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"NATVENT" SOFTWARE PREDICTIONS VERSUS FULL-SCALE ESTIMATES OF WIND INDUCED NATURAL VENTILATION IN A SWINE BARN

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ABSTRACT:

Ventilation rates in a naturally ventilated swine barn were estimated based on measured CO_2 levels. Tests were conducted using continuous ridge opening widths of 0, 25 and 125 mm. Ventilation rate coefficients were determined considering wind speed and direction, and size of sidewall openings. These coefficients were compared to those predicted by the NatVent software package which uses data from a wind tunnel study of a scale model of a naturally ventilated building. These comparisons indicated good agreement between the NatVent predictions and barn measurements for the three ridge openings tested. If rotating doors are used in the sidewalls instead of vertical sliding panels, the free area of the opening is more appropriate to use than the horizontally projected area when predicting wind induced ventilation rates.

RÉSUMÉ

Les taux de ventilation dans une porcherie ventilée naturellement ont été évalués selon une méthode basée sur la mesure des niveaux de CO_2. Des essais furent entrepris avec des ouvertures continues du faîte du toit de 0, 25 et 125 mm de largeur. Les coefficients de ventilation naturelle ont été déterminés en tenant compte de la direction et de la vitesse des vents, et les aires d'ouvertures des murs et du faîte du toit. Les coefficients expérimentaux sont comparés à ceux prédis par le logiciel "NatVent". NatVent produit des coefficients de ventilation naturelle basés sur des essais sur modèles réduits en soufflerie aérodynamique.

Les coefficients de ventilation naturelle experimentaux coïncident avec les prédictions de NatVent pour les trois ouvertures au faîte du toit. Lorsque des portes rotatives sont utilisées comme ouvertures dans les murs au lieu des panneaux verticaux, l'aire de référence pour le calcul de la ventilation naturelle doit être la surface efficace totale d'ouverture au lieu de la surface projetée à l'horizontal.

INTRODUCTION

For the Canadian climate, sizing of the large sidewall, ridge and end wall openings should be based on wind forces. The prediction of the wind induced natural ventilation for livestock housing with large ventilation openings can be obtained using NatVent, a computer software package. NatVent predicts the ventilation rate coefficients based on the pressure difference method using data obtained from wind tunnel studies of various scale models.

This study compares the ventilation rate coefficient predicted by NatVent to actual measurements taken in a typical finishing pig barn.

LITERATURE REVIEW

The most common model for wind induced natural ventilation was presented by numerous authors (ASHRAE, 1989; Hellickson *et al.*, 1983; Vickery *et al.*, 1983, Choinière, 1991) and is presented as

$$Q = C_Q V A_{ref} \qquad [1]$$

where Q = wind induced ventilation rate
V = wind speed
A_{ref} = reference opening area
C_Q = ventilation rate coefficient

ASHRAE (1989) and Hellickson *et al.* (1983) proposed that the C_Q values range between 0.25 and 0.35 for a wind diagonal to the building length, and between 0.5 and 0.6 for wind perpendicular to the building when "A" is the opening area of the windward sidewall only. Vickery *et al.* (1983) presented totally different C_Q values when the total opening area around the building is used as a reference. Boyd (1985) and Bröckett and

Albright (1987) proposed that the horizontally projected sidewall opening area should be used as the reference to calculate wind induced natural ventilation.

Aynsley *et al.* (1977) presented various discharge coefficients for different types of sidewall openings and discussed the use of horizontally projected sidewall opening area versus the effective opening for rotating doors and louvres measured perpendicular from the door to the wall.

Choinière (1991) carried out a comprehensive wind tunnel study on open and sealed scale models in order to obtain precise pressure coefficient data for most naturally ventilated buildings commonly used for livestock housing across Canada. Consequently, more precise ventilation rate coefficients can now be calculated.

Choinière *et al.* (1989) attempted to calculate the ventilation rates in a naturally ventilated swine finishing barn based on carbon dioxide measurements and the estimated carbon dioxide production rates of the pigs. Their aim was to compare the effects of different ridge opening widths on ventilation rates during warm summer conditions. From these calculated ventilation rates, Choinière (1989) proposed some ventilation rate coefficient values for the three ridge widths. He also discussed the effects of using the horizontally projected versus the measured area for rotating doors on the ventilation rate coefficient values. Traditionally, the horizontally projected area has been used for rotating doors (Bruce, 1978; Boyd, 1985). However, some airflow pattern observations performed by Choinière *et al.* (1988a and b) on scale models and observations in swine barns (Choinière *et al.* (1989)) tend to show that the air enters the barn with an upward direction along the surface of the rotating door. This suggests that the effective opening area should be measured perpendicularly from the rotating doors to the edge of the sidewall opening.

OBJECTIVES

NatVent predicts ventilation rate coefficients based on the pressure difference method from wind tunnel data for low-rise agricultural buildings. Ventilation rate coefficients can also be estimated based on carbon dioxide measurements inside a swine finishing barn and the use of the constant concentration method.

The objectives of this study are:

1 - to compare the ventilation rate coefficients predicted by NatVent versus those estimated from actual carbon dioxide measurement for the three different ridge opening widths of 0, 25 and 125 mm;

2 - study the effect of the projected versus the effective opening area for the rotating doors on the ventilation rate coefficients.

METHODS AND PROCEDURE

Barn Description

Tests were carried out in a 10.8 x 23.0 m warm naturally ventilated pig barn (Fig. 1) located near Spencerville, Ontario. The barn was oriented north-south, and had a 4.35 m ridge height and a sloping ceiling. Adjacent buildings were mainly to the north and east causing a minimum of interference to the prevailing south-westerly winds. Rotating 2100 x 900 mm ventilation doors in both sidewalls were controlled by a modulated automatic control system based on temperature (Munroe *et al.* (1991).

Figure 2 shows a sidewall rotating ventilation door for the barn in the fully open position and indicates the horizontally projected and effective opening areas. The projected opening area as shown is equivalent to 13% of the overall sidewall area, while the effective area represents 24% of the sidewall area.

Table 1 presents the total horizontally projected and effective areas for the building. The latter is the sum of the sidewall and ridge openings.

The barn had a ridge opening length of 19.2 m. During this study, the ridge opening width was set at either 0, 25 or 125 mm using a manual cable and winch system. There were no end wall openings.

Instrumentation and Test Procedure

As described by Choinière *et al.* (1990), 20 thermocouples were used to determine the temperature distribution over a cross-section at the centre of the barn, while 22 other thermocouples located 0.9 m above the floor indicated temperature distribution along the length of the barn. Outside temperature, along with wind speed and direction were monitored near the barn using a standard 10 m high weather station. All the sensors were read every 10 s and their readings then averaged for each 5 minute period. These data were then used to compute the long term average temperatures and standard deviations for each thermocouple location.

As described by Choinière *et al.* (1989), the CO_2 concentration inside the barn was monitored based on an average of 21 points (7 locations in each of 3 similar cross sections). Plastic tubing (5 mm diameter) and a centrifugal fan extracting a total of about 5 L/s was used to draw air simultaneously from the 21 locations into a mixing box. The CO_2 concentration in this box was measured every 10 s and the readings averaged over a 5 minute period. The exterior CO_2 concentration was measured once during the day two to three times per week. It was always between 325 and 350 ppm.

During the test period, the target temperature at pig level was 18.5°C corresponding to optimum conditions for finishing pigs weighing 25 to 90 kg. When the temperature near the thermostat reached or exceeded its set point of 18.5°C, the ventilation doors began to open. They would continue to open in increments of about 25 mm every 3 minutes until they were fully open or until the temperature at the thermostat fell below its set point, in which case the doors would begin to close. It took approximately 1 h for the doors to move from a fully closed to a fully open position.

Tests were carried out between June 6 and August 10, 1988. The ridge opening width (0, 25 or 125 mm) was changed every three days. However, because of occasional problems with equipment or instrumentation, the equivalent of approximately 850 h of data were obtained during this time.

The pig population was noted twice per week. Typical pig densities were 15 pigs per pen (0.72 m^2/pig). A total of 300 finishing pigs ranging from 25 to 90 kg were housed in this barn during the study. Pigs between 25 and 55 kg were feeder fed *ad libitum*, while heavier pigs were floor fed twice per day.

Calculation of Ventilation Rate

The ventilation rates were calculated using the equilibrium method described by Feddes *et al.* (1983) and Feddes and DeShazer (1988). The numbers of pigs being feeder or floor fed and estimated animal weights were noted twice weekly. The assumed instantaneous CO_2 production rates were estimated based on the hourly CO_2 production data obtained by Feddes *et al.* (1983) (personal communication) and the measured instantaneous average CO_2 concentration in the barn.

Data Selection for the Calculation of Ventilation Rates

In order to depict open country conditions, only the data concurrent with wind within the south to west sectors (Fig. 1) were considered for the calculation of ventilation rates. This selection eliminated winds that passed over adjacent buildings to the north and east and possibly picked up exhausted CO_2.

Simultaneous measurements of outside and inside CO_2 concentrations were not made as only one CO_2 analyzer was available. Due to the plants' cycle from daytime photosynthesis to nighttime respiration, Desjardins (1989) indicated that under low wind speed conditions the concentration of CO_2 in and over corn fields could increase from 350 ppm during the day to 400 to 600 ppm during the night. This increase occurs rather abruptly at sunset. Based on the equilibrium method, CO_2 concentrations of 400 ppm in this barn and 350 ppm outside would indicate ventilation rates of 4 to 5 air changes per minute. Small errors in measured outside CO_2 concentrations could lead to large errors in predicted ventilation rates under these conditions. Since the test facility was adjacent to a corn field, only daytime CO_2 data collected between 6:00 h and 20:00 h were used in computing ventilation rates. In addition, all data representing concentrations less than 400 ppm were grouped together and noted as being less than or equal to 400 ppm and were not considered in the calculation of the ventilation rate coefficients.

To ensure that the ventilation doors were fully open, data were only considered if the temperature at the thermostats had been above the thermostat set point for at least 30 min.

In Fig. 5, some data points lay above C_Q = 0.6 and are not shown on the graph. However, these points were used in calculating the best-fit polynomial.

Ventilation Rate Coefficients

The ventilation rate coefficients (C_Q) for each time interval were calculated using Eq. 2.

$$C_Q = \frac{Q}{VA_{ref}} \qquad [2]$$

where the reference area (A_{ref}) is the total effective area given in Table 1. Data are included for wind angles from 0° to 110° (0° being south and 90° being west). A polynomial best-fit program (NWA StatPak, 1983) was used to obtain an experimental C_Q curve.

Ventilation Rate Coefficients from NatVent

The software, NatVent, was used to predict the ventilation rate coefficients for this swine barn using the projected or effective sidewall opening sizes for each of the three ridge widths.

RESULTS AND DISCUSSION

As shown in Figs. 3 to 6, the swine barn ventilation rate coefficients are quite dispersed for all wind angles. This dispersion can be mainly attributed to two factors: 1) the basic imprecision of the prediction model for CO_2 production by the pigs which varies according to pig weight, activity levels, feeding system, etc.; and 2) the precision of the CO_2 measurements inside and outside the building (only 100 ppm precision).

The results show the general trend of lower C_Q values for wind angles of 0° to 30° and higher values for wind perpendicular to the building length (90°).

Figures 3, 4 and 5 present the estimated ventilation rate coefficients based on CO_2 measurements in the swine barn, the polynomial best-fit and the predicted ventilation rate coefficients using NatVent.

With the 0 mm ridge width (Fig. 3), the best-fit curve of the swine barn data and the NatVent prediction curve are quite close for wind angles between 30° and 100°, but diverge for angles below 30°, however, very few data were available for these low angles. The results from Figs. 4 and 5 show that the NatVent predictions are in very good agreement with the swine barn data.

Figure 6 presents the ventilation rate coefficients calculated using the horizontally projected area as a reference area in Eq. 2. The coefficients based on CO_2 measurements in the barn are considerably higher as compared to the NatVent predictions. Consequently, when the pressure difference method (used in NatVent) is used to predict the wind induced ventilation rates for a building with rotating doors, the effective sidewall opening area should be used rather than the projected area.

SUMMARY AND CONCLUSION

The ventilation rate coefficient predictions (based on the pressure difference method from wind tunnel data for low-rise agricultural buildings) by NatVent are compared to the calculated ventilation rate coefficients obtained using measurements of CO_2 levels in the barn and estimated CO_2 production by the pigs. Tests were carries out for ridge opening widths of 0, 25 and 125 mm.

The results show that:

1 - the NatVent predictions and the coefficients based on CO_2 measurements in the barn are in good agreement for the three ridge opening widths when the total reference area includes the effective sidewall opening areas and the ridge opening areas;

2 - in order to use the pressure difference method and NatVent to predict the wind induced ventilation rates for a building with rotating doors, the effective sidewall opening area should be used rather than the projected area.

RÉSUMÉ ET CONCLUSION

Les prédictions des coefficients de ventilation naturelle par le logiciel NatVent (calculées par la méthode des différences de pression selon des essais en soufflerie aérodynamique sur modèles réduits) sont comparées aux coefficients expérimentaux obtenus par la mesure des taux de CO_2 dans une porcherie. Des essais avec des ouvertures continues au faîte du toit de 0, 25 et 125 mm de largeur ont été effectués.

Les résultats montrent que:

1 - les prédictions des coefficients de ventilation naturelle sont en accord avec les résultats éxperimentaux en porcherie pour les trois ouvertures au faîte du toit considérant que l'aire de référence inclue la surface efficace totale d'ouverture dans les murs et celles au faîte du toit;

2 - pour prédire correctement les coefficients de ventilation naturelle avec le logiciel NatVent, pour un bâtiment avec des portes rotatives, la surface efficace totale d'ouverture doit être utilisée au lieu de la surface projetée horizontalement.

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Table 1. Total opening areas for the 0, 25 and 125 mm ridge widths using the projected or effective sidewall opening ares.

Ridge Widths (mm)	Ridge Area (m^2)	Total Projected Area (m^2)	Total Effective Area (m^2)
0	0	14.36	27.20
25	.46	14.82	27.66
125	2.32	16.68	29.51

Effective sidewall area = 18 doors x .72 m x 2.1 m = 27.20 m^2
Projected sidewall area = 18 doors x .38 m x 2.1 m = 14.36 m^2

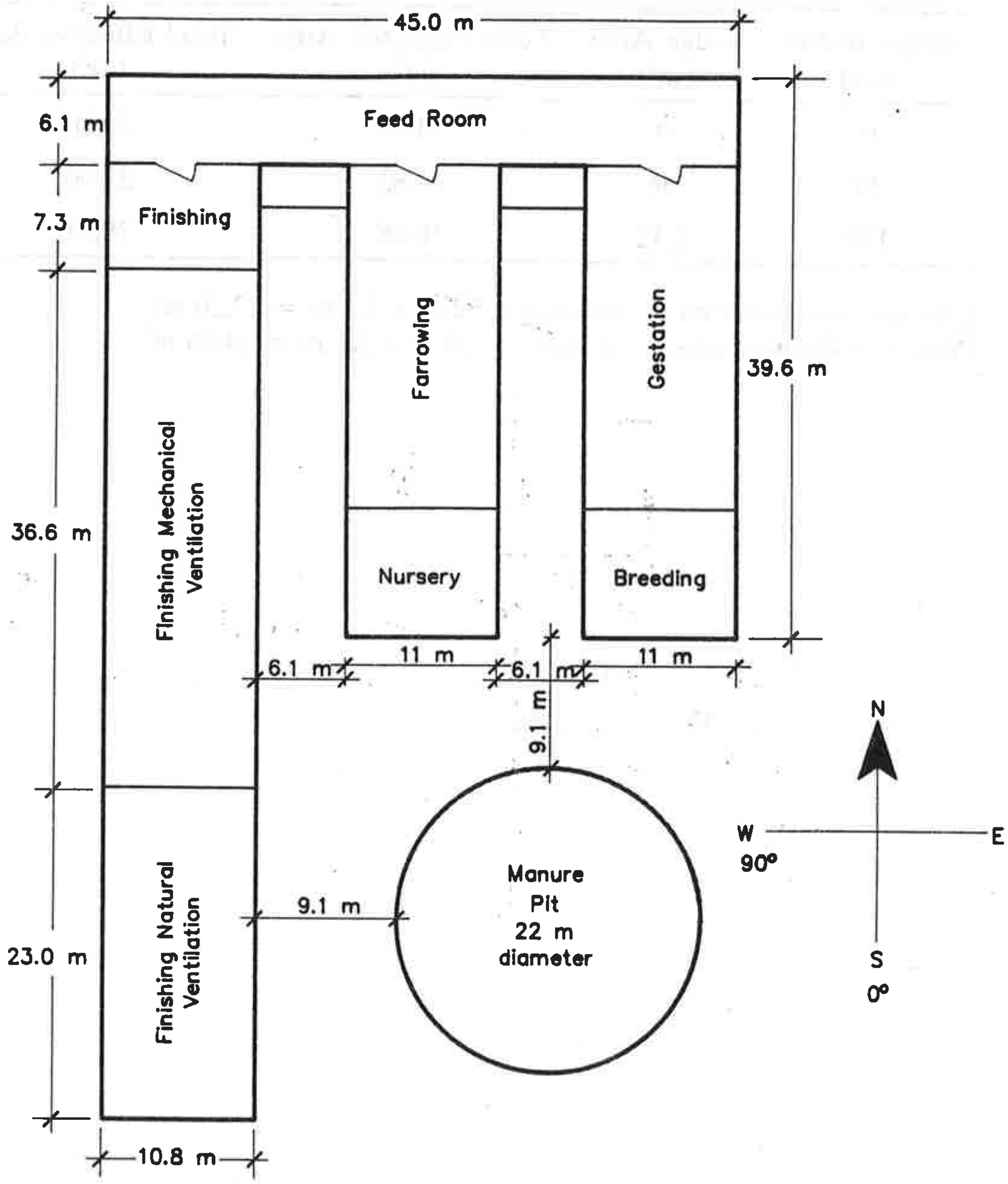

Figure 1. Research site for swine barn tests, Albert de Wit, Spencerville, Ontario.

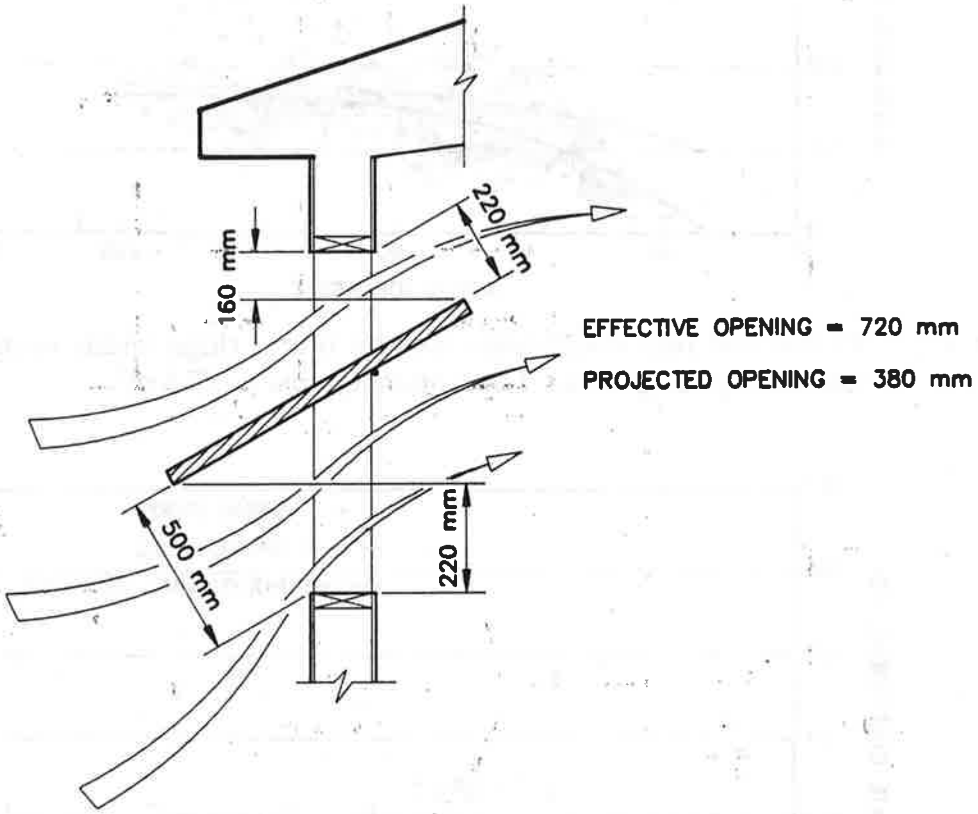

Figure 2. Rotating door design for natural ventilation, projected and effective opening areas.

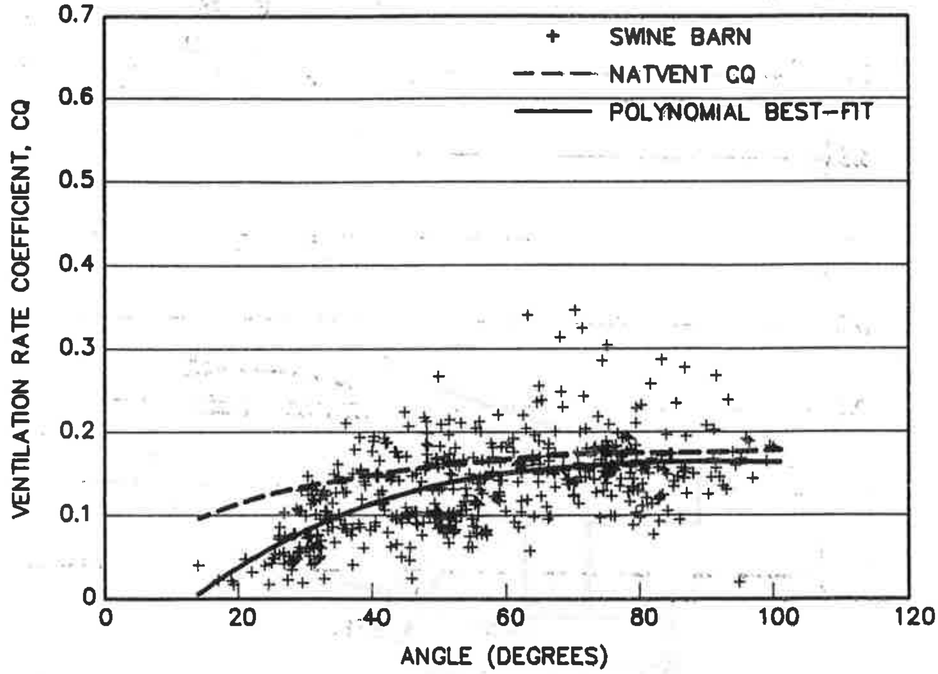

Figure 3. Ventilation rate coefficients for the 0 mm ridge width using the effective sidewall opening area. Total opening area is 27.2 m^2.

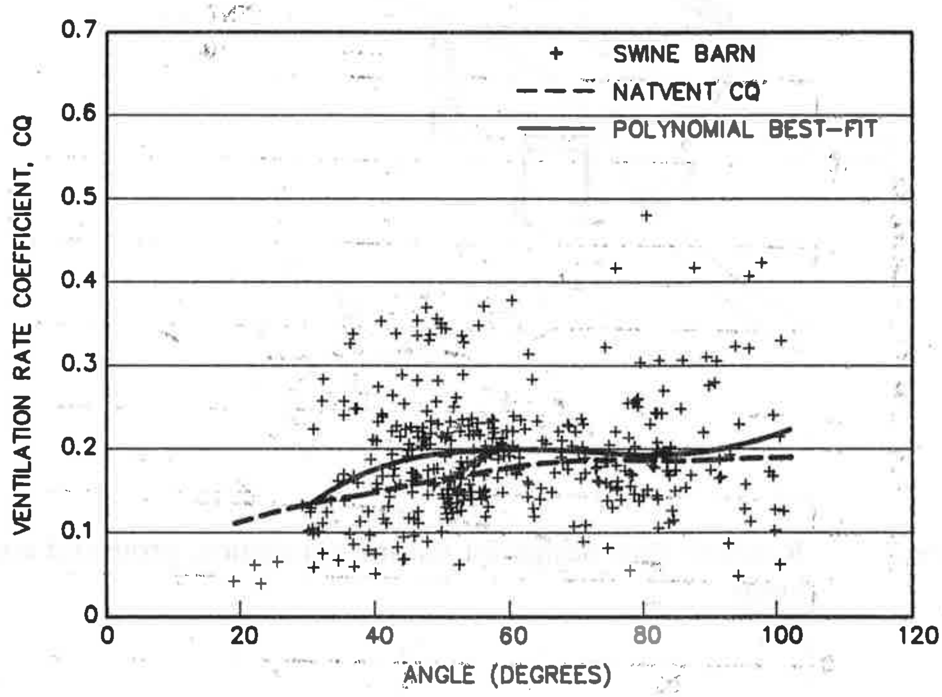

Figure 4. Ventilation rate coefficients for the 25 mm ridge width using the effective sidewall opening area. Total opening area is 27.7 m^2.

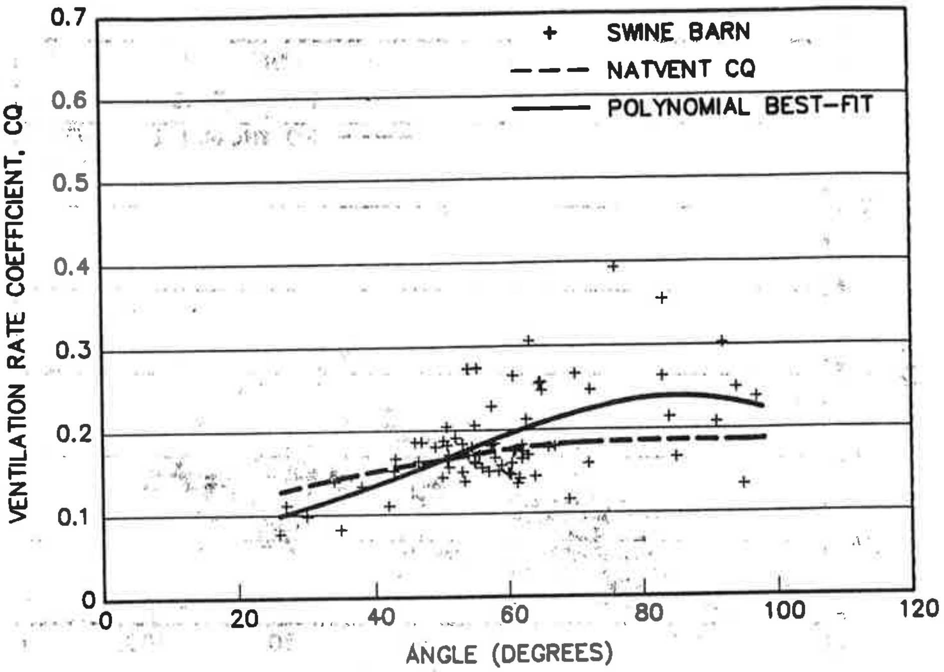

Figure 5. Ventilation rate coefficients for the 125 mm ridge width using the effective sidewall opening area. Total opening area is 29.5 m^2.

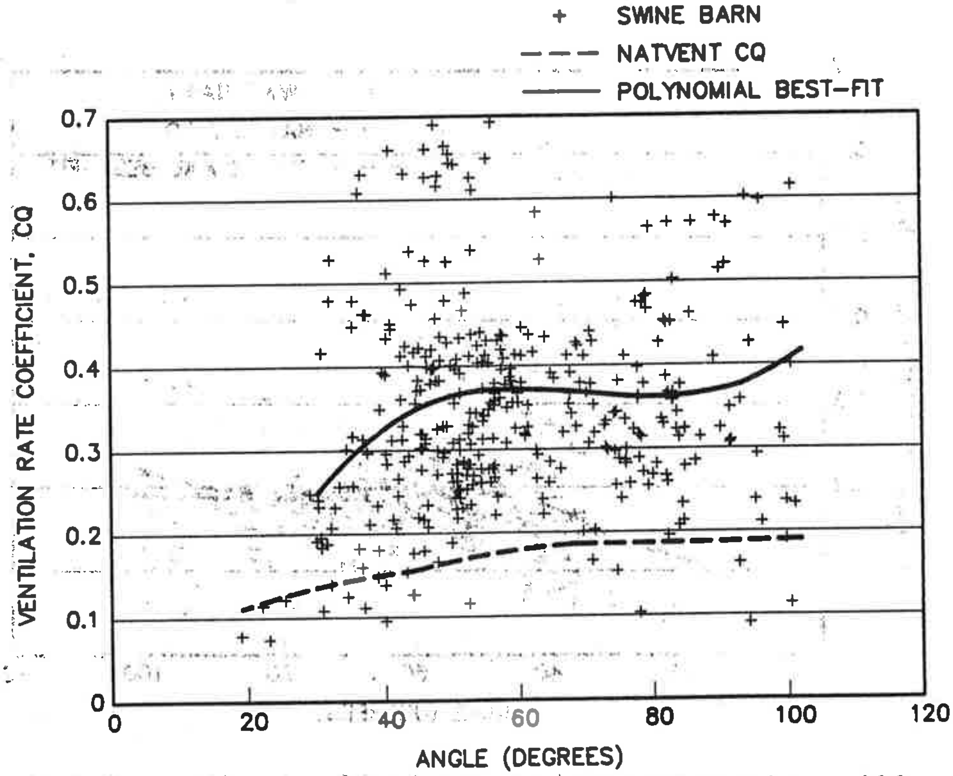

Figure 6. Ventilation rate coefficients for the 25 mm ridge width using the projected sidewall opening area. Total opening area is 14.8 m^2.