of the different climate zones in Sudan as shown by model flow chart (Fig. 1).

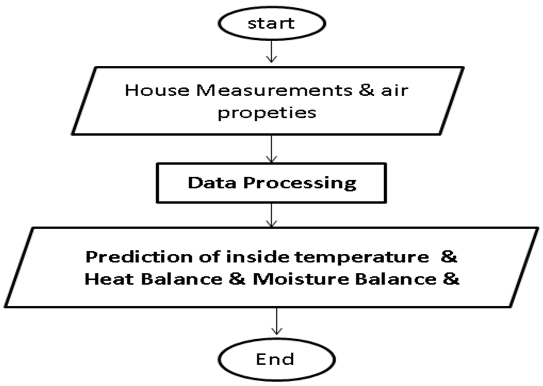

Fig. 1. Flowchart showing a General Model Framework

2-Validation and verification of the model:

The model was validated with data obtained experimentally during the summer (season 2016) from the poultry house of the Department of Animal Production of Collage of Agricultural Studies at Sudan University of Science and Technology (SUST). Severo et al (2003) also reported similar findings of modeling.

The experimental house is equipped with a length 28, m, a width 11 m, and a height 1.2 m, Roof heat transfer factor and Wall heat transfer factor 1.6 m2c/w and Number of bird 20000, with average weight of bird 2 kg. It is assumed that the saturation Efficiency is 90%, temperature difference is 4 c, and outdoor air temperature is 45c, The radiation absorption of 0.4, Sun radiation of 1010 w, k Pa, relative humidity of 60 %, , wet bulb region temp of 22 c, and pressure of 101.325 kPa, warm air leakage rate to the barn 20%, and specific heat 1.0 were taken in the calculations. It is considered that the poultry house mean temperature inside of 45, efficiency of 66 %, RH is 63, inside mean fan is 34. It was showed the available inputs on the output for the city of Khartoum (Table 2). Kristensen et al (2000) also corroborated with the findings of present study.

Application data for 5- cities: The results of model application to obtain specification of optimum operating parameters for each one of the five cities representing the five climatic zones of Sudan (Table 3). Gates et al (1995) also reported similar findings.

Clarify the flow of the leak hot air into the hangar on the increase in the average temperature of the fold of the Interior (Fig. 2). Clarify the inverse relationship between the humidity and fan air abroad from the barn (Fig. 3). It was showed the impact of increased temperature on the average temperature of the house interior status (Fig. 4). Timmons and Gates (1988), Kittas et al (2001) and Willits (2003) also advocated the similar findings of the present study.

Table 2: Standard input data for Khartoum used for sensitivity analysis

					Inputs				
Parameter Chang rate	0.2	0.4	0.6	0.8	1.00	1.2	1.4	1.6	1.8
T out side	8.36	16.72	25.08	33.44	41.8	50.16	58.52	66.88	75.24
RH out	8.36	16.72	25.08	33.44	48	57.6	67.2	76.8	86.4
Delta T	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	7.2
Air seepage	4	8	12	16	20	24	28	32	36
					Outputs				
Mean temp inside	20	22	24	26	27	29	31	33	35
RH inside	65	65	65	65	65	65	65	65	65
Mean Q fan	6.8	13.6	20.4	27.2	34	40.8	47.6	54.4	61.2

Table 3: Climatic zone of Sudan

City	Outputs							
	Temperature out side	RH out	Delta Temp	Air seepage	Mean temp inside	Efficiency %	RH inside	Mean Q fan
Dongola	43	48	4	20	34	53	63	34
Khartoum	42	56	4	20	35	47	64	34
Wad Madani	41	71	4	20	38	21	63	34
Sinnar	42	87	4	20	41	55	63	34
Damazin	40	86	4	20	31	53	64	34

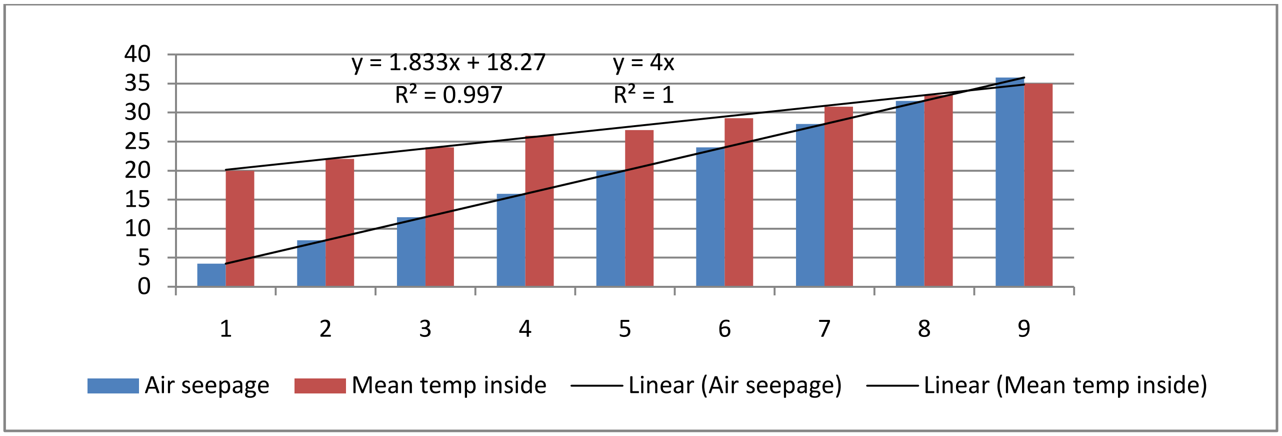

Fig. 2: The relation between air seepage and mean temperature

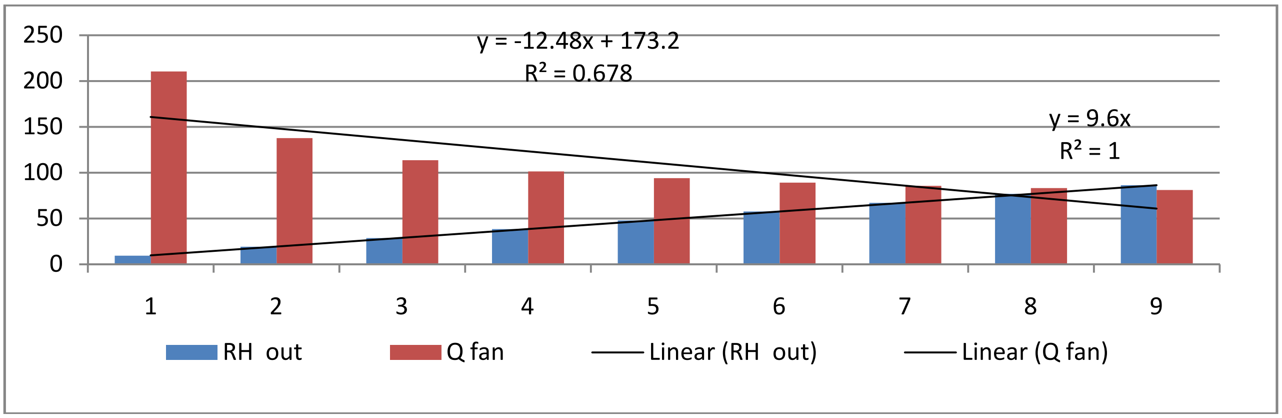

Fig. 3: The relation between humidity and Mean Q fan

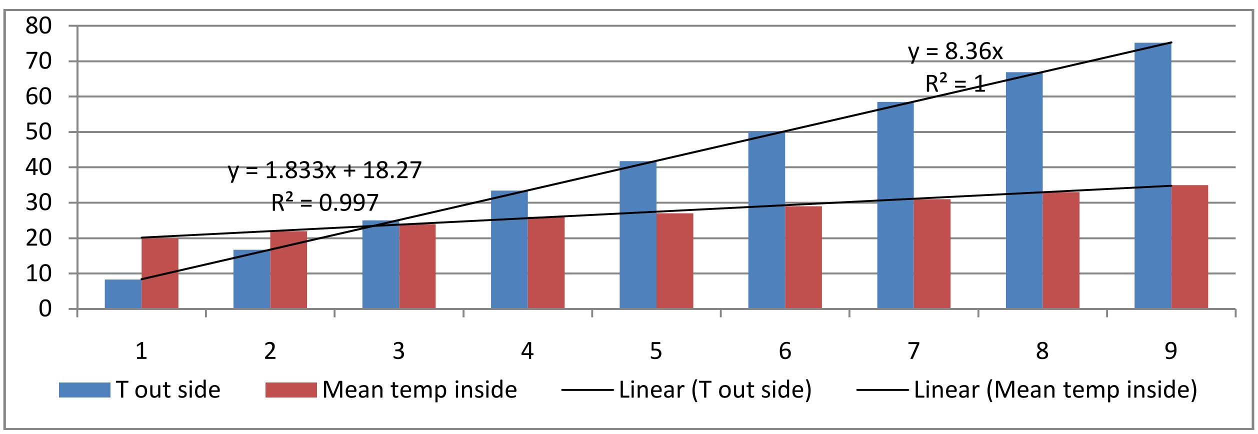

Fig. 4: The relation between T outside and Mean temp inside

Table 3: Climatic zone of Sudan

City	Outputs							
	Temperature out side	RH out	Delta Temp	Air seepage	Mean temp inside	Efficiency %	RH inside	Mean Q fan
Dongola	43	48	4	20	34	53	63	34
Khartoum	42	56	4	20	35	47	64	34
Wad Madani	41	71	4	20	38	21	63	34
Sinnar	42	87	4	20	41	55	63	34
Damazin	40	86	4	20	31	53	64	34

Conclusion

This study developed a simplified mathematical model in steady state to simulate heat transfer and effects of outside temperature and relative humidity on inner environment of fan and pad controlled poultry house in Excel sheet. The model sensitivity was made by determining the effects of changing model input parameters on model outputs. Sensitivity analysis of effects of changing some important inputs of the model (outside temperature and its changes, RH) by 20% increment and decrement on some model outputs (internal mean temperature, inside RH, and fan discharge) was made. The results showed that the difference between inside and outside air temperature was strongly related to the ventilation rate as well as to the incoming solar radiation. The model is applied for five Climatic zones of Sudan to generate optimum environmental operating parameters of poultry house suitable to each zone.

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