Effect of ridge opening width on natural ventilation performance during summer

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Choinière, Y. and Munroe, J.A. 1993. Effect of ridge opening width on natural ventilation performance during summer. Can. Agric. Eng. **35**:281-287. Inside temperatures and estimated ventilation rates based on CO_2 measurements were compared in a naturally ventilated barn under summer conditions using ridge opening widths of 0, 25, and 125 mm. Only minimal inside to outside temperature differences were measured for any ridge opening width during the day. There were higher frequencies of high ventilation rates with either the 25 or 125 mm wide ridge opening as compared to the closed ridge; however, the estimated ventilation rates were greater than one air change per minute 80, 87, and 92% of the time for the 0, 25, and 125 mm ridge opening widths, respectively. The size of sidewall and ridge openings required for summer ventilation could therefore be based on wind effects alone since thermal buoyancy effects are considered to be negligible.
Keywords: natural ventilation, summer, ridge width
Les effets des ouvertures continues au faîte du toit de 0, 25, et 125 mm de largeur sur les températures intérieures et les estimés des taux de ventilation ont été étudiés dans une porcherie d'engraissement ventilée naturellement. Les différences entre les températures intérieures-extérieures étaient minimales avec les 3 ouvertures durant la journée. Les estimés des taux de ventilation semblaient être plus bas lorsque l'ouverture du faîte était fermée alors qu'il n'y avait presqu'aucune différence entre les ouvertures de 25 et 125 mm. Les estimés des taux de ventilation étaient plus élevés que la norme de 1 changement d'air par minute durant 80, 87, et 92% du temps pour les ouvertures de 0, 25, et 125 mm respectivement. Conséquemment, le facteur vent (vitesse et direction) doit être le critère de conception à considérer pour le dimensionement des ouvertures dans les murs et au faîte du toit car, durant le jour, l'effet thermal est négligeable.

INTRODUCTION

Current popular designs for warm naturally ventilated swine finishing buildings generally include large sidewall openings and a continuous ridge opening. However, there is a difference of opinion among designers regarding the effect of the ridge opening area on the inside temperatures and ventilation rate, particularly under warm weather conditions.

Munroe and Choinière (1993) proposed the use of a minimum ridge opening during cold weather. They also recommended further studies to determine the effect of different sized ridge openings on ventilation rate and temperature control. Subsequently, Choinière et al. (1990b) and Choinière (1991) carried out a scale model study of a typical naturally ventilated livestock building with gable roof. Results indicated only small differences in predicted wind-induced ventilation rates when using a series of chimneys (total area equivalent to a 25 mm wide continuous ridge opening) instead of a 150 mm wide continuous ridge opening.

A study was therefore initiated to determine the influence of ridge opening area on inside temperature distribution and ventilation rate during warm weather in a naturally ventilated swine finishing barn.

LITERATURE REVIEW

Temperature observations in naturally ventilated buildings

For insulated, naturally ventilated dairy barns, Kammel et al. (1982) in a study in north central United States, showed that inside temperatures were similar to outside temperatures during hot weather (above 25°C). They also stated that "when large sidewall doors are provided for warm weather conditions, the ridge opening should not be oversized". In eastern Ontario, Choinière et al. (1990a) reported near isothermal conditions (the same temperature inside as outside) for outside temperatures above 20°C for naturally ventilated swine finishing barns.

For a modified open front style swine finishing barn located in south western Ontario, Boyd (1985) reported that during the daytime, inside temperatures were often below outside temperatures. There were no vertical or horizontal gradients of temperature across or along the building. He noted that differences between inside and outside temperatures occurred during the night when thermostats caused the ventilation doors to close in order to maintain the desired inside temperature. This was also the period when lower wind speeds were recorded.

In the United Kingdom, Barrie et al. (1985) studied a naturally ventilated building for finishing pigs, with large sidewall openings but no ridge opening. Only small increases in inside temperature were noted and these were during periods of low wind speed thus indicating minimal adverse effects due to the absence of a ridge opening. On the other hand, Meyer and Goetsch (1984) recommended the use of a large ridge opening (600 mm wide) to obtain better temperature control during the changing fall and spring seasons.

Measurement of ventilation rates based on CO_2 levels

Hitchin and Wilson (1967) discussed two basic methods to measure ventilation rates with a tracer gas: 1) the rate of decay method; and 2) the equilibrium concentration method.

The rate of decay method consists of introducing a quantity of tracer gas at a high concentration into a ventilated airspace and measuring the rate of decay. Moulsley and Fryer (1985) used this rate of decay technique to investigate air leakage in broiler barns. The same technique has also been widely used in other ventilation rate experiments.

The equilibrium concentration method supposes that the tracer gas is emitted continuously at a uniform rate and that an equilibrium tracer gas concentration directly related to ventilation rate can be obtained in the airspace. Hitchin and Wilson (1967) discussed the difficulty in obtaining an equilibrium due to non-static weather conditions and non-uniformity of the tracer gas supply.

Based on the equilibrium method, Feddes and DeShazer (1988) proposed a simple way to predict the ventilation rate based on the difference in CO_2 concentration inside and outside and an assumed CO_2 production rate by the animals.

In a western Ontario study on a naturally ventilated pig finishing barn with a conventional ridge opening and large sidewall doors, MacDonald et al. (1985) measured interior CO_2 concentrations of 400 to 800 ppm during warm weather and about 3000 ppm during cold weather. The increase in the CO_2 concentration was attributed to a reduction in ventilation rate.

Wind tunnel studies of airflow patterns for naturally ventilated buildings conducted by Choinière et al. (1988a, 1988b) and Choinière (1991) indicated that some zones across and along the buildings were under or over ventilated. These observations enforced the statement of Hitchin and Wilson (1967) that air should be "sampled at several points, mixed and the composite concentration" then used to determine the ventilation rate.

CO_2 production by finishing pigs

Figure 1 shows the hourly CO_2 production data obtained by Feddes (personal communication, J.J.R. Feddes, Professor, Department of Animal Science, University of Alberta, Edmonton, AB). These data show large but rather cyclical variations over a 24 h period. Feddes et al. (1983) presented these data previously, but on a average daily basis, in studying the effects of temperature and feeding method on the CO_2 produced by finishing pigs.

Similar variations in heat production, which is directly related to CO_2 production, in relation to room temperature and feeding method were also reported by Van der Hel et al. (1986) and Verstegen et al. (1986).

OBJECTIVES

A naturally ventilated building for finishing pigs, with large sidewall openings and a continuous ridge opening, was investigated under isothermal (summer) conditions for three different ridge opening widths: 0 (closed), 25 and 125 mm. The objectives were:

1. to compare inside barn temperatures for different ridge opening widths;
2. to compare ventilation rates, based on measurements of CO_2 concentration, achieved with different ridge opening widths.

METHODS AND PROCEDURES

Barn description

Tests were performed in a 10.8 x 23.0 m warm insulated naturally ventilated pig barn (Fig. 2) located near Spencerville, ON. The barn was oriented north-south and had a 4.35 m ridge height and a sloping ceiling (1:8). Adjacent buildings were mainly to the north and east thereby causing minimum interference to the prevailing south-westerly winds. Rotating 2100 X 900 mm ventilation doors in both sidewalls were controlled by a modulated automatic control system based on temperature (Munroe et al. 1991) (Fig 3.). The opening area as shown is equivalent to 24% of the overall sidewall area.

The barn had a ridge opening length of 19.2 m. During this study, the ridge opening width was set at either 0, 25, or 125 mm using a manual cable and winch system.

Instrumentation and test procedure

As shown in Figs. 2 and 4, 20 thermocouples over a cross-section at the centre of the barn and 22 other thermocouples located 0.9 m above the floor (Choinière et al. 1990a) were averaged to indicate barn temperature. Outside temperature, and wind speed and direction were monitored near the barn using a standard 10 m high weather station. All the sensors were scanned every 10 s and their readings averaged over a 5 min. period. These data were then used to compute the long term average temperatures and standard deviations for each thermocouple location.

The CO_2 concentration inside the barn was monitored based on an average of 21 points (7 locations in each of 3 similar cross sections) (Figs. 2 and 4). A centrifugal fan extracted about 5 L/s of air simultaneously via plastic tubing (5 mm ID) from the 21 locations into a mixing box. The CO_2 concentration in this box was measured every 10 s and the readings averaged over a 5 minute period. The exterior CO_2 concentration was measured 2 to 3 times per week. It was always between 325 and 350 ppm.

During the test period, the target temperature at pig level was 18.5°C corresponding to optimum conditions for finishing pigs weighing 25 to 90 kg. When the temperature near the thermostat reached or exceeded its set point (18.5°C), the ventilation doors began to open. They would continue to open in increments of about 25 mm every 3 min until they were fully open, or until the temperature at the thermostat fell below its set point in which case the doors would begin to close at the same rate. It took approximately 1 h for the doors to move from a fully closed to fully open position.

Tests were carried out between June 6 and August 10, 1988. The ridge opening width (0, 25, or 125 mm) was changed every three days. However, because of occasional problems with equipment or instrumentation, the equivalent of approximately 850 h of data was obtained during this time.

Pig cleanliness, behaviour, mass, and feeding

Pig population and overall pig cleanliness and behaviour were noted twice per week. Typical pig densities were 15 pigs per pen (0.72 m^2/pig). A total of 300 pigs ranging from 25 to 90 kg were housed in this barn during the study. Pigs between 25 and 55 kg were feeder fed *ad libitum*, while heavier pigs were floor fed twice per day.

Calculation of ventilation rate

The numbers of pigs being feeder or floor fed and estimated animal masses were noted twice weekly. The hourly CO_2 production was estimated based on the data of Feddes (personal communication cited earlier) (Fig. 1) taking into account the method of feeding and switching from the low to the high temperature curve for $T \geq 25^{o}C$. The instantaneous ventilation rates were then estimated using the equilibrium method described by Feddes et. al. (1983) and Feddes and DeShazer (1988), based on the CO_2 production rate and the measured CO_2 concentration in the barn.

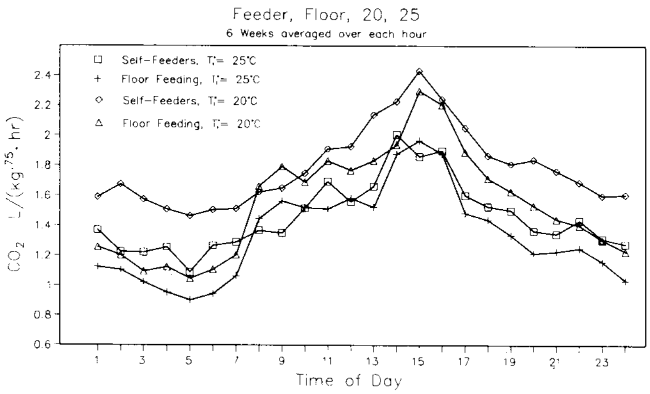

Fig. 1. Effect of room temperature and feeding method on CO_2 production by finishing pigs (Feddes personal communication).

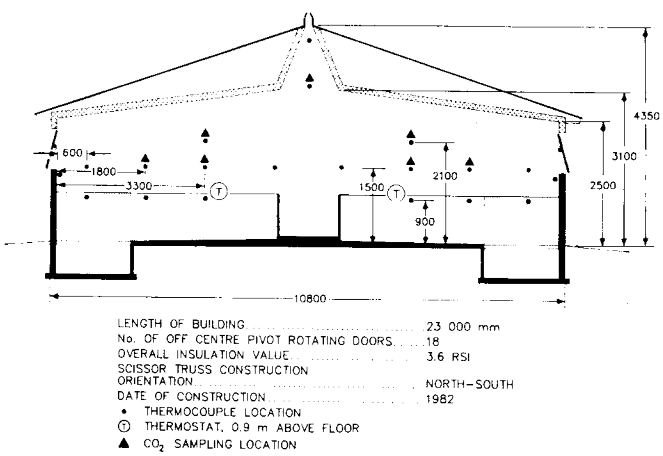

Fig. 2. Centre cross section of barn showing locations of thermocouples and CO_2 sampling.

Data selection for calculation of ventilation rates

To depict open country conditions, only the data concurrent with wind within the South to West sectors (Fig. 4) were considered for the calculation of ventilation rates. This selection eliminated winds that passed over adjacent swine buildings to the North and East, that were exhausting CO_2 which could possibly be reintroduced to the barn under study. As shown on Fig. 4, the wind direction was divided into five direction segments of 22.5^{o} each. For each ridge opening width, the wind speed and direction frequency distributions were determined and plotted.

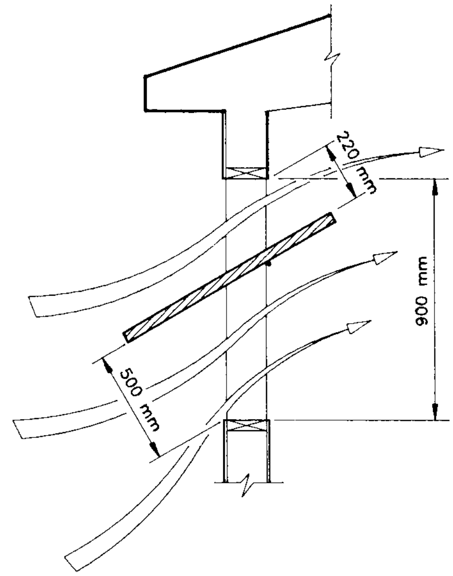

Fig. 3. Rotating sidewall door for a naturally ventilated building in fully open position.

Simultaneous measurements of outside and inside CO_2 concentrations were not possible since only one CO_2 analyzer was available. Because of the cycle of the plants from daytime photosynthesis to night time respiration, Desjardins (personal communication, R. Desjardins, Centre for Land and Biological Resources Research, Agriculture Canada, Ottawa, ON) indicated that under low wind speed conditions the concentration of carbon dioxide in and over corn fields could increase from 350 ppm during the day to 400 to 600 ppm during the night. This increase occurs rather abruptly at sunset. Based on the equilibrium method, CO_2 concentrations of 400 ppm in this barn and 350 ppm outside would indicate ventilation rates of 4 to 5 air changes per minute. Small errors in measured outside CO_2 concentration could lead to large errors in predicted ventilation rates under these conditions. Since the test facility was adjacent to a corn field, only daytime CO_2 data collected between 0600 h and 2000 h were used in computing ventilation rates. In addition, all data representing concentrations less than 500 ppm were grouped together and noted as being $\leq$ 500 ppm. To ensure that the ventilation doors were fully open, data were only considered if the temperature at the thermostats had been above the thermostat set point for at least 30 min.

RESULTS AND DISCUSSION

To make comparisons based on ventilation rate, the wind speed and direction frequency distributions for the different ridge opening width tests should be considered. Using the data selection criteria described previously, a total of 720, 799, and 194 data points could be used for the ridge opening widths of 0, 25, and 125 mm, respectively. Figures 5 and 6 show frequency distributions of wind direction and speed at the site during the study. These distributions appear to be similar to the frequency distributions of wind speed and direction for Eastern Ontario as observed by Zemanchik et al. (1991). Sufficient data points were apparently obtained to reflect typical conditions and allow comparison between tests using different ridge opening widths.

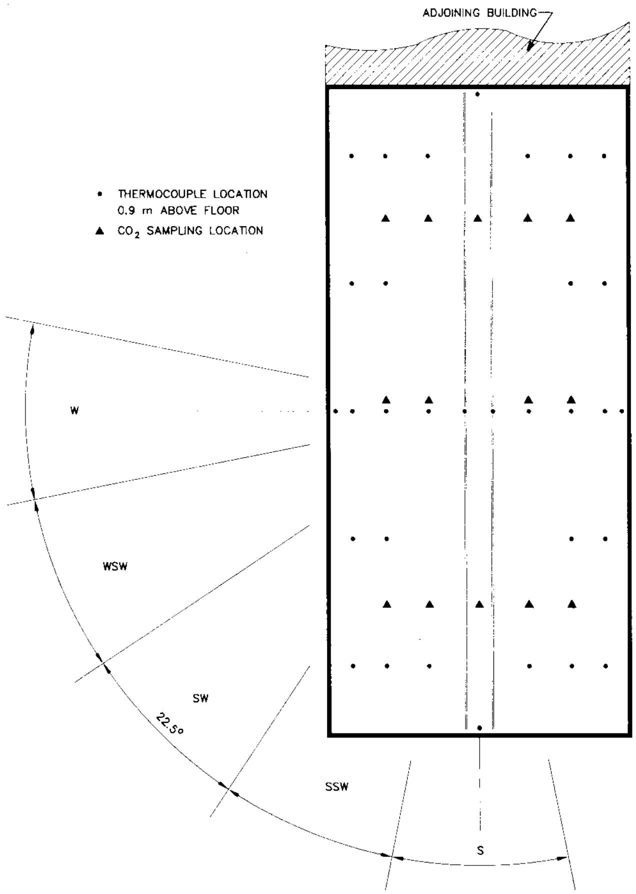

Fig. 4. Plan view of barn showing wind directions and locations of thermocouples and CO2 sampling.

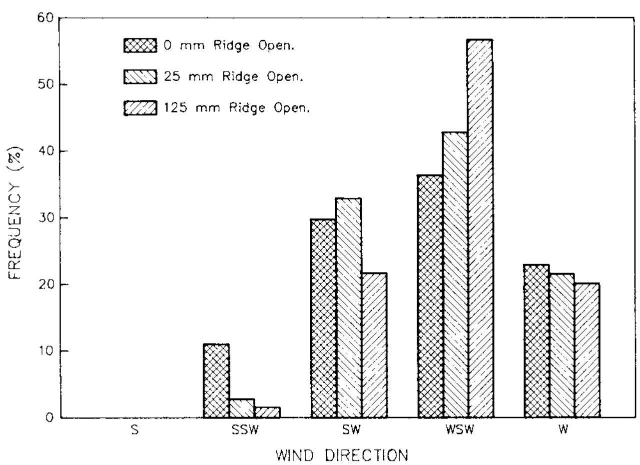

Fig. 5. Wind direction frequency distribution during selected portions of the study for ridge opening widths of 0, 25, and 125 mm.

Effect of ridge opening width

As shown on Fig. 7, there were no noticeable differences in inside temperature for the three ridge opening widths tested when the outside temperature was above 22°C. However, for outside temperatures below 22°C, there appeared to be slightly higher temperature rises with the totally closed ridge

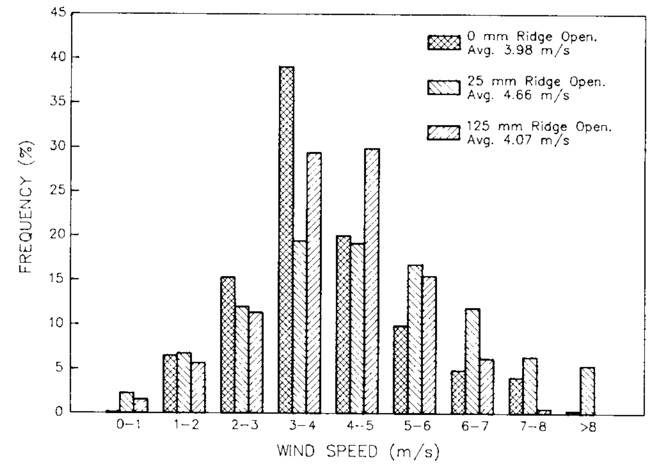

Fig. 6. Wind speed frequency distribution during selected portions of the study for ridge opening widths of 0, 25, and 125 mm.

as compared to either the 25 or 125 mm ridge openings.

Although not shown, during the night, when wind speeds were low and parallel to the building, slightly greater inside to outside temperature differences were observed with the totally closed ridge as compared to either the 25 or 125 mm wide ridge opening. There were no apparent differences in inside temperatures using ridge opening widths of 25 or 125 mm.

The period July 6 to 9, 1988 was extremely hot with a large diurnal outside temperature fluctuation, low wind speeds, and wind directions parallel to the building. The highest differences between inside and outside temperature, as well as the greatest inside temperature gradients along the barn that were recorded during the entire study, occurred at this time with the ridge closed and are shown in Figs. 8 through 11. Figure 8 indicates the temperatures recorded at the four corners of the barn. The intent in this figure is to show the variation in temperatures within the barn and how this variation changed from day to night. No attempt is made to identify which curve represents which corner as this was not

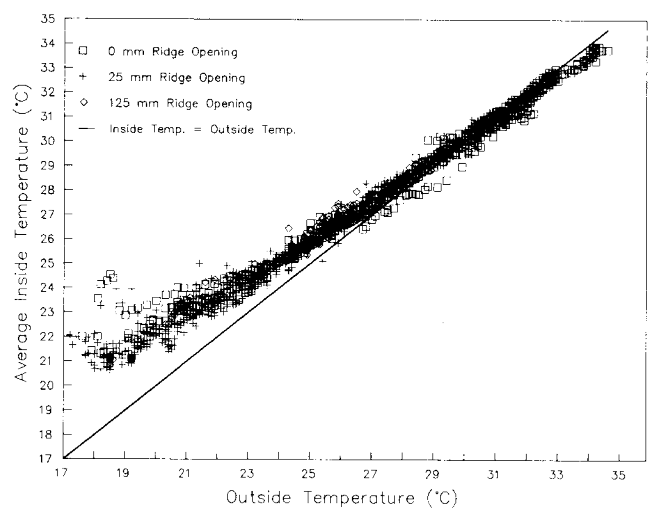

Fig. 7. Scatter diagram of average barn temperature *vs* outside temperature for all ridge configurations.

the concern. During the day, there was no difference between outside and inside temperatures, i.e. natural ventilation was occurring under isothermal conditions. During the night, the maximum temperature difference was 7°C; however, the inside temperature remained within the 18 to 23°C range, which is considered to be acceptable for these finishing pigs.

Inside temperature versus wind direction and speed

Frequently the peaks of wind speed coincided with the peaks of outside temperature during the day. This is evident for example in Figs. 9 and 11. This phenomenon had a positive impact on natural ventilation since it provided higher ventilation rate potential during periods of higher outside temperatures. Inside to outside temperature differences were near zero at this time (Figs. 8 and 9).

In eastern Ontario during the summer, winds tend to shift from westerly during the day to southerly during the night as shown in Fig. 10. At this site, south winds are considered to be inefficient in providing ventilation since they are parallel to the building length. Inside to outside temperature differences are typically highest at night under these conditions (Figs. 8 and 9).

Figure 8 also indicates some variation in inside temperatures within the building. During the night, as indicated in Fig. 10, the winds varied primarily between south and west. This created air circulation within the barn from north to south as described previously by Choinière et al. (1988b, 1990a). The lower temperatures were recorded at the north end (the main air inlet zone) and the higher temperatures at the south end (the main air exhaust zone).

Pig cleanliness and behaviour

During the 8 weeks of the study, pigs using self-feeders were generally dirtier in appearance than those floor fed. This could be due to the more continuous pig activity in the pens with feeders or to floor feeding encouraging pigs to dung in non-feeding areas. At the end of July and the beginning of August, many pens became more dirty. No noticeable differences in pig cleanliness were noted among the three ridge opening widths.

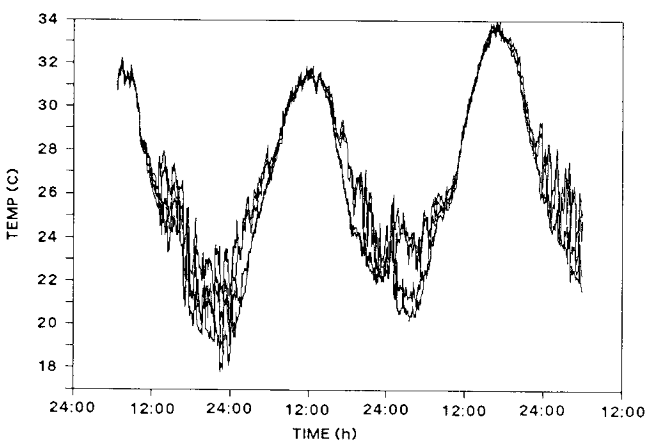

Fig. 8. Temperatures measured in four corners of the barn to show change in magnitude of variation within the barn from day to night; no emphasis is placed on which curve represents which corner. Ridge closed (July 6-9, 1988).

Operator comments

The operator was least satisfied using a closed ridge. His preference was the 25 mm opening because it appeared to reduce rain infiltration as compared to the ridge opening of 125 mm. As well, the additional sunlight provided by the open ridge was considered to be an important factor. Despite our records taken on animal

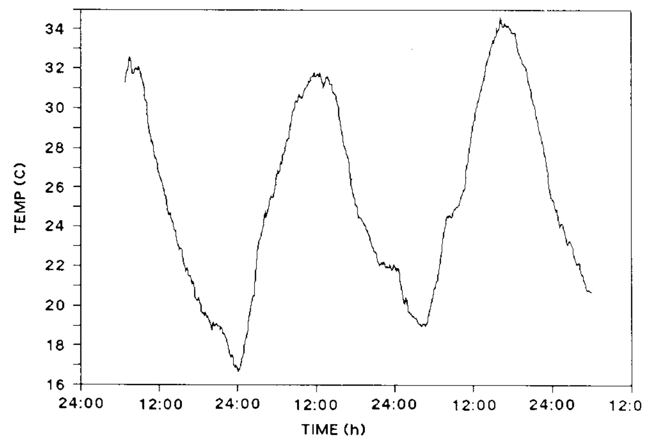

Fig. 9. Outside temperature (July 6-9,1988).

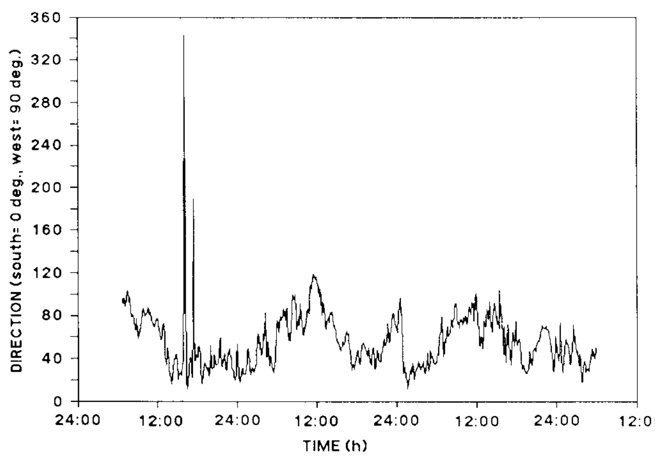

Fig. 10. Wind direction (July 6-9, 1988).

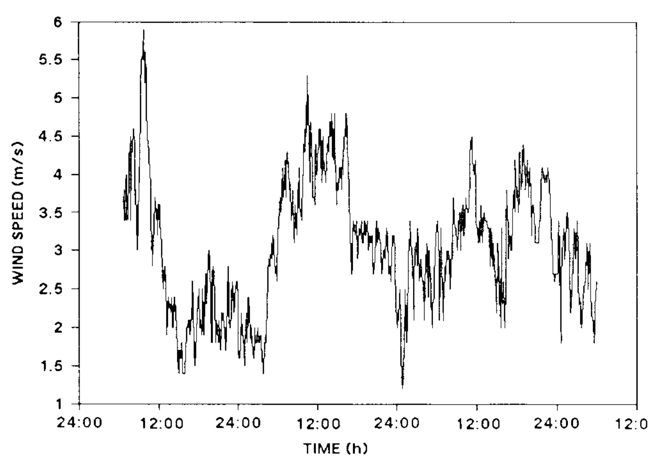

Fig. 11. Wind speed at 10 m height (July 6-9, 1988).

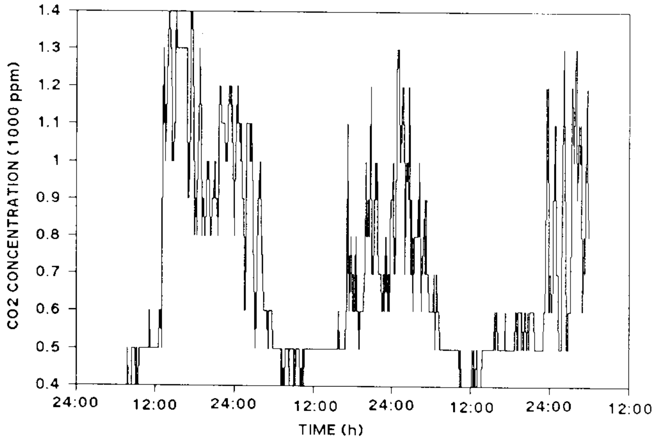

Fig. 12. CO_2 concentration with the ridge closed (July 6-9, 1988).

cleanliness, the operator felt that he noticed an improvement in pig cleanliness with an open ridge versus a closed ridge.

CO_2 concentrations

Figure 12 shows CO_2 concentrations measured during July 6-9 for the closed ridge tests based on the average of measurements from the 21 sampling locations. The lowest CO_2 concentrations were monitored during the day and were coincident with peaks of inside and outside temperatures (Figs. 8 and 9). The highest CO_2 levels were measured during the night when winds were more parallel to the building and of low speed, however any contributing effect due to possible increases in outside CO_2 level during the night was unknown. Generally, the lowest CO_2 concentrations were recorded during the day when the wind speed was above 2 to 3 m/s and when the wind direction was perpendicular to the building length.

Spot checks indicated that when there were temperature gradients in the barn, indicating incomplete mixing, there was also some variation in CO_2 concentration. The latter tended to vary directly with local temperature; i.e. higher CO_2 concentrations coincided with higher local temperatures.

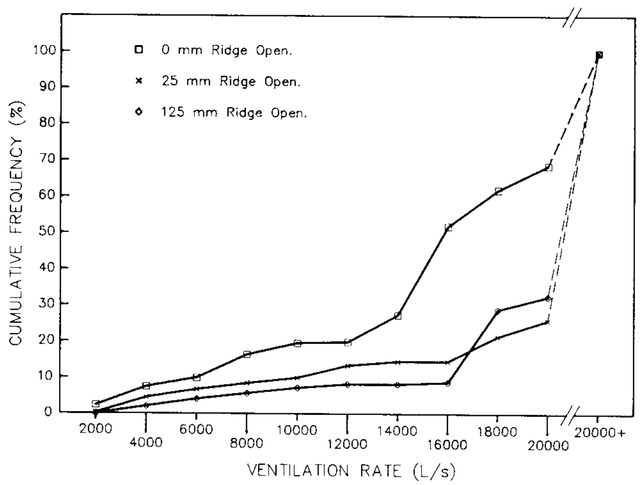

Fig. 13. Cumulative frequency distributions of estimated ventilation rates during selected portions of the study for ridge opening widths of 0, 25, and 125 mm. One ac/min is equivalent to 12 m^3/s.

Calculated ventilation rates

Figure 13 compares the cumulative frequency of the calculated ventilation rates for the different ridge opening widths. There were higher frequencies of high ventilation rates with either the 25 or 125 mm wide ridge opening as compared to the closed ridge; however, the estimated ventilation rates were greater than one air change per minute 80, 87, and 92% of the time for the 0, 25, and 125 mm ridge opening widths, respectively. For this finishing barn with 60 kg pigs, one air change per minute would be equivalent to approximately 12 m^3/s and a CO_2 concentration of less than 580 ppm. A ridge opening of 25 and 125 mm appears to have a positive effect on the ventilation rate as compared to a totally closed ridge. This might not apply if the sidewall openings were considerably smaller than those in the barn tested here.

The discontinuity at the ventilation rate of 20 m^3/s (for 60 kg pigs in this barn, this is approximately equivalent to 500 ppm CO_2 or less) reflects the inaccuracy in predicting high ventilation rates when the difference between inside and outside CO_2 levels is small (for example < 30-50 ppm), and approximates the sensitivity of the CO_2 analyzer.

As reported by Zemanchik et al. (1991), the adverse effects of these low ventilation rates would depend on the frequency, and number of consecutive hours during which they occurred. The relation between the meteorological data (wind speed and direction) and the ventilation rates should be investigated for local conditions in order to verify the feasibility of using natural ventilation for a particular region.

Design of naturally ventilated buildings for Canadian climates

Since the inside and outside temperatures are approximately the same during the warmest period of the day (Figs. 8 and 9), thermal effects are minor; consequently, the required opening area (sidewall or ridge), for design purposes, should be based on wind forces only. With no ridge opening, the large sidewall openings appear to minimize inside to outside temperature differences during periods of low wind speed and adverse wind direction.

In this naturally ventilated finishing barn, the use of chimneys, as proposed by Munroe and Choinière (1993) in lieu of a continuous open ridge for winter ventilation would appear to be quite adequate for summer ventilation as well. Chimneys 600 x 600 mm every 8 m would have the equivalent area of a 45 mm wide continuous ridge opening.

CONCLUSIONS

A naturally ventilated swine finishing barn with large sidewall openings and a continuous ridge opening was studied using three different ridge opening widths (0, 25, and 125 mm). From this study, the following conclusions can be drawn:

1. Negligible inside to outside temperature differences were maintained during the day for the three ridge opening widths tested. Slightly higher inside to outside

temperature differences were observed with the closed ridge during the night as compared to either of the open ridges.

2. There were higher frequencies of high ventilation rates with either the 25 or 125 mm wide ridge opening as compared to the closed ridge; however, the estimated ventilation rates were greater than one air change per minute 80, 87, and 92% of the time for the 0, 25, and 125 mm ridge opening widths, respectively.
3. To provide sufficient ventilation during the peaks of outside temperature during the day, the size of the sidewall and ridge opening areas of naturally ventilated buildings can be based on wind forces only since the thermal buoyancy effect is minor at this time. It must be remembered however that this building had ventilation openings equivalent to 24% of the overall sidewall area.

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