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Heat Gain and Wind Effects on Insulated Attic Ventilation Ducts

BY

J.A. Munroe
Engineering Research Service
Research Branch, Agriculture Canada
Ottawa, Ontario
K1A 0C6

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Agriculture Canada, Ottawa, Ontario, K1A 0C6

Predicted Heat Gain without Duct

Consideration will be given here to a typical animal building, say a swine feeder-finishing barn 36 ft wide with a galvanized roof, 4:12 slope, centre air inlet and filled to 80% capacity. Animal densities and air flow rates are as recommended in the Canadian Farm Building Code, i.e. 60 cfm/pig at 8 ft^2/pig.

The sol-air temperature method in the ASHRAE Handbook of Fundamentals was used to estimate the heat gain due to solar radiation in hot weather. The sol-air temperature is that temperature of the outdoor air which, in the absence of all radiation exchanges, would give the same rate of heat entry into the surface as would exist with the actual combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with the outdoor air.

The sol-air temperatures for a light roof and dark roof are 120^o and 162^oF respectively; these values assume an outdoor temperature of 85^o at 48^o North latitude. For 56^o North latitude, the sol-air temperatures are 116^o and 154^oF respectively.

The overall heat transfer coefficient for a steel roof in a typical CPS plan is really dependent only on the outside and inside film coefficients and therefore may be taken as :

$$U = \frac{1}{\frac{1}{1.15} + 0 + \frac{1}{4.0}} = 0.89 \text{ BTU/(hr)(ft}^2\text{)}(^oF).$$

If we assume a 5^o temperature rise in the attic then the heat flow into the attic is $H = UA\Delta T$

$$= 0.89 \times 36 \times (t_e - t_i)$$

$$= 0.89 \times 36 \times (120 - 90)$$

$$= 961 \text{ BTU/hr}$$

For this heat flow, the ventilating air would have a temperature rise calculated as follows:

$$\Delta t = \frac{Q}{0.24 \times q} = \frac{961}{0.24 \times 13.7 \times 60} = 4.9^{o}$$

where the air flow rate per foot of building is

$$\frac{32 \text{ ft pens}}{8 \text{ ft}^2/\text{pig}} \times \frac{60 \text{ cfm/pig}}{14 \text{ ft}^3/\text{lb}} \times 0.8 \text{ capacity} = 13.7 \text{ lb air/min}$$

Following the same procedure, it can be shown that the predicted temperature rise for a dark roof would be approximately 10F^{o}.

<u>Predicted Heat Gain with Insulated Duct</u>

The CPS plans currently show a triangular duct approximately 10½ ft wide at the bottom, 4½ ft high, with sloping sides each approximately 6½ ft long for this 36 ft wide building. The duct is formed with 2 in rigid polystyrene.

If we assume the attic temperature is 50F^{o} above outside as an extreme and assume the same air flows as in the previous example then the heat flow into the duct is $Q = UA\Delta T$

$$= 0.11 \times (2 \times 6\tfrac{1}{2}) \times 50 = 71.5 \text{ BTU/hr/ft building}$$

where $U = \dfrac{1}{\frac{1}{1.32} + 8 + \frac{1}{6.0}} = 0.11 \text{ BTU/(hr)(ft}^2\text{)(}^{o}\text{F)}$

Thus, at an air flow rate of 13.7 lb air/min/ft building the temperature rise of the air is $\dfrac{71.5}{0.24 \times 13.7 \times 60} = 0.36\text{F}^{o}$.

<u>Predicted Wind Effects on Air distribution From Duct</u>

Again the same example of a 36 ft wide feeder-finishing barn will be used; the length of the building will be assumed as 106 ft giving a maximum summer air flow rate of 25000 cfm based on animals housed at 100% capacity. The cross sectional area for the attic duct in this building is approximately 26 ft^2. A few situations can now be considered with regard to predicted variations in air flow along the duct through a uniform width slot.

Case 1. No wind, duct open both ends, full ventilation (25,000 cfm), fans running at 1/8 in static pressure.

In this case the static head at the duct entrance would be the negative of the velocity head. The velocity at the entrance would be $\left(\frac{25000}{2 \times 26}\right) = 480$ fpm, thus the static head would be

$$\Delta P = \left(\frac{V}{4005}\right)^2 = \left(\frac{480}{4005}\right)^2 = 0.014 \text{ inches}$$

of water. The pressure drop across the slot would therefore vary from 0.125 inches at the centre of the building to 0.125 - 0.014 = 0.111 inches of water at the ends of the building.

Recall that $\Delta P \propto V^2$, or

$$\frac{\Delta P_1}{\Delta P_2} = \frac{V_1^2}{V_2^2}$$

In this case the velocity at the building center would be

$\sqrt{\frac{0.125}{0.111}}$ = 1.06 times the velocity at the ends. Air flow is of course directly proportional to velocity.

Case 2. Wind pressure against open end of duct 0.4 in. of water (30 mph), other end of duct closed, full ventilation, 25000 cfm.

The velocity at the duct entrance would be $\frac{25000}{26} = 962$ fpm and the velocity head would thus be $\left(\frac{962}{4005}\right)^2 = 0.058$ in of water. This situation would lead to an air flow variation of $\sqrt{\frac{0.4 - 0.058 - (-.125)}{0.4 - (-.125)}} = 0.89$

Case 3. Partial ventilation during winter, say 10% of maximum or 2500 cfm. One end of duct open.

In this case the air velocity at the end of the duct would be

$$\frac{0.1 \times 25000}{2 \times 26} = 48 \text{ fpm.}$$ This would give a velocity head

equal to $$\left(\frac{48}{4005}\right)^2 = 0.00014 \text{ in of water}$$

which can be considered negligible.

From the preceding three cases it can be seen that the variation in pressure in the duct due to decreasing velocity is greatest during summer periods when ventilation rates are high. When ventilation rates are low, very little variation in airflow along the duct should occur. If the whole attic is used as a plenum (i.e. no insulated duct) then again air velocities should be low and little variation in air flow through the slot along the length of the building should occur.

Note however that all the preceding assumes one has an inlet slot which the operator can control from essentially 0 in to 2 or 3 in in width. The inlet slot of course should be uniform in width from one end to the other. The preceding two items will likely be the biggest problem to overcome with any type of air inlet. Thus it would seem that the critical element in inlet design relating to uniformity of air flow is not whether one uses or doesn't use a duct, but rather that one has an inlet baffle or some other means of adjusting the inlet slot easily, uniformly, and down to a very narrow width (say 1/8 in).

A center air inlet and side air inlet (leaflets 9711, 9712) are currently being printed. The centre air inlet was built in a farmers barn and works well; the side air inlet has been constructed and installed in a poultry building (spring, 1976) and, to date, works well. Adjustment in both systems is made using a boat winch which is effective, inexpensive, simple and readily available.