IMPROVING VENTILATION IN OPEN-TYPE POULTRY HOUSING[1]

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Introduction

Today, poultry is essentially all grown within some type of structure. Generally, the housing styles are either open type, curtain sided housing or totally enclosed housing. Enclosed housing has the obvious disadvantage of requiring mechanical ventilation 100 % of the time, while open sided housing relies on natural forces of wind and temperature difference to produce air exchange. Some poultry housing utilizes a combination of natural and mechanical ventilation, which has been referred to in the literature as flex housing (also a term that was introduced by the author, and therefore explains some of the apparent popularity). Timmons and Baughman (1983) conducted a comparative study among the 3 types of housing for a 12 month period raising broilers under typical southeastern US conditions. The yearly averages were as follows:

Table 1. Summary of bird performance and house operating costs for 3 types of housing.

	Flex	Enclosed	Open
Wt, kg(lb)	1.92(4.23)	1.98(4.37)	1.93(4.25)
F/G, kg/kg	2.01	2.03	2.01
Electric Usage, kJ/bird	792	227	526
Fuel Usage, gal/1000 birds	35.5	45.2	55.0

It is fairly obvious from this table that there are advantages and disadvantages with each type of housing. The obvious advantage of open housing is the much smaller electrical usage rate. It is also seen that performance of the birds in the open or flex type housing was below that produced within the enclosed housing. It is also generally accepted that establishing differences in bird performance due to housing or management methods is difficult at best. As a result, the use of open style housing has seen a resurgence in popularity the last few years. The design and management emphasis has been on natural ventilation and appropriate management for such systems. This paper will review some of the fundamentals associated with this type of housing.

Poultry Comfort.

The thermal comfort of a bird depends on the capability of the bird to maintain its body temperature at a constant level of 41.5 C (106.7 F). The bird must lose metabolic heat in order to

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maintain the body set point temperature. The loss of metabolic heat is done either in the form of sensible heat or latent heat. Reece and Lott (1982) and Timmons and Gates (1988) provide heat production data for broilers and turkeys, respectively, as a function of body weight and temperature. Timmons and Gates (1988a) reviewed the literature on heat production for laying hens and concluded that the Reece and Lott (1982) data could also be used for laying hens, although they point out that latent heat production could vary greatly depending upon the housing and manure management methods used.

Latent heat loss is via direct evaporation through the skin (cutaneous) and by the lungs. Deshazer and Beck (1988) have reported that the cutaneous latent heat loss is about 25 % of the total latent heat loss.

Sensible heat can be lost in the following ways:

a) conduction (direct contact with another surface)
b) convection (air movement)
c) radiation (electromagnetic transfer)

Conductive and convective heat losses are dependent upon a temperature difference existing

$$\text{Heat Loss} = (C1) \times (T_{\text{bird surface}} - T)$$

where
C1 is a coefficient
T is temperature of air or floor

Radiation heat losses are proportional to temperature differences to the fourth power:

$$\text{Heat Loss(radiation)} = C2\,(T_{\text{bird surface}}^4 - T_{\text{wall/ceiling}}^4)$$

where
C2 is a coefficient
all temperatures are in Kelvin

Since the temperatures for radiation loss are raised to the fourth power and are in absolute temperature (°C + 273), small temperature differences of 1 or 2 C can cause significant radiation exchange between the bird's radiating surface and the receiving surface. Similarly, small differences in surface temperatures have tremendous impact on radiation, e.g. 30 C vs. 32 C creates a difference of 2.24×10^8 (fortunately the constant, C2, is very small!!). However, this does illustrate the first consideration to improve bird comfort, properly insulate all houses, even if they are to be used only as open houses to provide shade. I generally recommend a minimum of 1 inch of either expanded polystyrene extruded (R value of 5 per inch) or polyurethane (R value of 6.25 per inch). However, the cost to install 1.5 inches is the same as 1 inch and I think it is a good practice to use the 1.5 inch thickness. An added advantage of the extra thickness is that the material is much more rigid, which generally will result in a better installation.

Heat loads or radiation loads under uninsulated roofs can be large. Reece et al. (1976) reported temperatures in fan ventilated housing were reduced by 6 to 7 F by using roof insulation. Radiation loads are generally much higher than normally assumed. Bond et al. (1967) quantified the source and magnitudes of thermal radiation for shaded and unshaded animals. Surprisingly, it can be deduced from their measurements that a perfectly insulated shade (i.e. well insulated roof) will reduce radiant loads by 30% or more, with the remaining radiation load coming from the surrounding ground and by direct solar gain. For poultry houses, this then emphasizes the need to properly orient our housing (long axis east/west) to prevent direct solar gain for most of the day during the summer (high solar altitude).

Convective heat losses are very important heat loss mechanism for poultry, since there is no energetic demand incurred by the bird, but is entirely passive. However, the bird does have the capability to pump large quantities of blood to the fleshy areas of its head and to the feet to increase surface temperature. This capability enhances both radiation heat loss and convective heat loss. Convective heat loss is

$$Q\ conv = (A) \times (h) \times (Tsurface - Tair)$$

where A hot surface area, ft^2
h is convective coefficient, $BTU/hr.ft^2.F$
Tsurface is wattle area, or other area of bird of a specific temperature, F
Tair is air temperature, F

Once the temperature difference term has been maximized, then convective heat loss becomes proportional to the convective coefficient. Drury (1966) experimented with raising broilers at air velocities from 21 to 530 ft/min and showed increases in weight gain at all velocities. Temperatures were daily cycled from 70 to 95 F to represent typically stressful conditions. Siegle and Drury (1968) expanded the tests to subject broilers to temperatures from 20 to 40 C and still found reduced heat stress due to the increasing air velocities. However, at temperatures above deep body temperature (41.5 C), they found any increase in air velocity to be detrimental.

There seems to be a common consensus that air velocity is detrimental at high temperatures. Unfortunately, this understanding, which I feel goes back to the Siegle and Drury study, is misplaced! Obviously, for air temperatures above deep body temperature any velocity is bad, since we are then basically convectively cooking the birds. However, if a poultry house remains above 40 C for any length of time, the birds will expire anyway!

Convective coefficients, h, can be calculated in several ways, but will generally be proportional to the square root of the velocity (some empirical methods show velocity to the 0.605 power). While Drury's work showed an essentially proportional improvement in weight gain for velocities above 92 ft/min, there should be diminishing returns to increasing velocity because of the square root relationship between h and velocity. It thus becomes more of a practical consideration of equipment and operating costs. The data does suggest, though, that positive results can be achieved at least to 530 ft/min.

Air velocity can be created by mechanical ventilation. Popular methods include the use of paddle fans, tunnel ventilation or simply propeller, high speed fans hung within the building. Timmons and Baughman (1985) provide design recommendations for using paddle fans, and provided velocity data as a function of distance from the fan (see Figure 1). In general, I recommend paddle fans be placed on 24 foot centers, and to provide one row of fans for each 36 feet of building width. Some advantages of paddle fans are:

a) low cost (typically $150/unit)
b) low power usage (100 watt units)
c) directs air onto the backs of the birds
d) can be installed in open or closed housing
e) improves litter conditions (increases drying rates)

The major disadvantage of paddle fans is high failure rate.

Tunnel ventilation is becoming increasingly popular. This method concentrates all the fans in one end of the building and the inlets in the opposite end of the house. For a 400 by 40 foot broiler house with birds at 0.75 ft^2 per bird and 1.5 cfm per pound ventilation capacity, the tunnel ventilation effect will produce velocities of 250 feet per minute (average ceiling height of 12 feet). The tunnel velocity is calculated as the total air exchange rate divided by the room cross sectional area:

$$V = Q/A$$

where

V = room air velocity, ft/min
Q = total air exchange rate, ft^3/min
A = room cross sectional area, ft^2

Methods to increase this velocity either require greater fan capacity or lower "effective" ceilings. Researchers at North Carolina State University (Bottcher, 1989) are proposing a series of vertical hanging curtains across the house at several locations along the building length in order to create an artificially lower ceiling height and the associated increases in air velocity. The major disadvantage of tunnel ventilation is the temperature increase from the inlet to the fan exhaust. This temperature variation can cause considerable bird migration, which may require internal fences, at say, 1/4 points along the house.

Natural Ventilation.

Open poultry housing depends upon natural forces to provide air exchange. These forces are either produced by ambient wind conditions or buoyancy forces produced by temperature differences between the inside and outside air. Wind ventilation can be calculated as

$$Q_{wind} = A \times C \times V$$

where

Q_{wind} is air flow through the opening
A is area of opening
C is the effectiveness of the opening

C is between 0.5 to 0.6 for winds perpendicular to the wall opening but 0.25 to 0.35 for diagonal winds. Generally, a value of 0.35 is recommended for design. Since air exchange is proportional to opening area, the larger the opening the better. A common recommendation is a minimum of 50% or the total wall area.

Wind velocities and direction are typified by being constantly changing. Thus, although an average wind velocity may exist for a particular location, the magnitude and direction vary greatly with time (see Figures 2 and 3 and Table 2).

Air exchange is also provided by temperature difference between the inside and outside and the distance from the neutral pressure plane[2] to the outlet (the ridge opening). This flow, often called the stack effect, can be calculated as

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[2] During high natural ventilation rates (summer conditions), the neutral plane is the center of the sidewall opening.

$Qstack = A \times \{h \times (Ti-To)/Ti\}^{0.5}$

where

A is area of ride opening, ft^2
h is distance from neutral plane to outlet, ft
Ti, To inside and outside air, (absolute temperature), °R

Timmons et al. (1984) provided nomographs to calculate stack ventilation. If wind ventilation and stack ventilation occur simultaneously, then the total flow should be estimated as the square root of the sum of each component squared.

The use of ridge ventilators is often considered a necessary design feature in all naturally ventilated housing. However, Timmons et al. (1985) evaluated identical insulated housing with and without ridge ventilation and found less than 0.5 F difference in room air temperatures (see Table 3 for hourly temperature summaries). The ridge ventilated house in this study was actually a continuous opening 48 inches in width. Obviously, most ridge areas provided are less than 10% of what was evaluated by Timmons et al. (1985) and therefore explains my skepticism on the effectiveness of any ridge! It should be easily seen that stack ventilation requires a temperature difference to occur. Thus, during the summer time when buildings tend to be wide open, minimal temperature differences exist. As a result stack ventilation rates are also extremely small. However, continuous vented ridges are appropriate for attic ventilation where a ceiling is used to reduce attic temperatures and potential radiation gain through the ceiling to the housed birds.

Buildings that are narrower will naturally ventilate better than wider buildings. Many years ago, poultry buildings were typically 20 to 24 feet wide (or narrower) and were successfully used as naturally ventilated houses. Today, 60 foot wide buildings are common. It should be obvious that a 60 foot wide house will not ventilate the same as a 20 foot wide house. The wider the house, the more attention that is needed to supplement natural ventilation with mechanical ventilation.

Building Separation.

If open style housing is used, then the site plan becomes much more critical. Design spacing can be calculated from the following formula:

$D = 0.4 \times H \times (L)^{0.5}$

where D = separation distance, ridge to closest wall of next building, ft
H = height of obstructing building (or tree barrier), ft
L = length of obstructing building, ft

The rational of this formulae is that as the wind moves over and around obstructions, the wind stream separates and creates a wake where the velocities are much smaller. The wake area between buildings will also contain higher concentrations of contaminants (dust, aerosol bacteria, etc.) than the air outside of the wake. As a result, proper building separation can promote the quality of air movement for the downstream houses and will minimize the temperatures for the adjacent buildings. I think the adverse effects of adjacent buildings are generally underestimated. For large complexes, the solar heat buildup can be substantial from graveled areas, roofs, and animals. By providing more green space between buildings, the cumulative adverse effects of other companion buildings are minimized.

Site Considerations.

If a poultry house is to rely upon natural ventilation, it is imperative that a proper site is chosen. The site chosen should be in an area where natural wind conditions prevail. Building sites that are in natural depressions or are bordered on one or more sides by tree or building barriers should be avoided.

For existing buildings, proper maintenance of grounds by keeping grass mowed is very important to maintain what wind velocity exists.

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Fig. 1 —Air velocity profiles near the floor as radial distance, x, from fan axis increases (1.42 m diameter paddle fan suspended 3.7 m above floor).

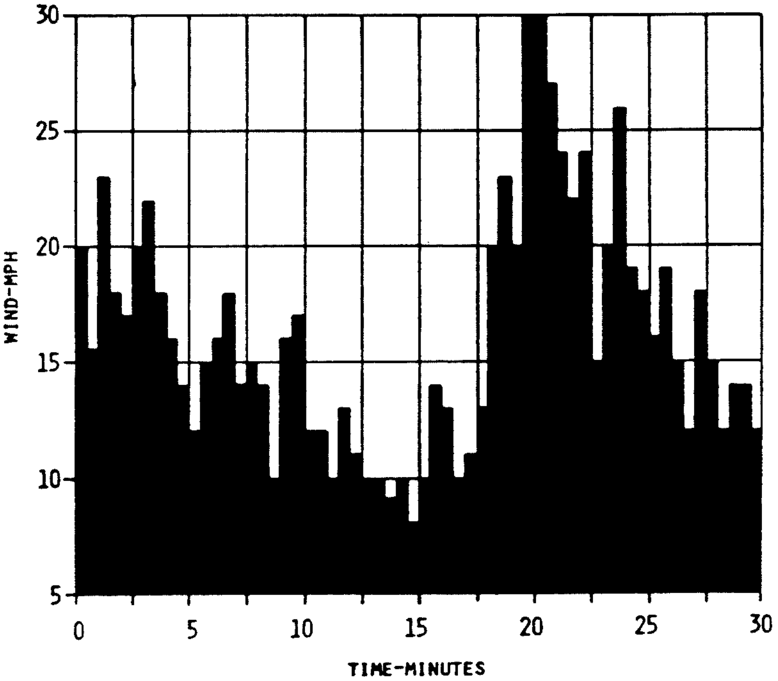

FIG. 2 Wind speed variation with time (Adapted from Hinrichs and Wolfert).[1]

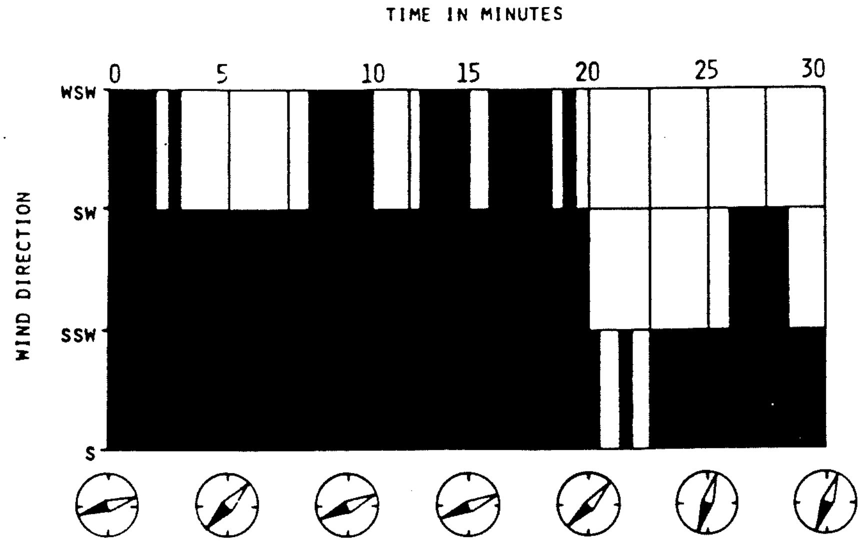

FIG. 3 Frequence and magnitude of changes in wind direction (Adapted from Hinrichs and Wolfert).[1]

Table 2. AVERAGE WIND SPEED AT SELECTED LOCATIONS IN THE UNITED STATES (SOURCE: CLIMATIC ATLAS OF THE U.S., U. S. DEPARTMENT OF COMMERCE, ESSA,(2).

State and location	Average wind speed, m/s	State and location	Average wind Speed, m/s
Ala., Mobile	3.5	Mo., Springfield	5.8
Alaska, Anchorage	3.0	Mont., Great Falls	6.2
Ariz., Phoenix	2.4	Nebr., Omaha	5.2
Ark., Little Rock	3.9	Nev., Las Vegas	4.3
Calif., Sacramento	4.2	N. J. , Newark	4.4
Colo., Denver	4.5	N. Mex., Albuquerque	3.8
Conn., Hartford	4.4	N. Y., Albany	3.8
D.C., Washington	4.3	N. C., Raleigh	3.4
Del., Wilmington	3.9	N. D., Fargo	6.4
Fla., Orlando	3.8	Ohio, Columbus	3.7
Ga., Atlanta	4.3	Okla., Oklahoma City	6.2
Hawaii, Honolulu	5.4	Oregon, Salem	3.2
Idaho, Boise	4.0	Pa., Harrisburg	3.3
Ill., Springfield	5.4	R. I., Providence	4.8
Ind., Indianapolis	4.8	S. C., Charleston	4.1
Iowa, Des Moines	5.4	S. Dak., Huron	5.3
Kansas, Topeka	5.0	Tenn., Knoxville	3.4
Ky., Lexington	4.5	Tex., Austin	4.3
La., New Orleans	4.0	Utah, Salt Lake City	3.9
Maine, Portland	4.3	Vt., Burlington	3.7
Md., Baltimore	4.6	Va., Roanoke	3.7
Mass., Boston	5.9	Wash., Seattle-Tacoma	4.8
Mich., Grand Rapids	4.4	W. Va., Charleston	2.8
Minn., Minneapolis	5.0	Wisc., Madison	4.5
Miss., Jackson	3.2	Wyo., Casper	5.9

TABLE 3. *The average hourly temperatures at bird level for the nonbrooding period in identical houses except for the use of a large continuous ridge vent on one of the houses (Trial 1: May 1 to June 19, 1980 nonbrooding period)*

	Hourly mean temperatures		
Time	Outside	Open ridge	Control
(hr)		(C ± SD)	
0100	18.8 ± 4.0	22.7 ± 4.1	23.6 ± 3.8
0200	18.2 ± 4.1	22.0 ± 4.1	23.9 ± 4.3
0300	17.8 ± 4.3	21.7 ± 4.2	22.8 ± 4.1
0400	17.3 ± 4.4	21.2 ± 4.7	22.5 ± 4.4
0500	17.3 ± 4.3	21.0 ± 4.6	22.3 ± 4.8
0600	17.0 ± 4.7	20.6 ± 4.4	21.9 ± 4.4
0700	17.4 ± 4.2	20.6 ± 4.5	22.2 ± 4.8
0800	19.6 ± 3.6	21.3 ± 3.6	22.1 ± 3.8
0900	21.5 ± 3.6	22.4 ± 2.9	22.7 ± 2.7
1000	23.0 ± 3.6	23.7 ± 2.8	24.0 ± 2.8
1100	25.0 ± 4.1	25.1 ± 3.2	25.0 ± 3.2
1200	26.5 ± 4.6	26.3 ± 3.1	26.3 ± 2.9
1300	27.5 ± 3.8	27.2 ± 2.7	27.4 ± 3.0
1400	28.2 ± 4.6	27.7 ± 3.2	28.0 ± 3.2
1500	28.6 ± 4.4	27.9 ± 3.4	27.9 ± 3.3
1600	28.7 ± 4.6	28.2 ± 3.3	28.5 ± 3.0
1700	28.5 ± 4.7	28.2 ± 3.4	28.4 ± 3.1
1800	28.8 ± 4.1	28.3 ± 3.1	28.3 ± 2.9
1900	28.4 ± 4.3	27.7 ± 3.1	27.9 ± 2.5
2000	25.8 ± 4.1	26.7 ± 2.9	27.3 ± 2.5
2100	22.3 ± 3.2	25.0 ± 2.9	25.8 ± 2.7
2200	20.6 ± 3.7	23.6 ± 3.4	24.7 ± 3.2
2300	19.7 ± 4.1	23.2 ± 4.0	23.9 ± 3.8
2400	19.2 ± 4.3	22.9 ± 4.0	23.7 ± 3.8
$\bar{X}$	22.6 ± 4.8	24.3 ± 3.6	25.0 ± 3.4