Comparison of a modulated vs nonmodulated control system in a warm naturally ventilated swine barn

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Munroe, J.A., Choinière, Y. and Blais, F. 1991. **Comparison of a modulated vs nonmodulated control system in a warm naturally ventilated swine barn.** Can. Agric. Eng. **33**:335-340. Two air inlet control systems for a naturally ventilated swine finishing barn were compared on the basis of temperature regulation during winter conditions . The barn was fitted with continuous above-centre pivot rotating doors in the sidewalls and a continuous ridge opening. The nonmodulated system used thermostats, compressed air cylinders and pistons to totally open or close the air inlets. The modulated control system used thermostats, a gear motor, and a time delay to step the inlets open and closed in small increments. Results showed that temperature fluctuations at pig level were reduced and temperature across the room at animal level was more uniform and generally warmer with the modulated as compared to the nonmodulated system.

Deux systèmes de contrôle des portes latérales dans les murs pour la ventilation naturelle furent comparés. La porcherie d'engraissement utilisée pour les essais avait des portes rotatives commes ouvertures des murs et une ouverture du toit continue. Le système de contrôle non-modulé était composé de thermostats et de cylindres à l'air comprimé pour ouvrir ou fermer complètement les portes latérales. A l'opposée, le système de contrôle modulé était composé de thermostats, de moteurs de multipliés, et d'un système d'horlogerie permettant d'ouvrir ou de fermer les portes latérales par petits increments réguliers. Les résultats démontrent que le système de ventilation naturelle à contrôle modulé a permis de réduire considérablement les fluctuations de températures au niveau des porcs et ce système a aussi réussi à maintenir généralement les zones de températures au plancher plus chaudes et plus uniformes comparativement au système de contrôle non-modulé.

INTRODUCTION

The ventilation system in any livestock building directly affects the air velocities, air exchange rates, air flow patterns and thermal patterns within the building. The influence of each parameter depends in part upon the ventilation system. There has been a recent resurgence of interest in naturally ventilated livestock buildings, and of attempts to establish the effect of design parameters on ventilation performance. In naturally ventilated buildings, and particularly in warm buildings, some sort of control mechanism is desirable to reduce the fluctuations of ventilation parameters such as air temperature and drafts. One type of commercial control system uses a thermostat to initiate the movement of large ventilation doors in the sidewalls. This system could be considered nonmodulated in that when activated, the doors moved immediately to the fully open or fully closed position. Experience indicated that such a system could result in large, rapid temperature fluctuations in the barn. A modified version of this system, wherein the element moving the ventilation doors was changed from a compressed air cylinder to an electrically driven gear motor and linear actuator is now available. The addition of time delays in the control circuitry permits the doors to open or close in small increments, thus resulting in a modulated system. A local farmer was recently converting from a nonmodulated to a modulated system, thus presenting an excellent opportunity to compare the performance of each system, in terms of interior temperature fluctuations with time and variation with location, in the same barn.

REVIEW OF LITERATURE

Natural ventilation has been described by Bird and De Brabandere (1981) and Milne (1983) as being a slow displacement of air from the inlet to the outlet. Choinière et al. (1988a, 1989) showed that airflow patterns were different for summer (isothermal) versus winter (nonisothermal) conditions. This difference in patterns was due to the difference in density of air entering the building as well as to the low pressure differences normally associated with natural ventilation. However, according to their observations, the winter air flow patterns should remain constant for outdoor temperatures below the 0-5°C range.

In Belgium, Daelemans et al. (1986) demonstrated that there was no animal production advantage to using a fan ventilated system as compared to using a well insulated, naturally ventilated building. In that case, large sidewall doors and chimneys were adjusted manually. Pig feed conversion ratio, daily gain, mortality, and carcass quality were similar for both types of ventilation systems.

According to Curtis (1983), an animal can survive and grow in a variety of temperature zones. 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). For this study the "optimal" zone for 40 kg finishing hogs was considered to be between 17 and 19°C, the "warm" zone to be between 19 and 25°C, the "cool" zone to be between 15 and 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 (1985) and Curtis (1983).

Curtis (1983) also stated the importance of ventilation patterns and temperature control in relation to animal activities such as eating, drinking, dunging and sleeping. A natural ventilation system should be able to establish comfort zones where pigs could sleep without excessive temperature fluctuations and free of drafts.

In the United Kingdom, Spackman et al. (1983) and Anon (1984) reported the capability of an automatically controlled, naturally ventilated (ACNV) system to maintain indoor temperature between 19-21°C in cold weather. The automatic controls included a gear motor and linear actuator which allowed the ventilation doors to open or close in small increments, resulting in a modulated ventilation system.

Ström and Morsing (1984) studied a similar building, except that a manually controlled ridge opening was used instead of the chimneys. They found that indoor temperature was maintained between 15 and 18°C while outdoor temperature varied between -20 and 0°C.

Bird and De Brabandere (1981) measured indoor temperature fluctuations of 5-10°C in an automatically controlled, but nonmodulated, naturally ventilated barn. Borg and Huminicki (1986) reported work carried out in two ACNV hog barns, one having a modulated type, and the other a nonmodulated type of ventilation system. The nonmodulated system resulted in cyclical temperature fluctuations, corresponding to the opening and closing of ventilation doors, whereas the modulated system did not. As well, the former resulted in greater temperature fluctuations than did the latter. Borg and Huminicki again raised the question of what frequency and magnitude of temperature fluctuation are acceptable in a hog barn.

Choinière et al. (1988b) reported very good temperature control using a modulated automatically controlled system. Temperature fluctuations in the animal zone were small (std dev <2°C). Choinière et al. (1987) investigated the preferred thermostat location for automatically controlled naturally ventilated warm hog barns. Choinière et al. (1988c) evaluated the potential for using a wind sensor to ensure ventilation via leeward openings only. Results indicated no particular advantage in thermal conditions due to the use of such a sensor.

In Manitoba, Hodgkinson and Sheridan (1984) noted that some producers using naturally ventilated barns experienced more pig health problems, such as haemophilus pneumonia. It was felt that this was due to stresses caused by barn temperature fluctuations of 5-10°C over a 5 to 10-minute period. Nienaber et al. (1989), concluded that temperature cycles of 12°C or more should be avoided.

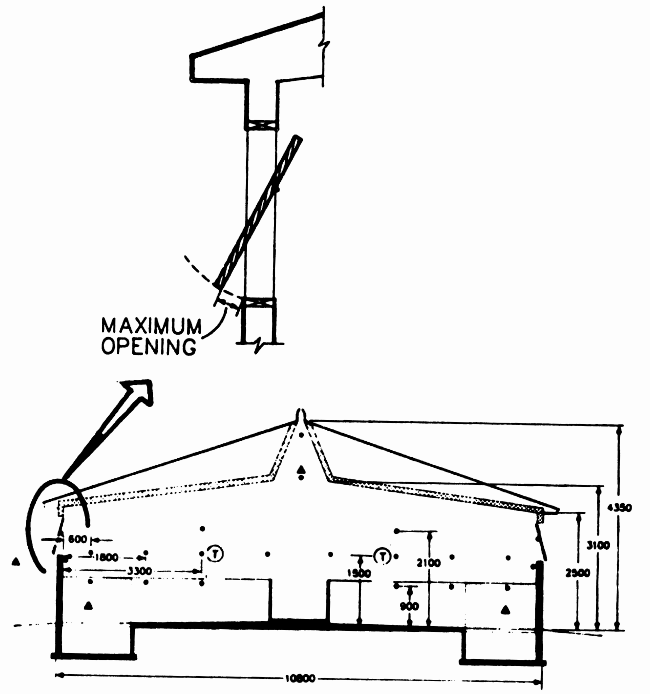
OBJECTIVES

The main objective of this study was to compare the performance of a modulated versus a nonmodulated natural ventilation system in the same swine barn by considering temperature profiles and fluctuations, gas levels, and relative humidities obtained with each system.

TEST PROCEDURES AND INSTRUMENTATION

The monitored barn was a 10.8 x 23.0 m naturally ventilated growing/finishing barn owned by A. de Witt, Spencerville, ON. A cross section of this barn is shown in Fig. 1. The barn was originally fitted with a nonmodulated ventilation system comprised of two thermostats, compressed air cylinders and pistons which opened or closed ventilation doors, solenoid valves and an air compressor. In operation, the thermostat would actuate the solenoid valves which in turn caused the air operated pistons to fully open or close the ventilation doors. The maximum opening of the doors was typically 150-200 mm but this maximum was adjustable.

In the winter of 1985, the operating system that controlled the ventilation doors was changed to a modulated type. This system was comprised of two thermostats, time delays, and gear motor driven actuators that opened or closed the ventilation doors. The adjustable timer control energized the thermostat periodically, for example, every three minutes, which in turn activated the 24V dc gear motor to open or close the ventilation doors. Another adjustable timer controlled how long the gear motor remained energized after being activated, for example 3 seconds. This short period only allowed the doors to open or close in increments of 20-30 mm, thus providing modulation to the operation of the system. The thermostats had a dead band of about 2°C. Both the nonmodulated and modulated system were distributed by Faromor Inc., Waterloo, ON.



LENGTH OF BUILDING.................................23 000 mm
No. OF OFF CENTRE PIVOT ROTATING DOORS...........17
OVERALL INSULATION.................................3.6 RSI
SCISSOR TRUSS CONSTRUCTION
ORIENTATION..NORTH–SOUTH
DATE OF CONSTRUCTION...............................1982
● TEMPERATURE SENSORS
▲ CO_2 AND RH MEASUREMENT
Ⓣ THERMOSTAT
ALL DIMENSIONS ARE IN MILLIMETRES

Fig. 1. Cross-section of barn showing location of thermocouples, and CO_2 and RH measurements.

As indicated in Fig. 1, 20 thermocouples were used to sense temperatures over a cross section of the barn at about mid-length. Outside temperature, wind speed and direction were measured at a weather station installed next to the barn. While testing, all weather station and barn temperature readings were taken at intervals of 10 seconds. A land drainage program, Macdrain, (Kok and Tremblay 1988) was used to plot isothermal contours from the data.

Air flow patterns were observed using air current smoke tubes. Carbon dioxide (CO_2) levels were determined using a hand pump and gas detection tubes at four locations (Fig. 1). Relative humidity was determined using a sling psychrometer.

Between January and November 1985, approximately 30 tests of 1 hour duration each were performed for the nonmodulated system. Following conversion to the modulated system, approximately 140 tests were carried out. For comparison purposes, test data for the modulated and nonmodulated systems were chosen such that outside conditions (temperature, wind speed and direction) were similar. Test periods selected were March 26, 1985 for the nonmodulated system and March 17, 1986 for the modulated system. Reference data for these test periods are given in Fig. 2.

Previous work with a nonmodulated system (Choinière 1985) had indicated better performance in terms of smaller temperature fluctuations and variations, using only leeward ventilation as opposed to only windward ventilation. Further work by Choinière et al. (1988c) with a modulated system found that better thermal performance was obtained simultaneously using both leeward and windward openings as compared to using either one separately.

In the present study, selected 1-h test data periods were used to compare the performance for the best case of the modulated system (simultaneous leeward and windward openings) with the best case of the nonmodulated system (leeward openings only). The manually operated continuous ridge opening was maintained at 20-30 mm wide until the exterior temperature dropped to about -10°C at which time the opening was reduced to 12 mm wide.

RESULTS AND DISCUSSION

Figure 2 shows a comparison of temperatures monitored using the modulated vs nonmodulated control systems. Particular data sets were selected in order to obtain similar weather conditions. In addition, two exterior temperature conditions (approximately -3°C (Case A) and -11°C (Case B)) were selected to illustrate some differences that occur with decreasing temperature. Although not compared statistically, all results shown were considered typical for the respective control system and weather conditions indicated.

Figure 3 indicates the temperature zones, based on average temperatures over the 1-h test periods, established at the central cross-section of the barn as well as temperature stability over the same 1-h test period.

In Fig. 2, it can be seen that fluctuations were greater at a given location for Case A for the nonmodulated system vs modulated system (up to 10° vs up to 6°C respectively). As well, the minimum temperatures were about 4°C lower with the nonmodulated system. For Case B, the temperature fluctuations remained approximately the same for the nonmodulated system (up to 10°C), but decreased slightly with the modulated system. The temperature variation across the barn at any given time, which is very evident with the nonmodulated system, was reduced with the modulated system.

The interior temperature varied in a cyclic pattern in all cases. For Case A, the period appeared to be about 35 minutes for the nonmodulated system, and slightly shorter for the modulated system. For Case B, the period decreased to approximately 8-9 minutes for the nonmodulated system whereas it increased slightly for the modulated system. This is likely due to the fact that at the lower outside temperature (Case B), the sidewall doors were only open 12-25 mm with the modulated system whereas they still opened to about 75 mm with the nonmodulated system or closed completely. This smaller change in door opening size with the modulated system would lead to smaller changes in the ventilation rate, and slower changes in interior thermal conditions.

Figure 3 shows that no portion of the floor was considered to be a cold zone with the modulated system whereas a considerable portion of the floor on the leeward side of the building was considered to be cold with the nonmodulated system. Temperature stability was also much better with the modulated system for both Cases A and B.

The temperature variation with location and fluctuations with time appear consistent with the general airflow patterns described earlier by Choinière et al (1987) for these two ventilation systems. With the nonmodulated system (leeward openings only), air entered the building mainly by the leeward wall openings and exhausted at the ridge, resulting in lower temperature stability near the leeward wall. With the modulated system (simultaneous leeward and windward openings), air entered mainly through the windward wall and exhausted at the ridge and leeward wall.

Although not specifically recorded, the farmer observed that the dunging habits of the hogs were better with the modulated system as compared to with the nonmodulated system, particularly during periods when the outside temperature was fluctuating widely. This might be attributed to the smaller range of temperature fluctuation observed in the sleeping area of the pens with the modulated system.

During cold weather, with the nonmodulated system, the ventilation doors could freeze shut when they were in the closed position. The farmer noted a reduction in such freezing problems with the modulated system.

Gas and humidity levels

Gas and humidity levels were noted during the test period. As the readings were taken manually, they could not be taken simultaneously or continuously. With the nonmodulated system, readings were taken when the doors were closed, and again about 10 minutes after the doors opened.

With the modulated system, gas and humidity levels remained rather stable. CO_2 levels were lowest near the inlet (about 1500 ppm), increased towards the opposite side of the barn, and were highest near the ridge outlet (about 3000 ppm). Higher levels of CO_2 were recorded with cooler exterior temperatures. RH levels also appeared to be higher near the ridge.

With the nonmodulated system, CO_2 levels changed considerably depending on the position of the doors. These large changes in CO_2 levels coincided with fluctuations in air temperature; that is, as the air temperature dropped, so did the CO_2

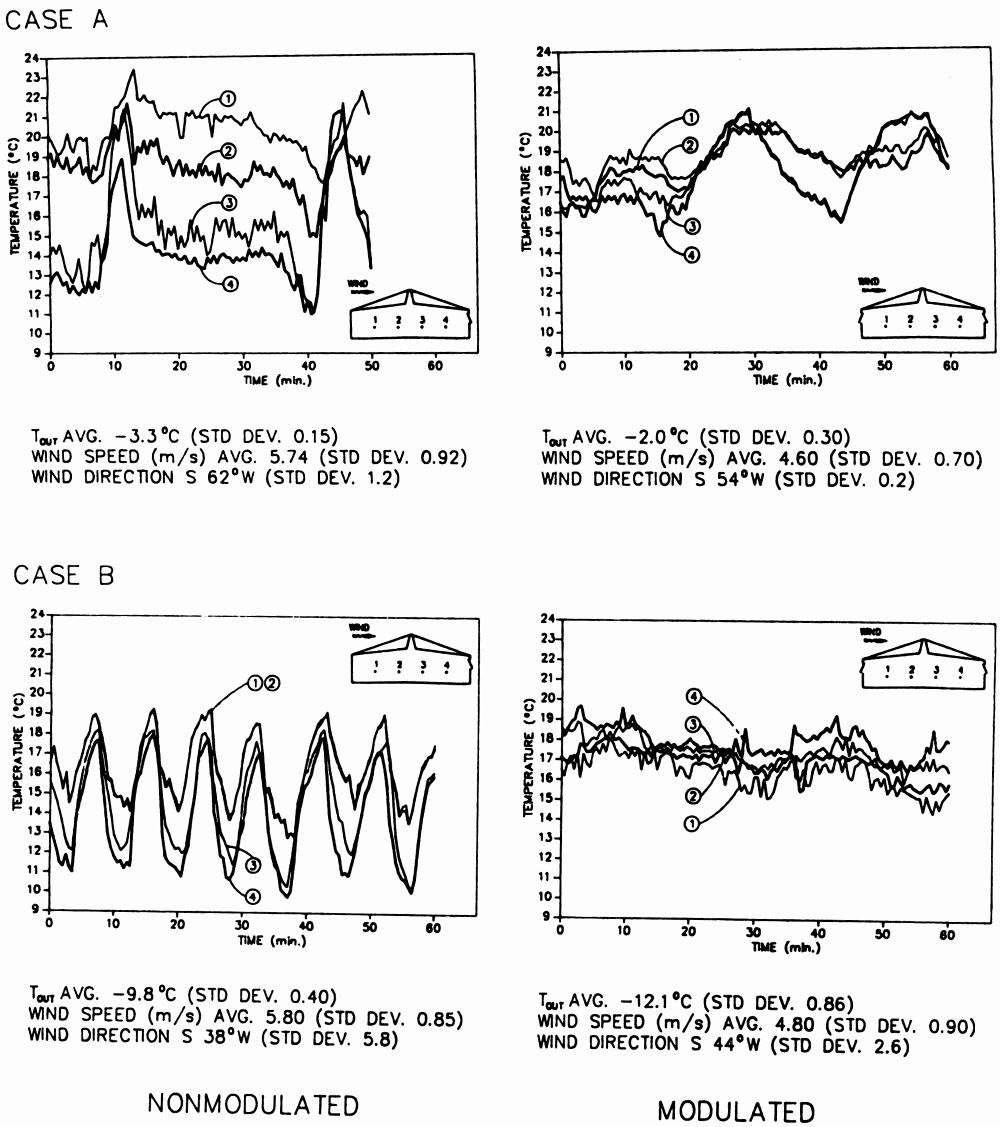


Fig. 2. Temperature variations at several locations near animal level using the modulated vs nonmodulated control system; the upper and lower figures represent results for exterior temperatures, T_{out}, of approximately -3°C (Case A) and -11°C (Case B) respectively.

level. This would be consistent with the fresh air being cooler and lower in CO_2, and the air following a path essentially from the inlet, to the opposite side of the barn and then drifting up to exhaust at the ridge. These results are also consistent with those of Brannigan and McQuitty (1971) and West (1977) showing gradients of gas levels from the inlet to the exhaust for a mechanically ventilated barn. Again, RH levels were higher near the ridge as compared to at pig level.

SUMMARY AND CONCLUSIONS

The performance of a nonmodulated ventilation system (doors fully open to approximately 75 mm or fully closed) was compared to that of a modulated system (doors open or close in small increments of approximately 20 mm every 3 minutes). Data were collected periodically over four years in the same barn — one year with one system, and the three following years with the other. For comparison, short time periods were selected using each system when outdoor conditions (temperature, wind speed and direction) were similar.

The results of this study showed that:

1. Temperature fluctuations at pig level with the modulated system were considerably less than those occurring with the nonmodulated system.

2. Temperature across the building at animal level was more uniform and generally warmer with the modulated system.

RESUME ET CONCLUSIONS

Les performances de deux systèmes de contrôle des portes latérales pour la ventilation naturelle furent comparées. Avec le premier système, les portes latérales se ferment ou s'ouvrent complètement de 75 mm approximativement selon la demande par les thermostats; ce système de contrôle est dit non-modulé. A l'opposé, le système de contrôle modulé permet de contrôler l'ouverture et la fermature des portes latérales par incréments approximatifs de 20 mm à chaque 3 minutes.

Quatre années consécutives de données furent récoltées

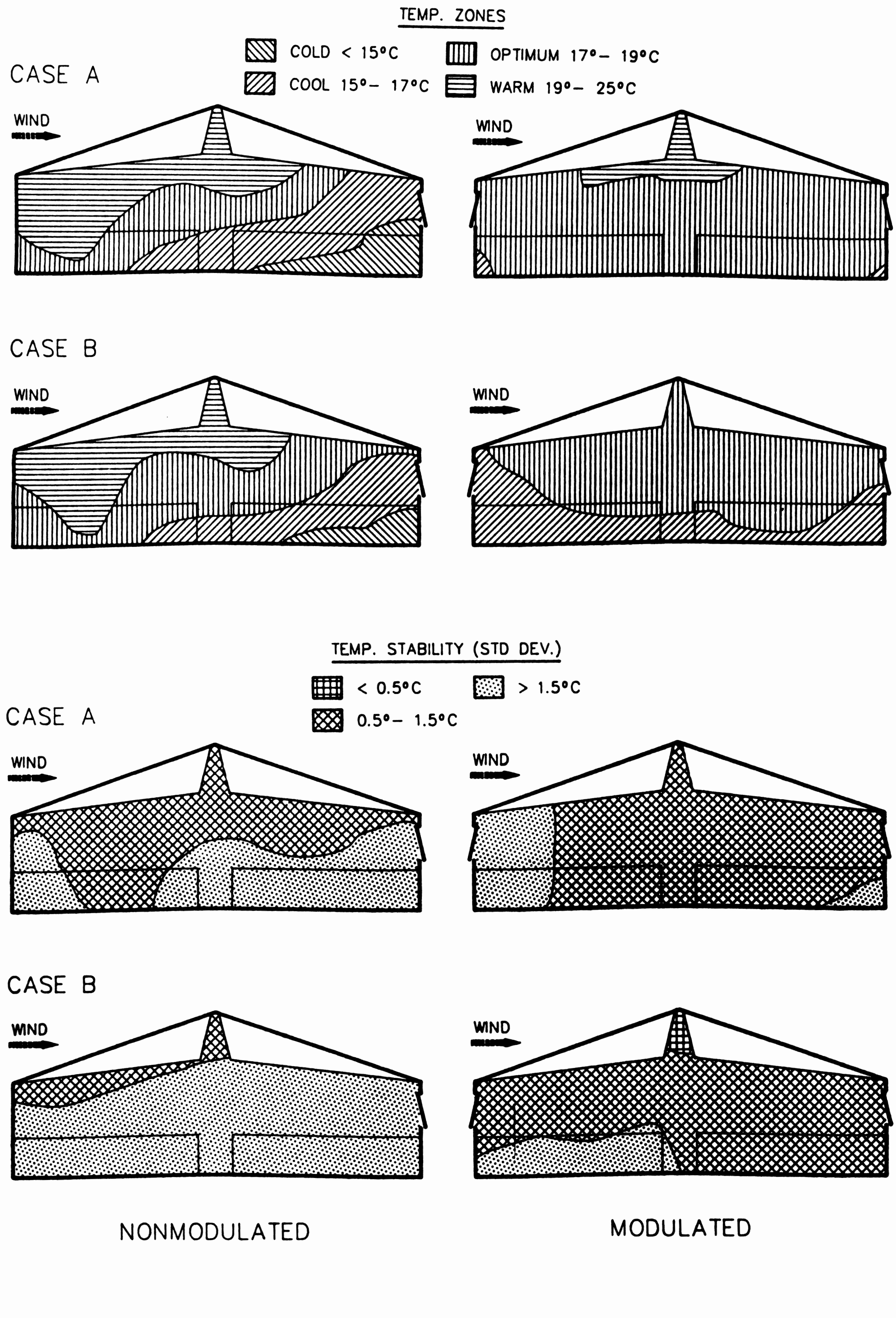


Fig. 3. Temperature zones, based on average temperatures over 1-h periods, and stability at a central cross-section of the barn for a modulated vs nonmodulated control system; Cases A and B represent exterior temperatures of approximately -3° and -11° C respectively; further details on exterior temperature and wind conditions are given in Fig. 2.

dans la même porcherie d'engraissement - la première année avec le système de contrôle non-modulé et les trois suivantes avec le système de contrôle modulé. Dans le présent document, de courtes periodes d'essais furent sélectionnées lorsque les conditions climatiques (température, vitesse et direction du vent) étaient similaires.

Les résultats de cette étude démontrent que:

1.Le système de ventilation naturelle à contrôle modulé a permis de réduire considérablement les fluctuations de température au niveau des porcs comparitivement au système de contrôle non-modulé.

2.Le système de contrôle modulé maintient généralement les zones de températures au plancher plus chaudes et plus uniformes comparé au système de contrôle non-modulé.

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REFERENCES

ANON. 1984. Introduction: What is ANCV? Scottish Farm Building Investigation Unit, Aberdeen, Scotland. 8 pp.

BIRD, N.A. and R.L. De BRABANDERE. 1981. A swine finishing barn with automatically controlled natural ventilation. Paper No. 81-201, Am. Soc. Agric. Engrs., St. Joseph, MI.

BORG, R. and D.N. HUMINICKI. 1986. Natural ventilation in cold climates. Paper No. 86-115, Can. Soc. Agric. Eng., Saskatoon, SK.

BRANNIGAN, P.G. and J.B. McQUITTY. 1971. Influence of ventilation on distribution and dispersal of atmospheric gaseous contaminants. Can. Agric. Eng. 13(2):69-75.

CHOINIÈRE,Y. 1985. Natural ventilation versus mechanical ventilation for swine housing. Alfred College of Agriculture and Food Technology, Alfred, ON.

CHOINIÈRE, Y., F. BLAIS and J.A. MUNROE. 1987. Preferred thermostat location for a naturally-ventilated swine barn. Paper No. 87-4554, Am. Soc. Agric. Engrs., St. Joesph, MI.

CHOINIÈRE, Y., F. BLAIS and J.A. MUNROE. 1988a. A wind tunnel study of airflow patterns in a naturally ventilated building. Can. Agric. Eng. 30(2):293-297.

CHOINIÈRE, Y., J.A. MUNROE, G. DESMARAIS, Y. RENSON and O. MENARD. 1988b. Minimum ridge opening widths of an automatically controlled naturally ventilated swine barn for a moderate to cold climate. Paper No. 88-115, Can. Soc. Agric. Eng., Saskatoon, SK.

CHOINIÈRE, Y., F. BLAIS, O. MENARD, J.A. MUNROE, J.A. and D.J. BUCKLEY. 1988c. Comparison of the performance of an automatic control system with exterior temperature and wind direction sensors with a standard control system for an naturally-ventilated swine barn. In: Proc. of the Third International Livestock Environment Symposium. Am. Soc. Agric. Engrs., St. Joseph, MI. No. ASAE1-88, pp 22-31.

CHOINIÈRE, Y., F. BLAIS, J.A. MUNROE and J.M. LeCLERC. 1989. Winter performance of different air inlets in a warm naturally ventilated swine barn. Can. Agric. Eng. 31(1):51-54.

CURTIS, S.E. 1983. Environmental management in animal agriculture. The Iowa State University Press, Ames, IA. 410 pp.

DAELEMANS, J., A. MATON and R. MOERMANS. 1986. Etude concernant l'applicabilité des porcheries compartimentées pour le logement des porcs à l'engrais. Revue de l'agriculture 39(3): 665-685.

De La FARGE, B. 1981. Is there any influence of indoor climate on fattening pigs? A new design for fattening houses. Commission International de Génie Rural. 22 pp.

HODGKINSON, D.G. and M. SHERIDAN. 1984. Field problems with natural ventilation in swine buildings. Paper No. 84-407. Can. Soc. Agric. Eng., Saskatoon, SK.

KOK, R. and S. TREMBLAY. 1988. Macdrain: A surveying and drainage design system for the microcomputer. Can. Agric. Eng. 30(2):195-201.

MILNE, R.J. 1983. Natural ventilation for warm housing. Chapter 12, Ventilation Manual. Ont. Min. Agric. Food, Toronto, ON.

NIENABER, J.A., G.L. HAHN, H.G. KLEMEBE, B.A. BECKER and F. BLECHA. 1989. Cyclic temperature effects on growing-finishing swine. J. Therm. Biol. 14:233-237.

SPACKMAN, E., A. ARMSBY, M. BECKET and C. SHEPERD. 1983. An analysis of the environmental control achieved in an automatically controlled naturally ventilated farrowing house. Paper No. 121, Winter Meeting, Brit. Soc. Anim. Prod., Reading, England.

STRÖM, J.S. and S. MORSING. 1984. Automatically controlled ventilation in a growing/finishing pig house. Nat. Inst. Agric. Eng. International Conference, Cambridge, England.

WEST, D.L. 1977. Contaminant dispersion and dilution in a ventilated air space. Trans. ASHRAE 83(1):125-140.

YOUSEF, M.K. 1985. Stress physiology in livestock. Vol. II. Ungulates. CRC Press, Boca Raton, FL. 261pp.