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Mathematical Modeling of Ventilation System for Closed Poultry House in Tropical Climate Conditions

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Abstract – The goal of this research was to create and test a simplified steady-state mathematical model for predicting temperature distribution in a commercial poultry house with a negative pressure ventilation system and inside misting. The best combinations of energy generated by misting, ventilation rate, global heat loss coefficient for the roof, and global heat loss coefficient for the wall were found to maintain the majority of the installation with temperatures within the optimal thermal comfort range for the birds (27 to 29 °C) for external temperature conditions of 31 to 45 °C. This model is suitable for dry bulb temperature of 34 °C. The purpose of this study was to determine the temperature tolerance in commercial poultry housing while applying the steady-state heat balance.

Keywords – Poultry house, temperature tolerance, heat balance, mathematical model, evaporative cooling

Introduction –

Poultry is currently one of the fastest expanding parts of India's agricultural industry. While agricultural crop output has been increasing at a pace of 1.5 to 2% per year, egg and broiler production has been increasing at a rate of 8 to 10% per year. India is ranked sixth in the global poultry market (using FAOSTAT rankings). With a compound growth rate of 18 percent, the domestic poultry sector is the largest growing segment. Poultry meat, which is India's most popular meat, has seen a significant increase in investment. India's yearly boiler meat production is estimated to be at 4.8 million tons. The yearly value of India's poultry sector, which includes broilers and eggs, is $ 12.96 billion. Egg production expanded from 30 billion in 2000 to 65 billion in 2014, with per capita egg consumption growing from 28 to 65 per year over the same time period. India is presently one of the world's fastest growing main chicken markets.

Poultry breeders must be able to maintain the livestock and poultry due to higher poultry consumption of meat. The closed house system is one of the most important components in producing healthy poultry farms. Because birds require various room temperatures throughout each growth stage, an efficient system needs proper air ventilation management. [1]

The thermal environment (temperature, relative humidity, wind speed, and sun radiation) is significant to animal production because it regulates broiler homoeothermic, which is responsible for ensuring the welfare and productive responses of the poultry birds. [2] As a result, while temperature is the most important climatic metric, the overall climate indoors is dictated by the dynamics of the building's sensible and latent heat. As a result, while calculating heat and mass balances, the water vapour emitted from various sources such as broilers, the raising system, the heaters, and the degree of natural ventilation should all be considered. Gases formed from heat and water vapour production dynamics, such as CO2, should also be included because they have an impact on the environment and animal welfare. The closed house system is recently used for the broiler production. [3] In order to achieve maximum efficiency in chicken production, the thermal environment must provide optimum comfort levels. When the temperature rises above a certain point, the body of the broiler must make physiological adaptations in order to sustain homoeothermic conditions, causing them to either retain or dissipate heat. [4]

Mechanical ventilation and a wind tunnel with a cooling pad can manage the temperature and relative humidity of the air in this enclosure. The broiler's metabolic heat, cage material exposed to sun radiation, heat from the brooder, and heat from litter fermentation can all be reduced via the ventilation system in the closed house.[5] Tropical environmental conditions required by poultry houses in the form of a control system to optimize environmental management of broiler closed houses, resulting in the growing of livestock with economic characteristics such as rapid growth, production of meat with low food conversion, and ready to cut at a young age. One of the variables that contributes to lower productivity. In closed house systems, the broiler is the unequal airflow rates surrounding the dwelling. The housing system's non-uniform distribution of air flows resulted in an uneven distribution of air temperature and relative humidity throughout the building. Animal performance may suffer as a result of this ailment, as well as an increase in animal mortality. Using computational fluid dynamics, the problem of air flow distribution in the house may be investigated swiftly and simultaneously.[6]

As a result, the purpose of this research was to create a simple mathematical model in steady state that could be used to calculate the average temperature ventilation distribution along the length of a tunnel poultry house structure with adiabatic evaporative cooling by means of misting

EFFECT OF TEMPERATURE ON POULTRY PRODUCTION:

The ideal poultry housing temperature for mature birds is widely agreed to be between (15°C and 25°C), which is referred to as a thermal comfort zone. The temperature in the poultry housing should be kept within this range for optimum production and growth. However, within this temperature range, the animal will eat more food in order to generate enough metabolic heat to compensate for the increased heat dissipation. Food consumption reduces when the ambient temperature is between (25°C -30°C). Nonetheless, the loss in productivity is not significant; it is less than 3%. As a result, this range is referred to as the economic or acceptable range. [7]

Materials and Methods

The experiments were performed in Chopda Dist- Jalgaon in poultry house from April to May 2021. The altitude of the study area is 190 m and geographic coordinates of area are Longitude: 75° 17' 58.06" E , Longitude: 75° 17' 58.06" E The 7500 poultry birds with an average age of 30-45days and house density of 17 birds per m.[2]

Poultry house

The poultry house was design as part of a closed system. Modern poultry houses were constructed of or bricks wall and concrete floor, sheet metal zinc roof and were integrated with a mechanical ventilation and cooling system. The size of house is 45.72 m in length, 9.14 m in width and 4.57 m in height 0.60m overhung and a roof with 25% inclination with capacity of 7500 birds. The average bird density was 17 bird/m^2. In present experiment poultry birds are kept on litter floor. The floor and the foundation were made with concrete.

Ventilation System

The negative pressure tunnel ventilation building with five exhaust fans were used. The poultry house was supplied with exhaust fans that drain the air from inside the house to the outside. The fan model and dimension The fans was installed at side wall from inner side of the house. The capacity of each fan was 100 cfm. When the fan was running, the shutters are kept open and they are closed by gravity when the fan was not in use.

Cooling system

In this experiment, direct evaporative cooling systems were used. Homogeneous sprinkling (misting) was used at the roof height with misting according to Richard S Gates misting flow rate (m_w) of 0.1675kg/s (approx. 90 gal/h) with fraction of mist evaporation β = 0.33 [9]

Heat Balance equation

The study deals with the sensible heat and latent heat balance for steady state conditions. The ventilation rate acquired from temperature control was supposed to be used to manage humidity in this commercial facility. This procedure has been used by other many authors. The Sensible Heat Balance Equation considered for this study was based on that proposed by the ASAE Standard EP270.5 DEC01 (ASAE, 2001) and CIGR Report (CIGR, 2002) Applying this general equation to our climatic conditions, the following expression was obtained:

Energy balance Equation in poultry house

= Heat generated by birds + Heat generated by Roof + Heat generated by Roof – Heat loss due to Ventilation - Heat loss due to evaporation

$$q_S + q_R + q_W - q_V - q_E = 0$$

Where

q_S = sensible heat produced by the birds (J/s)

q_R = Heat generated by Roof (J/s)

q_W = Heat generated by Wall (J/s)

q_V = Heat Loss due to ventilation (J/s)

q_E = Heat Loss due to Evaporation (J/s)

First two terms of the equation (q_S, q_R, and q_W) are always heat generated sources but for maintaining comfort condition inside the house this heat draw out of the poultry house. Throughout summer time, whilst the Inside temperature is lower than the outdoor temperature because of the evaporative Cooling, the air inside the building is heated via the walls and ceiling. The maximum essential loss of heat is due to air flow (qv) which needs to make sure. The good enough temperature and humidity should be within the building. Heat produced by equipment’s like electric motor, lighting system not considered in account. Heat due to beam column Truss is not also considered. Heat due to poultry birds feeding and drinking equipment are not also considered. Heat related to floor is also not considered in account. During typical hot summer conditions, bird heat represents 97 per cent of the total heat production in a broiler house. This confirms that there is little to gain by increasing house insulation above what is typically recommended since the majority of the heat is being produced by the birds. Sensible heat loss, which results in an increase in house air temperature, is the heat dissipated by birds through heat transfer to the surrounding air. Latent heat loss is the heat lost from a bird through the evaporation of moisture from its respiratory system resulting in an increase in house humidity. [10]

Heat generated by birds = Sensible heat produced by the birds (qs) = (J s-1)

Heat generated by Roof =U roof *A roof *Δt

Heat generated by Wall = U wall *A wall *Δt

Heat loss due to Ventilation = U wall *A wall *Δt

Where

Uroof = Heat transfer coefficient for the roof, W/m2*K

Aroof = Area of the roof, m2

Uwall = Heat transfer coefficient for the wall, W/m2*K

Awall = Area of the roof, m2

Sensible heat and latent produced by poultry birds an equation developed by Pederson and Thomson in his paper was used as given below [12]

q_t = 9.81 m_a 0.75(4.10-5(20-td) 3+1)

qs = 0.83 qt (0.8-1.85*10-7(td+10)4)

Where

qt = Total heat produced, J/s

qs = Sensible heat produced, J/s

ql = Latent heat produced, J/s

m_a = mass per animal, live animal kg

td = Dry bulb temperature, °C

Global heat transfer coefficient for the building materials like wall roof for thermal modeling of livestock building change in climate conditions by Cooper, K., Parsons, D. J., Demmers [13]

Global heat transfer coefficient for the roof = 1.5 W m-2 K-1

Global heat transfer coefficient for the roof = 5.5 W m-2 K-1

Consider model 1

In this model calculate the temperature difference using sensible heat produced by poultry birds, number of birds and mass per animal considering specific heat capacity and air mass flow rate as per the given equation below. Heat loss due to evaporation and heat loss due to ventilation are not considered.

ΔT_1 = qs*na*ma / m*Cp

Consider model 2

In this type of model is same as model 1 but considering heat loss due to evaporation and calculate temperature difference.

Evaporated vapour fraction into mass water flow into latent heat of the air vaporizing is computed for adiabatic evaporative cooling. By Gates et al [14]

Heat loss due to Evaporation = β*mw*hfg

Where

β – Evaporated vapour fraction

Fraction of mist evaporation =0.33 (According to Richard S. Gates and et al)

Misting flow rate mw = 0.1675kg/s (approx.90gal/h)

m_w –Mass water flow, water kg s-1

hfg – Latent heat of the air vaporizing, J kg-1, using 2.43 x 106 j kg-1

Equation to calculate temperature difference is as given below

ΔT_2 = qs*na*ma - B*mw*hfg / m*Cp

Heat loss due to Evaporation (Misting)

β* mw * hfg = ql *na *0.33

Where

β – Evaporated vapour fraction

Fraction of mist evaporation = 0.33, (β =0.33) (According to Richard S. Gates and et all, 1995)

According to relation between product of mass of water flow and latent heat of vaporizing is equal to product of latent heat produced and number of poultry birds.[15]

m_w * hfg = ql *na

Where

ql – Latent heat produced, W kg-1 of live animal mass

na – Number of poultry birds

mw – Mass water flow, water kg/s

hfg – Latent heat of the air vaporizing, J kg-1, using 2.43 x 106 j kg-1

Consider model 3

In this model consider as same as model 2 but heat loss due to ventilation by the roof and wall. Calculate the temperature difference as per the given equation.

m*Cp*(delT) = qs*na*ma +Uroof*Aroof*(delT) + Uwall*Awall*(delT)-(B*mw*hfg)- ((delT)*U*A)

Rearrange the Equation

m*Cp*(delT)-Uroof*Aroof*(delT)-Uwall*Awall*(delT)+((delT)*U*A)=qs*na*ma - (na*ql*0.33)

As we compare all three model and calculate temperature difference for dry bulb temperature of 40^o C and air mass flow rate varies from 8 to 16 Kg/s and mass of poultry bird 2.5kg of single bird number of birds are 7500.

Table 1 Comparison between air mass flow rate with model 1, model 2 and model 3 with temperature

m	Del T in Degree C		
KG/S	Model 1	Model 2	Model 3
8	-7.7	-13.1	-19.97
9	-6.9	-11.7	-16.78
10	-6.3	-10.5	-14.46
11	-5.7	-9.5	-12.71
12	-5.3	-8.7	-11.34
13	-4.9	-8.1	-10.23
14	-4.5	-7.5	-9.32
15	-4.3	-7.0	-8.56
16	-4.0	-6.6	-7.92

Where m = air mass flow rate Kg/s and

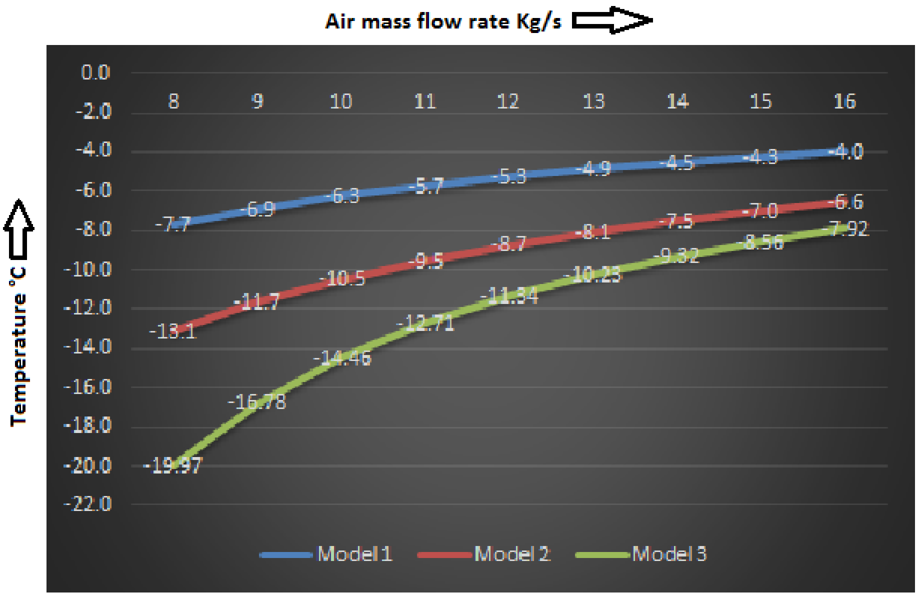

Figure 1 Comparison between air mass flow rate with model 1, model 2 and model 3 with temperature.

As per the graph plotted air mass flow rate (Kg/s) v/s temperature ^{O} C it is observed that for model three shown maximum temperature difference was observed as compare to model one and two. As comfort condition for bird as per ASAE is about 28^{O}C shows the best agreement with air mass flow rate of 12Kg/s is about -11.34 ^{O}C.

As another way considering the equation for model three and variation in dry bulb temperature for hot tropical countries varying from 31 to 45^{O}C for air mass flow rate m=10Kg/s, m=12Kg/s and m= 14Kg/s.

Table 2 Comparison between dry bulb temperatures, air mass flow rate and temperature difference.

m	dBT	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31
m=10	delT	-12.2	-14.5	-15.7	-16.0	-15.5	-14.5	-12.9	-11.0	-8.8	-6.4	-3.9	-1.4	1.1	3.6	6.1
m=12	delT	-9.6	-11.4	-12.3	-12.6	-12.2	-11.3	-10.1	-8.6	-6.9	-5.0	-3.1	-1.1	0.9	2.8	4.7
m=14	delT	-7.9	-9.4	-10.1	-10.3	-10.0	-9.3	-8.3	-7.1	-5.7	-4.1	-2.5	-0.9	0.7	2.3	3.9

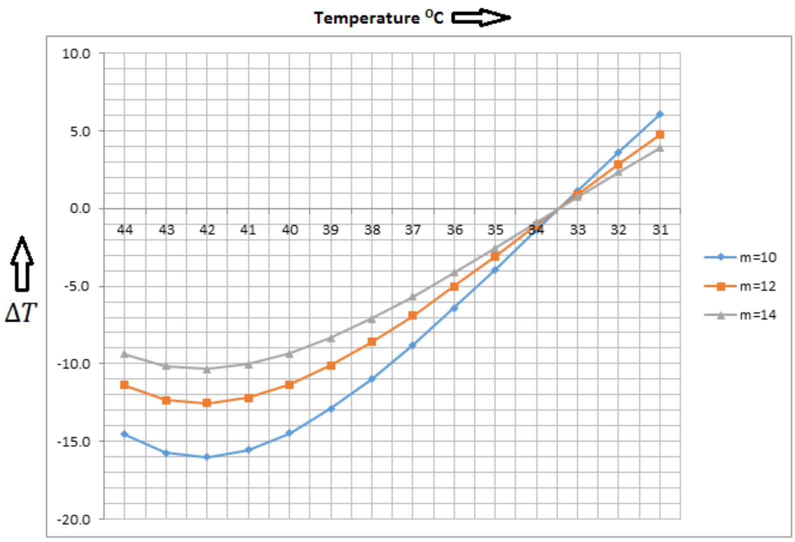

Figure 2 Comparison between dry bulb temperatures, air mass flow rate and temperature difference.

Result and Conclusions –

An effective method for determining inside temperature in poultry houses is the steady-state heat balance model. In this paper mathematical modeling of ventilation system for closed poultry house in tropical climate conditions is developed according to this to get conclude that the model is suitable for improving poultry houses with negative pressure ventilation and interior misting. This model suitable for only in hot tropical climatic conditions for temperature more than 34 ^{O}C. at that time exhaust fans was working with temperature difference between inside and outside when mass flow rate m=12.

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