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Numerical Simulation of Natural Ventilation Rates in Laying Hen Houses

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Abstract: The ventilation, which is made with help of windows, doors and other air inlets and outlets without using an air mover such as fans is called natural ventilation. Natural ventilation depends on wind force and thermal buoyancy. This study was carried out in a laying hen house in northern part of Turkey, at the coast of Black Sea. Wind velocity, air temperature and relative humidity values inside and outside the laying hen houses were measured during the hottest month for that region. A simulation program was developed for controlling the natural ventilation rates in the laying hen house then the data were verified by the developed software. The software proved that additional forced ventilation is needed for the welfare of animals in Black Sea region during the hottest month of the year.

Key words: Simulation program, natural ventilation, software, laying hen, poultry, egg

INTRODUCTION

The tremendous worldwide production of poultry (broilers, laying hens, etc.) has brought the problem of ventilation with itself since, it enables to breed and house intensively with big capacities (Dagtekin *et al*., 1999). Environmentally controlled facilities for poultry require ventilating systems to exchange air and maintain acceptable indoor environmental conditions year round. The environment factors in a poultry house are Albright (1991), ASAE (1993), Anonymous (1998), Kic and Gürdil (1999) and ASHRAE (1993):

- Air distribution and circulation
- Temperature
- Humidity
- Air composition

As in all types of animal houses a ventilation system in poultry house must: provide adequate fresh air at all times, distribute fresh air uniformly without causing drafts, regulate temperature, exhaust the respired moisture and remove odors and gases (Anonymous, 1998; Vest and Tyson, 1998).

Generally, ventilation is described as exchanging the fresh air with the respired and ambient air mixed with noxious gases by using natural and mechanical methods (TSE, 1987; Yaganoglu, 1988; ASAE, 1993). Natural ventilation is the movement of air through specified building openings by the use of natural forces produced by wind and temperature difference (Yaganoglu, 1988; Janni and Jacobson, 2003). The ventilation rate depends on the wind speed and direction, interference of nearby obstructions such as hill or buildings and the size, design and location of outlet and inlet openings. Natural ventilation is the oldest form of ventilation and has been used for as long as housing has been provided for animals. Low initial cost and low energy costs are primary factors that make it the most common type of ventilation. This type of ventilation is dependent on natural forces and consequently has numerous limitations. These include such factors as the nature of the climate, geographic area, terrain, obstructions to the wind, environmental requirements and others that must be considered in the design of a natural ventilation system and its subsequent management (Albright, 1991). Besides, factors which affect the performance of natural ventilation systems are: animal heat, production, orientation of structure, roof slop, eave openings, ridge openings, side wall openings, side wall height, insulation and other structural details. In this study, a numerical simulation program was developed for controlling the natural ventilation rates in the laying hen houses then the measurements were verified by the developed software.

MATERIALS AND METHODS

The research was carried out in a laying house in northern part of Turkey in Black Sea region. Measurements of air temperature, air relative humidity and air velocities were recorded during the hottest month for that region in order to test the adequateness of natural ventilation rates for laying hens. The measurements were done by TESTO 400 data logger then the collected data were transferred to computer.

The computer program, which was developed to determine the natural ventilation rates in laying hen houses, was done in MS Visual Basic programming language. Then the verification of the developed numerical simulation program was done.

Determination of natural ventilation rates realized by wind forces and thermal buoyancy was done by using the methods below. The methods were explained as follows.

Natural ventilation by wind forces: On a building 3 different pressure zones occur due to wind forces (Kic and Broz, 1995). These are;

- Positive pressure that pushes the outside air into the building through the air inlets
- Negative pressure that pulls the inside air from the building through air outlets
- Neutral pressure where there is no air flow between the building and the outside air

The value of the static pressure on the structure occurred by wind forces changes upon geometric shape of the structure, resistance of the cracks and openings and also the direction and the velocity of the wind. Velocity pressure effecting the structure at given wind velocity is as follows:

$$P_v = \frac{1}{2}\rho.v^2 = 0.6.v^2$$

where:

P_v = Wind pressure (Pa)

ρ = Density of air ($kg\ m^{-3}$)

v = Wind velocity ($m\ s^{-1}$)

The average wind velocity, dominant wind direction, seasonal and daily changes in velocity and direction of the wind and the obstructions (building, hill, tree, etc.) that will effect the wind are taken in consideration in predicting the effect of wind. These factors can effect on the pressure zones formed by the wind on the structure.

It's not possible to determine precisely the natural ventilation rates. Therefore, the empirical equation below is recommended in predicting ventilation rates formed by the wind forces (Albright, 1991):

$$Q = E.A.v$$

where:

Q = Ventilation rate ($m^3\ s^{-1}$)

A = Area of air inlets (m^2)

v = Wind velocity ($m\ s^{-1}$)

E = Efficiency of air openings

For the wind blowing perpendicular to air openings; E = 0.50.....0.60 and for the non-perpendicular blowing wind E = 0.25-0.35 is recommended. The wind rarely blows perpendicular to agricultural structures and for this reason (E = 0.35) is recommended for the agricultural structures (Albright, 1991).

Natural ventilation by thermal buoyancy: When the air temperature inside the building is different from the outside air temperature pressure gradients occurs between the structure and outside air depending on density difference. The inside air with low density rises upwards when the inside air is hotter than the outside air. The rise realizes with the buoyancy effect equal to mass of outside air entering into building. This is called chimney effect. The inside air rising upwards in the building is removed outside while the outside air enters into the building. The ventilation rate formed by thermal buoyancy has direct proportion with the vertical distance between the air inlets and outlets and with pressure difference. The velocity of the air, which is moved by the temperature difference of inside and outside air, is calculated by the equation below depending on ideal gas laws;

$$v = \theta\sqrt{2g\Delta h\frac{T_i - T_o}{T_i}}$$

where:

v = Air velocity at air outlet ($m\ s^{-1}$)

θ = Efficiency of air openings

Δh = Vertical distance between air inlets and air outlets (m)

T_i = Inside air temperature (K)

T_o = Outside air temperature (K)

g = Gravity ($m\ s^{-2}$)

Opening efficiency is taken into consideration due to air friction at inside surfaces of air outlet and also for the reduction in air velocity due to cooling down of the air while passing through the air outlet. Barre and Sammet have recommended (θ = 0.3....0.5) value for this factor. Similarly, 0.65 value is recommended at sharp edged orifices (ASAE, 1993), but there is no suggestion for the friction losses. For the wide air outlets with square, rectangle or circle cross section and with heat insulation at outer surface (θ = 0.6....0.7) value is recommended by many researches.

The air velocity is determined at air inlets or at outlets then this value is multiplied by opening area for the prediction of ventilation rate. However, the ventilation rate for the animal houses can be easily calculated by the energy and mass balance equations. Air inlet and outlet areas for providing the required ventilation rate can be calculated as follows:

$$\left(\frac{Q}{A}\right)^2 = \theta^2.2g\Delta h\frac{(T_i - T_o)}{T_i}$$

$$A = \left(\frac{Q}{\theta}\right)\sqrt{\frac{T_i}{2g\Delta h\,(T_i - T_o)}}$$

If air inlet area is equal to outlet area the ventilation rate is calculated by the Eq. 1. Otherwise the calculated value must be corrected according to Fig. 1.

Combined effect of wind forces and thermal buoyancy: As mentioned before the natural ventilation rate in the buildings depends on combined effect of wind forces and air temperature differences of inside and outside air. One of them can be dominant on other at some conditions. The sum of ventilation rates provided by each factor is not equal to the ventilation rate obtained by the combined effect of these factors. Although some researches reported that the combined ventilation rate of these 2 factors is equal to square root of the sum of ventilation rates of each factor, the total ventilation rate can be found from a graph (Fig. 2) (ASHRAE, 1993).

In this method, the ventilation rates depending on the 2 factors are found by the equation above. Then the proportion of the ventilation rate due to temperature differences to the ventilation rate due to wind forces is calculated and the total ventilation rate is found from the graph.

In this computer program, natural ventilation rate due to thermal buoyancy is calculated by the inside and outside air densities, which are obtained by the inside and outside air temperature and relative humidity values and concerning total static pressure balance (Gürdil *et al*., 2001).

$$M_v = \mu_i.S_i.\sqrt{2.pi.\rho_e}$$

$$p = p_i + p_o$$

$$\mu_i.S_i.\sqrt{2.(p - p_o).\rho_e} = \mu_o.S_o.\sqrt{2.p_o.\rho_i}$$

$$V_e = \frac{M_v}{\rho_e}$$

where:

M_v = Mass flow of ventilation air (kg s^{-1})
V_e = Volume flow of ventilation air (m^3 s^{-1})
μ_i = Correction factor for air inlets
μ_o = Correction factor for air outlets
S_i = Area of air inlets (m^2)
S_o = Area of air outlets (m^2)
ρ_i = Density of inside air (kg m^{-3})
ρ_e = Density of outside air (kg m^{-3})
p = Total static pressure (Pa)
p_i = Inside static pressure (Pa)
p_o = Outside static pressure (Pa)
h = Vertical distance between air inlet and outlet (m)

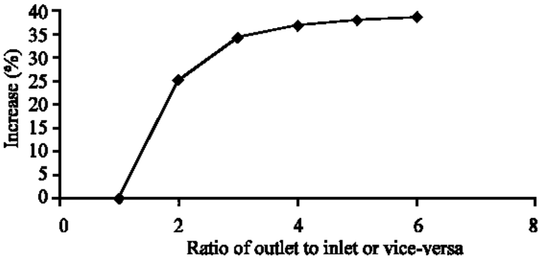


Fig. 1: Ventilation rate depending on the ratio of outlet to inlet

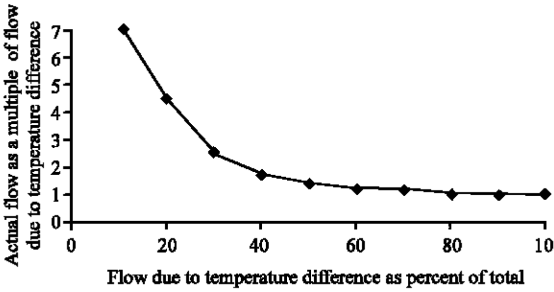


Fig. 2: Natural ventilation rate depending on combined effect of wind forces and thermal buoyancy (Albright, 1991)

Calculation of air density according to air temperature and relative humidity is given below (Wilhelm, 1976):

$$\ln(p_{ws}) = \frac{-7511.52}{T} + 89.63121 + 0.023998970T - 1.1654551\times10^{-5}T^2 - 1.2810336\times10^{-8}T^3 + 2.0998405\times10^{-11}T^4 - 12.150799\ln(T)$$

$$W = 0.62198\frac{p_w}{P - p_w}$$

$$p_w = \frac{P\times W}{0.62198 + W}$$

$$v_h = \frac{R\times T}{P}(1 + 1.6078W)$$

$$\rho = \frac{1}{v_h}$$

where:

p_{ws} = Water vapor saturation pressure (kPa)
p_w = Water vapor pressure (kPa)
W = Humidity ratio
R = Gas constant (J kg^{-1} K^{-1})
T = Temperature (K)
P = Total pressure (kPa)
v_h = Specific volume (m^3 kg^{-1})
ρ = Air density (kg m^{-3})

RESULTS AND DISCUSSION

The measurements were done in August because the August is the hottest month in that region according to the last 30 years records (Anonymous, 2008). Inside and outside air temperature and relative humidity values were recorded regularly. The measurements at air inlets were taken from both sides of the poultry house and inside the house at bird level, at 1.5 m above the ground and at air outlets. Wind velocities at air inlets and outlets were also recorded regularly. Some results of the measurements are given as graphs (Fig. 3-6). The collected data was too much thus, a summary of the results were given in the Fig. 3-6. Therefore, the numbers from 1-11 in x axis in the Fig. 3-6 represents every other day in August. Concerning

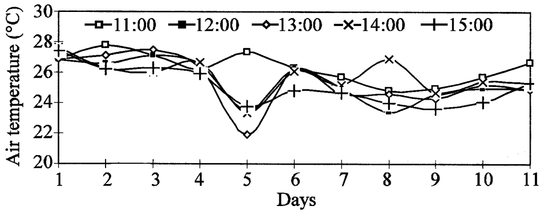


Fig. 3: Fluctuation of air temperatures at air inlet

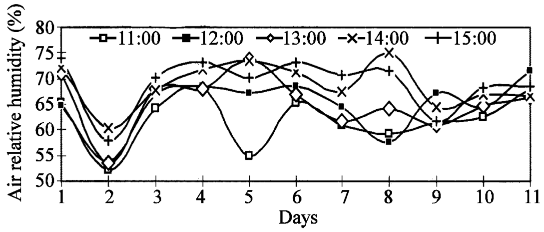


Fig. 4: Fluctuation of air relative humidities at air inlet

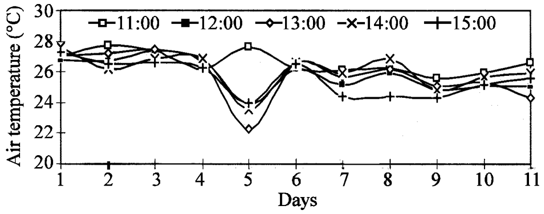


Fig. 5: Fluctuation of air temperatures at air outlet

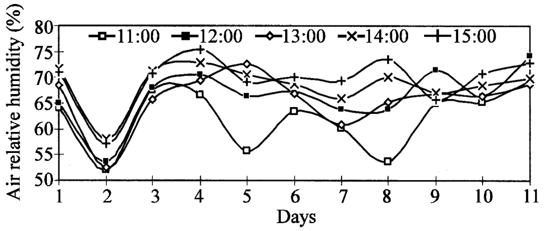


Fig. 6: Fluctuation of air relative humidities values at air outlet

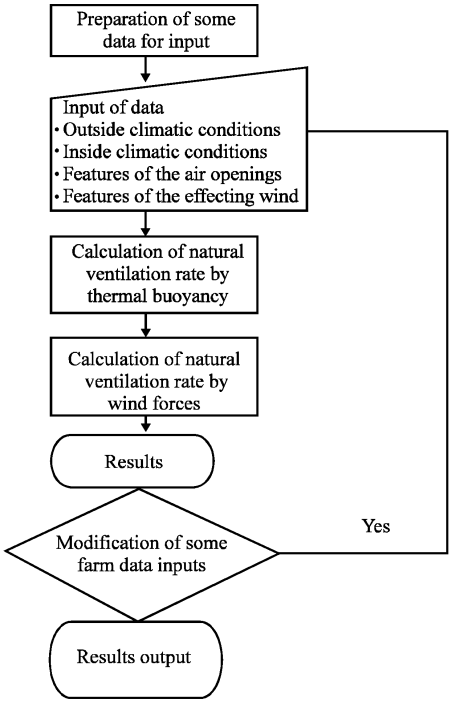
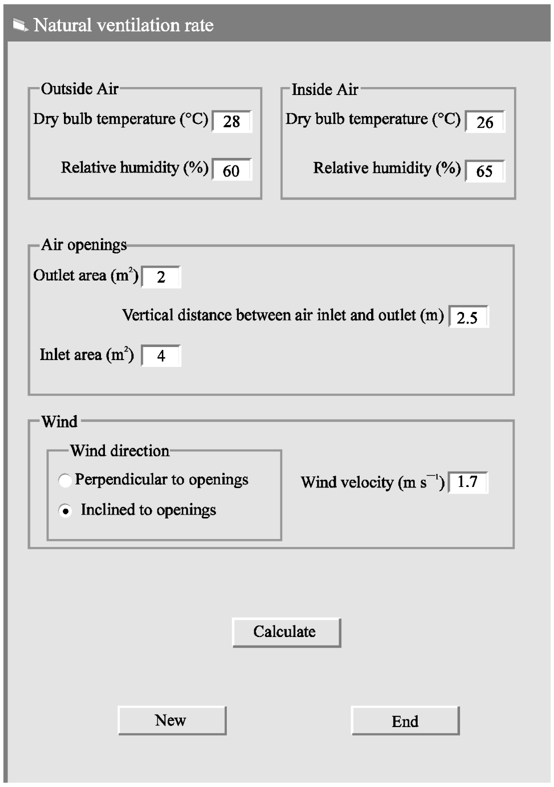


Fig. 7: Algorithm of the program


Natural ventilation rate

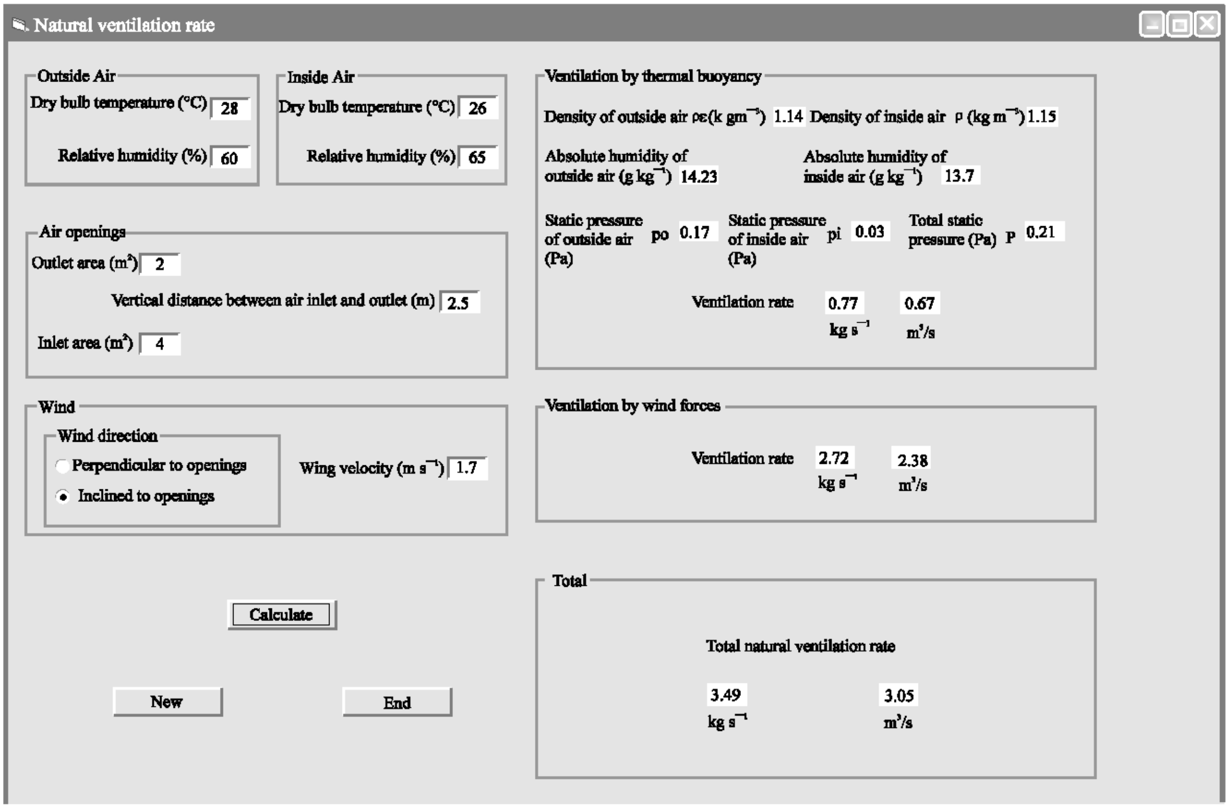
Outside Air
Dry bulb temperature (°C) 28
Relative humidity (%) 60

Inside Air
Dry bulb temperature (°C) 26
Relative humidity (%) 65

Air openings
Outlet area (m^2) 2
Vertical distance between air inlet and outlet (m) 2.5
Inlet area (m^2) 4

Wind
Wind direction
○ Perpendicular to openings
● Inclined to openings
Wind velocity (m s^{-1}) 1.7

Fig. 8: Defining the conditions



Outside Air
Dry bulb temperature (°C) 28
Relative humidity (%) 60

Inside Air
Dry bulb temperature (°C) 26
Relative humidity (%) 65

Air openings
Outlet area (m^2) 2
Vertical distance between air inlet and outlet (m) 2.5
Inlet area (m^2) 4

Wind
Wind direction
○ Perpendicular to openings
● Inclined to openings
Wing velocity ($m\ s^{-1}$) 1.7

Ventilation by thermal buoyancy
Density of outside air ρε($k\ gm^{-3}$) 1.14 Density of inside air ρ ($kg\ m^{-3}$) 1.15
Absolute humidity of outside air ($g\ kg^{-1}$) 14.23
Absolute humidity of inside air ($g\ kg^{-1}$) 13.7
Static pressure of outside air (Pa) po 0.17
Static pressure of inside air (Pa) pi 0.03
Total static pressure (Pa) P 0.21
Ventilation rate 0.77 $kg\ s^{-1}$ 0.67 m^3/s

Ventilation by wind forces
Ventilation rate 2.72 $kg\ s^{-1}$ 2.38 m^3/s

Total
Total natural ventilation rate
3.49 $kg\ s^{-1}$ 3.05 m^3/s

Fig. 9: Numerical simulation of natural ventilation rates in the laying hen house

the adequateness of actual natural ventilation rates the data is given just for the hottest period of the day, that is from 11 am to 15 pm.

Numerical simulation of natural ventilation rates in the laying hen house was done by the developed computer program. The software is developed by MS Visual Basic 6.0 programming language. Algorithm of the program is given in Fig. 7.

According to the results, it's seen that the laying hens were exposed to higher relative humidity values and lower air velocities in the afternoon section. Thus, supplemental ventilation or cooling is needed in this time period of the day. Since, the relative humidity values were high enough for the laying hens, it wouldn't be suitable to use evaporative cooling system in the poultry house. Only ventilating the poultry house with high air velocities (2 m s^{-1}) is recommended when the air relative humidity exceeds 75%.

The verification of the developed software was done by the collected data. The outside and inside air conditions, features of the air openings and features of the blowing wind effecting the laying hen house are defined (Fig. 8). Then the program calculates the natural ventilation rates by thermal buoyancy, by wind forces and the total natural ventilation rate occurred in the laying hen house (Fig. 9).

CONCLUSION

The verification of the developed software was done by the collected data. This software proved that the realized natural ventilation rates for the hottest month (August) of the region and for the hottest period of the day (11am-15pm) were not enough for the laying hens thus, it's advised that an additional forced ventilation is needed for the welfare of the animals.

The aim of this program is to give practical solutions to engineers, designers and farmers in the design and operation of the animal house. This program can also be used for the automation of the laying hen house when it's combined with the appropriate sensors.

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