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COMPARISON OF MODULATED VS NONMODULATED CONTROL SYSTEMS FOR SIDEWALL AIR INLETS IN A NATURALLY VENTILATED SWINE BARN

by

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ABSTRACT

Two inlet control systems for a naturally ventilated swine finishing barn were compared during winter on the basis of temperature regulation, CO_2 and NH_3 concentrations, and electricity consumption. 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, and air cylinders to totally open or close the air inlets. Barn temperature fluctuations of 6-10°C within a 30 to 35 minute period were noted for any given location. CO_2 concentrations ranged between 1500 and 3500 ppm depending on whether the inlets were open or closed. NH_3 remained rather constant at 6-8 ppm.

The modulated control system used thermostats, a gear motor, and a time delay to step the inlets open and closed. At animal level, barn temperature fluctuations of about 1-3°C were noted for any given location. CO_2 concentrations ranged from 2800-3200 ppm, and NH_3 concentrations from 5-7 ppm.

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. How each parameter is affected depends in part upon the ventilation system used. There has been a recent resurgence of interest in naturally ventilated livestock buildings, and of attempts to establish the effect of different design parameters on ventilation performance. To reduce the fluctuations of ventilation parameters such as air temperature and speed which were common in naturally ventilated buildings, some sort of control mechanism is desirable, particularly in warm buildings. One type of commercial control system uses a thermostat to initiate the movement of large ventilation doors, for example in the sidewalls of a swine barn. This system could be considered nonmodulated in that the doors, when activated, 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 slowly 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, presenting an excellent opportunity to compare the performance of each system in the same naturally ventilated barn.

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Mention of specific manufacturers names is for information only, and does not imply endorsement over other manufacturers of similar equipment.

REVIEW OF LITERATURE

Natural ventilation has been described by Bird and De Brabandere (1981) and Milne (1983) as being a slow replacement of air from the inlet to the outlet. Choinière et al. (1986) showed that airflow patterns were different for summer (isothermal) versus winter nonisothermal conditions. This was due to differences in densities of air entering the building as well as the low pressure differences normally involved with natural ventilation. According to their observations and using the corrected Archimedes numbers as discussed by Leonard and McQuitty (1985), 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 performance advantage to using a fan ventilated system as compared to a well insulated, naturally ventilated building. In this 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.

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. It is a system quite similar to one which has been used in Ontario since 1984.

Ström and Morsing (1984) studied a similar building, except 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.

According to Curtis (1983), an animal could survive and grow in a variety of temperature zones. The optimal temperature range for animal growth can be 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 particular temperatures and temperature zones and concluded that the "optimal" zone for finishing hogs was between 17 and 19°C, the "cool" zone between 15 and 17°C, and the "cold" or discomfort zone was below 15°C. These temperatures and zones are repeated here in Table I.

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. (1986), concluded that temperature cycles of 12°C or more should be avoided. Zhen Yao (1986) also emphasized that temperature fluctuations of more than a few degrees should be avoided, and as a result encouraged the use of control systems on naturally ventilated barns.

Concerning power consumption of naturally ventilated barns, MacDonald et al. (1985) reported that the operating costs for fan ventilation averaged $0.44/hog produced as compared to $0.04/hog for natural ventilation. This was based on electricity at $0.045/kWh.

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. As well, the electric power consumption of each system was to be compared.

TEST PROCEDURES AND INSTRUMENTATION

The barn monitored, was a 10.8 x 23.0 m naturally ventilated growing/finishing barn owned by A. de Witt, Spencerville, Ontario. A cross section of this barn is shown in Figure 1. The barn was originally fitted with a nonmodulated ventilation system comprised of two thermostats, compressed air hydraulic cylinders which opened or closed ventilation doors, solenoid valves and of course an air compressor. In operation, the thermostat, on temperature rise or fall, would actuate the solenoid valves which in turn caused the hydraulic cylinders to fully open or close the ventilation doors. The maximum opening of the doors was adjustable.

In the winter of 1985, the operating system that controlled the ventilation doors was changed to a modulated type. This system comprised two thermostats, time delays, and gear motor driven actuators that opened or closed the ventilation doors. The adjustable timer control activated 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 was energized after being activated, for example 3 seconds. This short period only allowed the doors to move in increments of about 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, Ontario.

As indicated in Figure 1, 20 T-type thermocouples were used to sense temperatures over a cross section of the barn at about midlength. A weather station installed next to the barn provided outside temperature, RH, wind speed and direction. During a test, all readings were taken at 10 s intervals, and transferred via a datalogger to an IBM PC for further analysis using commercial software (Lotus 1-2-3). A land drainage program (MacDrain) was used to plot isothermal contours from the data.

Air flow patterns were observed using air current smoke tubes. Carbon dioxide (CO_2) and ammonia (NH_3) levels were determined using a hand pump and gas detection tubes at four locations (Figure 1). Relative humidity was determined using a sling psychrometer while air velocities were determined using a hot-wire anemometer.

Energy consumption of each system was monitored by a kilowatt-hour meter. Only the ventilation equipment was monitored, i.e, power consumed by lighting was not included. No supplemental heat was provided in the barn.

For comparison, test periods 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 Table II.

During tests with the nonmodulated system, the windward doors were closed and only the leeward doors were used for ventilation control. With the modulated system, the windward doors were used for ventilation control. As explained by Choinière et al. (1986), poorer ventilation performance, as indicated by greater temperature fluctuations and larger cold or unstable zones, would be expected when ventilating with windward doors.

RESULTS AND DISCUSSION

Temperature

Figures 2 and 3 show the temperatures monitored at five different locations in the same barn cross section for a 40-min test period. These curves were considered typical for the ventilation systems monitored. Temperature fluctuations were up to 10°C for any given location with the nonmodulated system, but were less than 3°C with the modulated system. As well, the nonmodulated system produced more rapid temperature changes coinciding with the opening of the ventilation doors. In Figure 3, this is observed at about 35-min intervals. Inspection of other data (not shown in Figure 3) indicated that this time interval decreased with outside temperature, being about 7-10 min when the outside temperature was -20° to -10°C. This cyclic, large, rapid change in temperature was not apparent with the modulated system (Figure 2).

The different temperature zones produced by each system are shown in Figures 4 and 5. As well, proportions of floor area in each temperature zone are given in Table III. Less of the floor area was considered to be a cold region, and more considered to be a warm region with the modulated system as compared to with the nonmodulated system, even though the modulated system used windward doors for ventilation.

Temperature fluctuations, observed with each system are shown in Figures 6 and 7. Temperatures appeared much more stable, particularly at animal level, with the modulated system.

The percentages of time each of four locations at animal level were within particular temperature ranges are given in Figures 8 and 9. With the nonmodulated system, the two locations on the leeward (inlet) side of the barn were in a cold zone much of the time. With the modulated system, only one location was found to be in a cold zone, and even then for only a small portion of the time.

Overall, operation with the modulated system resulted in more of the animal area being in the optimal or warm zones, and as well reduced the range of temperature fluctuation.

Although not specifically recorded, the farmer observed that the manuring habits of the hogs were better with the modulated system as compared with the nonmoduated 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.

Gas and humidity levels

Table IV lists gas and humidity levels 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 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). RH levels also appeared to be higher near the ridge.

With the nonmodulated system, CO_2 levels changed considerably, depending of course on whether the doors were open or closed. These large changes in CO_2 levels appeared to coincide with fluctuations in air temperature; that is, as the air temperature dropped, so did the CO_2 level. This would be consistent with the fresh air being cooler and of course 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 Branigan 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. However, RH did not appear to depend strongly on whether the doors were open or closed. This would suggest that absolute humidity was decreasing since temperature was decreasing, both as a result of incoming fresh air.

Electrical engery consumption

Over equal one-year periods, the nonmodulated system consumed 157 kWh of energy while the modulated system consumed 1 kWh. Although the modulated system used less energy, it is important to note that neither system used a significant amount when compared to what might be expected with a fan ventilated barn.

CONSIDERATIONS FOR FUTURE WORK

Based on measurements taken during this study, it appears that there is a direct relationship between CO_2 level and air flow patterns in the barn. Further work is required to establish more completely and quantitatively this relationship. Attempts could then be made to estimate ventilation rates in a naturally ventilated building by measuring CO_2 levels at a minimum number of specific locations. As CO_2 at animal level would be of prime interest, it would be beneficial to know the correlation between CO_2 level at animal level and other specific locations in the barn, where for example a CO_2 sensor might be more conveniently located.

SUMMARY AND CONCLUSIONS

The performance of a nonmodulated (doors fully open or fully close) ventilation system was compared to that of a modulated (doors open or close incrementally) system. Data were collected over two years in the same barn -- one year with one system, the second year with the other. For comparison, short time periods were selected in each of the two years when outdoor conditions (temperature, wind speed and direction) were similar.

The results of this study show that:

1. Temperature fluctuations at pig level (less than 3°C) with the modulated system were considerably less than those occurring with the nonmodulated system (up to 10°C).

2. A much smaller proportion of the floor area (at animal level) would fall within the cool or cold zones with the modulated system than with the nonmodulated system.

3. CO_2 levels in the barn fluctuated greatly due to the complete opening and closing of doors with the nonmodulated system.

4. CO_2 levels increased along with temperature in the direction of air flow from the inlet, across the barn and up to the open ridge.

5. The energy consumed by the modulated system was relatively much less than that consumed by the nonmodualted systems, however in both cases the overall amount consumed was extremely small.

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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. of Agric. Eng., St. Joseph, MI.

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, Ottawa, Ontario.

Choinière, Y., F. Blais, and J.A. Munroe. 1986. Airflow patterns in naturally ventilated buildings using a wind tunnel. Paper No. 86-122. Can. Soc. of Agric. Eng., Ottawa, Ontario.

Choinière, Y., F. Blais, J.A. Munroe, and J.M. Leclerc. 1986. Winter performance of different air inlets in a naturally ventilated swine barn. Paper No. 86-121. Can. Soc. of Agric. Eng., Ottawa, Ontario.

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

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.

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. Belgique.

Hodgkinson, D.G., and M. Sheridan. 1984. Field problems with natural ventilation in swine buildings. Paper No. 84-407. Can. Soc. of Agric. Eng., Ottawa, Ontario.

Leonard, J.J. and J.B. McQuitty. 1985. Criteria for control of cold ventilation air jets. Paper No. 85-4014, Am. Soc. of Agric. Eng., St. Joseph, MI.

MacDonald, R.G., G. Houghton and F.A. Kains. 1985. Comparison of a naturally ventilated to mechanically ventilated hog finishing barn. Paper No. 85-402. Can. Soc. of Agric. Eng., Ottawa, Ont.

Milne, R.J. 1983. Natural ventilation for warm housing. Chapter 12, Ventilation Manual. Ont. Min. of Agric. and Food, Toronto, Ont.

Nienaber, J.A., G.L. Hahn, H.G. Klemebe, B.A. Becker and F. Blecha. 1986. Cyclic temperature effects on growing-finishing swine. Paper No. 86-4026, Am. Soc. of Agric. Eng., St. Joseph, MI.

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, British Soc. of Animal Production.

Ström, J.S. and S. Morsing. 1984. Automatically controlled ventilation in a growing/finishing pig house. NIAE International Conference, Cambridge, England.

West, D.L. 1977. Contaminant dispersion and dilution in a ventilated air space. Trans. of ASHRAE, (1983)1:125-140 (Tech. Bulletin No. 2437).

Yousef, M.K. 1985. Stress physiology in livestock. CRC-Press, Vol. II. Ungulates. 261 pp.

Zhen Yao, W., L.L. Christianson and A.J. Muehling. 1986. Air movement in neutral pressure swine buildings - similitude theory and test results. Paper No. 86-4532, Am. Soc. of Agric. Eng., St. Joseph, MI.

TABLE I TEMPERATURE RANGES FOR DIFFERENT COMFORT ZONES FOR FINISHING PIGS, AIRSPEED <0.3 m/s

Zone	Temperature Range (°C)	Description	Reference
Warm	19-25	Between optimal and UCT	De La Farge (1981), Yousef (1985)
Optimal	17-19	Comfort	De La Farge (1981), Yousef (1985)
Cool	15-17	Between LCT and optimal	De La Farge (1981)
Cold	< 15	Below LCT, discomfort	De La Farge (1981), Curtis (1983)
Unstable		Std. Dev. of any point > 0.5°C	

TABLE II WEATHER CONDITIONS FOR THE TEST PERIODS FOR THE TWO VENTILATION SYSTEMS

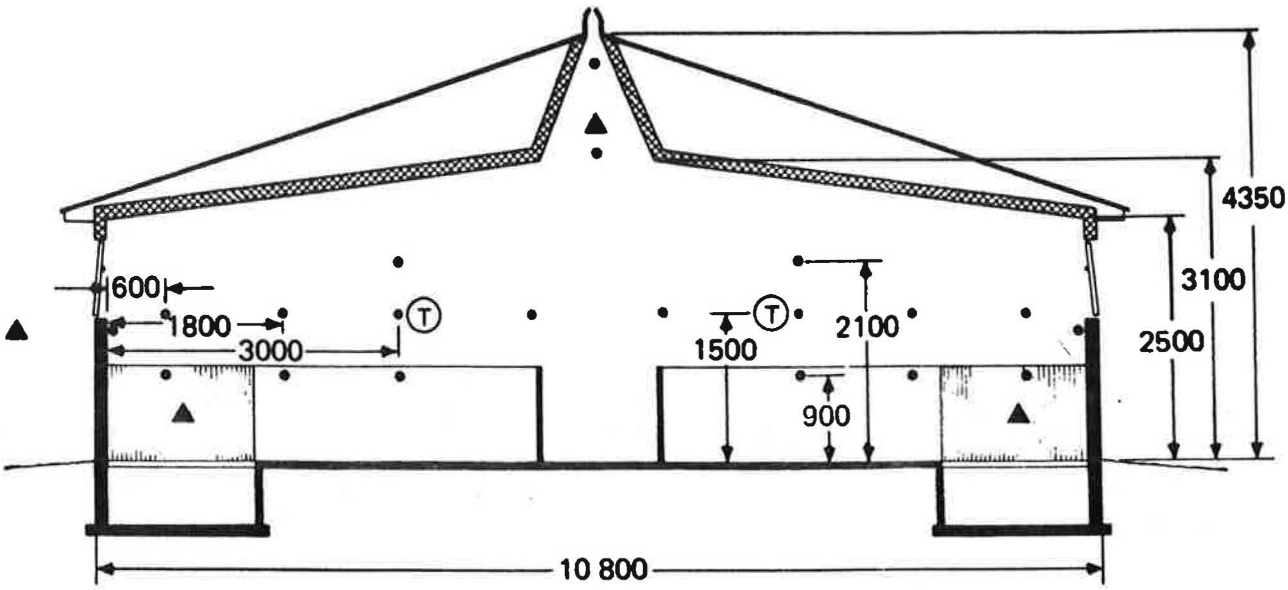
	Nonmodulated	Modulated
Date	85.03.26	86.03.17
Outside temperature (°C)		
Average	-3.28	2.11
Std. Dev.	0.15	0.22
Wind speed (m/s)		
Average	5.74	3.83
Std. Dev.	0.92	0.69
Wind direction		
Average	S61.7°W	S77.3°W
Std. Dev.	1.2°	8.9°
Relative Humidity (%)		
Average	42.5	87.3
Std. Dev.	1.6	2.0

TABLE III PERCENTAGE OF FLOOR AREA IN EACH OF FOUR THERMAL ZONES FOR THE TWO VENTILATION SYSTEMS

Zone	Nonmodulated	Modulated
Cold	44	11
Cool	25	35
Optimal	31	35
Warm	0	19

TABLE IV TYPICAL CO_2, NH_3, AND RH LEVELS NOTED WITH THE TWO VENTILATION SYSTEMS

Parameters	System	Inlet side	Opposite side	Near ridge
CO_2 (ppm)	Nonmodulated			
	doors open	1300	1800	2300
	doors closed	3100	2700	3500
	Modulated	1500	2400	3000
NH_3 (ppm)	Nonmodulated			
	doors open	4.5	2.5	5
	doors closed	5.0	5.0	6
	Modulated	4	6	6
RH (%)	Nonmodulated			
	doors open	60	60	70
	doors closed	60	60	70
	Modulated	62	65	70
Avg. temp. (°C)	Nonmodulated			
	doors open	11	18	20
	doors closed	19	22	23
	Modulated	16	20	21



Length of the building .... 23 000 mm
No. of off center pivot rotating doors 17
Overall insulation .... 3.6 RSI
Scissor truss construction
Orientation .... North - South
Date of construction 1982

- ● Temperature sensors
- ▲ CO_2, NH_3, RH, Measurement
- (T) Thermostat

All dimensions are in millimetres

Fig. 1 Cross section of barn showing location of thermocouples and CO_2, NH_3 and RH measurements

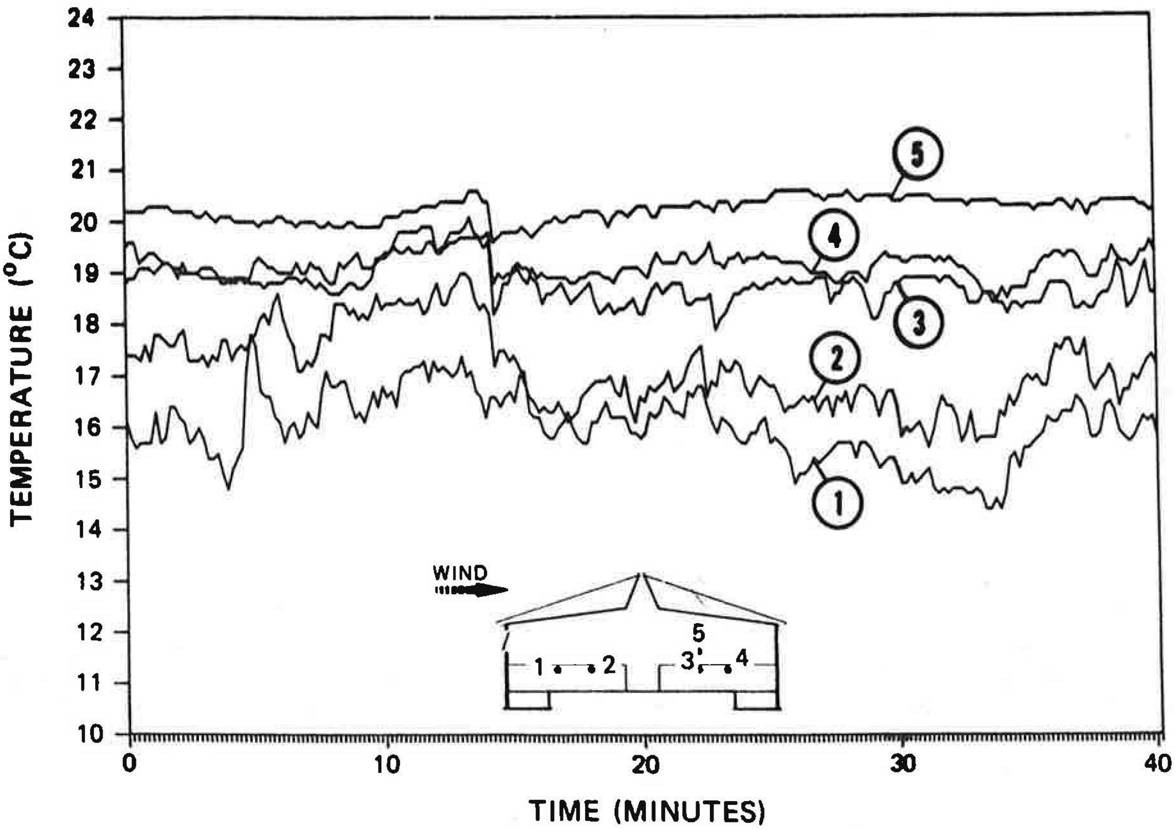


Fig. 2 Temperatures at five locations using the modulated ventilation system (86.03.17)

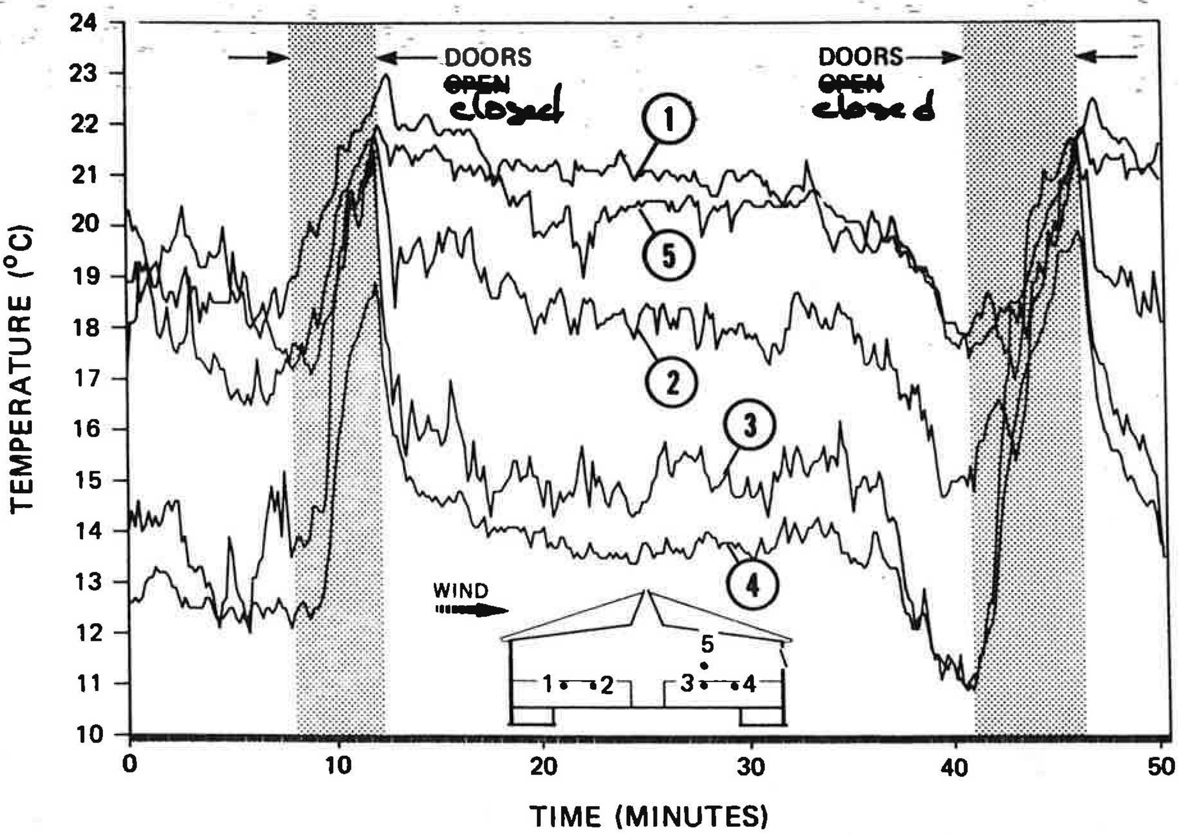


Fig. 3 Temperatures at five locations using the nonmodulated ventilation system (85.03.25)

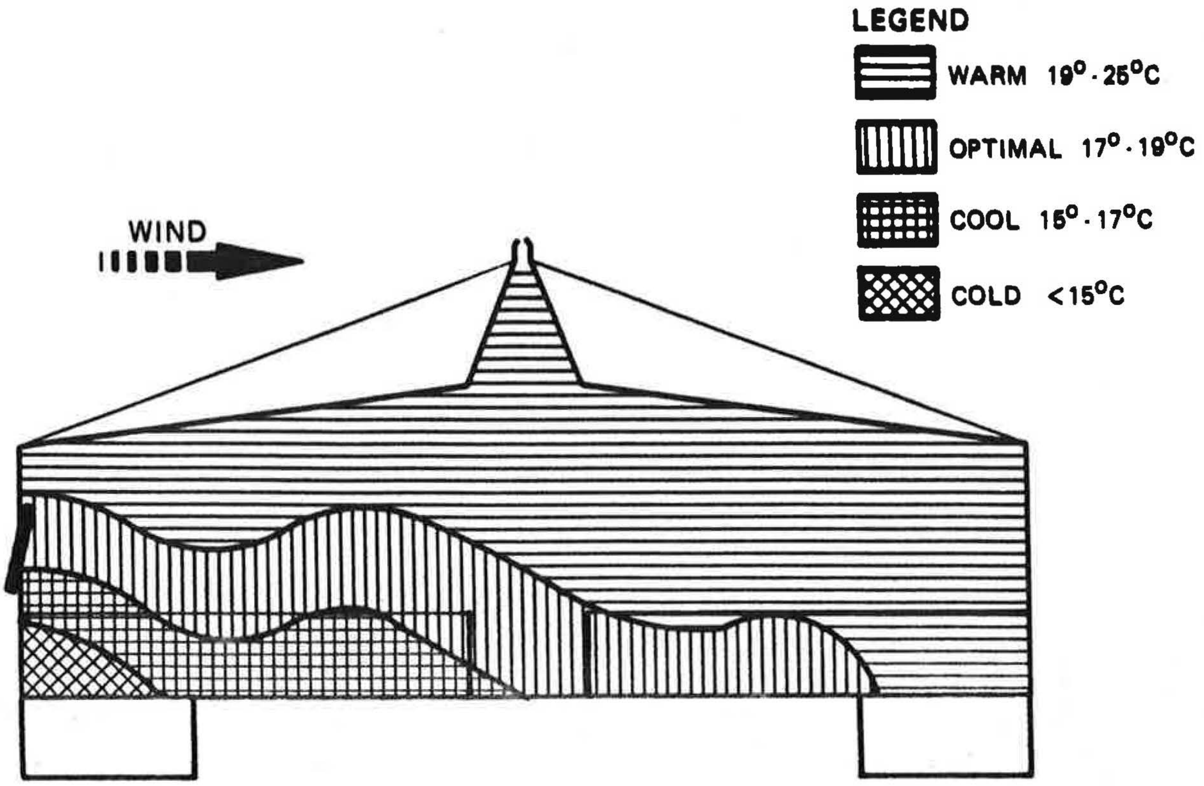


Fig. 4 Temperature zones obtained using modulated system and windward doors

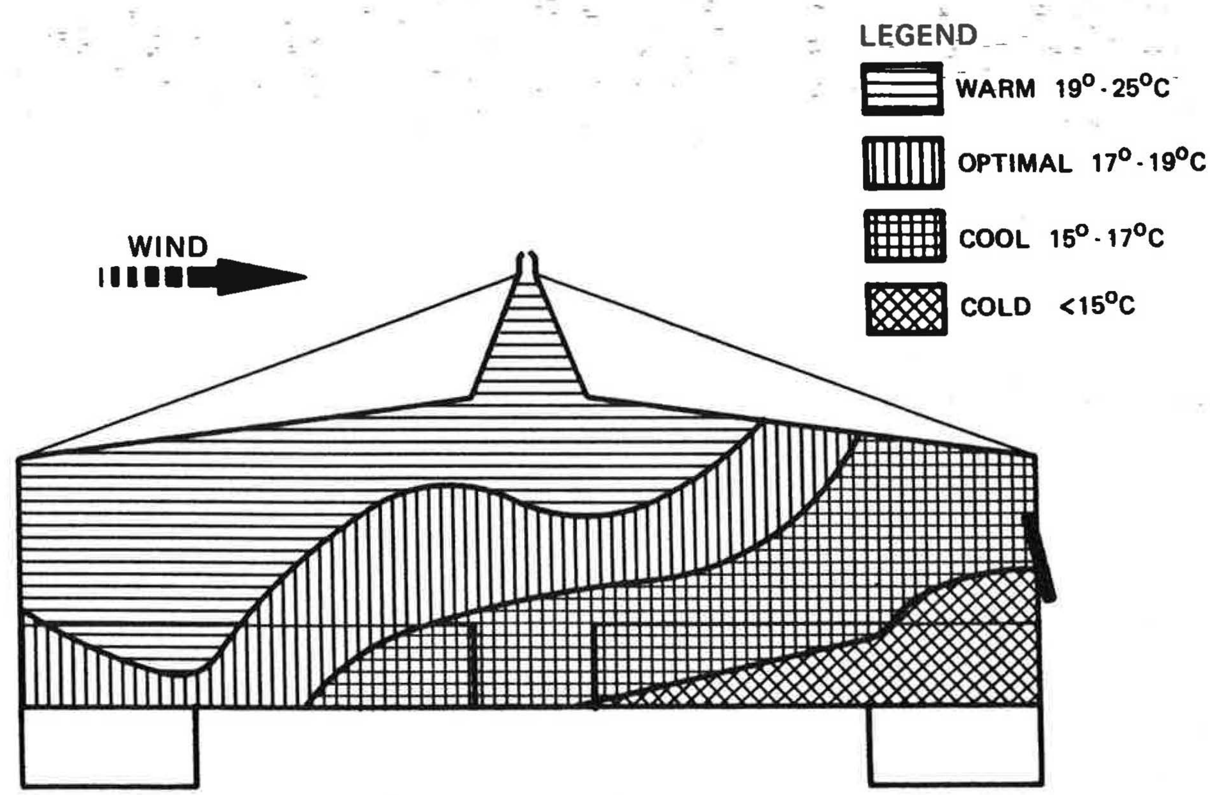


Fig. 5 Temperature zones obtained using nonmodulated system and leeward doors

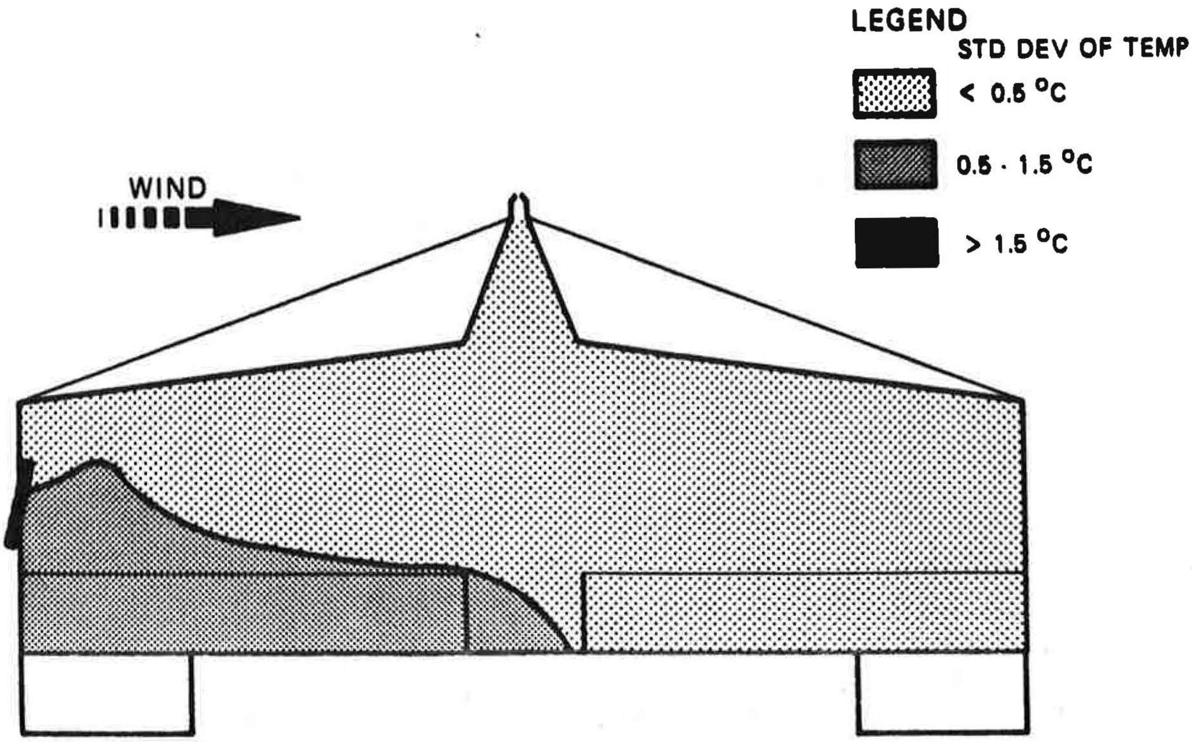


Fig. 6 Temperature stability obtained using modulated system

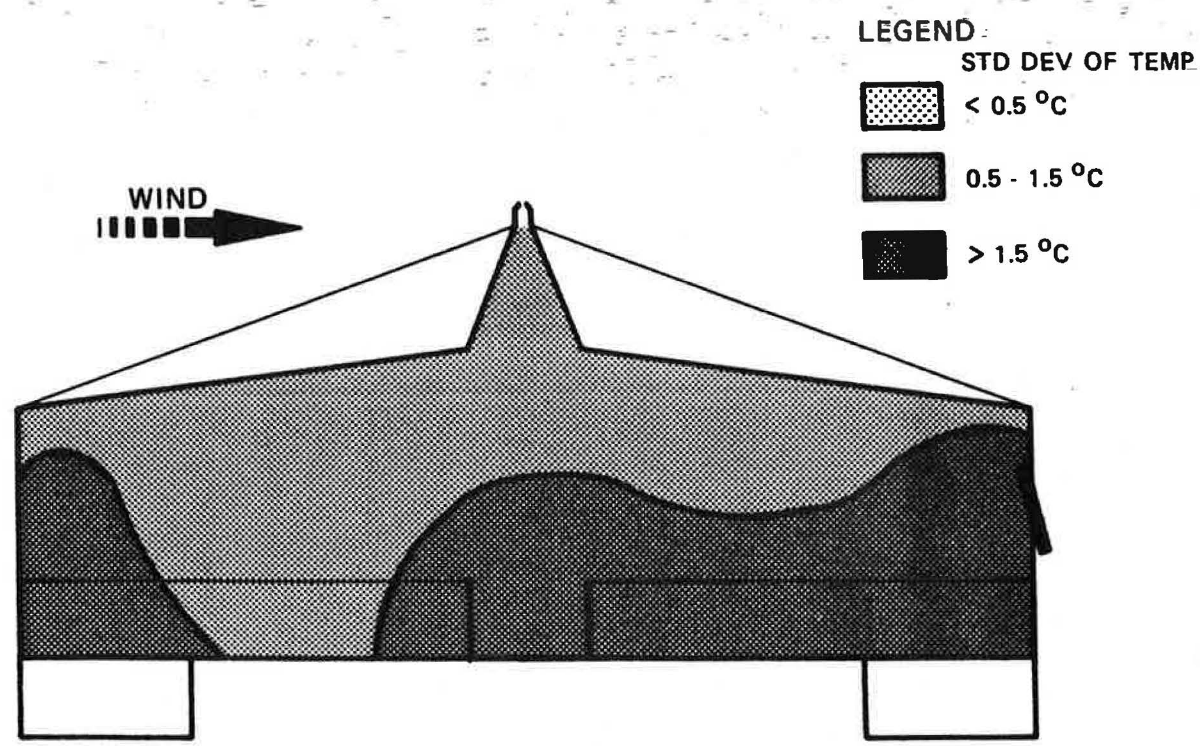


Fig. 7 Temperature stability obtained using nonmodulated system

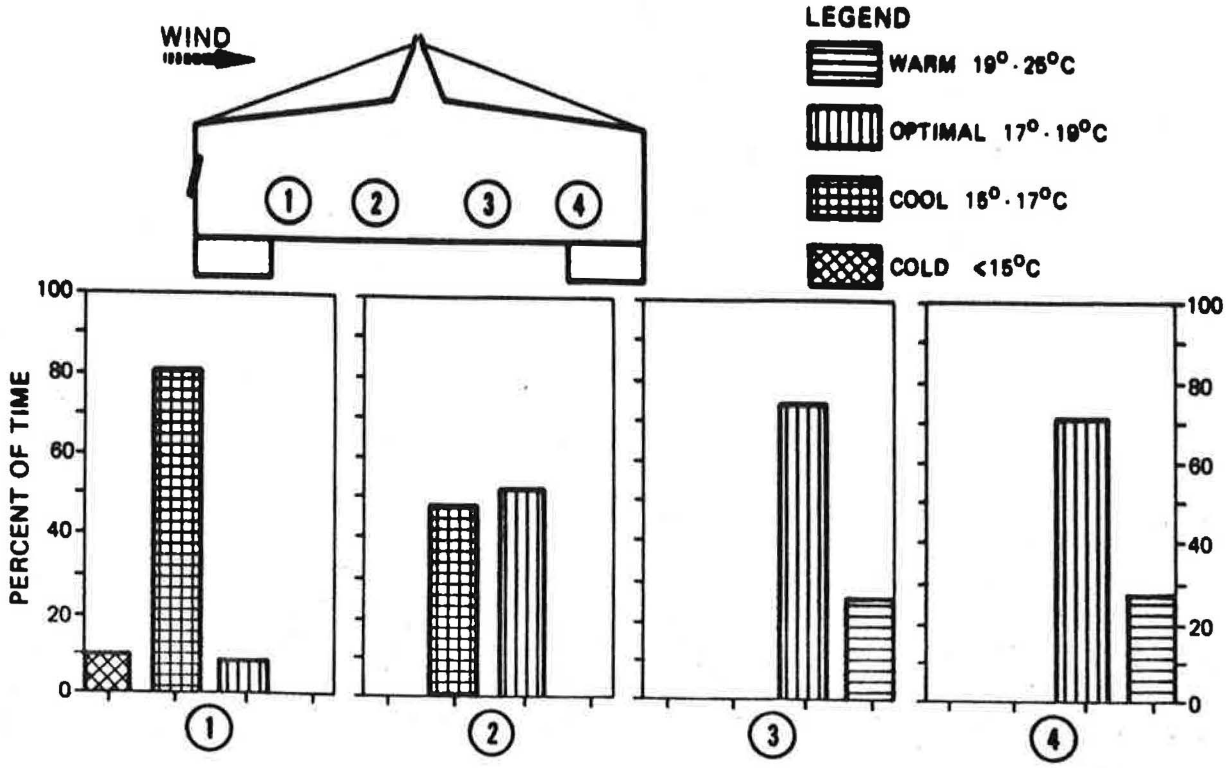


Fig. 8 Histograms of thermal zones for four locations; modulated system

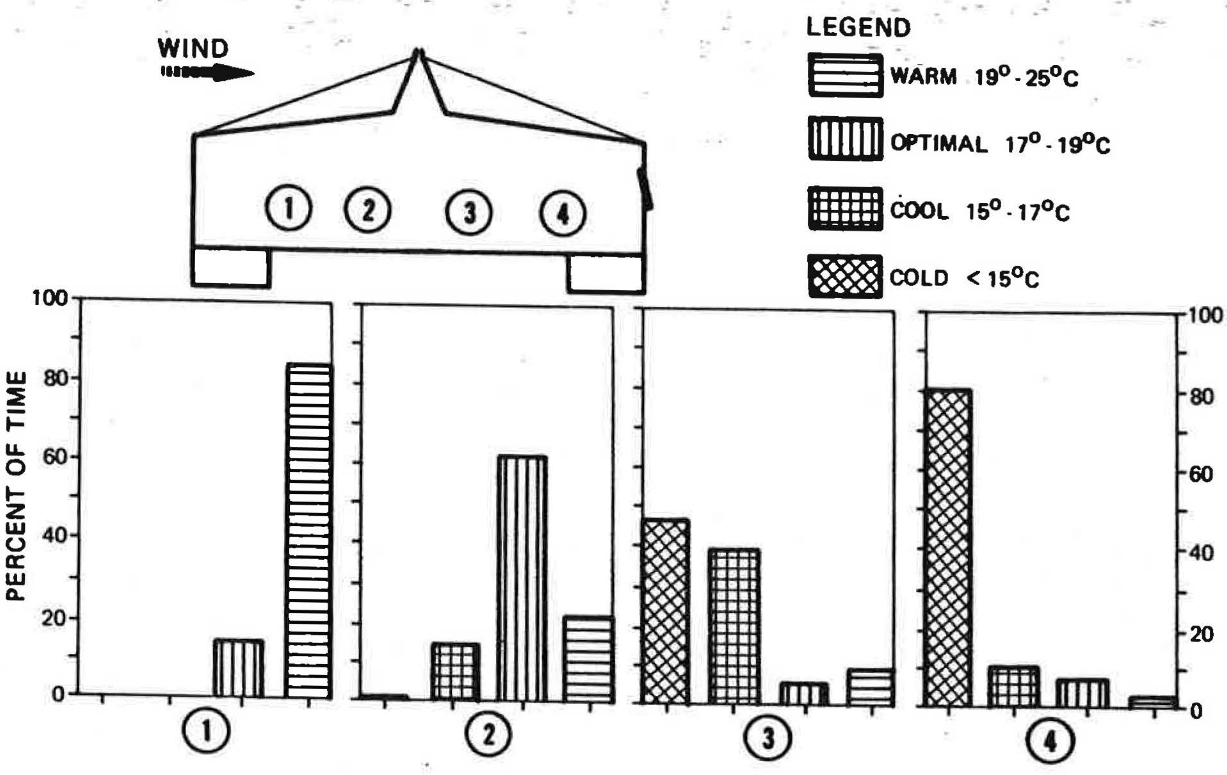


Fig. 9 Histograms of thermal zones for four locations; nonmodulated system