

Application of a computer model for naturally ventilated livestock buildings in Alberta under summer conditions

H. ZHOU¹, J.J.R. FEDDES¹, J.J. LEONARD¹ and R. BORG²

¹Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB, Canada T6G 2P5; and ²Alberta Agriculture Food and Rural Development, Red Deer, AB, Canada T4N 6K8. Received 30 September 1996; accepted 22 September 1997.

Zhou, H., Feddes, J.J.R., Leonard, J.J. and Borg, R. 1997. **Application of a computer model for naturally ventilated livestock buildings in Alberta under summer conditions.** *Can. Agric. Eng.* 39:327-334. NatVent, a computer model for predicting the performance of natural ventilation in livestock buildings and greenhouses, was evaluated using data collected in summer from two naturally-ventilated swine barns. An insulated, naturally-ventilated weaner-grower barn was monitored in Lacombe, and a new naturally-ventilated finisher pig barn was monitored in Olds, both in Alberta. The barn at Lacombe met the open country criteria required by NatVent and the measured results and NatVent predictions were in good agreement ($R^2 = 0.98$). Because the barn at Olds was attached to another structure, its measured ventilation rates were lower than those predicted by NatVent when the wind was from the direction of the attached structure.

NatVent, un modèle de prédiction des performances des systèmes de ventilation naturelle dans les bâtiments d'élevage et les serres, a été évalué avec des données recueillies durant l'été dans deux porcheries. Deux bâtiments d'élevage porcin de l'Alberta, le premier, une pouponnière, situé à Lacombe, isolé et ventilé naturellement, et le second, un bâtiment neuf pour l'engraissement, situé à Olds, également ventilé naturellement, ont été suivis. Le bâtiment de Lacombe rencontrait le critère d'isolement requis pour l'utilisation du logiciel NatVent, et les résultats des mesures correspondaient avec les prédictions de NatVent ($R^2 = 0.98$). Parce que le bâtiment de Olds était rattaché à une autre structure, ses taux de ventilation étaient plus faibles que ceux prédits par NatVent, lorsque le vent soufflait dans la direction de la structure annexe.

INTRODUCTION

Natural ventilation is induced by the natural forces of wind and thermal buoyancy. Hence, naturally-ventilated buildings rely on wind and temperature differences between the building and the environment to exchange air with the environment. With more advanced control systems, natural ventilation systems are growing in popularity as substitutes for existing mechanical ventilation systems because they require less energy, have lower maintenance requirements, provide a reduction in noise levels, and allow more natural lighting. Furthermore, natural ventilation systems are generally safe in the event of power failure because the positions of the ventilation openings do not change and the exchange of the barn air is not interrupted. However, because natural ventilation systems depend on climatic conditions, their performance is subject to some variability. Barrington et al.

(1994) reported that in properly oriented naturally ventilated buildings, one can expect low ventilation rates 12 to 27% of the time for up to a 24h duration.

Choinière (1991) estimated that when ventilation fans are used, the dollar-equivalent of power consumption is \$1.00 per finisher pig and about \$15.00 per year for a dairy cow. According to Borg (1992), in Ontario alone, \$9.2 million would be saved per annum on electricity by the conversion to naturally-ventilated animal buildings. Similarly, the energy savings in Alberta would amount to over \$2.5 million per annum. Thus, the potential for natural ventilation systems is high as it offers a safe and economic alternative to mechanical ventilation systems in animal housing.

Choinière (1991) used a simple model to estimate the magnitude of wind-induced natural ventilation based on wind speed and direction:

$$Q = C_q V A \quad (1)$$

where:

Q = wind induced ventilation rate (m^3/s),

C_q = ventilation rate coefficient,

V = wind speed (m/s), and

A = reference opening area (m^2).

The ventilation rate coefficient, C_q , is a function of the discharge coefficient, C_d , and the internal and external pressure difference. The application of C_q to the natural ventilation model is a method used by designers to predict ventilation rates in any building. A corresponding C_q value exists for each building/wind-direction combination.

Choinière et al. (1992) designed a software program (NatVent) for application to naturally ventilated livestock buildings and greenhouses. NatVent predicts values of C_q for different angles of incidence of wind and can be used to design and/or evaluate naturally-ventilated livestock buildings. The program requires the input of the dimensions and the characteristics of the building, the building site, the size and location of openings on the side walls, end walls and roof, the choice of building orientation, the local design temperatures, and a description of the livestock.

With the information provided by the user, NatVent predicts the ventilation rate coefficients for various wind

directions using the pressure difference method and data obtained from wind tunnel studies of scaled, naturally-ventilated building models. NatVent also evaluates building performance for any given geographic location using weather data (temperature, wind speed, and wind direction) collected over several years.

Building performance is assessed by the program using weather data since natural ventilation is climate-dependent. The weather data from thirty-two weather stations in Canada are used by NatVent. For a building not located where a weather station is sited, the user is required to choose a station nearest to the building location. The climatic pattern across Alberta is represented by data from five weather stations (Lethbridge, Calgary, Red Deer, Edmonton, and Grande-Prairie).

NatVent provides guidelines for livestock-building design which include recommended average ventilation rates, average proximal ventilation rates, number of single-hour events below recommended ventilation rates, number of three-hour consecutive events below recommended ventilation rates, the expected percent success, and the levels of satisfaction of the tested design.

NatVent has the potential to be very useful as a tool for designing naturally-ventilated animal houses in different regions across Canada. However, the operation of natural ventilation systems is weather-dependent. Prior to this study, NatVent had not been used to predict ventilation rates under Alberta weather conditions. Thus, the objectives of this study were to evaluate the performance of NatVent as a tool for predicting ventilation rates under summer conditions in Alberta and secondly, provide useful design information for application of this software in the province.

MATERIALS AND METHODS

Description of barns

Two barns, located in Lacombe and Olds in Alberta, were monitored between July and September, 1993.

Barn B-1 (Lacombe) The barn was an insulated, naturally-ventilated, weaner-grower pig barn. The barn was 11.1 m wide, 39.06 m long, with 2.8 m high sidewalls and a roof angle of 17°. The insulation values of the wall, roof, and foundation were 2.1, 3.5, and 1.4 m²K/W, respectively. It was divided into east and west sections and was oriented in an east-west direction. Only the east section of the barn was monitored in this study because the west section was not fully stocked. The east section was 11.1 m wide by 13.11 m long and had five 2.13 m by 0.6 m intermittent openings fitted with rotating ventilation doors on each side wall. A 1 m by 2 m door was installed into the end wall and kept closed at all times. The barn had a continuously variable ridge opening with a 200 mm maximum width. The ridge opening was opened fully during this study. A total of 239 weaner-grower pigs having masses between 18 and 42 kg were housed in the east section of the barn.

Barn B-2 (Olds) The barn was a new, insulated, naturally-ventilated finisher pig barn managed by Olds College. The barn was 12.15 m wide by 56.63 m long with a sidewall height of 2.86 m and a 17° roof angle. The barn was oriented

in an east-west direction and was connected perpendicularly to the west side of another existing pig barn. The sidewall vents in the barn each consisted of a 550 mm continuous opening which ran along the length of the barn, with vertical ventilation doors in each side wall and intermittent chimneys (600 mm by 600 mm) located at 5.5 m intervals along the ridge. The chimneys were not equipped with baffles and were fully open at all times. A 1.2 m by 1.2 m adjustable opening in the end wall was kept closed throughout this study. A total of 190 finisher pigs having masses between 55 and 95 kg were housed in this barn.

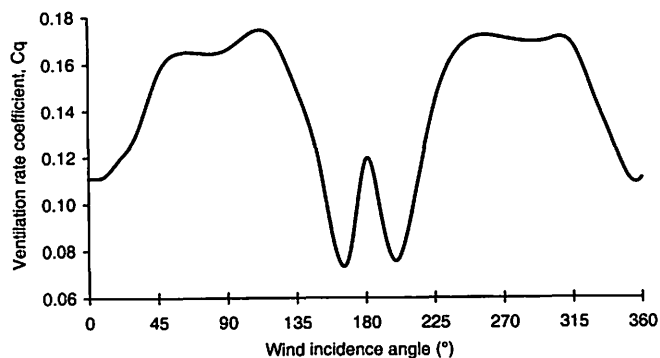


Fig. 1. The Ventilation Rate Coefficient Curve for Barn B-1.

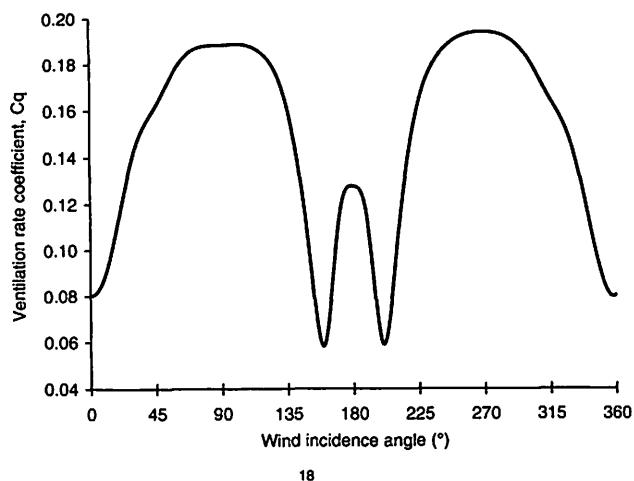


Fig. 2. The Ventilation Rate Coefficient Curve for Barn B-2.

Data input to NatVent

The dimensions and characteristics of the barns and sizes and locations of openings on the side walls, end walls, and roof were programmed into NatVent. NatVent calculated the area of each opening on each side of the barn and determined the pressure coefficient associated with the opening. In addition, the pressure difference method was used to determine the internal equilibrium pressure coefficient and the ventilation rate coefficients (C_q) for each wind angle. Based on the determined values of C_q and angles of incidence of wind, other values of C_q were obtained by interpolation and fitted to a curve of C_q versus wind angle of incidence (Figs. 1 and 2).

Next, the type of animal housed in the barn was input into

Table I: Recommended summer ventilation rates from NatVent

Barn	Animal type (hogs)	Number of animals	Ventilation rate (L/s per animal)	Required ventilation rate (L/s)
B-1	weaner grower	239	35	8365
B-2	finisher	190	35	6650

the NatVent program. Under swine production, only two options were available, i.e. grower-finisher hogs and gestating sows. For this study the grower-finisher option was selected as being most representative of the weaner-grower animals in Barn B-1 and was representative of the pigs housed in B-2. The number of animals housed in the barn under study was the input for NatVent which then determined the summer ventilation rate as recommended by Agriculture Canada (1988). The summer ventilation rates as predicted by NatVent are presented in Table I.

To predict barn performance, barn location relative to province and region, design air temperatures, and barn orientation were input into NatVent. With the required information input into the program, NatVent read weather data stored in the program memory and modified the input information to contain the date, number of summer hours/day, time, dry bulb temperatures equal to or greater than 20°C, wind speed, and wind direction. Summer hours are defined by NatVent as those with ambient temperatures greater than or equal to 20°C.

For the given design temperature and building orientation, NatVent calculated the average measured and predicted ventilation rates (Table II) and the percentage of the sampling events where low ventilation rates occurred for one to three consecutive hours (Suchorski-Tremblay et al. 1991).

Instrumentation

A data logger (Datataker DT100, Data Electronics, Melbourne, Australia) was used as an interface between an IBM-286 compatible computer and thermistors, a relative humidity sensor, a carbon dioxide analyzer, a cup anemometer, a wind vane, and vent-opening sensors in the barns.

Experimental procedures

Three calibrated thermistors (UUB31J1, Fenwall Electronics, Framingham, MA) were used to monitor the interior

Table II: *The results of a NatVent calculation for barns B-1 and B-2

	Barn B-1		Barn B-2	
	20°C	29°C	20°C	29°C
Measured vent rate (L/s)	6145	6739	13424	14911
Predicted vent rate (L/s)	5377	5701	5923	6068
One hour event (%)	74.4	68.5	25.6	20.4
Three hour event (%)	44.2	28.3	6.6	3.7
Maximum duration (h)	16	8	12	6

* The orientation angle of each barn was 90°. Results were recorded when the ambient temperatures were 20°C and 29°C.

temperature of the barns at animal level. Each barn was divided into three equal sections and a thermistor was located in the middle of each section along the length of the barn, 1.2 m from the floor. The relative humidity sensor (model HT-220, Rotronics Instrument, Huntington, NY) was suspended 1.2 m above the floor at the centre of each barn.

Carbon dioxide (CO₂) concentration inside the barn was measured by drawing air samples with an air pump (Dol-101-AA, Gast Manufacturing Corp., Benton Harbor, MI) through 5 mm plastic tubing from the three thermistor locations. To collect equal air samples from the three locations, valves inserted in the tubes were adjusted until the air flow rates from the three different locations were equal. Consequently, the exhaust stream of the pump was assumed to contain the average CO₂ concentration in the barn. A flow meter on the exhaust stream was used to ensure a constant airflow rate of 350 mL/min through an infra-red gas analyzer (Model 865, Beckman Industrial Corp., Fullerton, CA) which measured the CO₂ concentration. To protect the gas analyzer from dust particles, the air was filtered before being drawn into the plastic tubing from the three sampling locations. The CO₂ concentration outside the building was measured by precision gas detector tubes (Matheson Safety Products, East Rutherford, NJ) twice a week.

The positions of the ventilation door openings were continuously monitored by potentiometers that were turned by a pulley and cord attached to the ventilation doors. The ventilation doors for each sidewall were operated by one controller, thus one potentiometer was used for each sidewall to sense its opening position.

Wind speed and direction were monitored by a cup anemometer and wind vane mounted on a steel frame on the roof of the barn 10 m above ground level. The outside temperature was measured with a thermistor fixed to the anemometer on the roof of the barn.

Outputs from all sensors were scanned every three minutes by the data logger. Data were transferred to the computer, stored on disk, and later analyzed. The field tests were conducted between July 24 and September 2, 1993. The precision of the temperature sensor, relative humidity (RH) sensor, and the CO₂ analyzer were 1°C, 5%, and 50 ppm, respectively. The CO₂ analyzer was calibrated periodically with a certified zero gas and representative span gas. The temperature and RH sensor were periodically checked with a sling psychrometer.

Determination of ventilation rates

Ventilation rates were determined from actual CO₂ measurements according to the method described by Feddes et al. (1983) and Feddes and DeShazer (1988). These were compared to the rates predicted by NatVent. The measured ventilation rates were calculated based on the difference in carbon dioxide concentration inside and outside the

barn and on an assumed rate of carbon dioxide production by the animals.

This method of determining ventilation rates based on the CO₂ concentrations may be represented by the equation (CIGR 1984):

$$Q = \text{CO}_2 \text{ product } 10^6 / (\text{CO}_2 \text{ in} - \text{CO}_2 \text{ out}) \quad (2)$$

where:

- CO₂ product = 0.163 H_{product} (L/h),
- H_{product} = F[29(m+2)^{1/2}-40] (W),
- m = pig body mass (kg),
- F = 4 × 10⁻⁵(20-T_i)³+1 (corrected by the temperature) and,
- T_i = inside temperature (°C).

RESULTS AND DISCUSSION

Data collected

Data collected on four randomly-chosen “summer” days, when the ventilation doors were fully open, were used to evaluate the performance of NatVent. A plot of wind direction, wind speed, temperature, opening size, interior CO₂, and interior RH against time, for data collected on one of the four days are presented in Fig. 3.

A comparison of the internal and external temperatures showed that both temperatures peaked at the same time. Choinière et al. (1990) observed a similar trend, demonstrating that the buildings responded quickly to changes in external temperature. Furthermore, the external temperatures were often higher than the internal temperatures, as was also observed by Boyd (1985). In contrast, Kammel et al. (1982) and Choinière and Munroe (1993) indicated no marked difference between the internal and external temperatures, thereby signifying wind-induced natural ventilation occurred under isothermal conditions in hot weather when external temperatures were over 20°C. Exterior temperatures could appear to be higher than interior temperatures if the temperature sensor used on the outside was not adequately screened from direct solar radiation. Also, evaporative heat losses may lower interior temperature at lower ventilation rates.

The side wall openings in both barns were adjusted every day because the internal temperature in the barns dropped below the set tem-

perature during the night hours. Each barn was controlled by an automatically controlled natural ventilation (ACNV) system based on inside temperature. The ACNV system consisted of a controller, thermostats, and linear pneumatic actuators that controlled the ventilation door opening area. However, the side wall openings of barn B-1 were adjusted more frequently than the openings in barn B-2. The probable cause for the more frequent adjustments in barn B-1 may have been the higher target temperature of 20°C compared to the target temperature of 18.5°C in barn B-2. Moreover, the number of instances when the internal temperature in barn B-1 was below the target temperature was greater than occurred in barn B-2. This could be due to the smaller animals in Barn B-1 producing less heat.

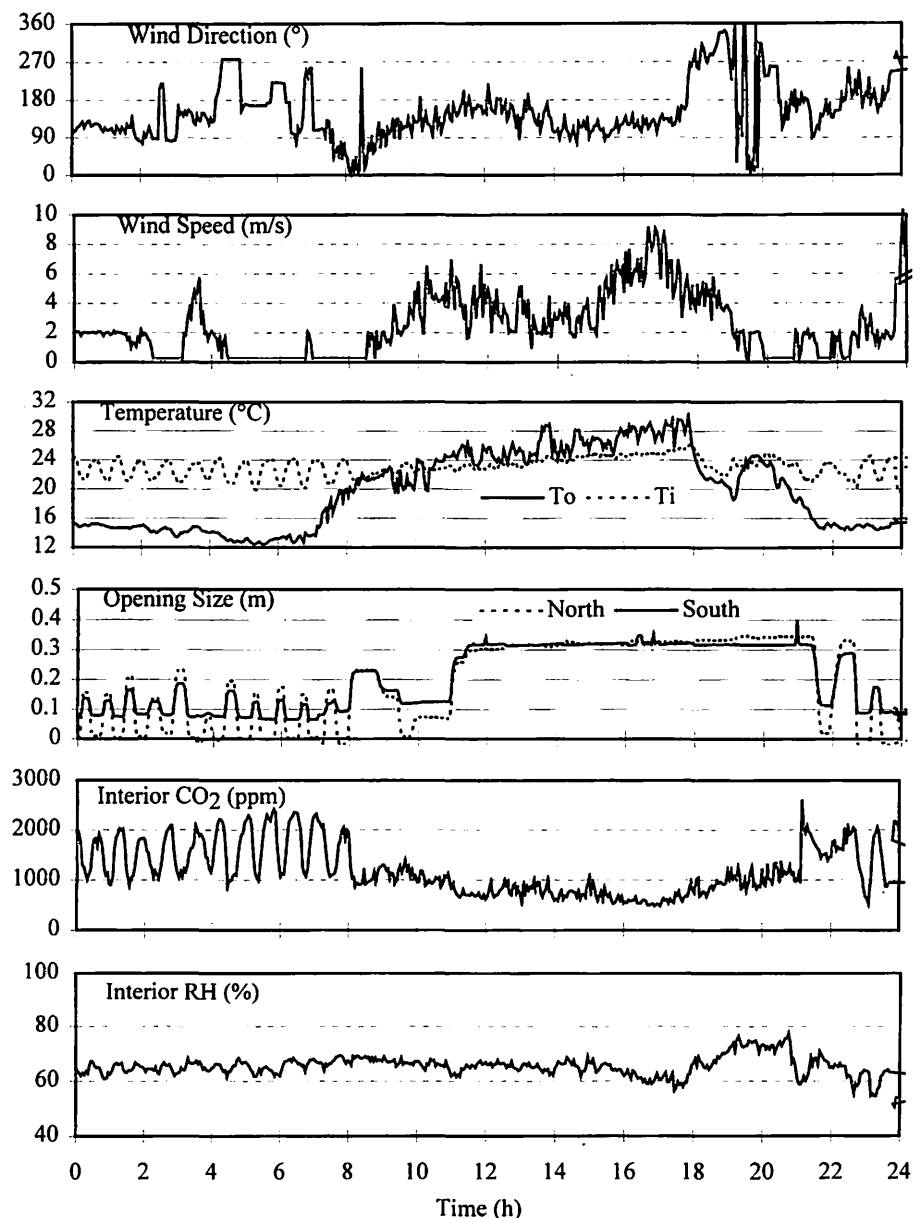


Fig. 3. An example showing typical data collected in one day.

The external CO₂ concentrations ranged between 330 and 360 ppm. Internal CO₂ concentrations, as presented in Fig. 3, varied with variation in size of side wall openings, wind speed, and direction. The CO₂ concentrations also varied with wind speed and direction even when the side wall openings were kept fully open, indicating that the variation occurred because of varying ventilation rates in the barns. Lower CO₂ concentrations coincided with higher ventilation rates in agreement with the model by Feddes and DeShazer (1988).

The relative humidity in both barns ranged between 40 and 80% and met the requirements specified by ASHRAE (1993) for swine housing. Hence, these results effectively showed that under Alberta summer conditions the ventilation obtained not only sufficed for controlling the temperature in the warm weather but was also adequate for controlling moisture (Albright 1990).

Ventilation rate coefficient curves from NatVent

The ventilation rate coefficient curves calculated by NatVent are presented in Figs. 1 and 2. The calculations were based on unit wind speed and unit opening area. The curves show the overall performance of both barns with respect to wind angle and building orientation. For example, the ventilation rates through the barns were calculated using Eq. 1. The reference opening area, A , was constant in each barn. For a given wind speed, V , the expected ventilation rates, Q , at angles parallel to the barn (near 0, 180, and 360°) were low compared to rates determined at angles perpendicular to the barn (near 90 and 270°) because of the values of C_q at those angles. Least ventilation would occur in a building when the direction of the wind is parallel to the building length and the greatest ventilation would occur when the wind direction is perpendicular to the building length.

At 90 and 270°, the ventilation rate coefficients were nonsymmetrical even though both barns were symmetrical and the area of the openings were the same on both sides. The nonsymmetric characteristic of the ventilation coefficients may be attributed to barn B-1 having two sections and barn B-2 being attached to a second pig barn.

When determining ventilation rate coefficients, both barns were assumed to contain "multiple rooms". When a building contains multiple rooms, NatVent takes into consideration only one of the rooms, measurements of the selected room openings, and the overall building measurements. Other surfaces of the building are treated as surfaces with no openings.

The ventilation rate coefficients presented in Fig. 1 (i.e. for barn B-1) were markedly lower than those presented in Fig. 2 (for barn B-2) at approximately 90 and 270°. This may have occurred because of the smaller sidewall openings in barn B-1 compared to barn B-2 and because of the rotating sidewall doors in barn B-1. Since the doors were located in the middle of the sidewall and had a limited maximum opening position, they reduced the effective size of the openings. Consequently, rather than use the total height of 600 mm as the effective maxi-

Table III: Levels of satisfaction predicted by NatVent

Location	Orientation angle (°)	Percent success (%)	Level of satisfaction
Lacombe	90	48.6	not recommended
Olds	90	85.6	excellent

mum height of side wall opening in NatVent, 300 mm was used.

Satisfaction ratings

Finally, NatVent presented levels of satisfaction for the barns as shown in Table III. The percentage success of achieving the recommended ventilation rate in barn B-1 was 48.6%. Thus, being less than 50%, the level of satisfaction presented was "not recommended" and in conclusion, "most operators and experts dislike these types of barns".

The unsatisfactory percentage success and level of satisfaction of barn B-1 may again be attributed primarily to the size of the side wall openings. The effective maximum height of sidewall openings was 300 mm during this test period. Had the effective height of the side wall openings been the total height of the openings, i.e. 600 mm, the predicted percentage success would have increased to 74.5% and the level of satisfaction been presented as "good".

The percentage success of barn B-2 was high (85.6%) and the level of satisfaction presented as "excellent". The satisfactory performance of barn B-2 may be ascribed to the newness of the barn with its 550 mm high continuous opening along its length and vertical ventilation doors in each side wall. Thus, the maximum effective height of side wall openings was equal to the total height of the openings because the vertical ventilation doors provided a larger opening and consequently increased ventilation through the barn. However, the interference by buildings around barn B-2 was not taken into consideration, though it may have been significant.

Comparison of ventilation rates

Plots of predicted and measured ventilation rates against time for each barn, on four days when the side wall panels were fully opened, are presented in Figs. 4 and 5.

The measured ventilation rates in barn B-1 were in very good agreement with the predicted ventilation rates (Fig. 4). The very good agreement between measured and predicted

Table IV: The measured and predicted average ventilation rates in the barns

Barn B-1		Barn B-2	
Measured rate (L/s)	Predicted rate (L/s)	Measured rate (L/s)	Predicted rate (L/s)
3317	3472	7837	7981
4429	4540	5802	10812
4829	4946	3607	8611
2900	2854	3225	8374

Table V: A comparison of the measured and predicted ventilation rates in the two barns

Barn B-1		Barn B-2	
R ²	Std. Dev. (L/s)	R ²	Std. Dev. (L/s)
0.98	162	0.26	6192

ventilation rates on all four days in barn B-1, compared with barn B-2, occurred because of the location of barn B-1 relative to other buildings or obstructions around it. Hence, the effect of the wind on ventilation in the barn was unaffected by the wind direction. On the other hand, in barn B-2 (Fig. 5), the measured ventilation rates were in very good agreement with the predicted rates on only one day (August 20). On all the other days, the measured ventilation rates in barn B-2 were below the rates predicted by NatVent. In barn B-2, the measured ventilation rates only agreed with the predicted rates when the wind came from a north-east to south-east direction. When the wind blew from any other direction, the other buildings in the vicinity obstructed the flow to the barn openings.

A statistical analysis of mean ventilation rates (Table IV) obtained (Figs. 4 and 5) was conducted to compare the measured and predicted ventilation rates. Regression coefficients (R²) and standard deviations (s) between the measured and the predicted ventilation rates are presented in Table V. Means of the measured ventilation rates were plotted against means of predicted ventilation rates (Figs. 6 and 7).

The results of the statistical analysis of ventilation rates (Table V) in barn B-1 indicated that the measured ventilation rates were in very good agreement with the ventilation rates predicted by NatVent (Fig. 6). This demonstrated the ventilation rates predicted by NatVent were valid for barn B-1.

On the other hand, the statistical analysis of ventilation rates in barn B-2 indicated the measured rates were not in agreement with the rates predicted by NatVent (Fig. 7). However, this does not imply that NatVent predictions were not valid

for barn B-2. Again, the measured ventilation rates were lower than the predicted rates because of the interference by other buildings. Had barn B-2 been located in the open country, as was barn B-1, the ventilation rates predicted by NatVent would have been valid when the wind came from the obstructed side of the building.

A comparison of the average ventilation rates presented in Table IV and the summer ventilation rate recommended by NatVent (Table I) shows that the average ventilation rates in barn B-1 were below the required rate. Thus, the assessment made by NatVent for barn B-1 was "not recommended". This appears to be attributed in part to the limited number of

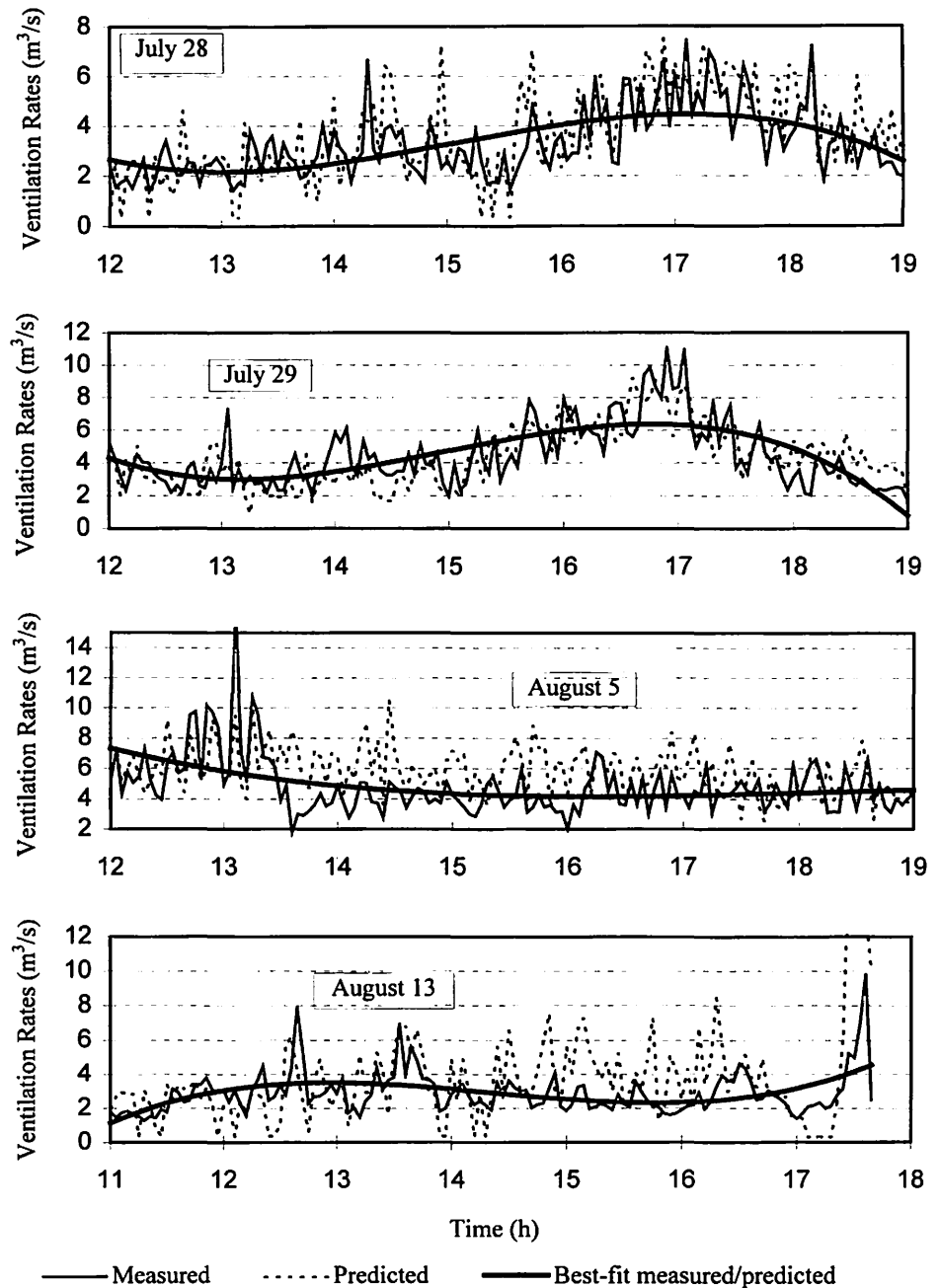


Fig. 4. A comparison of predicted and measured ventilation rates for barn B-1.

options of animal types in NatVent, hence the ventilation rate was recommended for grower-finisher hogs while barn B-1 housed weaner-grower hogs and the recommended summer ventilation rates were over-estimated. Along with this, the reduced effective area of the side wall openings (8.7%) in comparison to that (15%) recommended by Choinière and Munroe (1993) resulted in the low ventilation rates.

The average ventilation rates (Table IV) and the recommended rate (Table I) for barn B-2 might have been in better agreement had there been no interference by other buildings in its vicinity.

Furthermore, barn B-2 (Olds) was located approximately midway between two weather stations, namely Calgary and Red Deer. Hence, using weather data from either weather station to assess building performance of barn B-2 would yield different results. Consequently, for effective use of NatVent in predicting building performance in Alberta, it may be essential to use weather data in the immediate locality.

SUMMARY AND CONCLUSIONS

Two naturally-ventilated swine barns were monitored in Alberta during the summertime. A natural ventilation design analysis software (NatVent) was used to predict the ventilation rates in the barns, based on various dimensions and characteristics of the barns, details on the type of swine operation, and the local weather data. Comparisons were made between measured ventilation rates and NatVent predictions. The following conclusions were drawn from this study:

1. The measured ventilation rates based on carbon dioxide measurements in the barns and the ventilation rates predicted by NatVent were in good agreement when open country conditions were met, i.e. the wind was unobstructed. For barn B-1 the coefficient of determination was 0.98 and the estimated standard error was 162 L/s.
2. NatVent performed well when applied to the design and evaluation of naturally-ventilated livestock buildings under Alberta summer weather conditions. However, the number of options of types of operation should be increased. In addition, the number and loca-

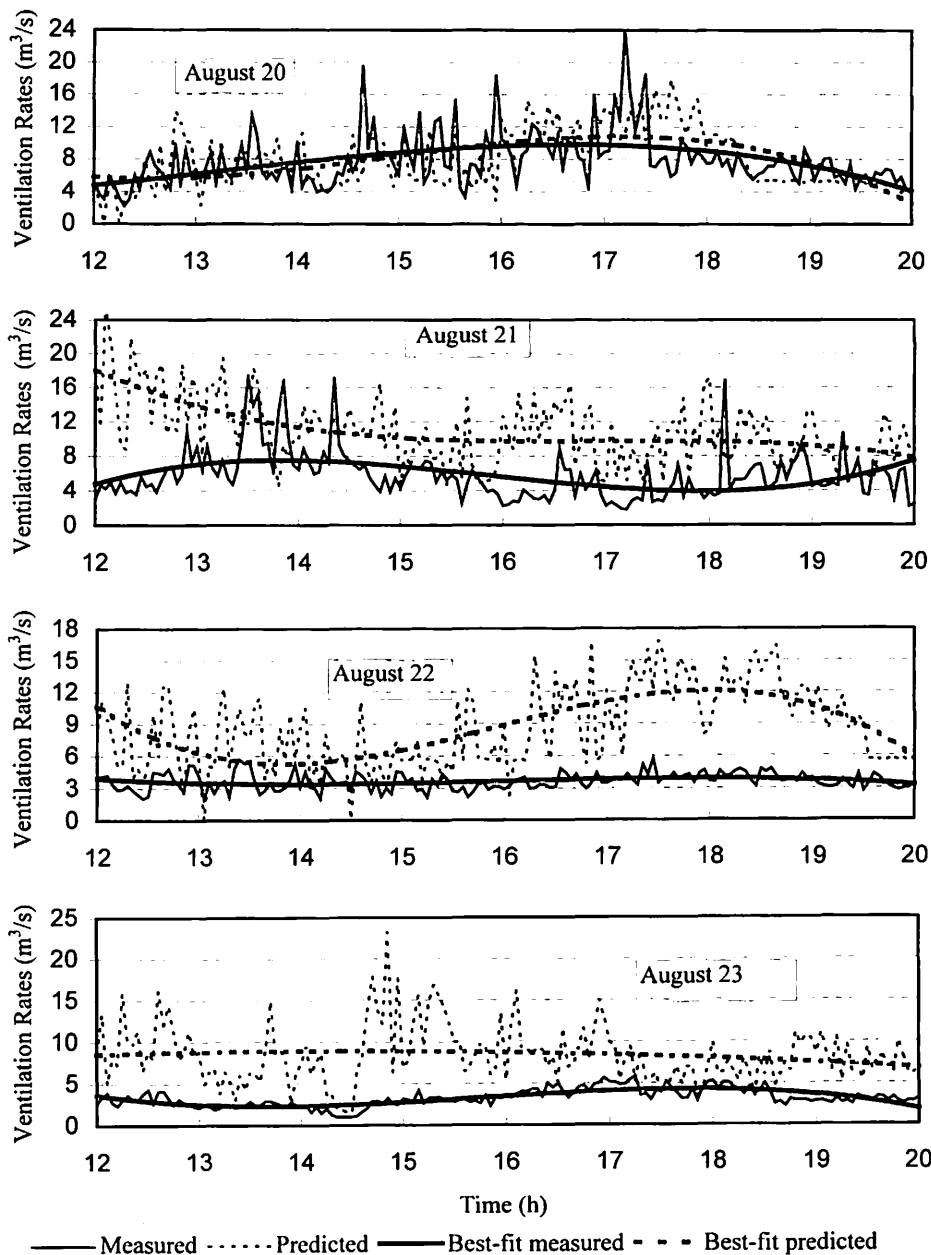


Fig. 5. A comparison of predicted and measured ventilation rates for Barn B-2.

tion of weather stations needs to be expanded for Alberta.

3. The area of side wall openings in naturally-ventilated buildings should be equal to or greater than 15% of the total side wall area in order to provide sufficient ventilation rates through the building in hot weather conditions in Alberta.

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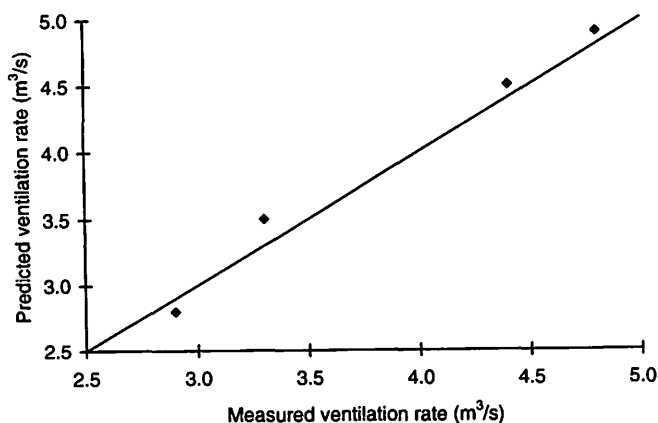


Fig. 6. The measured and predicted ventilation rates for Barn B-1.

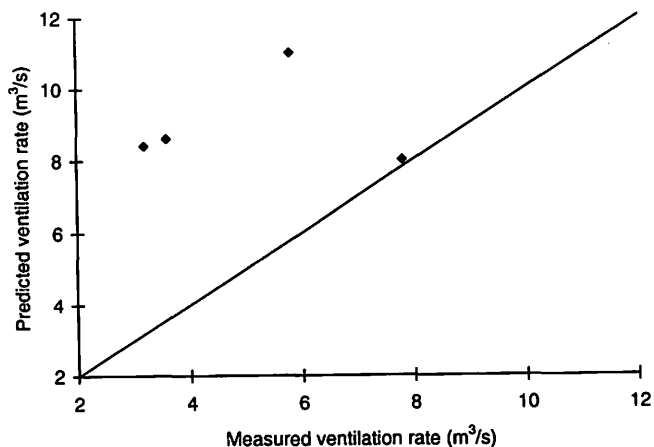


Fig. 7. The measured and predicted ventilation rates for Barn B-2.

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