INTRODUCTION

The limitations of animal shelter ventilation with respect to winter heat balance were outlined by Turnbull (4, 5). Pattie (1, 2) showed that better control of humidity could possibly be achieved by use of a porous ceiling air inlet, but that a ceiling of low porosity is not likely to allow any significant water vapor exfiltration. Turnbull (6) at Ottawa found that a 0.31% porosity perforated ceiling resulted in significantly lower relative humidity in winter than a ventilation system with adjustable perimeter slot inlets. This could not be explained by water vapor exfiltration through the ceiling insulation, nor by the conservation of heat resulting from cold air infiltration through the insulation. It is possible that the barn humidity was reduced in the coldest weather by increased condensation on the ceiling surface chilled by the layer of cold air as it was emerging through the perforations. This condensation is not considered satisfactory, and the experiment was extended by installing a fully-porous ceiling at Normandin, Quebec.

THE NORMANDIN EXPERIMENT

A dairy barn at Normandin Quebec had been remodelled for modified environment free-stall housing in 1970. At that time it was partly insulated with 1 inch (2.54 cm) of rigid polystyrene insulation attached to the lower edge of the steel roof purlins. However, winter weather at Normandin was too cold for satisfactory manure removal; at outside temperatures below −20°F (−29°C), manure in the barn froze too hard for mechanical removal. Design January temperature at Normandin is −26°F (−32°C) compared with −17°F (−27°C) at Ottawa.

In 1972 this barn was modified by adding exhaust ventilation fans and a suspended fully-porous ceiling. The free-stall area of the barn was 50 X 180 ft (15 X 55 m), and included 80 free stalls, feeding for silage and hay, and 2 manure

Figure 1. Normandin free-stall dairy barn with porous ceiling ventilation system.
Breaks in the curve for calculated $T_a$ (Figure 3) correspond to thermostat settings at which the ventilation rate changed due to constant versus cycling fan operation. With some imagination it is possible to see corresponding 'flat spots' in the plotted data. It would appear, for example, that the thermostat controlling the three big fans ($Q_v$ up to 27,950 cfm) was set to start at about $T_l = 52^\circ F$ ($11^\circ C$), not $60^\circ F$ ($15^\circ C$) as used in obtaining the calculated $T_a$ curve. Figure 4 shows that the theoretical and actual attic temperatures ($T_a$) fitted well on outside temperature ($T_o$). Theoretical attic temperatures calculated from equation (2) tended, however, to estimate below the actual $T_a$ in very cold weather, and above actual $T_a$ in warm weather.

This implies that in very cold weather, $(T_o < -10^\circ F (-23^\circ C))$ actual heat flow through the ceiling was greater than that predicted on the assumption of no ventilation through the porous ceiling insulation.

Day temperatures as well as the night temperatures from Figures 3 and 4 are summarized in Figure 5.

The upper part of Figure 5 also shows theoretical inside relative humidity (RH$_i$) calculated from equation (1). This was done by computer using an iteration process, since the $h_i$ term of equation (1) contained three interdependent variables ($T_i$, $M$ and $Q$). RH$_i$ was predicted to reach 100% (saturation) at $T_o = +5^\circ F (-15^\circ C)$.

Humidity was not recorded, but regular observations by the Normandin dairy staff indicated that the barn did not fog until $T_o$ was $-20^\circ F (-29^\circ C)$ and colder, under calm (no wind) conditions. The authors observed a layer of fog up to about 5 ft (1.5 m) above floor level one calm morning at $T_o = -18^\circ F (-28^\circ C)$. With wind, the critical outside temperature where fog appeared was observed to be somewhat lower, possibly due to increased attic ventilation.

During the 1972-73 winter, chore operations such as manure removal could be done easily, down to $T_l = 10^\circ F (-12^\circ C)$ with $T_o = -40^\circ F (-40^\circ C)$. With the natural convection ventilation as used for two previous winters, manure frequently had frozen too solidly for scraping, accumulating from 8 to 10 inches (20 to 25 cm) in the cow passages. Also, the barn had been filled with fog whenever $T_o$ was below $0^\circ F (-18^\circ C)$.

With no vapor barrier and no ceiling under the porous insulation, heavy frosting might be expected in the insulation. This was not the case. Some areas of the exposed insulation showed slight frosting at the lower surface; other areas had slight frosting at the top (attic) surface. Air infiltration apparently controlled frosting within the ceiling insulation thickness. At all ventilation rates, static pressure difference through the porous ceiling was too low to be measured with an inclined-tube manometer.

Depending on wind direction some frosting accumulated on the bird screening covering the leeward attic openings. This was easily removed with a long-handled broom and presented no real problems. To keep snow out of the attic, it was necessary to close the west gable ventilator door during snowstorms blowing from the west.

Predicted attic temperature varied between inside and outside temperatures. In the coldest night periods ($T_o = -30$ to $-40$ degrees Fahrenheit ($-34$ to $-40$ degrees Celsius)) measured attic temperatures tended to be about 10 degrees Fahrenheit (6 degrees Celsius) above that predicted by assuming only conductive heat transfer. This would indicate that air flow was not uniformly downward through the porous ceiling, but in fact flowed both upward and downward, increasing heat loss by ventilation to the attic space.

This could partly account for inability to maintain above-freezing barn temperatures. Further tests are planned with an additional layer of insulation, laid with joints staggered to the present layer.

Barn relative humidity was predicted to reach saturation at about $T_o = +5$ degrees Fahrenheit ($-15$ degrees Celsius) whereas fog was not observed until $T_o$ approached $-20$ degrees Fahrenheit ($-29$ degrees Celsius). This would indicate that the fully porous ceiling was effective in passing considerable water vapor to the attic space without proportionally increasing the heat loss due to ventilation.

Relatively low rates of air infiltration through porous insulation were effective in controlling condensation or frosting within the insulation. This indicates that with negative-pressure ventilation and well-ventilated space on the cold side of the insulation, a vapor barrier is not really essential.

**SUMMARY**

The Normandin dairy barn with fully-porous ceiling was not insulated enough to achieve 'controlled environment' as normally defined. It was possible however to maintain a temperature rise ($T_l - T_o$) of up to 50 degrees Fahrenheit (28 degrees Celsius) at $T_o =$ $-40$ degrees Fahrenheit ($-40$ degrees Celsius). Predicted inside temperature $T_l$ and attic temperature $T_a$ versus outside temperature $T_o$ were close to measured values, although inside temperature tended to be slightly below that predicted except during the very coldest weather.

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REFERENCES


Figure 5. Inside temperature ($T_i$) and calculated relative humidity (RH$_i$) versus outside temperature ($T_o$).