The Effects of Natural Ventilation Air Exchange on Psychrometric Results in Poultry Houses in Hot Environment---Design Characteristics

S. Mutaf [1], S.Alkan[1], N.Seber[1]

[1]Akdeniz University, Faculty of Agriculture, Department of Animal Science
07059, Antalya / TURKEY
E-mail: smutaf@akdeniz.edu.tr

ABSTRACT

The present study was carried out in order to investigate the effect of summer and winter natural ventilation air exchange on psychrometric results in closed and open type poultry houses and the possibility of increasing its efficiency.

This research had been conducted in three poultry houses located at different altitude that had different dimensions, construction and insulation levels. Inside and outside air temperature and relative humidity measured by sensors and averages were calculated for 2 hourly periods in 24 hours in summer and winter season.

The data obtained from the experiments indicated a significant relationship between the efficiency of ventilation and structural dimensions. The necessary summer ventilation rate was calculated as 4.5 m^3 h^{-1} kg^{-1} body mass and the inside and outside dry-bulb temperature difference was accepted as 2 ^oC.

The natural ventilation design characteristics and structural dimensions necessary to increase the efficiency of natural ventilation system in poultry houses should be with the roof slope not less then 20^o–30^o , the ridge provided with continuous capped ventilation opening, the proportion of the effective outlet area to effective inlet area (A_2/A_1) at least 1/2 or 1/3, the ridge height of the building not less then 4-5 m and the building width not exceed 12 meters.

Key Words: Poultry house, Hot environment, Natural ventilation, Design characteristics Psychrometric results

INTRODUCTION

Thermal environmentally controlled facilities for poultry houses require ventilating systems to exchange air and maintain acceptable indoor thermal conditions all year-round. In a poultry building, moisture and heat produced by the birds themselves are always available to raise the air temperature and moisture above that of the external air. The warmed and moisturized air must be replaced with cooler and dryer outside fresh air. The capacity of air to absorb heat and moisture depends on its psychrometric conditions (Janni and Jacobson, 1995).

The present study was carried out to investigate the effects of natural ventilation air exchange on psychrometric results in poultry houses and the possibility of increasing its efficiency.

MATERIALS AND METHODS

Experimental Equipment and Procedures

This research had been conducted in three poultry houses located at different altitudes that had different dimensions, construction and insulation levels. One of the three poultry houses was closed type with windows; the other two were open type with curtains (Table 1 and Figure 1).

Table 1. The characteristics of poultry houses

House No	House Type	Ventilation Type	Roof slope (∡ °)	k* value ($w\ m^{-2}\ \mathbf{K}^{-1}$) (End–side walls)	(Roof)	(Window)	(Curtain)
1	Close (sea level)	Natural	21.00	1.19	0.58	5.20	-
2	Open (sea level)	Natural	8.50	1.61	1.08	-	5.74
3	Open (high altitude)	Natural	14.00	1.61	0.72	-	5.74

* k: thermal transmittance

Inside and outside air temperature and relative humidity measured by temperature and humidity sensors. Measurements were generally made at 15-minute intervals changing among the poultry houses from time to time and averages were calculated for 2 hourly periods in 24 hours in summer and in winter season. The outside air temperature and relative humidity were measured through shielded stations. Then the calculated averages of data were used for evaluations.

Calculation of Effective Air Outlet-Inlet Areas and Stack Height

The temperature difference between inside and outside induces air movement due to buoyancy and known as the stack effect. Ventilation capacity by stack effect can be calculated by the following equation (Bruce, 1973):

$$V_2 = 0.0382\ A_2^{2/3} \times (Q_{HsBs}\ H_2)^{1/3} \qquad (1)$$

Effective outlet area can be solved from equation (1) and we got:

$$A_2 = 134\ V_2^{3/2} \times (1/\ Q_{HsBs})^{1/2} \times (1/\ H_2)^{½} \qquad (2)$$

Where effective stack height was taken from (Andersen, 1982):

$$H_2 = \{1/\ [1+ (A_2\ /\ A_1)^2]\} \times H_1 \qquad (3)$$

Where, $\mathbf{V_2}$ is ventilation capacity ($m^3\ s^{-1}\ kg^{-1}$ body mass), $\mathbf{A_2}$ is effective outlet area ($m^2\ kg^{-1}$ body mass), (Q_{HsBs} is $Q_{Hs} + Q_{Bs}$), $\mathbf{Q_{Hs}}$ is sensible heat production of chicken ($W\ kg^{-1}$ body mass), $\mathbf{Q_{Bs}}$ is sensible heat gain or loss through the structure elements ($W\ kg^{-1}$ body mass), $\mathbf{H_2}$ is effective stack height (m), $\mathbf{A_1}$ is effective inlet area ($m^2\ kg^{-1}$ body mass), $\mathbf{H_1}$ is distance between the center of the inlet area and the upper edge of the stack (m).

Some Psychrometric Fundamentals

Psychrometrics is the study of the physical and thermal properties of dry air and water vapour mixture.

Evaporative cooling is essentially an adiabatic saturation process. It follows upward of a constant wet-bulb temperature line. Sensible heat is converted to the latent heat in the added vapour. This is indicated by a negative ratio: (h_{si} - h_{so} / $h_{ti} – h_{to}$). The sensible heat of the initial air evaporates the water, lowering the air dry-bulb temperature.

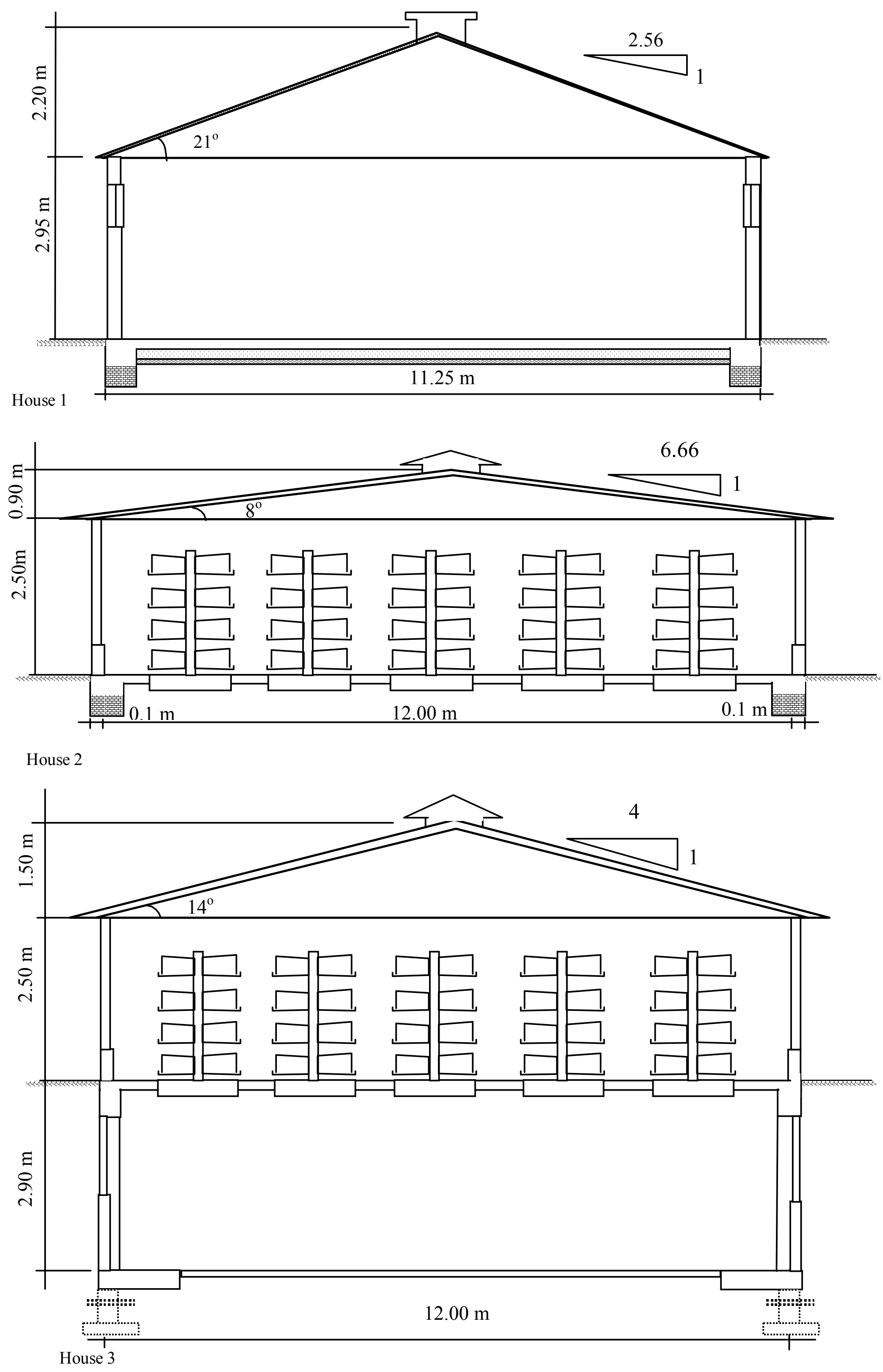

Figure 1. Dimensions of poultry buildings

Heating and humidifying of ventilating air occur as it moves through the poultry buildings. Poultry produce heat and water vapour, which added to the incoming ventilating air. A positive ratio of the difference between inside and outside sensible heat to the difference of the total heat (h_{si}-h_{so}/h_{ti}-h_{to}), indicates that the percentage of the heat from the ratio was absorbed as sensible heat. Where, $\mathbf{h_{si}}$ is sensible heat of the inside air (kJ kg^{-1} dry air), $\mathbf{h_{so}}$ is sensible heat of the outside air (kJ kg^{-1} dry air), $\mathbf{h_{ti}}$ is total heat of the inside air (kJ kg^{-1} dry air), $\mathbf{h_{to}}$ is total heat of the outside air (kJ kg^{-1} dry air). In this case, inside dry-bulb temperature will be higher than outside temperature.

Ventilation Rate

Necessary air flow rate in the poultry houses were calculated by following equation:

$$V_{Hs} = [(Q_{Hs} \pm Q_{Bs}) - (X_{floor} \text{ x } 680)] / (Cp \text{ x } \rho_i \text{ x } \Delta t) \quad (4)$$

$$X_{floor} = \beta \text{ x } A_{mfa} \text{ x } \Delta P_{H2O} \text{ (Caenegem and Wecsler, 2000)} \quad (5)$$

Where, $\mathbf{V_{Hs}}$ is summer condition ventilation rate (m^3 h^{-1} kg^{-1} body mass), $\mathbf{Q_{Hs}}$ is sensible heat production of chicken (W kg^{-1} body mass), $\mathbf{Q_{Bs}}$ is sensible heat gain or loss through structure elements (W kg^{-1} body mass), $\mathbf{X_{floor}}$ is quantity of water evaporated on the floor (kg_{H2O} $h^{-1}kg^{-1}$body mass), **680** is evaporation heat of water (Wh/kg), $\mathbf{C_p}$ is specific heat of air (Wh $kg^{-1}K^{-1}$), ρ_i is density of air (kg/m^3), $\Delta \mathbf{t}$ is temperature difference between inside and outside (^oC), $\beta \approx 7{,}15\ 10^{-5}$ (kg $m^{-2}h^{-1}Pa^{-1}$) at the altitude 300-500m., $\mathbf{A_{mfa}}$ is wet floor area (m^2), $\Delta \mathbf{P_{H2O}}$, is vapour pressure difference between air and wet floor(Pa).

The average differences between inside and outside dry-bulb air temperature were accepted as 2^o C in calculation of necessary ventilation rate in the poultry houses of the tropic days ($to \geq 30^o$ C) (Mutaf et al., 1989; Mutaf, 1990).

RESULTS AND DISCUSSION

Psychrometric Results

The effects of summer and winter natural ventilation air exchange on psychrometric conditions were summarized in figures 2, 3, 4, 5 and 6.

In summer, the dry-bulb temperature differences between inside and outside were between 1 – 3 ^oC, in general inside dry-bulb temperature of the poultry buildings were found lower than outside dry-bulb temperature between 10:00 a.m. and 6:00 p.m., but it was higher than outside dry-bulb temperature of other times (figures 2, 3, 4). So, evaporative cooling was observed between 10:00 a.m. and 6:00 p.m. that it takes sensible heat to evaporate liquid water. When the dry-bulb temperature difference between inside and outside is much smaller there is much less of an increase in the air's moisture capacity.

A negative ratio (hsi – h_{so} / h_{ti} – h_{to}) indicates that sensible heat was converted to latent heat. In this case, inside dry-bulb temperature was lower than outside dry-bulb temperature. During the evaporative cooling process the air's dry-bulb temperature decreased approximately 1-2 ^oC and humidity ratio increased.

The potential amount of cooling depends on the difference between the dry-bulb and wet-bulb temperatures. Evaporative cooling adds moisture to the air, and increases the air's humidity ratio and relative humidity. Evaporative cooling capacity of the inside air is limited when the outdoor air's relative humidity is very high. The greater difference between the dry-bulb and wet-bulb temperatures, the greater the potential cooling.

In warm air, moisture control in poultry building is fairly easy to accomplish because of the large moisture holding capacity of the warm air. But, heat stress of hot and humid air can be a big problem, because the birds have a difficulty getting rid of their body heat.

The air's high water content does not allow the birds to remove much heat by evaporation in their respiratory system. If the outdoor air is warm and moist, it is even harder to maintain an acceptable litter moisture conditions.

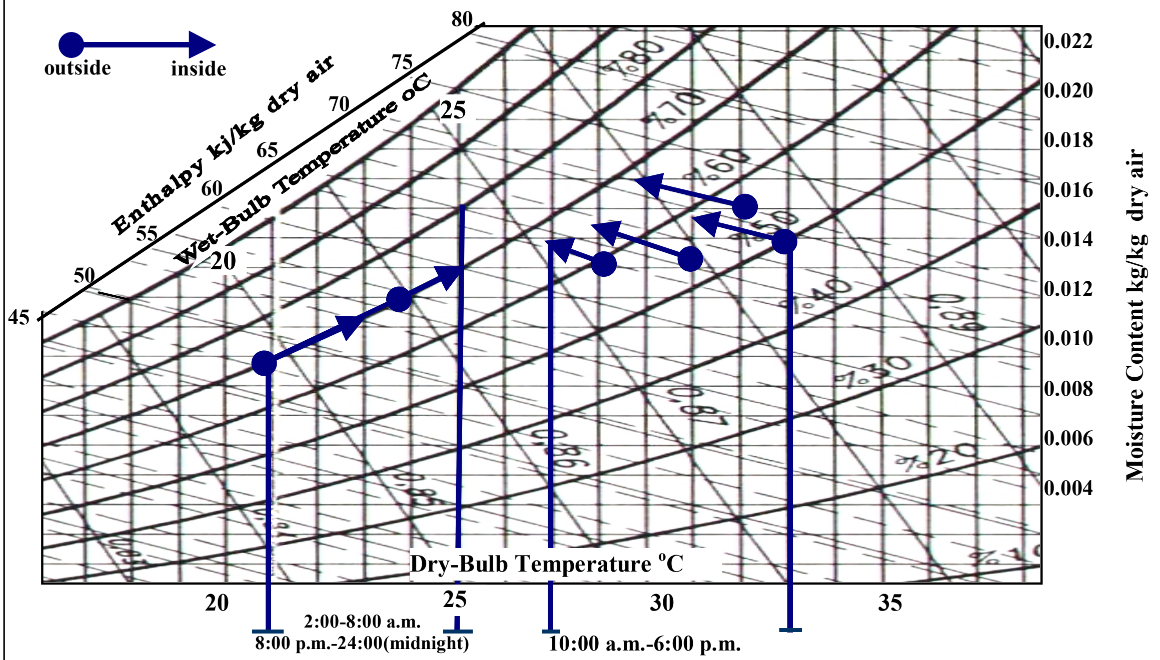

Figure2. Psychrometric changes in **house 1** for 24 hourly period in summer

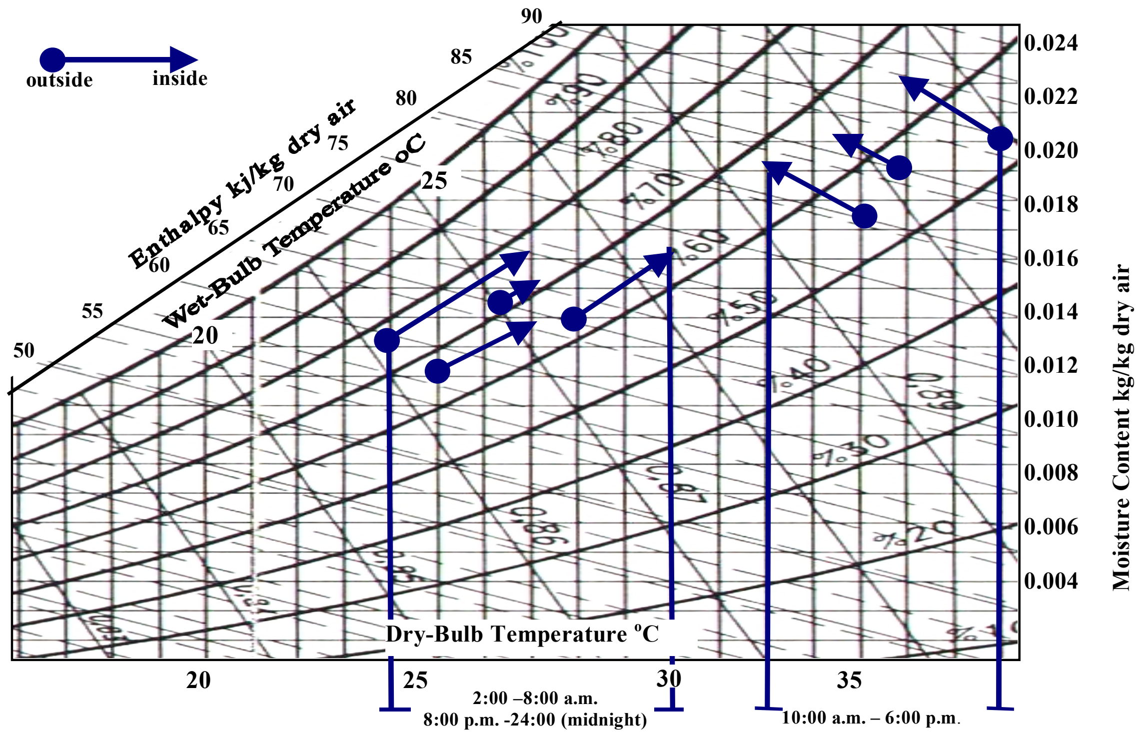

Figure 3. Psychrometric changes in **house 2** for 24 hourly period in summer season

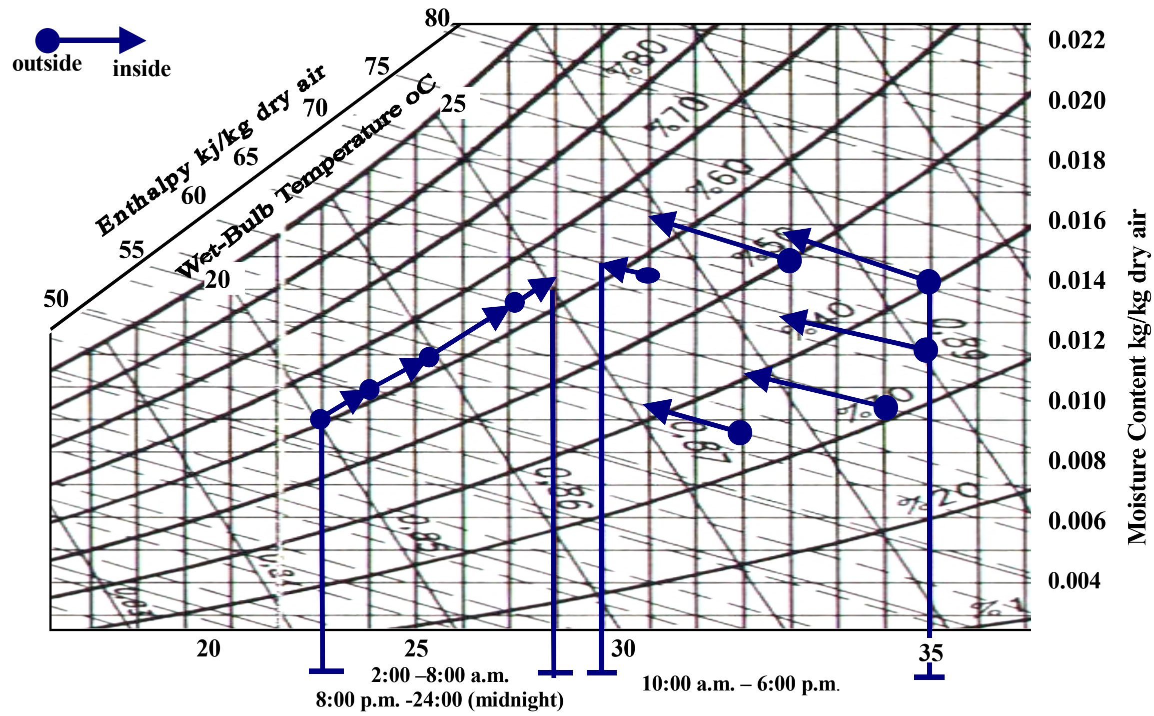

Figure 4. Psychrometric changes in **house3** for 24 hourly period in summer season

Heating and humidifying of the ventilating air was observed at other times then 10:00 a.m. and 6:00 p.m. as it moves through the buildings. A positive ratio ($h_{si} - h_{so}$ / $h_{ti} - h_{to}$) means that the percentage value some of the heat was absorbed as sensible heat. In this case, inside dry-bulb temperature was higher than that of outside temperature (figures 2, 3, 4). The change in the air's enthalpy content occurs due to the change of sensible heat because of temperature rise, and latent heat change is due to the absorption of water vapour.

In winter, the difference between inside and outside dry-bulb temperatures were found between 2 and 18^{o}C, and inside dry-bulb temperature of the poultry building were observed higher than outside dry-bulb temperature, as shown in figures 5, 6. The outdoor air dry-bulb temperature were observed between 3 and 13^{o}C in general between 10:00 a.m. and 6:00 p.m., and between – 4^{o}C and + 9^{o}C at other times. Inside dry-bulb temperature of the poultry buildings were found between 12 and 15^{o}C daily (24 h).

It was observed that heating and humidifying of ventilating air occur as the air moves through building in winter. Through ventilation, cold or cool outdoor air is brought into the poultry house. Sensible heat from the birds or solar heat gain are transferred to the cool air and it gets warm. This warm air is exhausted from the building and replaced again with cooler outdoor air. This process is repeated perpetually.

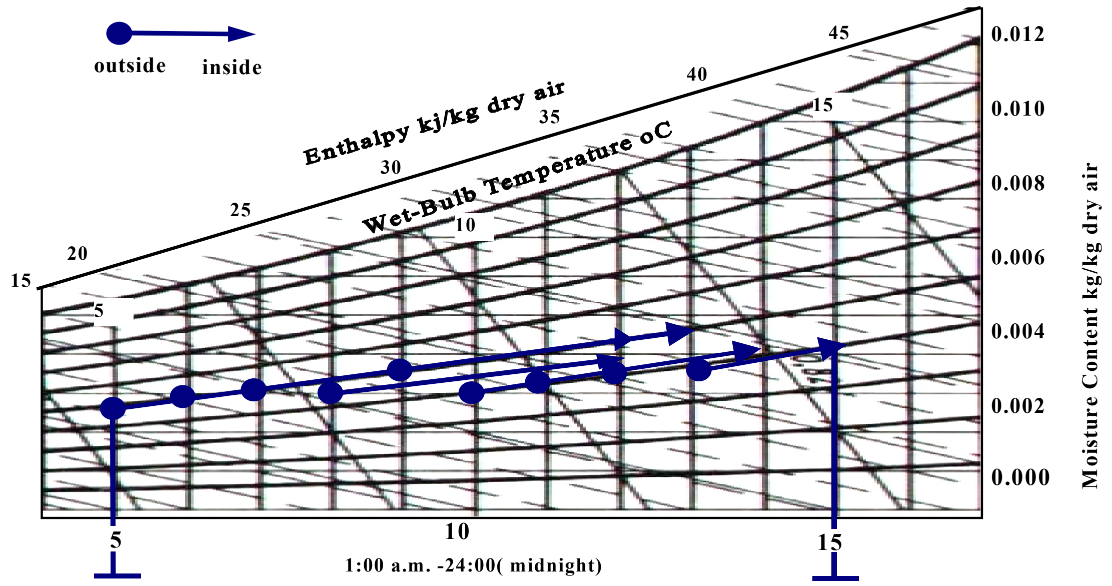

Figure 5. Psychrometric changes in **house 2** for 24 hourly period in winter

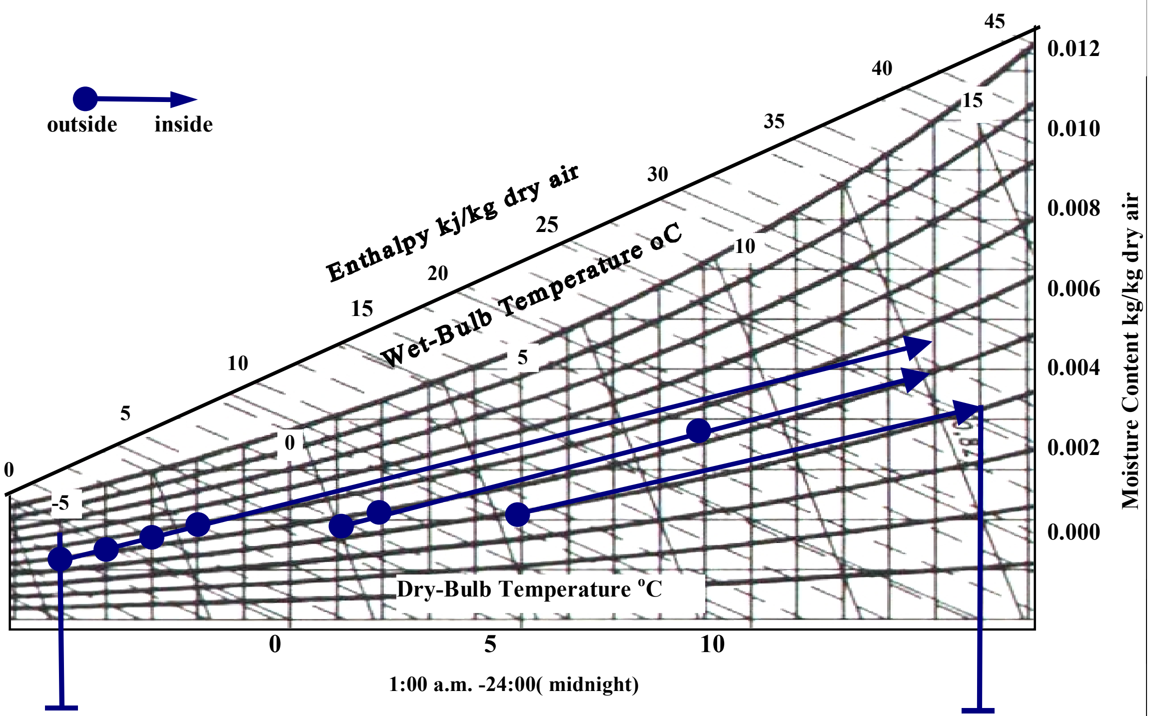

Figure 6. Psychrometric changes in **house 3** for 24 hourly period in winter

Necessary Ventilation Rate

Dry-bulb temperatures in poultry houses were measured at daytime between 29 **and** 38^{o}C, most of them were between 30 **and** 33^{o}C in summer season. But daily dry-bulb temperatures (24h) were between –4 ^{o} C and 13^{o}C in winter.

The sensible heat of the chickens was calculated as difference between total heat and latent heat modified by (CIGR, 1984; Caenegem and Wechsler, 2000; Pedersen and Tomsen, 2000; CIGR, 2002) which were calculated by the following equation:

$$Q_{Hs\,(30\,^oC)} = Q_{Ht}\,[0.64\,(1+ 0.02\,(20 - t)) - (2.4 \times 10^{-4} \times t^2)] \quad (6)$$

Where, $\mathbf{Q_{Hs}}$ is sensible heat production at 30^o C (W), $\mathbf{Q_{Ht}}$ is total heat production at 20^{o}C (W), **t** is dry-bulb temperature of air (^{o}C).

The sensible heat production of 2 kg chickens **(Q_{Hs})** was calculated 1.88 W kg^{-1} body mass at 30^{o}C dry-bulb air temperatures according to the equation 6. The sensible heat load **(Q_{Bs})** from structure elements by conduction and radiation of insulated poultry buildings are about 65-68 % of the sensible heat, which produced by chickens **(Q_{Hs})** between 10:00 am. - 6:00 pm.(Mutaf, 1980). The dry-bulb temperature difference was accepted as 2^{o}C in summer season. The necessary summer airflow rate (V_{Hs}) was calculated according to the equation 4 as **{V_{HS} = [1.88+(1.88x0.65)-(6.4x10^{-4}x680)] : (0.28x1.061x2)}** 4.5 m^3 h^{-1} kg^{-1} body mass.

Effective Outlet Area

For 30^o C dry-bulb air temperature in poultry buildings when V_{Hs} = 4.5 m^3 h^{-1} kg^{-1} body mass and Q_{HsBsXf} **{Q_{Hs} + Q_{Bs} – (X_{floor} x 680) = [1.88+(1.88x0.65)-(6.4x10^{-4} x 680)]}** 2.67 W kg^{-1}body mass were calculated, we got effective outlet area from equation 2:

$$A_2 = 134\,(4.5 / 3600)^{3/2}(1/ 2.67)^{1/2}(1/ H_2)^{1/2} = 3.6\times10^{-3}\,(1/H_2)^{1/2} \quad (7)$$

Where, $\mathbf{A_2}$ is effective outlet area (m^2 kg^{-1} body mass), $\mathbf{H_2}$ is effective stack height (m)

Geometrical Outlet and Inlet Areas

Geometrical outlet and inlet areas were calculated as following equations:

$$A_{2g} = A_2 / C_2;\ A_{1g} = A_1 / C_1 \quad (8)$$

Where, $\mathbf{A_{2g}}$, $\mathbf{A_{1g}}$ are geometrical outlet and inlet areas (m^2 kg^{-1} body mass), $\mathbf{C_2}$, $\mathbf{C_1}$ are construction coefficient outlet and inlet areas (**C_2= 0.82, C_1= 0.65**, Andersen, 1982)

When necessary geometrical outlet area for summer season is inserted in equation 7 and C_2 is used as 0.82, we got:

$$A_{2g} = (3.6\times10^{-3} / 0.82) \times (1 / H_2)^{1/2} = 4.39\times10^{-3}\,(1 / H_2)^{1/2} \quad (9)$$

When the necessary geometrical outlet area was calculated, the necessary geometrical inlet area was found from following equation:

$$A_{1g} = [(A_1 / A_2)(C_2 / C_1)]\,A_{2g} \quad (10)$$

Necessary geometrical outlet and inlet area per running meter of building was:

$$A_{2g} = 4.39\times10^{-3} \times B \times sd \times (1 / H_2)^{1/2} \quad (11)$$

$$A_{1g} = \{[(A_1 / A_2) \times (C_2 / C_1)] \times A_{2g}\} / 2 \quad (12)$$

Where, $\mathbf{A_{2g}}$ is geometrical outlet area for each meter of building (m^2 m^{-1} building length), $\mathbf{A_{1g}}$ is geometrical inlet area for each meter of side wall (m^2 m^{-1} building length), **B** is building width (m), **sd** is stock density (kg body mass m^{-2} floor area).

The necessary geometrical summer outlet areas in different stack height and roof slope were summarized in Table 1. The stack height were based on the following values, which were:

$$a_1 = 0.9 \text{ m}, \quad a_2 = 0.3 \text{ m}, \quad \alpha = 20^o \text{ and } 30^o$$

$$B = 12 \text{ m}, \ A_2/A_1 = 1/1, 1/2, 1/3, \ sd = 20 - 38 \ \text{kg/m}^2 \ (\text{Figure 7})$$

Table 2. Necessary geometrical summer outlet opening areas at natural ventilation

Ratio (A_2/A_1)	Roof slope (∡ °)	Effective stack height (H_2, m)	Geometric area A_{2g} (m^2m^{-1} building length)	Roof slope (∡ °)	Effective stack height (H_2, m)	Geometric area A_{2g} (m^2m^{-1} building length)
1/1	20	1.69	0.81	30	2.33	0.69
1/2	20	2.70	0.64	30	3.73	0.55
1/3	20	3.04	0.60	30	4.19	0.51
1/5	20	3.24	0.59	30	4.47	0.50

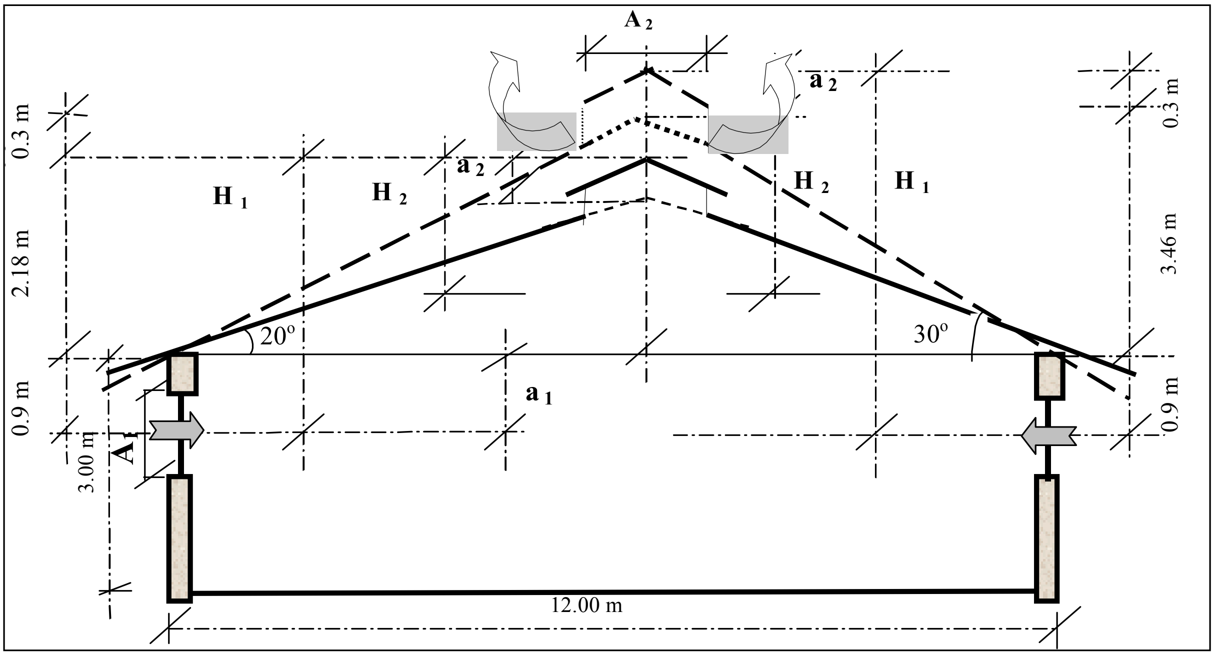

Figure 7. Dimensioning at natural ventilation

As can be seen in Table 2 and figure 7, with increasing roof slope from 20° to 30° effective stack height (H_2) increases approximately 27-28 % and necessary geometrical outlet opening areas decreases at 14-15 % level. Meanwhile necessary geometrical outlet opening areas also changes with the ratios of the effective outlet area to effective inlet areas (A_2/A_1). The decreases of necessary geometrical outlet opening areas were calculated as 20-21%, 25-26% and 27-28% with the changes in the proportion of areas (A_2/A_1) from 1/1 to 1/2, 1/1 to 1/3 and 1/1 to 1/5, respectively.

CONCLUSION

As it can be seen in the article, it is possible in theory, to maintain acceptable indoor thermal conditions year-round to ventilate existing poultry houses by means of natural ventilation with a reasonable air outlet opening areas, and besides a reasonably inlet opening areas in the walls, even when the stock density are as optimal as those in poultry buildings.

These results are effectual only in calm weather. The ventilation capacity increases due to cross-flow ventilation; during wind blow and especially in winter this may cause some control problems but wind deflectors on both sides of the ridge can help. However, the atmospheric conditions such as wind velocity and wind directions have a direct influence on the stable climate (Brehme and Krause, 2002).

According to the present results in accordance with the previous study (Mutaf, 1988) the natural ventilation design characteristics and structural dimensions necessary to increase the efficiency of natural ventilation system in poultry houses are:

- the roof slope which should not be less than 20-30^o,
- the ridge which should be provided with continuous capped ventilation opening,
- side wall openings which is recomended to comprise at least 40-50% of the long side wall areas,
- the proportion of the effective outlet area to effective inlet area (A_2/A_1) which should be at least 1/2 or 1/3, depending on the ratio C_1/C_2.
- side wall height of the building should not be less than 2.75-3.00 m,
- the building width which should not exceed 12 meters for the natural ventilation and sufficent inside air circulation.

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