CSAE SCGR

CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING
SOCIÉTÉ CANADIENNE DE GÉNIE RURAL

Paper No. 92 - 214

AUTOMATICALLY CONTROLLED NATURAL VENTILATION IN A MODIFIED ENVIRONMENT DAIRY BARN

by

J.A. Munroe[1], Y. Choinière[2], D. McKnight[3],

A. S.-Tremblay[2], L. Brunet[3]

1 Centre for Food and Animal Research, Agriculture Canada, Ottawa, Ontario, K1A 0C6

2 Unité des ressources d'ingénierie, Collège de technologie agricole et alimentaire, Alfred, Ontario, K0B 1A0

3 Kemptville College of Agriculture Technology, Kemptville, Ontario, K0G 1J0

For presentation to the
CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING
at the **Agricultural Institute of Canada Annual Conference**
July 5 - 9, 1992 - Brandon, Manitoba

ABSTRACT: Traditionally, modified environment barns have been lightly insulated and depended upon permanent or manually operated openings in the walls and ridge for ventilation. In 1991, a free-stall heifer barn at Kemptville College was renovated to incorporate a natural ventilation system consisting of a series of chimneys and automatically controlled sidewall curtains complete with windbreaks.

The purpose of this study was to determine the frequency and extent of sidewall curtain movement, monitor indoor environment, and determine the minimum sidewall and ridge openings required to ensure adequate winter ventilation.

Preliminary results obtained during the winter of 91/92 indicate that the curtains moved almost every day including when the outside temperature was below -20°C. Excellent temperature regulation was observed. High relative humidity was noted (>90%) however, when accompanied with indoor temperatures of 0-5°C, indoor environment appeared to be excellent.

Papers presented before CSAE meetings are considered to be the property of the Society. In general, the Society reserves the right of first publication of such papers, in complete form; however, it has no objections to publication, in condensed form, with credit to the Society and the author, in other publications prior to use in the Society's publication. Permission to publish a paper in full may be requested from the CSAE Secretary, Box 306, Sub Post Office #6, Saskatoon, Saskatchewan, Canada S7N 0W0. The Society is not responsible for statements or opinions advanced in papers or discussions at its meetings.

RESUMÉ

Habituellement, les étables à environnement modifié sont peu isolées et le contrôle des ouvertures dans les murs et au faîte pour la ventilation naturelle est fait manuellement.

En 1991, une étable à logette pour les taures de remplacement a été complètement rénovée au Collège de Kemptville. Le nouveau système de ventilation naturelle comprend plusieurs cheminées et des rideaux plastiques continus contrôlés automatiquement. Un panneau brise-vent a été ajouté par-dessus les rideaux plastiques.

Les buts de cette étude sont de mesurer les mouvements des rideaux plastiques ainsi que leurs fréquences, de vérifier la qualité de l'air intérieur et de déterminer les ouvertures minimums nécessaires dans les murs et des cheminées pour assurer une ventilation adéquate durant l'hiver.

Les résultats préliminaires de l'hiver 91/92 indiquent que les rideaux plastiques sont réajustés à chaque jour à l'exception des longues périodes de froid extrême (température en-dessous de -20°C).

Le contrôle de la température intérieure est excellent.

Lorsque les températures intérieures du bâtiment varient entre 0 et 5°C, des taux d'humidité relative au-dessus de 90% ont fréquemment été mesurés. Malgré ces hauts taux d'humidité, la qualité de l'environnement intérieur semblait être excellente.

INTRODUCTION

Automatically controlled natural ventilation systems are being used with considerable success in Eastern Ontario in warm fully insulated buildings. Applications include tie-stall and free-stall dairy barns, swine growing/finishing and gestation barns, and some poultry barns. Typically a continuous ridge opening or a series of chimneys is manually controlled while the size of sidewall openings is automatically controlled using thermostats and an electronic timing circuit.

To date cold and modified environment dairy barns have relied on open ridges, and windows or doors in the sidewalls for natural ventilation however the control of the size of these openings has been manual. Earlier design required the operator to open or close each individual opening while later designs were improved by incorporating a winch and cable system whereby several openings could be manually controlled at one time and in a more gradual fashion. This still required the operator to be continually

monitoring the weather and his barn and to decide if, when, and how much to adjust the ventilation opening sizes. Diligent operators could generally maintain good environmental conditions in the barn but difficulties could arise when weather conditions changed rapidly or not as predicted. This was of particular concern during cold and changing weather.

Given the good temperature control achieved in warm naturally ventilated barns using an automatic control system it was decided to install a similar automatic control system in a modified environment barn. The inside environment conditions as well as frequency and extent of adjustment of the sidewall openings would be monitored throughout the winter period. As well, the chimney opening size in the ridge and minimum sidewall opening size could be adjusted to try and determine what the minimum settings should be to ensure adequate minimum ventilation in cold weather.

The feasibility of using such an automatically controlled natural ventilation system in a modified environment barn, and estimates of the sidewall and ridge openings required to ensure adequate ventilation were discussed earlier by Choinière et al. (1990).

OBJECTIVES

The objectives of this study were as follows:

1. to monitor the frequency and extent of sidewall opening adjustment effected by the automatic control system over a winter season
2. to monitor the indoor environmental conditions achieved by measuring temperature relative humidity and CO_2 concentrations as well as outside weather conditions
3. to compare the inside environmental performance achieved for different given minimum sidewall and chimney opening sizes in order to determine minimum sizes required to ensure adequate ventilation

METHODS AND PROCEDURES

Barn Description

The barn on the Kemptville College campus was originally 12 m wide with slotted floor pens for beef cattle along both sides of a 3.6 m wide centre feed alley. This barn was recently converted for dairy heifers by extending the width 2.4 m each way in order to add two rows of free-stalls. A cross-section of the renovated barn is shown in Fig.1 and plan in Fig.2.

The original ventilation system consisted of a 0.6 m wide open ridge, and a flexible plastic curtain over a lengthwise continuous 1.2 m high opening in each sidewall. The curtain could be raised or lowered manually using a cable and winch system in order to adjust the size of the sidewall openings. Freezing inside and entrance of rain and snow by the ridge were problems with this barn.

As part of the renovation, the continuous ridge opening was sealed and replaced with a series of seven chimneys each with its own adjustable inside baffle similar to that shown in Canada Plan Service leaflet M-9760, *Natural Ventilation For Warm Housing*. With the chimney baffles in the fully open position, the total throat area of the chimneys was equivalent to approximately a 50 mm wide continuous ridge slot.

The same type of flexible curtain and cable system was retained for the sidewalls, however the manual winch was replaced by an modulated automatic control system. This control system is commercially available and specifically designed for naturally ventilated buildings. A windbreak as described by Choinière and Munroe (1990) and shown in Canada Plan Service leaflet M-9760 was also added.

The insulation values of the roof, sidewall and curtains were approximately RSI 2.4, 0.8 and 0.2 respectively.

Automatic Control System

As previously discussed by Munroe et al. (1991), this type of modulated control system caused the curtains to open or close in increments of about 20 mm every three minutes in response to an electronic thermostat. One thermostat was used to control each sidewall curtain and was located at midlength of the barn about 3 m from the sidewall and 2.4 m high - just out of the reach of the cattle. The thermostats were set to activate the curtains to open when the inside temperature exceeded 3.5°C. It was felt that this temperature was as low as we should go in order to keep any freezing problems in the barn to a minimum. The dead band of the thermostat was set at 0.5°C

Chimney and Sidewall Opening Sizes

Different sizes of chimney and minimum sidewall openings were tested to determine what openings must be maintained to ensure acceptable inside environmental conditions in cold weather. For a given test, the baffles in the chimneys were set at either the fully open, half open, or closed position. These settings would be equivalent to continuous ridge opening widths of approximately 50, 25, or 0 mm respectively. Limit switches on the actuators for the sidewall curtains were set to control the minimum opening at either 25 or 50 mm. This is in the range estimated by Choinière et al. (1990) as being required for adequate winter ventilation in

modified environment barns. In addition, other limit switches prevented the curtains from opening beyond half their maximum, the intent being to guard against the curtains possibly opening fully due to some control system failure.

The combinations of the three possible chimney openings and two minimum sidewall openings gave a total of six tests. Each test lasted two days with three tests being carried out each week. This allowed several repetitions of all tests during the winter thus helping to ensure that overall each test setup faced similar weather conditions.

Monitoring and Recording

The temperatures in the animal area of the barn were determined using four thermocouples at animal level and one near the ridge in each of three cross sections of the barn for a total of 15 thermocouples. One sensors installed just above animal level and one near the ridge, at each of two locations along the barn, monitored relative humidity. Air samples were continuously drawn through 10 mm diameter tubes from 24 locations in the barn. All tubes entered a common mixing box from which the air was withdrawn by a single pump. The CO_2 concentration measured in the exhaust stream of this pump was considered to be the average CO_2 concentration in the barn.

Linear displacement transducers were attached to the actuators for the curtains. This enabled a continuous monitoring of the actual vertical position of the curtain.

A 10 m high weather station was erected approximately 20 m from the building and provided wind speed, wind direction, outside temperature and outside relative humidity. An additional CO_2 analyzer and sampling tube monitored the outside CO_2 level.

All sensors except the linear displacement transducers indicating curtain position were scanned every 20 s and averaged over a 3 min. interval. The linear displacement transducers were scanned once at the end of each three minute interval. The three minute interval was selected to match the scanning frequency of the modulated thermostat which activated the curtains.

Data was then recorded through a data logger to a microcomputer for further analysis.

Animal numbers and feeding levels were transferred manually from normal barn records.

RESULTS AND DISCUSSION

Although the analysis of the results has not yet been completed, some preliminary observations are noteworthy. Three data sets (Figures 3, 4 and 5) were selected to show typical responses during different weather conditions.

Curtain Operation

There were only 11 occasions over the winter when the curtains were at their minimum opening position continuously for more than 12 h, including three occasions lasting more than 24 h (namely 29, 34 and 46 h). Usually the curtains did not begin to close from their maximum opening position until the outside temperature dropped to -5°C, or lower if the wind speed was low, As well, they did not reach their minimum opening position until the outside temperature dropped to at least -15°C. At colder temperatures, the operation of the curtains was more dependent on wind speed. If wind speeds were low, the curtains were often operating when temperatures were below -20°C.

Inside Barn Temperature

Temperature control within the barn was very good. There was little fluctuation in temperature from point to point within the barn space. The band in the top part of Figs. 3,4, and 5 indicating inside temperature is actually five individual lines representing the five thermocouples at the centre cross-section of the barn. When the curtains were operating, the barn temperature remained quite steady at approximately 4°C. The barn would remain at this temperature until the curtains closed to their minimum position at approximately -15°C. When the curtains were closed to their minimum position and the outside temperature continued to drop, then the inside barn temperature would also drop but usually not as much. The coldest temperature noted in the barn over the winter period was -6°C and this occurred on a windy day when the outside temperature was -25°C. On the coldest day, the outside temperature dropped to -30°C but due to lower wind speeds, the barn temperature only dropped to -4°C.

Inside Barn Relative Humidity

Relative humidities in the 80-95% range were common however very seldom were there signs of moisture problems such as fogging, frost on nailheads, dripping from the ceiling, coughing by the cattle, or complaints from operational staff. Based on the authors' experience, inside environmental conditions during any inspection visits were always considered to be very good. Traditionally with such high relative humidity readings one would expect some of the aforementioned moisture problems. The authors feel that these problems were minimal because of the lower barn temperatures and

the automatic control system permitting the curtains to open as soon as outside weather conditions improved.

CO_2 Levels

The CO_2 levels varied in the barn due both to varying ventilation rates and cattle activity. Concentrations did approach 3000 ppm on two occasions when the outside temperature dropped to approximately -30°C and the wind speeds were low.

Chimney and Sidewall Opening Sizes

Although the analysis of data is incomplete, it is of interest to look at the 11 occasions when the sidewall curtains were closed to their minimum position continuously for 12 h or more. Table 1 gives the frequency of events versus opening size. Certainly there were more events of the curtains being closed when the chimneys were fully open. Had a traditional continuous ridge opening of 150 mm been used , it is likely that there would have been many more occasions when the curtains would have remained continuously at their minimum position for 12 h or more.

Differences between a minimum sidewall opening of 25 versus 50 mm are not as clear.

Overall it appears that the combinations of chimney and sidewall openings used provided very good environmental conditions in the barn over the cold periods of the winter. As well, there were seldom long periods when the automatic control system was not activating the curtains. This frequency of adjustment would not be feasible with a manually controlled system.

SUMMARY AND CONCLUSIONS

A commercially available automatic control system using modulated thermostats was incorporated into the natural ventilation system of a modified environment dairy heifer barn. The thermostats were set at 3.5°C and inside environmental conditions and curtain movement were monitored over the 91-92 winter period. Ventilation openings consisted of seven chimneys with a total wide open throat area approximately equivalent to a 50 mm wide continuous ridge opening, and continuous sidewall openings complete with an automatically controlled flexible curtains. Tests were run over the winter whereby the chimneys were set at their closed, half, or fully open position, and the minimum opening of the curtains at 25 or 50 mm.

Very good environmental conditions were maintained in the barn throughout the winter even though outside temperatures dropped to -30°C. There were only 11 occasions when the curtains remained at their minimum opening apposition continuously for more than 12 h.

Further analysis of the data will be required to determine the required minimum sidewall and chimney opening sizes to ensure adequate winter ventilation rates.

RÉSUMÉ ET CONCLUSION

Une étable à taure à environnement modifié a été rénovée pour utiliser un nouveau système automatique de ventilation naturelle. Les thermostats ont été réglés à 3.5°C. L'environnement intérieur ainsi que les mouvements des rideaux plastiques ont été mesurés durant l'hiver 91-92. Cette étable a 7 cheminées qui, lorsqu'ouvertes à leur position maximum représente une ouverture continue au faîte du toit de 50 mm. Les ouvertures dans les murs consistent de rideaux plastiques contrôlés automatiquement recouverts de panneaux pare-vents. Les essais hivernaux ont été faits avec les cheminées fermées, à demi-ouvertes ou complètement ouvertes en conjonction avec des ouvertures minimums continues de 25 ou 50 mm dans les murs.

Même avec des températures extérieures de -30°C, les conditions de l'environnement à l'intérieur étaient excellentes. Durant tout l'hiver 91-92, les rideaux plastiques sont restés immobiles durant 12 heures consécutives qu'à seulement 11 occasions.

Une interprétation approfondie des résultats est en cours pour déterminer l'aire d'ouvertures minimum des murs et des cheminées pour assurer une ventilation hivernale adéquate.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Dr. E. Lister, Director, Centre for Food and Animal Research, Agriculture Canada, Ottawa, Ontario; C. Weil, Head of the Agricutural Engineering Department and M. Paulhus, Principal, Alfred College of Agriculture and Food Technology, Alfred, Ontario; and J. Curtis, Principal, Kemptville College of Agriculture and Food Technology, Kemptville, Ontario, G. Garland, Head of Engineering Resources Unit, J. Johnston. Manager, and V. Spencer, Director of the Resources Management Branch, Guelph, Ontario for their support and funding.

Thanks are also extended to A. Olson, M. Lemieux, ans R. Pella of the Centre for Food and Animal Research for their assistance in making modifications to the ventilation system, the installation of moitoring equipment and the collection of data, and to M. Seguin and B. Dow of the Kemptville barn staff for their assistance throughout the study.

REFERENCES

Choinière, Y.; Munroe, J.A.; Suchorski-Tremblay, A. 1990. Control strategy for sidewall ventilation openings of cold and modified environment dairy housing. Paper No. 90-4557, Am. Soc. of Agric. Eng., St. Joesph, MI. 17 pp.

Choinière, Y.; Munroe, J.A. 1990. Principles and guidelines for natural ventilation of warm dairy housing. Paper No. 90-4552, Am. Soc. of Agric. Eng., St. Joesph, MI. 20 pp.

Munroe, J.A.; Choinière, Y.; Blais, F. 1991. Comparison of a modulated vs nonmodulated control system in a warm naturally ventilated swine barn. Can. Agric. Eng., 33:329-334. (ARC Contr. 1705)

minimum sidewall opening (mm)	chimney position		
	open	half open	closed
25	3	1	0
50	4	1	2

Table I. Number of occasions over the 1991-92 winter period when the curtains remained at their minimum opening position continuously for 12 h or more.

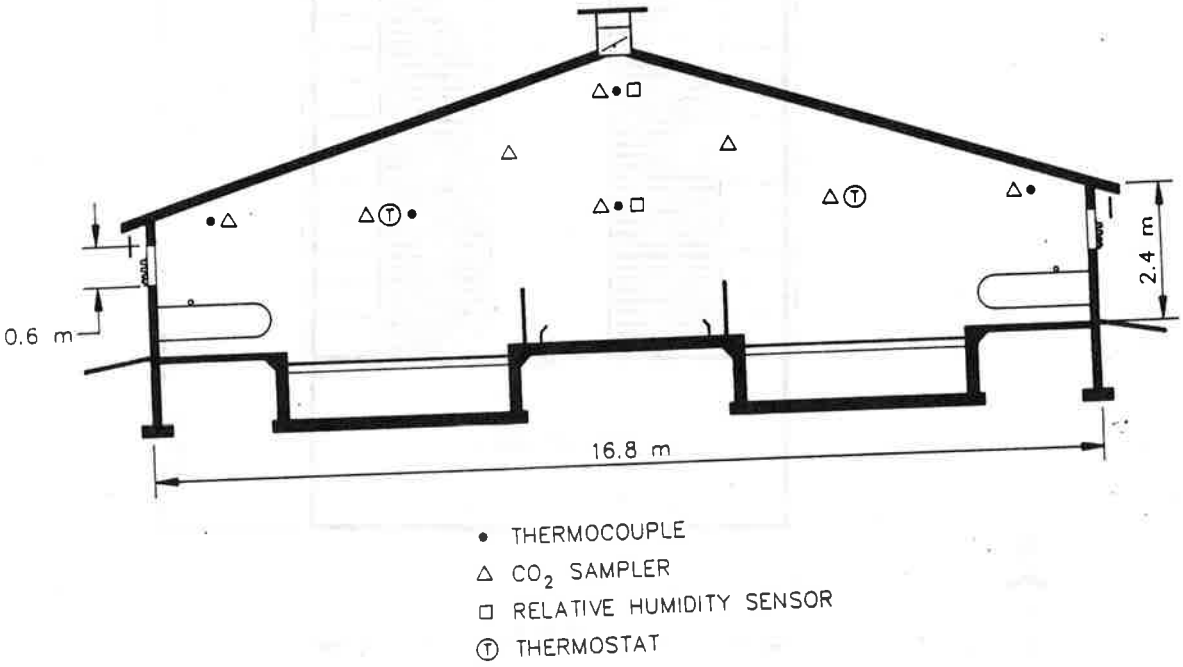

Fig. 1 Cross-section of naturally ventilated modified environment barn showing locations of temperature, humidity, and CO_2 sensors.

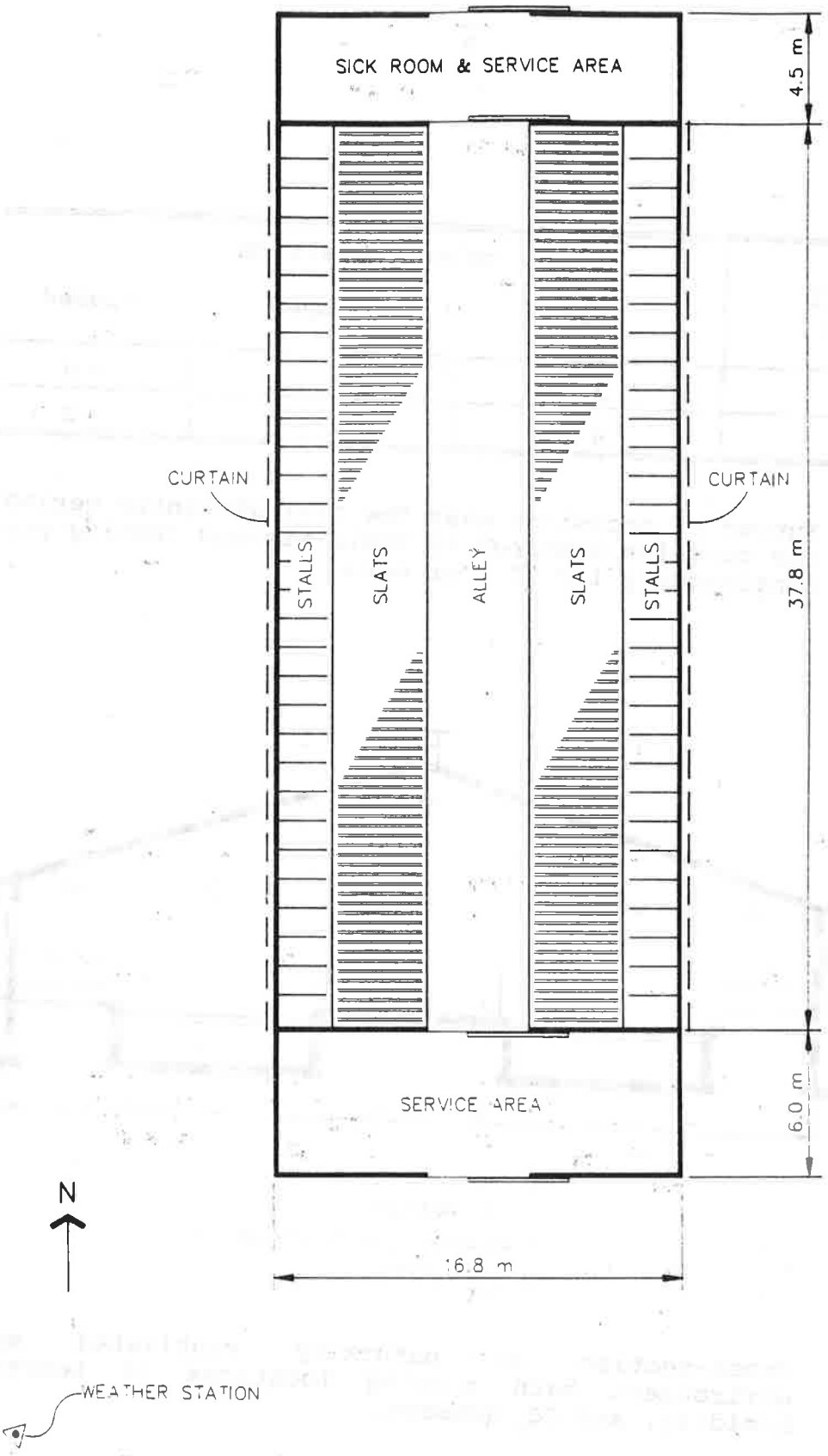

Fig. 2 Plan view of barn showing locations of sensors

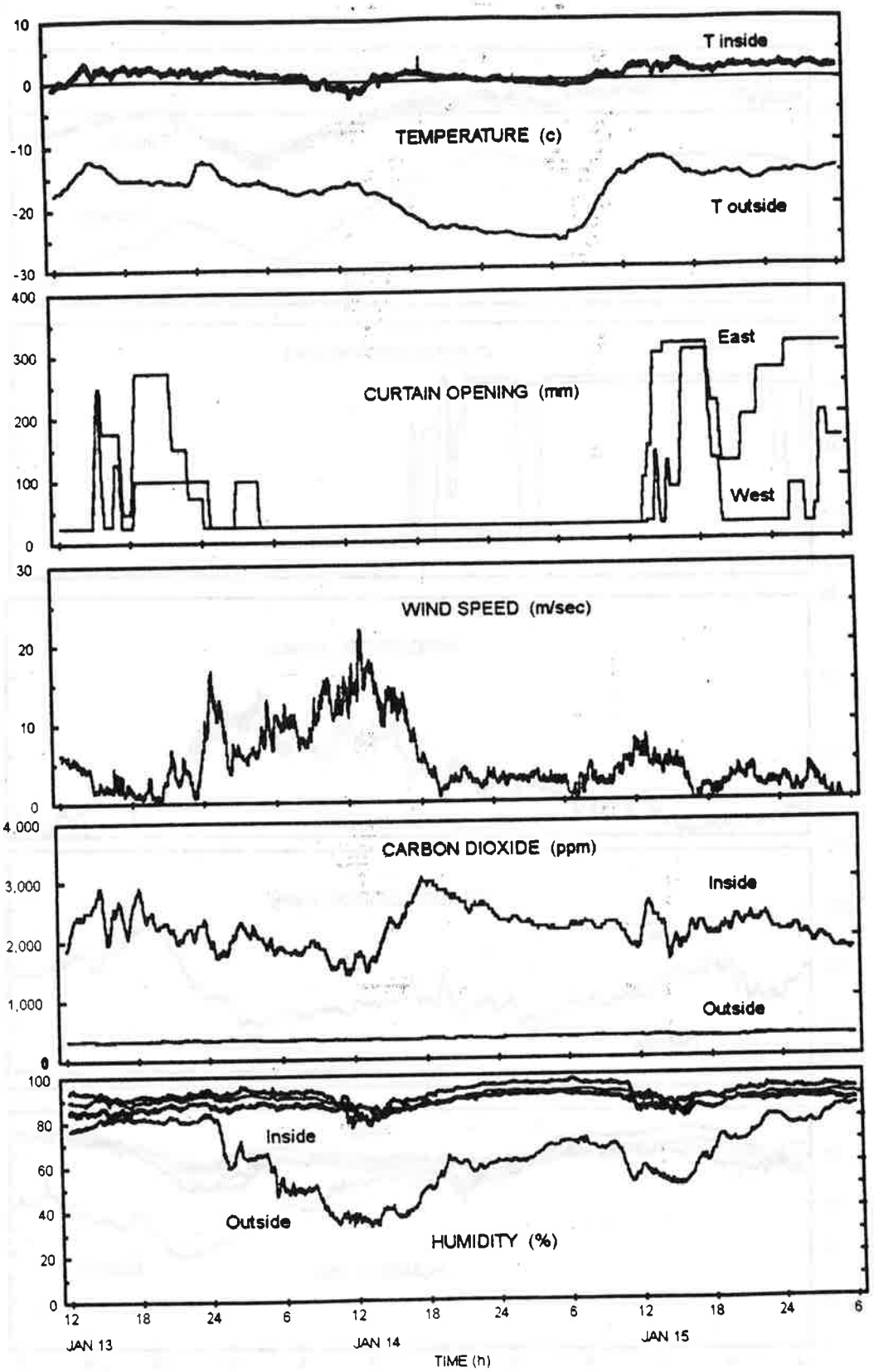

Fig. 3 Ventilation performance for Jan. 17 to 20; chimney set at half open and minimum sidewall opening set at 25 mm;

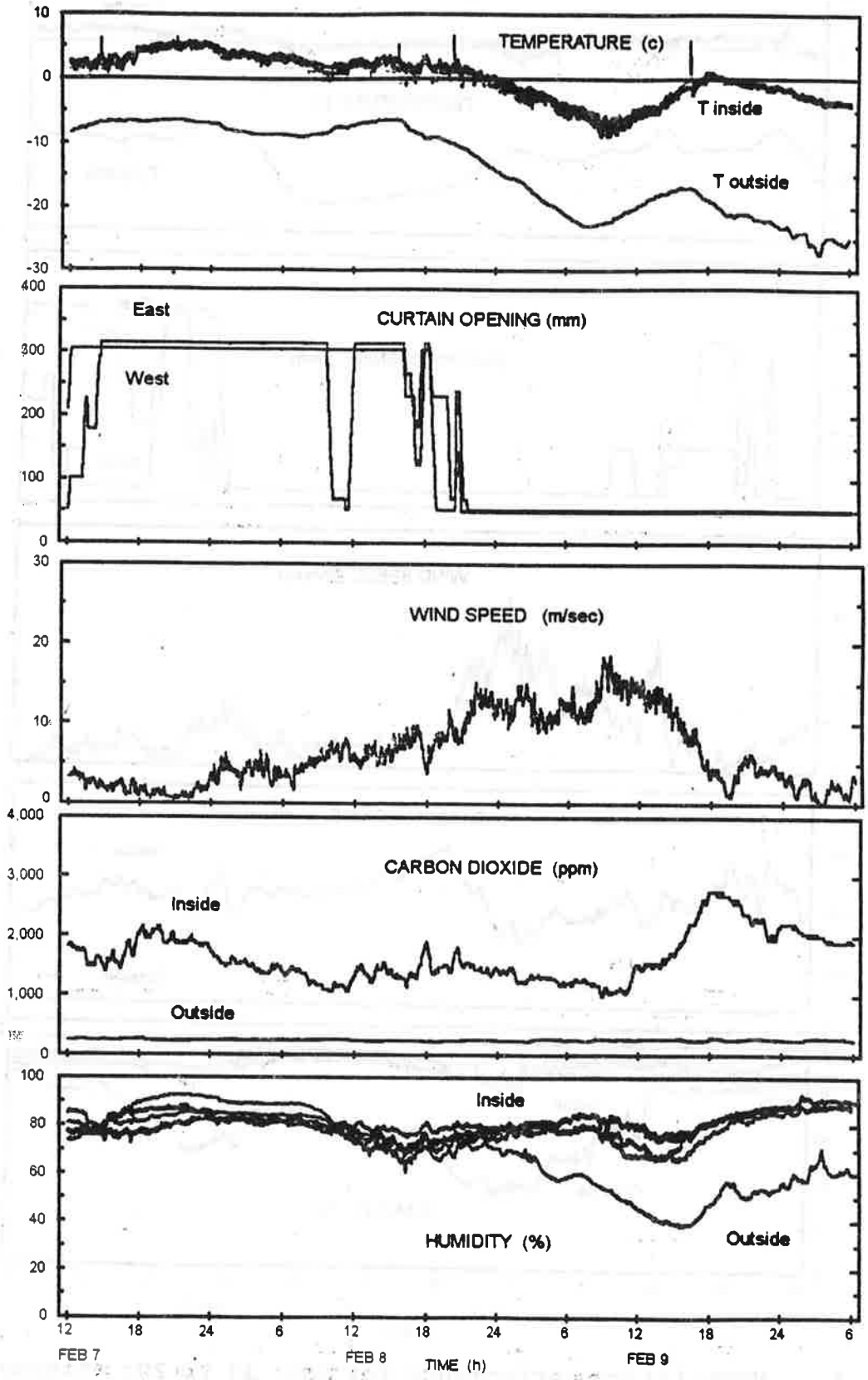

Fig. 4 Ventilation performance for Feb. 7 to 10; chimney set at half open and minimum sidewall opening set at 50 mm; weather gives a sharp drop in outside temperature.

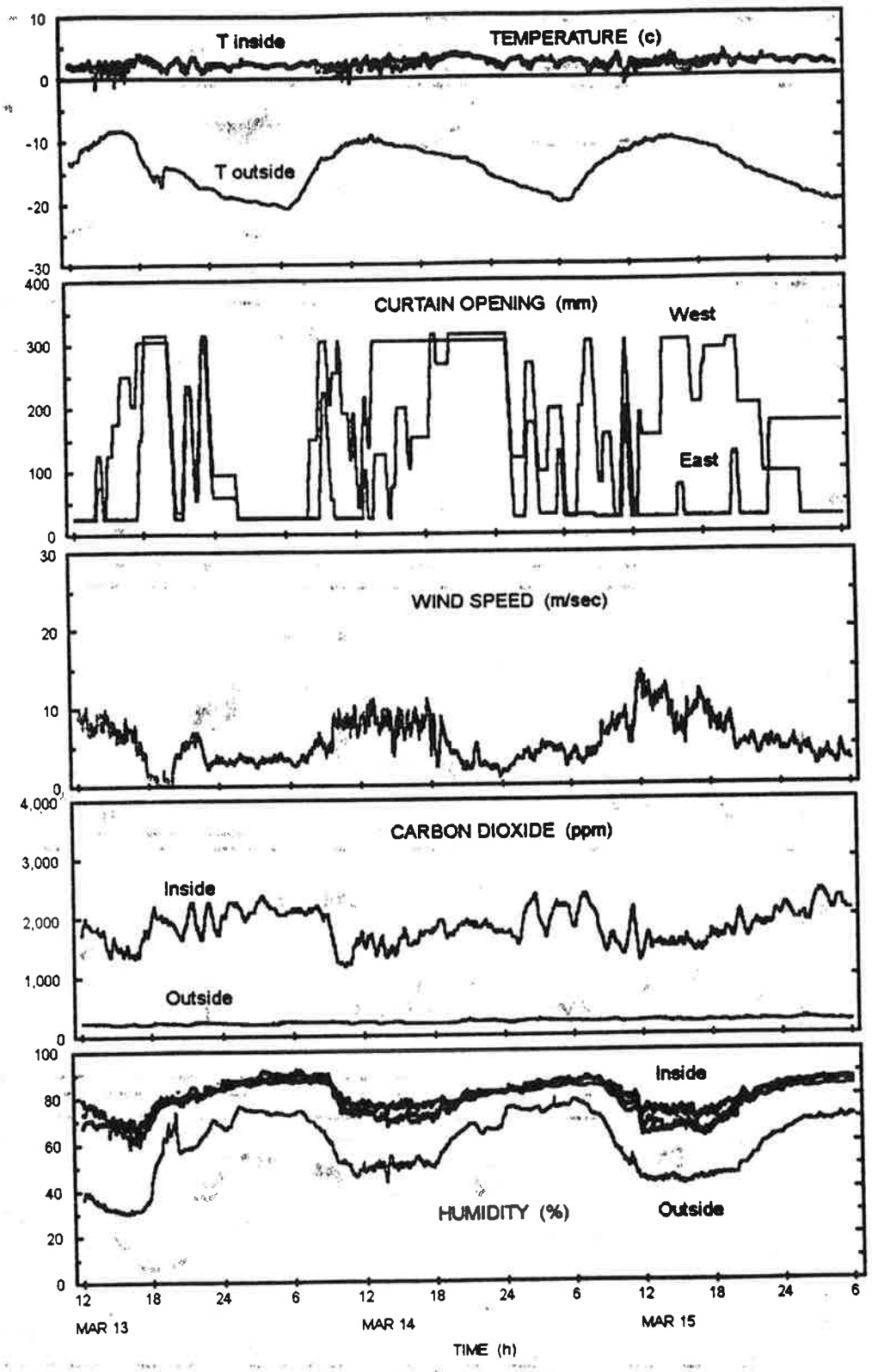

Fig. 5 Ventilation performance for Mar. 13 to 16; chimney set at closed position and minimum sidewall opening set at 25 mm; large fluctuations in outside temperature.