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Estimating Fuel Savings by Ceiling Fan Operation

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Issue of Temperature Stratification in Broiler Housing

Air temperature in a heated building is usually higher near the roof than that near the floor. Under steady-state heating conditions, convection causes stratification of the temperature within the building and a vertical temperature gradient can be assumed in many heated buildings, including broiler housing.

Earlier studies reported the magnitude of vertical temperature stratification without ceiling fans, and the benefits in fuel savings as a result of ceiling fan operations. In a study involving eight curtain-sided broiler houses on various farms, Bottcher et al. (1988) found temperature stratification from ceiling to floor were as high as 15 °F. They also found that stratification in dropped ceiling houses was not substantially different from houses with open trusses. Adding ceiling fans reduced floor-to-ceiling temperature rise by as much as 27.4 °F when a house was not ventilated for five hours. Flood et al. (1998) found an overall 11% lower gas consumption and 5.5% higher electricity consumption in a trial conducted over 6 flocks in two curtain-sidewall commercial scale houses.

Why Ceiling Fans Could Save Energy

Heat is lost from a broiler house by conduction and convection through the ceiling and walls, and by warm air exhausted through the ventilation fans. By decreasing the air temperature near the ceiling, conceptually two portions of the heat loss can be reduced. First, the conduction and convection heat loss from building envelop is reduced due to a smaller temperature difference (ΔT) between inside temperature close to the ceiling and ambient temperature. Secondly, heat exhausted through ventilation and leakage is replaced for every minute when the exhaust fans are operating. Less heating energy is wasted if the temperature at the upper part of the building is equal to the desired temperature at floor level. In another word, a surplus of heat is required when large temperature stratification exists. The extra heat loss is positively correlated with the degree of vertical temperature stratification and the ventilation rates.

A simple theoretical model developed by Teitel and Tanny (1996) calculated the energy needed to supply a surplus of heat to reach a desired temperature at floor level in a stratified heated building. The results showed that the heating energy increases with the initial vertical temperature gradient in the heated enclosure and with the enclosure height (Figure 1). The results of this surplus heating model can be adopted in the calculation to predict the amount of fuel savings of a broiler farm after installing a group of ceiling fans.

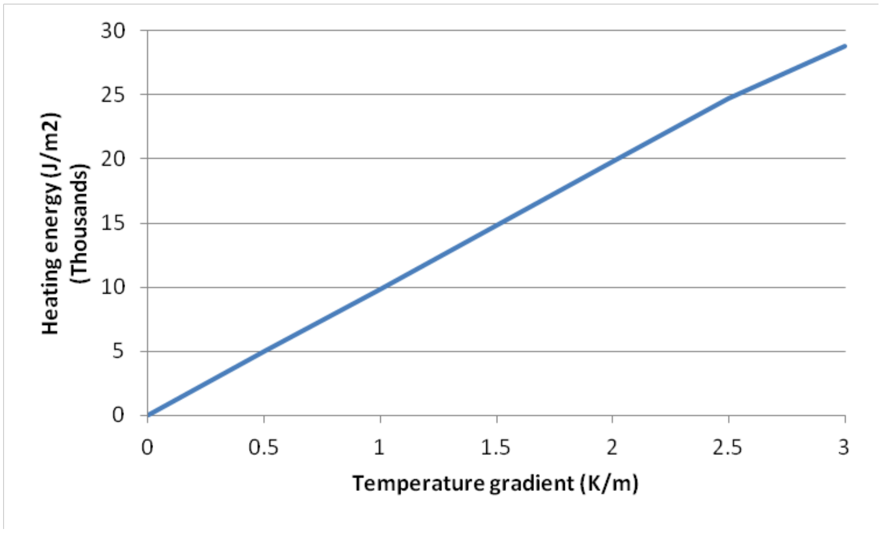

Figure 1. Energy requirements as a function of the initial temperature gradient with ceiling height of 4 m (13 ft) (reproduced from Teitel and Tanny, 1996)

Temperature stratification occurs when temperature differences cause sufficient air density differences to generate air movement by natural convection (Gebhart, 1971). Temperature stratification can be reduced with forced air mixing when the inertial forces of the mixing air are sufficient to overcome the buoyant forces driving convection. Thus, factors that directly influence temperature stratification in broiler houses are the areas and temperatures of the surfaces inside the house, house tightness, ventilation rates, interior air velocities, outside air temperature (T_o), air viscosity and geometric parameters (building dimension, heater positions, heater type, etc.) (Bottcher et al., 1988).

How to Estimate the Energy Savings

The initial temperature gradient of a specific house is generally unknown. Bottcher et al. (1988) recorded temperature gradient of 1.0 to 1.6 °F/ft for the three peaked-roof (open truss) houses, and 1.0 to 1.3 °F/ft for the three dropped ceiling houses, with pancake brooders at height of 2.5 ft and flock ages ranging between 7 and 28 days. Recently attempts were made to investigate temperature gradient in two relatively well insulated houses with radiant type brooders at 5.5 ft height at the Applied Broiler Research Farm of The University of Arkansas. Recorded temperature gradient ranged from 1.3 to 1.5 °F/ft.

The following equations can be used to predict the extra energy spent prior to ceiling fans' operation. Extra conductive heat loss through roof area (qc, Btu/hr) and surplus heat lost through air exchange (qv, Btu/hr) are calculated by equations (1) and (2), respectively.

$$qc = \frac{Ar}{R} * (Tc - Tt) \qquad (1)$$

Where A_r= Roof area, equivalent to floor area except for brooding period, m^2 (ft^2)

R = R-value of roof or ceiling insulation, m^2 K• hr/W (ft^2 F• hr/Btu)

T_c = Temperature at the ceiling, °C (°F)

T_t = Set-point temperature (target) inside the house, and assumed to be the target temperature near the floor where temperature sensors are located; $T_c - T_t$ is the vertical temperature stratification .

$$qv = q'v * Af * ACH = qv * Af * (\frac{VR}{V}) \qquad (2)$$

Where q'_v = the amount of energy needed to heat up the stratified air to reach a target temperature near the floor, J/m^2 (Btu/ft^2)

A_f = Floor area, m^2 (ft^2)

ACH = air change rate per hour, 1/hr

VR = ventilation rates, m^3/hr (cfm)

V = volume of the house, m^3 (ft^3)

The above heat loss can be calculated weekly for the first three weeks of a flock. As bird grow, set-point temperature and ventilation rates continuously change, so does heater operation and the extent of T stratification.

Energy saving is calculated by converting the sum of the two heat loss components to the quantity of propane gas. In order to predict the amount of fuel savings of a broiler farm after installing ceiling fans, the following assumptions are needed to conduct the calculation.

- Minimum ventilation rates were based on moisture removal, not ammonia removal (ammonia removal requires much higher ventilation)
- Temperature stratification (T_c-T_t) is the average value reported in the literature, or measured during a farm visit
- The heating value of propane gas is 92,000 Btu/gallon

Implications and Discussion

Knowledge of building tightness is important in determining the magnitude of potential energy saving when ceiling fans are operated. Proper managed sidewall ventilation inlets in a tighter house allow a natural air mixing when minimum ventilation fans operate on timer, leading to relatively smaller temperature stratification. This situation could lead to less benefit from ceiling fan operation.

This study also emphasizes the effect of minimum ventilation management on energy consumption. Proper managed sidewall ventilation inlets based on the existing tightness of the building would allow fresh air entering the building at the speed that promotes natural mixing. This could be part of the reasons of observed differences of temperature stratification in buildings without ceiling fans.

Reference

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