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MINIMUM RIDGE OPENING WIDTHS OF AN AUTOMATICALLY CONTROLLED NATURALLY VENTILATED SWINE BARN FOR A MODERATE TO COLD CLIMATE

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ABSTRACT

Conventional automatically controlled naturally ventilated (ACNV) barns have continuous ridge openings with widths ranging from 150 to 600 mm. A smaller ridge opening could help reduce environmental control and structural problems as well as initial construction costs. Minimum ridge opening widths of 6 and 20 mm (opening: floor area ratios of 1:2000 and 1:670 respectively) were studied in a hog finishing barn during moderate and cold weather. The minimum ridge opening concept was evaluated considering interior thermal performance, relative humidity and animal cleanliness. Recommendations for the use of a series of chimneys versus a continuous ridge opening to provide the minimum ridge opening are discussed. A control strategy for the minimum ridge opening concept is presented.

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 is expensive to build properly.

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 needed. A study was initiated to determine the ridge outlet area required to achieve at least the recommended minimum ventilation rates under winter conditions.

LITERATURE REVIEW

Natural ventilation for livestock housing has been investigated by Bruce (1975 and 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 Strom and Morsing (1984). Hellickson et al. (1983), Brockett and Albright (1984), 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. Strom and Morsing (1984) recommended equal areas of inlet and outlet, with both being automatically controlled. For cold climates, Meyer and Goetsch (1984), MacDonald et al. (1985), Borg and Huminicki (1986) summarized major environmental control and structural problems encountered in these buildings as being 1) - poor temperature control and 2) - freezing of the sidewall openings during cold weather.

Control strategy using large ridge opening

Jedele (1979), Bird and DeBrabandere (1981), Janni and Bates (1984), Meyer and Goetsch (1984) and Trivers (1986) discussed a control strategy whereby the sidewall openings were closed during

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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

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.

Choinière et al. (1987) reported the effects of thermostat location for automatically controlled sidewall openings in a warm naturally ventilated swine barn. The continuous ridge opening was manually controlled according to the weather conditions.

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 opening 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).

Comfort zone for finishing pigs

According to Curtis (1983), an animal can survive and grow in a range of temperatures. The optimal temperature range for animal growth is called the thermal comfort zone. This zone is somewhat above the lower critical temperature (LCT), but below the upper critical temperature (UCT). Choinière et al. (1986) discussed these aspects and considered the "optimal" zone for 40 kg finishing hogs to be 17-19°C, the "cool" zone to be between 15-17°C, and the "cold" or "discomfort" zone to be below 15°C. These considerations were based on work by De La Farge (1981), Yousef (1983), Christison (1988), Geers et al. (1988) and Hahn and Nienaber (1988).

Curtis (1983) also stated the importance of ventilation patterns and temperature control in relation to animal activities such as eating, drinking, dunging and sleeping. Choinière et al. (1986) emphasized that "a natural ventilation system should be able to establish a comfort zone where pigs could sleep without excessive temperature fluctuations".

OBJECTIVES

The purposes of this study were to:

- study the thermal performance of an automatically controlled naturally ventilated (ACNV) swine growing-finishing building with a ridge opening width of 6 mm or 20 mm, corresponding to an opening:floor-area ratio of 1:2000 and 1:670 respectively, during moderate ($5^oC<T_o<15^oC$) and cold ($T_o<5^oC$) weather;

- compare the inside thermal behavior for wind parallel or perpendicular to the barn;

- study moisture at animal and ridge levels for cold and extremely cold weather conditions ($T_o<5^oC$);

- observe pig cleanliness while using either ridge opening;

- establish design criteria for a minimum ridge outlet system using a series of chimneys for a warm, gable roofed hog finishing barn as illustrated by Canada Plan Service Plan M-3433.

METHODS AND PROCEDURES

Barn description

Tests were performed in a warm naturally ventilated hog barn owned by Albert de Wit, RR 4, Spencerville, Ontario. The barn is 10.0 X 23.0 X 4.35 m ridge height, oriented north-south. Scissor trusses provide a sloping ceiling. Adjacent buildings are mainly to the north of this barn, and caused a minimum of interference to the prevailing south-westerly winds. Each side of the barn had nine ventilation doors, each 2100 X 900 mm, pivoted above their centers. They were controlled by a modulated automatic control system based on thermostats (Choinière et al. 1987). A total of 315 finishing hogs ranging from 20 to 100 kg were housed in this barn during the tests.

This barn has a ridge opening length of 19.2 m. During the tests the ridge opening width was set at either 6 or 20 mm using a manually adjusted cable and winch system.

Instrumentation

The airflow patterns were observed using Dräger air current tubes (smoke).

As shown in Figure 1, 20 type T thermocouples were used to determine the temperature distribution of a cross-section at the center of the barn. Exterior temperatures, and wind speed and direction, at a 10 m height, were recorded by a weather station outside the barn. All sensors were read every 10 s and then averaged and recorded for each 10 minute period using a Kaye Digistrip II data logger connected to an IMB-PC. The data were then used to compute the long term average temperatures and standard deviations for each thermocouple location. These values were then used to plot isothermal lines and lines of equal standard deviation using a contour mapping program developed by Tremblay (1987).

Humidity readings were recorded with two thermohygrographs, one located 1.5 m above the floor and the other at the ridge (Figure 1).

Pig cleanliness and behavior

Overall pen cleanliness and behavior were noted twice per week. Notes included the number of pigs per pen (typically 15 hogs per pen, or 0.72 m^2/hog), pig average weight and pen cleanliness rated as follows: very dirty, dirty, dirty-clean, clean-dirty, clean or very clean. A very dirty pen would have a layer of manure over the floor and the hogs would be dirty. At the opposite end of the scale, a very clean pen would show no manure in the sleeping and eating areas and there would be no trace of manure on the hogs.

Testing procedure

Tests were carried out between October, 1987 and the end of February, 1988. The ridge opening (6 mm or 20 mm) was changed each week. However, because of the other tests being carried out and problems such as equipment or instrumentation failures, the equivalent of approximately 8 weeks of continuous data were obtained in this study. The thermostats were located 0.9 m above the floor (Choinière et al. 1987). From October, 1987 to January, 1988, the target temperature at pig level was 18.5°C corresponding to conditions for finishing hogs weighing 35 to 70 kg. From January to the end of February, 1988 the target temperature was lowered to 17°C since the hogs (70 to 100 kg) showed signs of tail biting. This problem was also observed by Geers et al. (1988).

Analysis of data

Temperature data were interpreted using two methods of analysis. The first consisted of evaluating data collected over the entire test period. Temperature data at pig level were plotted for each week of the test. This method allowed observation of the thermal behavior of the barn during a range of weather conditions. Such average temperatures and their respective standard deviations are presented in Table I.

For the second method of analysis, temperature data were selected where wind direction remained either parallel (south wind) or perpendicular (west wind) to the building length for periods of at least 10 h. These data were further classified into 3 ranges of exterior temperatures (T_o): intermediate ($5^oC<T_o<15^oC$); cold ($-15^oC<T_o<5^oC$); extremely cold ($T_o<-15^oC$). Typical profiles for these selected data are presented in Figures 2 and 3.

Humidity data were divided into three ranges: 65-75%, 75-85% and above 85%. The percentages of time during the total testing period when the relative humidity was within each of these ranges were determined. Data were tabulated separately for relative humidity recorded near pig level (1.5 m) and at the ridge level.

RESULTS AND DISCUSSION

Long term observations

Temperature data gathered during the entire test period were analysed to obtain an overall perspective of the barn thermal performance. For this analysis only the six temperature readings taken at pig level at the central cross section of the barn were tabulated (see Figure 1 - thermocouples No. 1, 2, 3, 4, 5, 6). These data are tablulated in terms of their average and standard deviation for the various test periods as noted in Table I. During the test period, exterior temperature fluctuated from -22^oC to 15^oC.

Table I shows that interior temperatures were maintained very close to the target temperatures (standard deviations within 0.6 to 2.2^oC). Moreover, no noticeable differences were observed in the thermal performance of the barn with either ridge (6 or 20 mm) opening for either target temperature.

Pig cleanliness

Generally, the cleanliness was ranked between clean and very clean for both ridge widths. Some pens were dirty for a short time when a defective thermostat caused standard deviations of temperature greater than 3°C over the sleeping zone. This temporarily disrupted the good manuring habits of the pigs until the thermostats were readjusted.

Pig behavior

The tail biting problem started at the end of December but did not significantly disturb the manuring habits. At this time the target temperature was 18.5 C and the hogs weighed between 50 and 70 kg. This problem was solved by lowering the target temperature to 17°C. This manoeuvre also slightly improved the manuring habits of the pigs.

Observations under specific weather conditions

The effects of wind direction and exterior temperature on the thermal behavior within the ventilated air space were discussed previously (Choinière et al. 1987). Figures 2 and 3 show typical profiles of temperature and their standard deviations obtained with ridge openings widths of 6 and 20 mm.

Figure 2 illustrates the thermal behavior of the barn under intermediate exterior conditions ($5^{o}C<T_o<15^{o}C$). Typical airflow patterns under these temperature conditions and with the wind perpendicular to the building are also shown in Figure 2. The air entered the windward side, then followed the ceiling to recirculate at the middle of the barn or crossed the barn and exited by the leeward side. The temperature profiles and the air patterns inside the barn were similar for both ridge openings.

Figure 3 shows a typical temperature profile and airflow pattern under cold weather conditions. Then the thermostat control system reacted by causing the sidewall openings to be very nearly closed most of the time. Most of the mixing of the incoming air occurred within 1 m of the sidewall openings as indicated by the temperature gradients close to the sidewalls. Generally, the incoming air dropped to the floor before crossing the barn. There were no differences in the temperature profiles for either ridge opening width.

Ridge opening width

Even though no major differences were noted from the temperature data for the two ridge widths, visual observations did indicate some differences in the reaction of the control system.

As described by Timmons and Baughman (1981), Bruce (1982), Brockett and Albright (1984) 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 height of the opening. This phenomenom can occur especially when the inlet area is larger than the exhaust area. Exhausting at the sidewall openings was frequently observed by the authors. As shown in Figure 3, the cold air entered at the lower part of the leeward well ventilation doors, warmed up and circulated inside the building. Finally, warm air was exhausted at the top part of the same doors. The windward doors acted as inlets because of the wind.

For the same cold weather conditions, the control system reacted by increasing the sidewall openings for the ridge width of 6 mm as compared to 20 mm, presumably providing the same net ventilation rate.

Freezing of sidewall doors

Freezing of sidewall openings varied with wind speed, direction and exterior temperature. Based on previous observations, freezing of the sidewall doors occurred during periods of exterior temperature below approximately -10°C for the conventional ridge ventilation system using a ridge opening width of 25 to 35 mm. But in this study, using the minimum ridge concept, the sidewall openings generally stayed in an open position for lower exterior temperatures than was the case with the conventional ridge opening. The freezing problems with the sidewall doors were considerably reduced especially with the 6 mm ridge opening.

Relative humidity levels for cold weather conditions

Table II presents humidity levels recorded during the experiment for both ridge opening widths and average exterior temperatures less than 0°C. It was considered that if excess moisture problems were likely to occur due to low ventilation rates, it would be under these temperature conditions.

According to Christison (1988), humidity levels between 50 and 85% for inside temperatures between 15 and 25°C are acceptable. On this basis, both ridge opening widths resulted in good performance with respect to humidity at the pig level. The results show a vertical gradient of humidity increasing about 10% RH from pig level to the ridge for both ridge opening widths. Trivers (1986) and Choinière et al. (1987) presented similar humidity gradient data for a naturally ventilated hog barn during cold weather.

High moisture levels at the ridge increase the concern about possible deterioration of wood and trussplate connectors.

Heat deficit temperature

A heat deficit occurs when the inside temperature drops significantly below the target temperature while the minimum required ventilation rate is being maintained.

Heat deficits were noted for exterior temperatures below -22°C and below -18°C for ridge opening widths of 6 and 20 mm respectively. Humidity levels were in the 85 to 95% range near the pig level indicating under-ventilation in both cases.

Minimum ventilation rates

During periods of extremely cold weather (T_o<-15°C) the control system reacted by closing the sidewall openings, leaving only a few cracks around their perimeters. Since a minimum ventilation rate must be maintained, the best location for the exhaust would be at the top of the barn where the highest humidity levels were observed.

Required ridge opening area

Based on the results obtained during the test period, with exterior temperatures ranging from -22°C to 15°C, a minimum ridge opening width of either 6 mm or 20 mm was sufficient to provide a minimum ventilation rate during extremely cold weather and still provide adequate temperature control for warmer weather. A minimum ridge opening:floor area of 1:2000 is therefore proposed. It is noted that the 6 mm width is only 25% of the 25 mm continuous opening width recommended by Meyer and Goetsch (1984) for winter conditions.

Use of chimneys

Based on the adequate thermal performances obtained with the minimum ridge concept, the reduced ridge opening area required for minimum ventilation suggests the possibility of replacing the continuous ridge opening with a series of adjustable chimneys as shown by Munroe and Choinière (1986).

The use of chimneys offers many advantages over the use of a continuous ridge opening: the chimney opening is easy to adjust with an interior rotating baffle; the construction costs for a series of chimneys are less than for a continuous adjustable open ridge; and the use of properly-made chimneys should eliminate the problem of wood truss exposure to moisture from condensation, rain and snow reducing the potential for deterioration of these building components.

Figure 4 shows a recommended design for chimneys to reduce condensation problems. Milne (1985) recommended a minimum insulation value of RSI 1.8 which corresponds to 50 mm of extruded polystyrene foam. An insulated rotating baffle is used to vary the effective area of the opening. The off-center hinge allows the baffle to move to the "closed" position automatically if the control wire loosens or breaks. In the "closed" position, a space of 25 mm is still left around the perimeter of the baffle to avoid total closure and prevent freezing problems. Each chimney has a maximum effective total open area of 0.18 m^2 when the baffle is vertical (fully open) and 0.043 m^2 when it is horizontal (fully closed).

Based on the above, Table III presents the number of chimneys required for a typical barn for finishing hogs such as CPS M-3433. One chimney per 8 m of building length would supply enough opening area with "closed" baffles to allow minimum winter ventilation.

Control strategy for the minimum ridge concept

To obtain desirable environmental conditions in the barn and maintain at least the minimum ventilation rates in winter, the building requires adequate insulation (the same as required for a warm mechanically ventilated building) and an automatic control system for the sidewall openings.

As described by Choinière et al. (1987), a control strategy for naturally ventilated buildings should consider weather conditions. Chimneys would require two adjustments per year; open when exterior temperatures were generally above 5°C, and closed otherwise. The automatic thermostat control system of the sidewall openings would then regulate the inside temperature.

During extremely cold conditions (below -15°C), the sidewall panels would be closed and the minimum ventilation rate would be achieved via the chimneys and air infiltration through cracks, around panels and elsewhere.

Summary and Conclusions

A minimum continuous ridge opening 6 mm or 20 mm wide was studied as a means of naturally ventilating a swine finishing barn from October 1987 to the end of February 1988. Also, interior environmental parameters were compared to examine the feasibility of replacing the continuous ridge opening of the typical naturally ventilated swine barn (CPS Plan M-3433) with a series of chimneys.

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

1. Good control of inside temperatures (standard deviation 1.5°C) at animal level was maintained for a target temperature of 17°C.

2. There were no noticeable difference in the thermal behavior

at the central profile of the barn for winds perpendicular or parallel to the building length in the three exterior temperature ranges studied, warm ($5^oC<T_o<15^oC$), cold ($-15^oC<T^o<5^oC$) and extremely cold ($T^o<-15^oC$).

3. Relative humidity near the pig level was between 65 and 85% for 93 and 96% of the time for ridge openings of 6 and 20 mm respectively.

4. Relative humidity at the ridge level was above 85 for 26% and 13% of the study time for ridge openings of 6 mm and 20 mm respectively. This is a concern with respect to structural deterioration of exposed truss joints at the ridge of the building.

5. No noticeable differences were observed in the general cleanliness of the finishing hogs for either ridge opening.

6. For moderate and cold climates, the minimum ridge opening concept could be used without adversely affecting environmental conditions at the pig level in the building tested.

Design recommendations

For a hog finishing barn such as CPS M-3433, built with the recommended level of insulation, and fitted with a commercially available automatic control system for the sidewall openings as described by Choinière et al. (1987), a series of chimneys spaced 8 m apart should be adequate for winter and summer ventilation. Ideally, the operator should fully close the chimney baffles in the chimneys during late autumn when exterior temperatures are generally below 5°C and reopen them when temperatures rise above this value. The automatically controlled sidewall panels can then provide the desired inside temperature regulation.

Further studies

Other aspects relating to the minimum ridge opening concept for natural ventilation of warm barns that require study are:

1. Warm weather performance (above 20°C)

2. Internal airflow patterns under isothermal (warm weather) conditions using a conventional sloped ceiling versus a flat ceiling.

3. A comparison of the internal environmental conditions using a series of chimneys versus a continuous open ridge of equivalent area.

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Table I. Average temperature (T) and standard deviation (STD) for thermocouples 1, 2, 3, 4, 5, 6, (Figure 1)

Date	Avg. outside temp. (°C)	Ridge opening (mm)	THERMOCOUPLE NO. 1		2		3		4		5		6	
			T(°C)	STD	T(°C)	STD	T(°C)	STD	T(°C)	STD	T(°C)	STD	T(°C)	STD
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	1.5
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. 6/87	-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
Oct. 23/87 to Jan. 7/88		6	18.1	1.4	18.4	1.3	18.7	1.2	18.1	1.2	18.2	1.4	16.6	1.9
		20	18.5	1.5	18.5	1.3	18.8	1.1	18.2	1.1	18.5	1.3	16.9	1.7
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
Jan. 11 to Feb. 23/88		6	16.7	1.2	17.0	1.4	17.5	1.0	17.4	1.0	17.3	1.2	15.6	1.9
		20	17.0	1.2	17.3	1.2	17.6	1.1	16.5	1.3	16.2	1.5	14.0	1.8

Note: target temperature at pig level was 18.5°C from Oct. 23/87 to Jan. 7/88 and and 17°C from Jan. 7 to Feb. 28, 1988.

Table II. Relative humidity near pig and ridge levels for cold weather ($T_o < 0^oC$)

	Relative humidity (%)	Percentage of total time
Ridge opening 20 mm		
Near Ridge level	>85	13.7
	75 -85	56.7
	65 -75	29.6
Near Pig level	>85	3.7
	75 -85	51.8
	65 -75	44.5
Ridge opening 6 mm		
Near Ridge level	>85	27.7
	75 -85	57.2
	65 -75	15.1
Near Pig level	>85	6.8
	75 -85	41.8
	65 -75	51.4

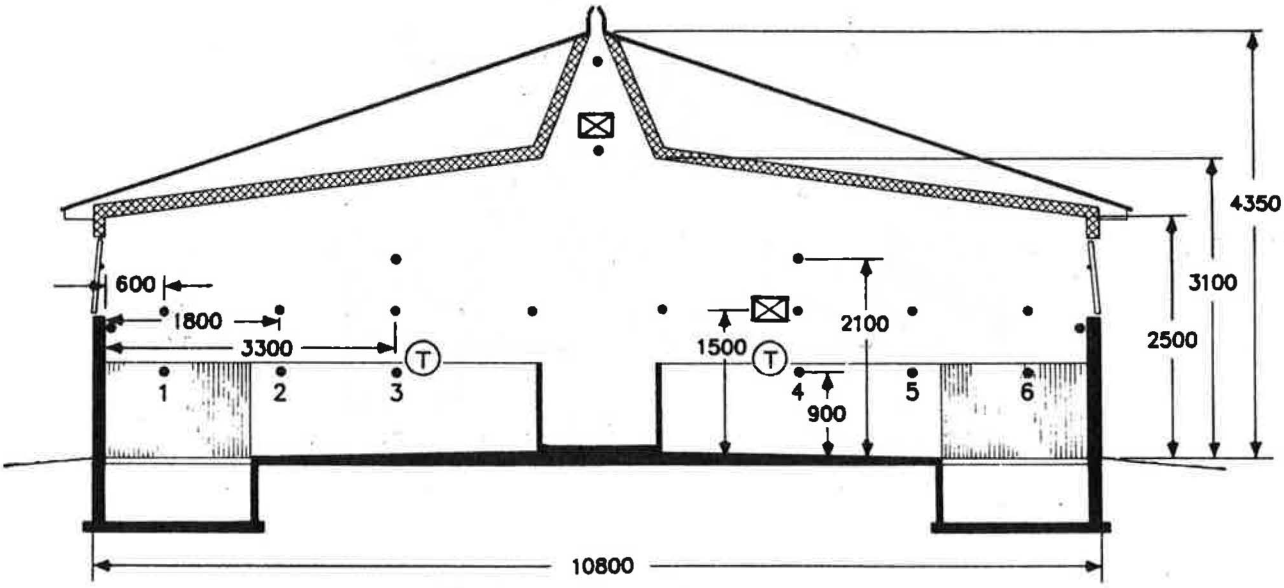
Table III. Number of chimneys required to replace open ridge

Tested ridge opening	Ratio of ridge opening to floor area	No. of chimneys required (winter)*	Ratio of chimney opening to floor area (summer)**
6 mm X 19.2 m	1/2160	2.7	1/510
20 mm X 19.2 m	1/650	8.9	1/155

Notes: Values based on typical hog finishing building such as CPS M-3433: 10.8 m wide X 23.0 m long and chimneys having 0.18 m^2 open area in the fully open position and 0.043 m^2 open area in the fully closed position.

*To give equivalent area of continuous ridge, with chimneys in fully closed position.

** Based on number of chimneys in col. 3 all fully open.



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 Central cross-section of barn showing location of thermocouples and thermohygrographs

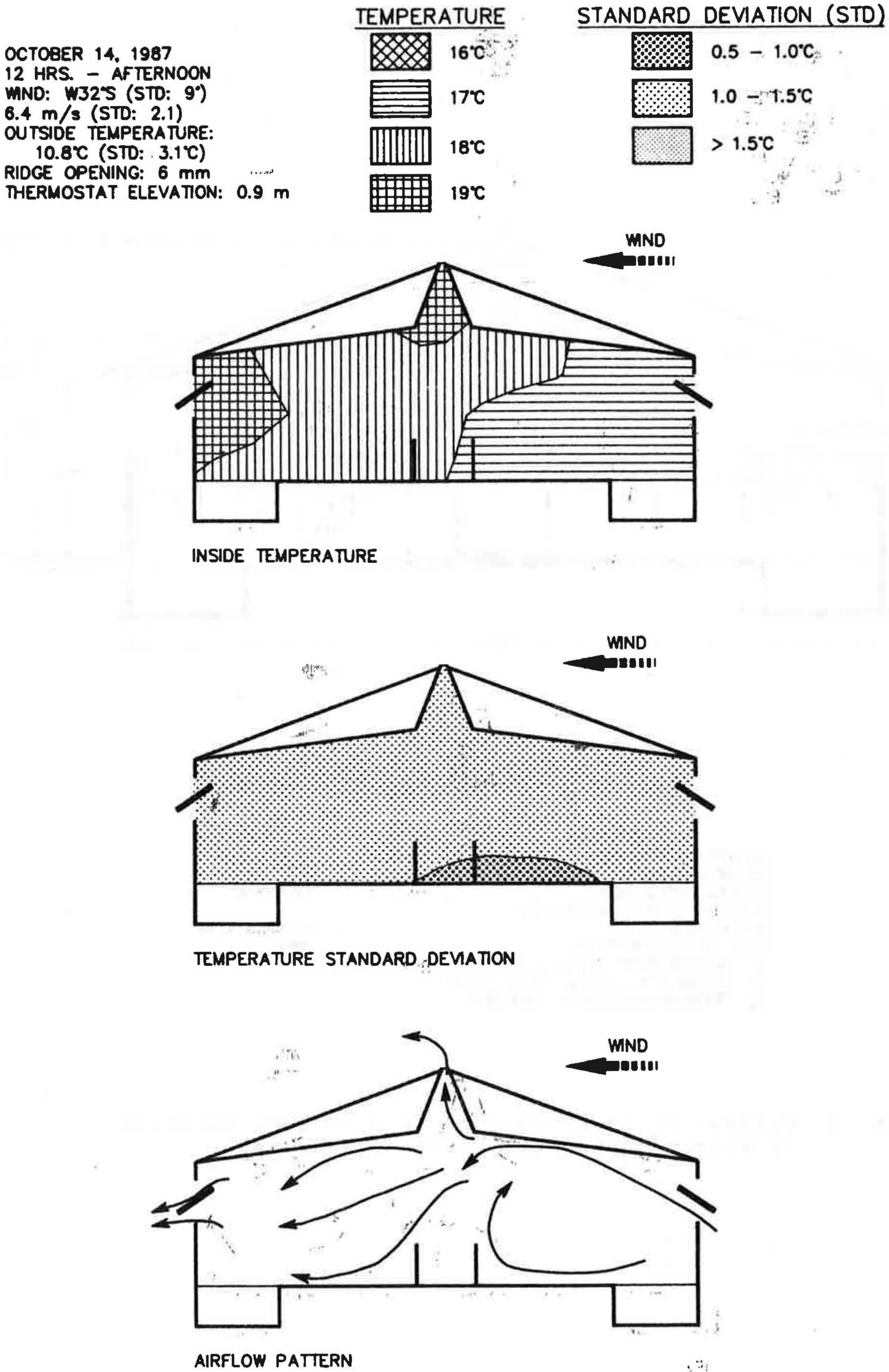


Fig. 2 Profile of temperatures, standard deviations and air flow patterns at a central cross-section for west winds, and intermediate weather conditions.

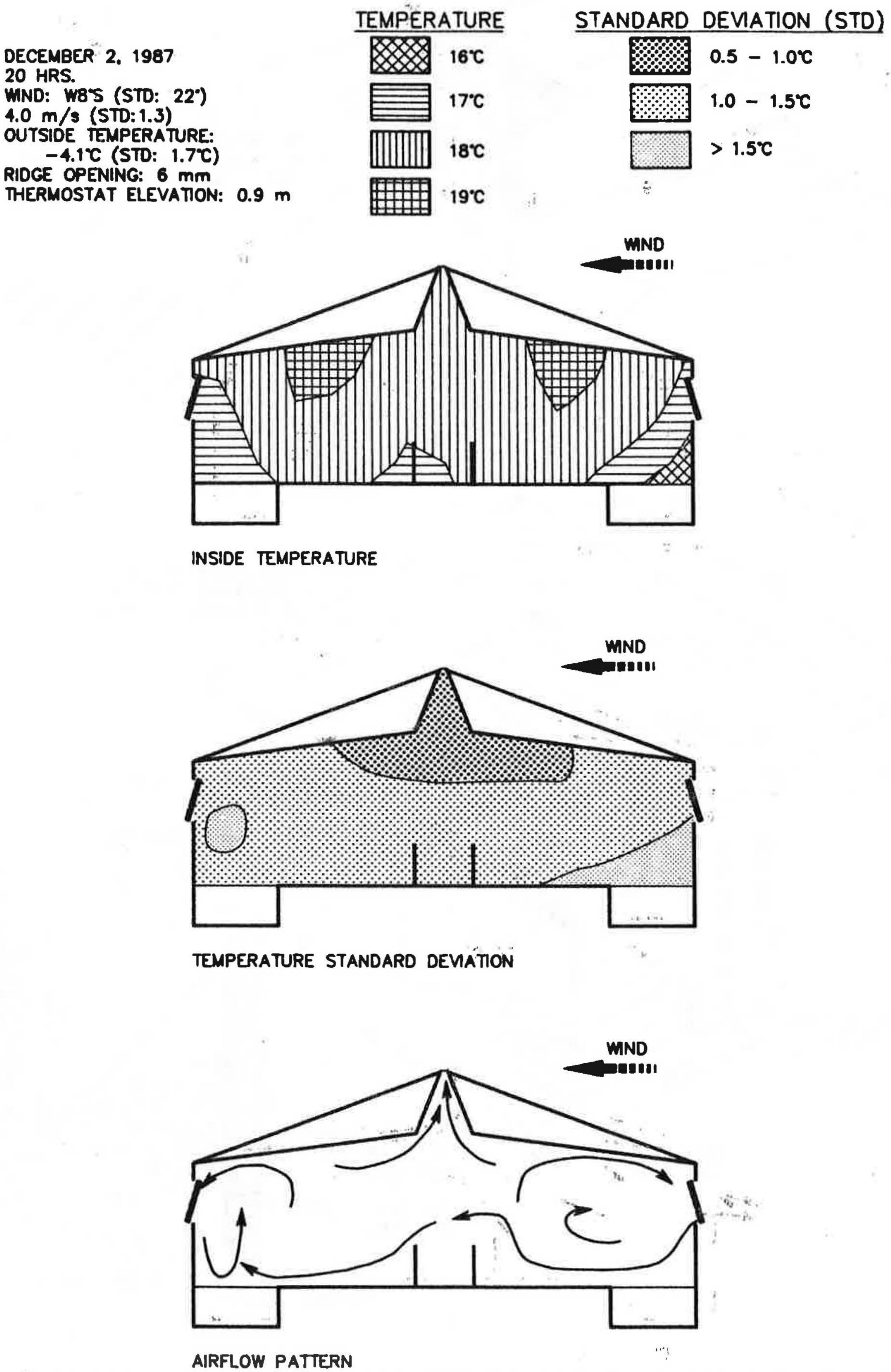


Fig. 3 Profile of temperatures, standard deviations and air flow patterns at a central cross-section for west wind, and cold weather conditions.

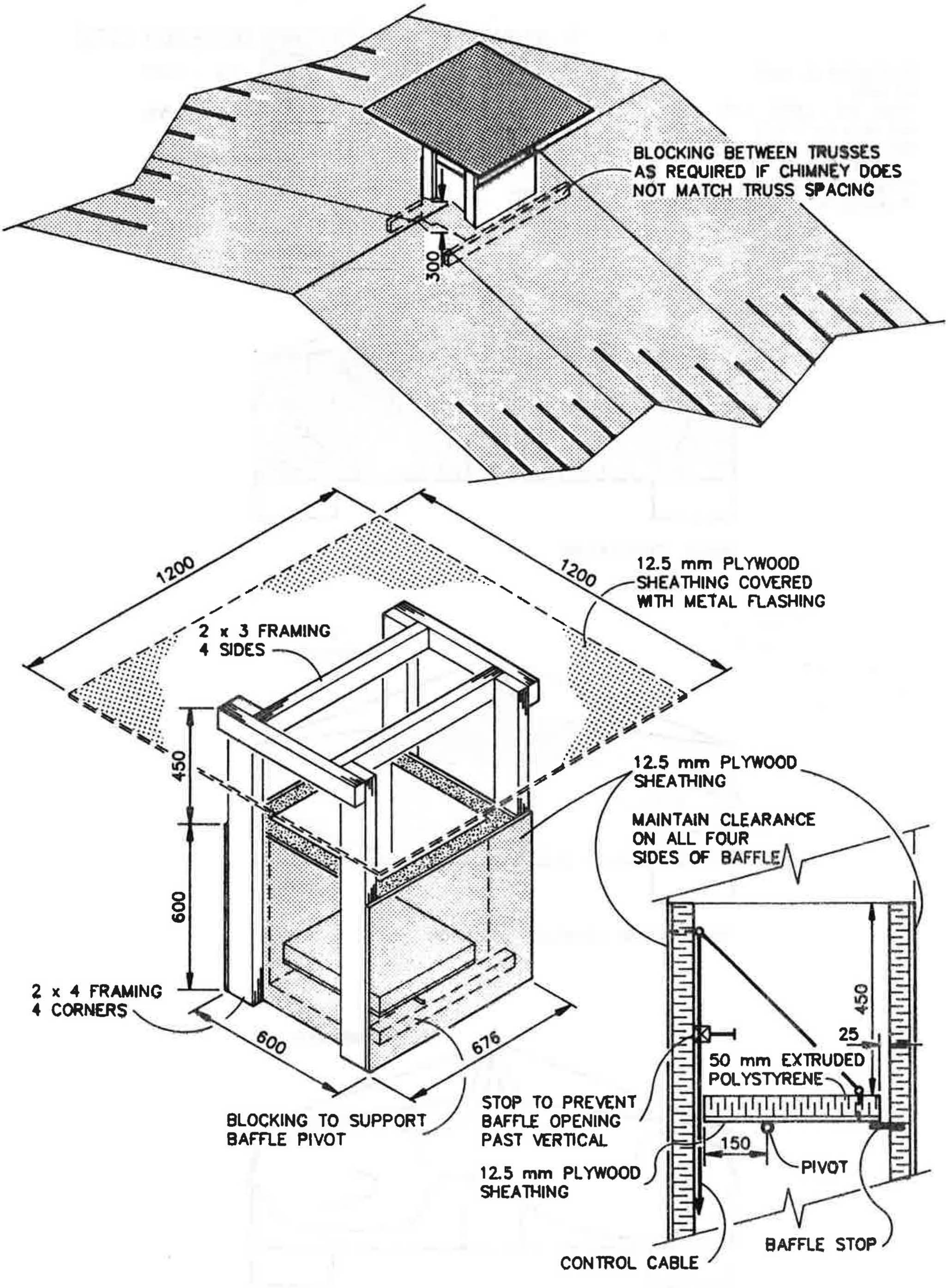


Fig. 4 Schematic of chimney with rotating baffle, effective opening area 0.18 m^2 in open position, 0.043 m^2 in closed position (all dimensions are in millimetres).