Minimum ridge opening widths for a naturally ventilated swine barn under cold weather conditions

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Munroe, J.A., and Choinière, Y. 1993. **Minimum ridge opening widths for a naturally ventilated swine barn under cold weather conditions**. Can. Agric. Eng. **35**:141-146. Traditional automatically controlled naturally ventilated (ACNV) barns for pigs in North America have had continuous ridge openings with widths ranging from 150 to 600 mm. This study evaluated the use of much smaller ridge opening widths of 6 and 20 mm (ridge opening to floor area ratios of 1:2160 and 1:650 respectively). Equivalent intermittent small openings could be less costly to construct. Inside temperature and humidity distributions were monitored during cold weather. Test results indicated that very satisfactory performance in terms of inside temperatures and humidities near pig level (1.5 m height) were obtained using either the 6 or 20 mm wide ridge opening. However high relative humidities near the ridge became a concern with the 6 mm opening.

Traditionnellement les porcheries ventilées naturellement d'Amérique du nord ont une ouverture continue au fâite du toit d'une largeur variant entre 150 et 600 mm. Dans cette étude, de plus petites ouvertures de 6 et 20 mm de large furent utilisées (représentant une ratio des surfaces des ouvertures du toit par rapport au plancher de 1:2160 et 1:650 respectivement). Les distributions des températures et des taux d'humidité relative furent enregistrées durant les périodes des froides de l'année. Les résultats indiquent des performances satisfaisantes en ce qui a trait aux températures et au taux d'humidité relative près de la zone occupée par les porcs (1.5 m au-dessus du plancher) lorsque l'ouverture au faîte du toit était soit de 6 ou de 20 mm de largeur. Cependant, les hauts taux d'humidité relative enregistrés au niveau de l'ouverture au faîte du toit avec l'ouverture de 6 mm de large peuvent présentés des problèmes potentiels. Des ouvertures intermittentes au faîte du toit avec une aire totale équivalente aux ouvertures continues peuvent être moins coûteuse à construire.

INTRODUCTION

Existing designs for warm naturally ventilated swine finishing buildings generally have large sidewall openings and a continuous ridge opening. During cold weather, some of these barns have environmental and structural problems including poor temperature control inside the building, freezing over of the sidewall and ridge openings, deterioration of the exposed wood trusses, and birds and snow entering at the ridge. In addition, the continuous ridge opening can be expensive to build. If a narrow continuous ridge opening resulted in adequate humidity and temperature control inside the building, then perhaps the narrow continuous ridge opening could be replaced by a series of less costly intermittent openings such as adjustable chimneys

An evaluation of a minimum ridge opening for warm naturally ventilated swine barns fitted with automatically controlled sidewall openings and a manually controlled ridge opening was therefore needed.

Satisfactory thermal performance was reported by Choinière et al. (1989, 1990) and Munroe et al. (1991) where a continuous ridge opening width of 20 mm was used. A study was initiated to determine if the same building would perform satisfactorily if the ridge opening width was closed to the minimum practically attainable.

LITERATURE REVIEW

Natural ventilation for livestock housing has been investigated by Bruce (1975, 1978) who proposed that the design of the necessary openings for the air inlet and outlet be based on thermal buoyancy alone. Using a mathematical model, he recommended that "the inlet size should be twice the area of outlets". Naturally ventilated buildings with large ridge openings were built using the recommendations of Bruce (1977) and Strøm and Morsing (1984). Hellickson et al. (1983), Brockett and Albright (1987), DeShazer et al. (1988), and van't Ooster and Both (1988) presented different models combining the thermal buoyancy forces and the wind forces. These models were used for designs of conventional buildings with various continuous ridge openings without taking into account the response of any control system. Strøm and Morsing (1984) recommended equal areas of inlet and outlet, with both being automatically controlled. However for cold climates, Meyer and Goetsch (1984), MacDonald et al. (1985), and Borg and Huminicki (1986) summarized major environmental control and structural problems encountered in these buildings as being poor temperature control and freezing of the sidewall and ridge openings, deterioration of exposed wood truss members beneath the open ridge, and the entry of birds, rain and snow at the ridge. In addition, the continuous ridge opening was costly to construct.

Air exchange processes for ridge openings

Bot (1983) studied the ventilation of a greenhouse by windows in the roof near the ridge. He noted that the thermal buoyancy effect on ventilation rate was important only at very low wind speeds and that sealing of the sidewall openings substantially reduced the ventilation due to the "stack" effect. He reported that "the air flow through the roof openings due to wind effects is assumed to be driven by fluctuating pressure differences over the individual openings". For ventilation due to wind, Malinowski (1971) described the mixing phenomenon for two holes, and the air exchange phenomenon, by penetration of eddies over an open surface area. The use of two chimneys as a ridge opening would create an air movement from one to the other, causing an air exchange within the building volume. The pulsing mixing process, where wind speed and direction conditions are rapidly changing, has been observed by Bird and DeBrabandere (1981), Meyer and Goetsch (1984), Milne (1985), MacDonald et al. (1985) and Borg and Huminicki (1986) in livestock buildings.

Control strategy using large ridge opening

Jedele (1979), Bird and DeBrabandere (1981), Janni and Bates (1984), and Meyer and Goetsch (1984) discussed a ventilation control strategy whereby the sidewall openings were closed during periods of cold weather leaving the ridge to act simultaneously as an air inlet and outlet. The sidewall openings were reopened when weather conditions were warmer or when the ridge alone was not sufficient to provide the desired ventilation rate. From this control strategy Meyer and Goetsch (1984) proposed a design of a continuous "Super-Ridge" 600 mm wide, automatically controlled by thermostats.

Control strategy using no ridge or minimum ridge openings

Using a manually controlled narrow ridge opening of 20 mm, suitable thermostat location, and a modulated type of automatic control system for the sidewall openings, Choinière et al. (1990) and Munroe et al. (1991) obtained stable temperatures and very low temperature fluctuations in a warm naturally ventilated swine barn. In Great Britain, Bruce (1979), Anon (1984), and Barrie and Smith (1986) presented a totally different control strategy based on the control of the sidewall openings for naturally ventilated buildings without ridge openings. However, no similar study using a closed ridge has been reported for the colder Canadian climate.

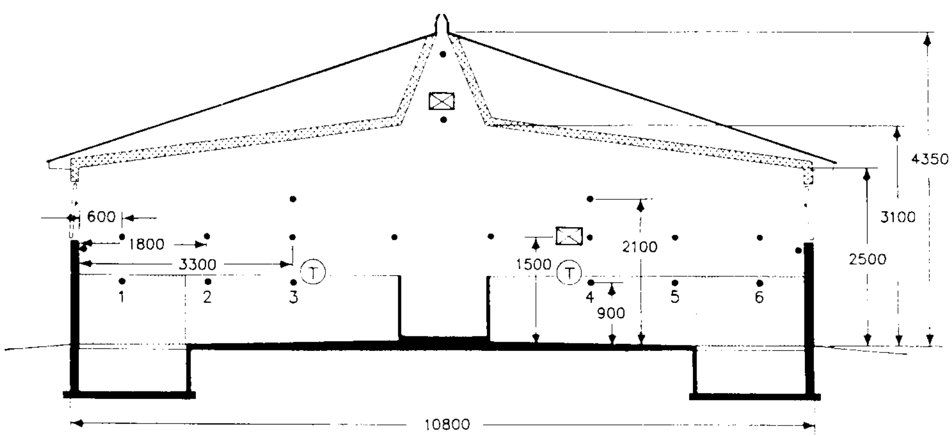
OBJECTIVES

The objectives of this study were (a) to determine the temperature distributions within an automatically controlled naturally ventilated (ACNV) 10.8 m wide swine growing-finishing building, during cold weather conditions using a continuous ridge opening width of 6 mm or 20 mm (equivalent to 1/2160 or 1/650 of floor area respectively); and (b) to compare relative humidities near animal and ridge levels for outside temperatures less than 0^{o}C.

METHODS AND PROCEDURES

Barn description

Tests were performed in a 10.8 x 23.0 m warm naturally ventilated hog barn (Fig. 1) located near Spencerville, ON.



LENGTH OF BUILDING.......23 000 mm
No. OF OFF CENTRE PIVOT ROTATING DOORS.......18
OVERALL INSULATION.......3.6 RSI
SCISSOR TRUSS CONSTRUCTION
ORIENTATION.......NORTH–SOUTH
DATE OF CONSTRUCTION.......1982
• TEMPERATURE SENSORS (T–TYPE THERMOCOUPLES)
Ⓣ THERMOSTAT, 0.9 m ABOVE FLOOR
⊠ THERMOHYGROGRAPH LOCATIONS

Fig. 1. Centre cross-section of barn showing location of thermocouples and thermohygrographs.

The barn was oriented north-south and had a 4.35 m ridge height and a sloping ceiling. Adjacent buildings were mainly to the north causing a minimum of interference to the prevailing 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). A total of 315 growing/finishing pigs ranging from 20 to 100 kg were housed in this barn during the tests.

The barn had a ridge opening length of 19.2 m leaving the ridge closed for 1.9 m from each end. During the tests the ridge opening width was set at either 20 mm or in the closed position using a manually adjusted cable and winch system to rotate the longitudinally hinged ridge baffles. In cold weather, this type of adjustable ridge does not completely seal in the closed position primarily due to some ice formation along the slot. In this particular installation the "closed" position left a ridge opening equivalent to a width of approximately 6 mm. The 20 and 6 mm ridge opening widths resulted in ridge opening area to floor area ratios of 1/650 and 1/2160, respectively.

Instrumentation

As shown in Fig. 1, 20 type T thermocouples were used to measure temperatures at the centre cross-section of the barn. Outside temperature and wind speed and direction at a 10 m height were monitored using a weather station installed near the barn. All sensors were read every 10 s and then averaged for each 10 minute period. These 10-min. averages were then used to compute the long term average and standard deviation for temperature at each thermocouple location. Humidity readings were recorded with two thermo-hygrographs, one located 1.5 m above the floor to reflect conditions near the pigs and the other near the ridge (Fig. 1).

Testing procedure

Tests were carried out between mid-October, 1987 and mid-February, 1988. The ridge opening width (6 mm or 20 mm) was switched about every two weeks; however, because of other tests being carried out during the same period and some problems due to equipment or instrumentation failure, the equivalent of approximately 8 weeks of data was obtained for this study.

The thermostats were located 0.9 m above the floor (Choinière et al. 1990) to try to reflect conditions at pig level. From October, 1987 to January, 1988, the target temperature was 18.5^{o}C and was based on conditions for finishing pigs with a mass of 35 to 70 kg. From January to the end of February, 1988 the target temperature was lowered to 17^{o}C as a reflection of the increased average size of the pigs in the room.

Analysis of data

The mean and standard deviation of temperature readings at each thermocouple location were calculated for each test period. This allowed observation of temperature variations and fluctuations within the barn during the range of weather conditions encountered.

Humidity data were divided into three ranges: below 75%, 75-85%, and above 85%. The percentages of time during the testing period when the relative humidity was within each of these ranges were determined. Data were tabulated separately for relative humidity recorded at the 1.5 m height and near the ridge.

RESULTS AND DISCUSSION

Long term observations

Temperature data gathered during the entire test period were analyzed to obtain an overall perspective of barn temperatures. For this analysis only the six thermocouple locations at the centre cross-section of the barn at the 0.9 m height were considered (Fig. 1) to better reflect conditions near animal level. During the overall test period, outside temperature ranged from -22^{o}C to 15^{o}C. The average and standard deviation of temperature at each of these locations for the various test periods are given in Table I.

Inside temperatures remained quite stable. There was a trend to lower mean temperatures and higher standard deviations near the sidewalls. This trend is also evident in Fig.2 and is consistent with results reported by Choinière et al. (1990) and Munroe et al. (1991). No practical differences were observed in temperature variations or fluctuations within the barn with either ridge opening width (6 or 20 mm) for either target temperature.

Relative humidity levels for cold weather conditions

Table II indicates humidity levels recorded during the study for both ridge opening widths and average outside temperatures less than 0^{o}C. It was assumed that if moisture problems due to low ventilation rates were to occur, they would likely occur under these temperature conditions.

According to Christison (1988), humidity levels between 50 and 85% for inside temperatures between 15 and 25^{o}C are acceptable. Relative humidity levels at the 1.5 m height above the floor were below 85% for 93 and 96% of the time for ridge opening widths of 6 and 20 mm, respectively. On this basis, both ridge opening widths resulted in good performance with respect to humidity near pig level (1.5 m height). The humidity levels near the ridge were generally higher compared to those at the 1.5 m height for both ridge opening widths. Trivers (1986) and Munroe et al. (1991) noted similar humidity gradients for a naturally ventilated hog barn during cold weather. High humidity levels at the ridge increase the concern about possible deterioration of wood structural members and truss plate connectors. Relative humidity near ridge level was greater than 85% for over twice the amount of time with the 6 mm wide as compared to the 20 mm wide ridge opening.

During periods of extremely cold weather (T_o<-15^{o}C) the control system reacted by closing the sidewall ventilation doors completely leaving only a few cracks around their perimeters. Air would enter and exhaust via infiltration and exfiltration through the ridge opening and across the building envelope. It was under these conditions for both opening widths that humidity levels sometimes exceeded 85%.

Other practical observations

Even though no major differences were noted based on the temperature data for the two ridge opening widths, visual observations did indicate some differences in the response of the ventilation control system. On numerous site visits, it was noticed that when the ridge opening width was closed from

Table I: Mean temperatures and standard deviations (°C) for six thermocouples

Date	Average outside (°C)	Ridge opening (mm)	Thermocouple no. 1		2		3		4		5		6	
Oct. 23 to Nov. 5/87	6	20	18.4	(1.5)	18.6	(1.2)	19.9	(1.0)	18.3	(1.0)	18.8	(1.3)	16.9	(1.8)
Nov. 23 to Nov. 30/87	0	6	18.2	(1.6)	18.6	(1.4)	18.8	(1.2)	18.4	(1.0)	18.6	(1.1)	17.2	(1.6)
Nov. 30 to Dec. 3/87	-1	6	18.2	(1.5)	18.4	(1.4)	18.8	(1.3)	18.6	(1.5)	18.6	(1.6)	16.8	(2.2)
Dec. 3 to Dec. 6/8	-3	20	18.7	(1.4)	18.2	(1.4)	18.8	(1.1)	18.2	(1.2)	18.4	(1.3)	16.5	(1.8)
Dec. 7 to Dec. 10/87	-2	20	18.5	(1.4)	18.5	(1.3)	18.8	(1.1)	18.3	(1.2)	18.5	(1.2)	17.4	(1.6)
Dec. 24 to Dec. 31/87	-7	6	17.0	(1.4)	18.2	(1.3)	18.6	(1.1)	17.7	(1.1)	17.8	(1.4)	16.0	(2.0)
Jan. 1 to Jan. 7/88	-9	6	18.2	(1.3)	18.5	(1.2)	18.5	(1.0)	17.7	(1.2)	17.8	(1.4)	16.6	(1.8)
Jan. 11 to Jan. 14/88	-8	20	17.0	(1.2)	17.3	(1.3)	17.6	(1.1)	16.5	(1.3)	16.2	(1.5)	14.0	(1.9)
Feb. 3 to Feb. 5/88	-14	6	15.3	(1.7)	15.6	(1.0)	16.3	(1.3)	16.7	(1.0)	16.7	(1.3)	14.3	(1.9)
Feb. 8 to Feb. 11/88	-14	6	16.3	(1.0)	16.5	(1.4)	16.9	(1.0)	17.1	(1.2)	17.0	(1.4)	15.5	(1.9)
Feb. 25 to Feb. 28/88	-8	6	18.6	(0.6)	18.9	(0.9)	19.4	(0.7)	18.3	(0.9)	18.3	(0.9)	17.1	(1.4)

Note: target temperature at 0.9 m above the floor (pig level) was 18.5°C from Oct. 23/87 to Jan. 7/88 and 17°C from Jan. 7 to Feb. 28, 1988.

Numbers in brackets indicate standard deviation.

Table II: Relative humidity near pig and ridge levels for cold weather ($T_0<0^{\circ}C$)[1]

	Total no. of hours	Relative humidity (%)	Percentage of total time
Ridge opening 20 mm	570		
Near ridge level		>85	13.7
		75-85	56.7
		<75	29.6
Near pig level		>85	3.7
		75-85	51.8
		<75	44.5
Ridge opening 6 mm	1100		
Near ridge level		>85	27.7
		75-85	57.2
		<75	15.1
Near pig level		>85	6.8
		75-85	41.8
		<75	51.4

[1] Data collected on various days between Nov. 30, 1987 and March 5, 1988, when the average outside temperature $T_0<0^{\circ}C$.

20 to 6 mm, the control system responded by increasing the sidewall door opening size, presumably in order to achieve the same net ventilation rate thereby maintaining a thermal balance. The reverse was observed when the ridge was opened from 6 to 20 mm.

As described by Timmons and Baughman (1981), Bruce (1982), Brockett and Albright (1987), and Timmons et al. (1984), changing the ridge outlet:inlet area ratio influences the height of the neutral plane above the floor. Bruce (1982) and Timmons et al. (1984) discussed the fact that the inlet opening becomes an exhaust if the neutral plane axis moves below the top of the opening. This phenomenon can occur especially when the intended inlet area is larger than the intended exhaust area. The authors frequently observed air exhausting at the sidewall openings during this study. As shown in Fig. 2, cold air entered at bottom of the leeward wall ventilation doors, then mixed and circulated inside the building while warm air exhausted at the top of the same doors. The windward doors acted as inlets at top and bottom.

Freezing of sidewall doors

Freezing of sidewall openings varied with wind speed, direction, and exterior temperature. Based on prior observations in this same barn, but using a ridge opening width of 25 to 35 mm, the sidewall doors began freezing shut during periods when the outside temperature dropped below approximately -10°C. Although not measured quantitatively, the freezing problems with the sidewall doors were less in this study with the 6 mm ridge opening width. This was probably as a result of the sidewall openings being slightly larger for the 6 mm ridge opening width as mentioned above and not closing completely until lower outside temperatures were reached as compared to the 20 mm ridge opening width.

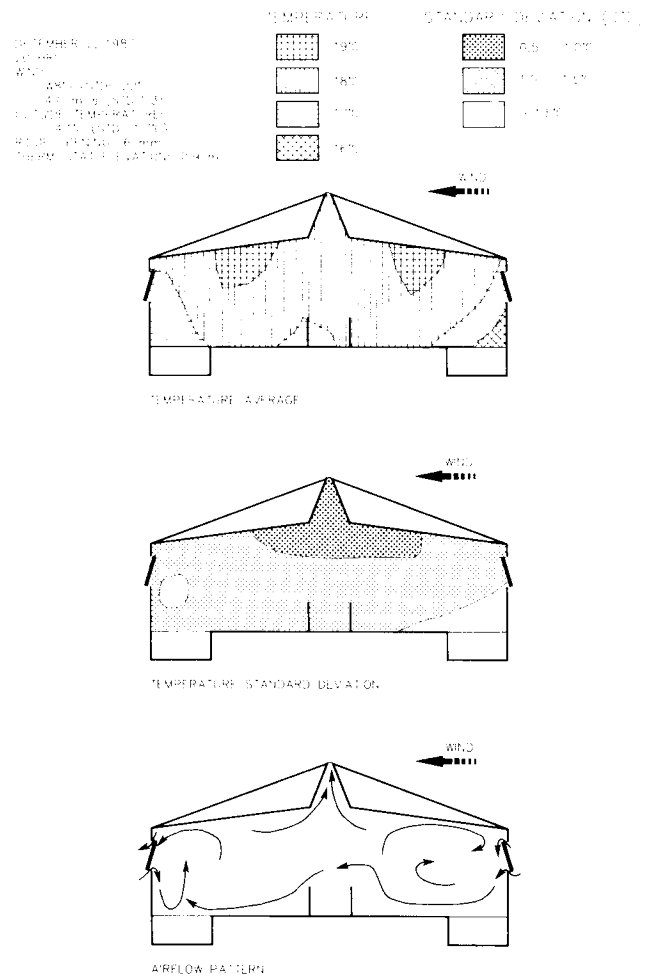


Fig. 2. Profile of temperatures, standard deviations and air flow patterns at a centre cross-section for cold weather conditions ($-15^oC<T<5^oC$).

SUMMARY AND CONCLUSIONS

The feasibility of using a narrow continuous ridge opening width was evaluated as a means of naturally ventilating a swine finishing barn from late October 1987 to late February 1988.

Tests with a 6 or 20 mm wide continuous ridge opening indicated the following conclusions:

1. Good control of inside temperatures over the sleeping area at animal level was maintained.
2. There were no noticeable differences in the temperature distributions at the centre cross-section of the barn for either the 6 mm or 20 mm wide ridge.
3. Relative humidity near pig level (1.5 m height) was below 85% for 93% and 96% of the time for ridge openings of 6 and 20 mm, respectively.
4. Relative humidity near the ridge was above 85% for 28% and 14% of the study time for ridge openings of 6 and 20 mm respectively. This becomes a concern with respect to structural deterioration of exposed truss joints at the ridge of the building. For this reason, a minimum ridge opening width of less than 6 mm is not recommended for this size and type of pig finishing barn.

Based on the good temperature and moisture control obtained during the test period, with outside temperatures ranging from -22^oC to 15^oC, a minimum ridge opening width ranging from 6 mm to 20 mm (1/2160 to 1/650 ridge opening area to floor area ratios respectively) would be adequate for a automatically controlled naturally ventilated pig finishing barn.

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