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# CONTROL STRATEGY FOR SIDEWALL OPENINGS OF COLD, MODIFIED AND WARM ENVIRONMENT DAIRY HOUSING

by

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**SUMMARY:**

This paper considers the feasibility, of using an automatic control system for adjusting the size of ventilation openings in such barns. Contol strategies for such systems are given along with recommendations for sizes of required permanent sidewall openings. Results are based on a field survey and a computerized ventilation program.

**KEYWORDS:**

ventilation, natural, modified, automated, dairy



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# INTRODUCTION

Types of housing for dairy in colder climates vary from fully insulated, warm buildings to uninsulated cold buildings. Warm buildings can be mechanically ventilated with fans or naturally ventilated with air moving primarily due to wind effects into and out off sidewall and ridge openings which are adjustable in size. The ventilation rate is automatically adjusted usually through a thermostat based control system that turns one or more fans on or off, or in the case of the naturally ventilated building, by a similar control system that regularly increases the size of the sidewall and possibly the ridge openings.

Modified environment barns are less well insulated and typically sidewall and ridge openings are infrequently adjusted. As a result the inside temperature follows more closely that of outdoors. Problems of indoor temperature fluctuation, high humidity, and fogging are common but largely dependent upon weather conditions and sizes of the ventilation openings.

Uninsulated cold barns must have adequate openings to ensure enough ventilation to approach outside conditions. As with modified environment barns the ventilation opening size is seldom adjusted.

It has been noted that some operators who take the trouble to frequently adjust the size of ventilation openings in modified environment barns can improve considerably the inside conditions. The installation of a manually operated cable control system reduces the inconvenience and effort required with such adjustments. The question then arises as to whether it would be feasible, practical, and economical to fully automate the ventilation system as is done in a warm naturally ventilated barn. The same question can also be addressed to the cold naturally ventilated barns. Assuming an automated ventilation system is installed, it then is of interest to develop and define control strategies for the optimum operation of either a modified or col environment barn.

# LITERATURE REVIEW

## Performance of naturally ventilated dairy barns

Milne (1985) reported a high level of satisfaction among many dairy farmers using natural ventilation in Southwestern Ontario. Most of these buildings were lightly or fully insulated, and some had an automatic control system for their sidewalls and ridge openings.

Over a two year period, Kammel et al. (1982) monitored exterior wind speeds, and inside and outside temperatures for four dairy facilities. Three barns had overall insulation values ranging from RSI 1.02 to 3.36 while one barn was not insulated. They noticed that during January and February, the average internal temperatures of the insulated barns were 6-19°C above the outside temperature. This temperature difference ($\Delta T_{in-out}$) varied according to the level of insulation and the areas of the ridge and sidewall openings. They reported an average 4°C temperature rise in the uninsulated barn. The highest $\Delta T_{in-out}$'s were recorded during periods of low wind speed.

The wide variability of the thermal performances could be attributed to such factors as the target temperature desired by the operator, the different magnitudes of the ventilation opening areas (ridge and sidewall), and the different air infiltration rates (through cracks, around doors, etc.). A higher target temperature inside the barn means lower ventilation rates and higher building conductive heat losses. The drop in $\Delta T_{in-out}$ with higher wind speeds indicated that air infiltration may affect considerably the rate of ventilation. This has been discussed as well in ASAE, Standard EP-270.5 (1987). When low outside temperatures and high wind speed occurred, the operator could only adjust the sidewall and ridge openings to help maintain the desired interior temperature and required ventilation rate for moisture control.

Kammel et al. (1982) reported that most of the operators would manually adjust the sidewall and ridge opening about three times per day - in the morning, during the day and at night. Preferrably, the operators should also adjust the openings in advance according to the weather forecast. They indicated that there was potential for using an automatic control system.

Holmes and Cramer (1984) monitored the $\Delta T_{in-out}$ for a warm 4-row dairy facility. The building had insulation values of RSI 2.1 for the walls and RSI 3.5 for the ceiling. Their results indicated a $\Delta T_{in-out}$ of 15-25°C during the month of February. The inside temperature was maintained above freezing even on two occasions when the outside temperatures reached -24°C and -26°C. The ventilation openings were manually adjusted, however the ridge opening had to be closed during cold and windy days.

No literature was found relating to the performance of an automatic control system for naturally ventilated dairy buildings.

Minimum sidewall and ridge openings for dairy barns

The Guidelines for Natural Ventilation produced by the Mid-West Plan Service (MWPS-33, 1989) contain basic recommendations on the sidewall and ridge openings required during the winter and summer periods. With no insulation, wider buildings require large ridge, eave and sidewall openings. The minimum openings for winter are permanent and not adjustable. On the other hand, for warm and well insulated buildings these openings should be adjustable, and automatic control systems are recommended.

The recommendations from the MWPS are in general agreement with similar material proposed through the Canada Plan Service (CPS). For winter operation, CPS Dairy Plans 2104 and 2106 (4 row free stall dairy barns) show 150 mm wide continuous soffit openings that can be reduced to 50 mm wide via a manually adjustable flap. Also shown is a continuous 250 mm wide ridge opening with closing capability. On the sidewalls, large vertical panels or rotating doors are used for summer ventilation. Only manual control of these openings is indicated.

Controversy still exists over the preference of warm environment, modified environment, or cold environment for dairy facilities. As well, the required winter minimum opening of the sidewall and the ridge, and the need or advantage of an automatic control system to improve the inside temperature control in dairy facilities are not well established. Studies reported in 1959 on the effect of ambient temperatures on milk production have been used in the ASAE Standard (1987). They show little effect on temperature on milk production.

Based on Albright (1983), Curtis (1983) and many others, there is no clear answer as to the effects of low inside temperatures, rapid temperature fluctuations, or high humidity levels on factors such as dairy cow comfort (stress level), long term animal health, reproductive efficiency, and cow longevity. As well, the effect of different types of housings on building material (wood, metal) deterioration and resultant building lifespan have not been investigated.

## ON-FARM OBSERVATIONS

Visits were made to several dairy farms with warm (very well insulated, RSI 3.5), modified environment (lightly insulated RSI 0.9), or cold barns (uninsulated, RSI 0.2). Large warm dairy barns with automatically control sidewall panels are very popular in Eastern Ontario. Based on discussions with the operators, the following summaries can be made.

### Fully insulated warm automatically controlled barns

Advantages:

1 - Very good control of inside temperature and moisture levels.
2 - Excellent cow health and productivity.
3 - No freezing problem for water bowls or gravity flow manure trenches.

4 - Pleasant working environment for employees.
5 - No need to manually adjust the sidewall openings.

Disadvantage:

1 - Extra construction and equipment costs.

<u>Lightly insulated modified environment barns</u>

Most had manually operated sidewall openings, continuous soffit openings widths that varied from 50 to 150 mm, and ridge openings from 150 mm to 250 mm.

Advantages:

1 - Very acceptable working environment.
2 - Reduced costs.
3 - Excellent cow health and productivity.

Disadvantages:

1 - Moisture level sometimes increased with changing weather (some fog).
2 - Some freezing problems during extremely cold weather.
3 - Control of barn temperature was more difficult.
4 - Without an automatic control system, more effort was required on the part of the operator to adjust sidewall openings.
5 - Several instances of deterioration of wood and metal (truss gusset plates) were noted.

Operators who added an automatic control system to adjust the sidewall panels were pleased with the work load reduction and no longer having to worry about adjusting the panels according to the weather forecast. During the winter, the target temperature in the barn was in the 2-5°C range, and was gradually increased to the 10-12°C range during the warmer seasons.

<u>Uninsulated cold environment barns</u>

None visited had any automatic control system for the sidewall panels.

Advantages:

1 - Lowest building costs.

Disadvantages:

1 - Frequent fog inside the building.
2 - Frequent freezing of automatic manure scrapers; heated water bowls required.

3 - More frequent observations of building material (wood and metal) deterioration.
4 - Unpleasant working environment for the operators.

The operators felt that the key of success for cold buildings was to have as much of opening area as possible, even during the winter in order to remove moisture produced within the building. The soffits were often left fully open providing a space 100-300 mm wide. Ridges openings, usually continuous, were 100-300 mm wide. Some operators complained about rain and snow infiltration with the larger ridge openings.

Based on these farm visits, the operators with modified environment and cold barns showed considerable interest in the use of an automatic control system. This was noted especially with careful operators of modified environment barns who were already making frequent manual adjustments of their sidewall and ridge openings. The soffit opening areas for the modified and cold buildings varied considerably from farm to farm. If vertical panels (solid or plastic curtains) were used, it would be possible to prevent the panels from closing completely, thereby leaving a permanent continuous opening for the minimum ventilation rates. This would eliminate the need for soffit openings. The addition of a wind break panel protecting this permanent continuous opening at the top of the vertical panel would reduce the potential for drafts on the cows during windy conditions (Choinière et al., 1989a, Choinière and Munroe, 1990).

## OBJECTIVES

The objective of this study was to select on paper a typical free stall dairy barn and based on computer simulation consider the feasibility of using an automatic control system for adjusting the size of the ventilation openings. If feasible, then a control strategy for the operation of such an automatic system would be developed. The warm environment, the modified environment and cold environment versions of the barn were to be considered. The need, if any, for permanent sidewall and/or ridge openings during the winter and their size were also to be determined.

## PROCEDURES

The ventilation program "VENT" described by House and Huffman (1987) was used in a simulation to calculate the heat balance , ventilation requirements and heat deficit temperatures for a typical drive-through 200-cow free stall dairy barn. This barn was 73 m long, 26 m wide and had a sidewall height of 2.7 m. The roof slope was 4:12 giving a total barn volume of 9236 $m^3$. In

Eastern Ontario, current practice is to recommend a continuous sidewall opening of 1050 mm. In the summer, the large doors at the end of the manure alleys and the feed alley can allow additional ventilation.

Three different insulation levels were chosen to represent either a warm barn, a modified environment barn, or a cold barn. For the warm barn, it was assumed that the ceiling and walls had an insulation value RSI 3.5, and that the sidewall panels and end doors had an insulation value of RSI 1.7. For the modified environment barn, it was assumed that the ceiling and walls had an insulation value of RSI 0.9, and that the doors and sidewall panels (flexible insulated curtain) had an insulation value of RSI 0.7. For the cold barn, only 12 mm plywood was assumed under the siding and roofing steel giving an insulation value of about RSI 0.2, and the sidewall curtain used was assumed to be uninsulated plastic.

The livestock density was assumed to 200 cows with an average weight of 630 kg.

The simulation was carried out for an inside desired (target) temperature of both 2 and 7°C. These target temperatures are in the range commonly used by operators in Eastern Ontario. The maximum allowable relative humidity was selected as 80%. It appears that at these temperatures the VENT program slightly underpredicts the sensible and latent heat production for milking cows as compared to the data provided by CIGR (1984), Harms and Johnson (1985) and the ASAE Standards (1987). The ventilation rates for moisture control calculated by the VENT program should be increased by 10-15%. Ventilation rates used in this paper have therefore been increased by 15% compared to the original VENT results. However the calculated heat deficit temperatures seemed valid.

For naturally ventilated buildings the minimum ventilation rate is accomplished by air infiltration through cracks, air exchange via the chimneys or open ridge, and air exchange via the sidewall openings.

Air exchange by infiltration

The ASAE Standards (1987) give infiltration rates for dairy facilities for tight or very tight construction. To use these equations, the pressure difference between inside and outside must be known. Choinière et al. (1990 b) demonstrated that this pressure difference depended upon the type of sidewall and ridge openings, as well as the angle of incidence of the wind and of course wind speed. It is beyond the scope of this paper to try and quantify the pressure variations due to these factors,and the resultant variations in air infiltration.

As a result, data from ASHRAE (1981 and 1989) and from DRP Co. (1989) were used to obtain a quick and simple estimation of the air infiltration. For a warehouse with 5.5 m sidewalls and 930 to 2800 $m^2$ of floor space, the minimum and maximum estimated air infiltration rates were 0.75 and 1.50 air changes per hour (ac/h) for good construction, 1.00 and 2.00 ac/h for average construction, and 1.50 and 3.00 ac/h for poor construction. For this study, it was assumed that from an air infiltration perspective, the warm fully insulated barns could be represented by good construction (avg. 1.1 ac/h), the modified environment barn by average construction (avg. 1.5 ac/h) and the cold barns by poor construction (avg. 2.2 ac/h).

Air exchange by chimneys

Choinière et al.(1988) studied the effect of ridge opening width on the moisture level and thermal performance of a warm, naturally ventilated swine barn. They concluded that only a minimum ridge opening was required during very cold weather to achieve the ventilation necessary for adequate moisture and temperature control. In that study, a ridge opening width of approximately 6 mm or a series of chimneys having an equivalent minimum opening area was found to be sufficient. Subsequent simulations using the VENT program indicated that in order to achieve the minimum ventilation rate required in the barn, each chimney would have to account for approximately 200 L/s. In this case, the chimneys were assumed to be 600 x 600 mm with a perimeter slot of about 25 mm. The air exchange rate would also be affected by wind speed and direction as well as temperature difference between inside and outside.

Determination of sidewall opening areas

There are many models for the prediction of airflow due to wind through sidewall openings in naturally ventilated buildings. The simplest form is the following (ASHRAE (1989), Vickery and Karakatsanis (1987)):

$$Q = C_Q \cdot V \cdot A$$

where $Q$ = volumetric ventilation rate ($m^3/s$)
$C_Q$ = flow coefficient
$V$ = wind speed (m/s)
$A$ = opening area of the sidewall ($m^2$)

The flow coefficient $C_Q$ depends on the types of sidewall, endwall and ridge openings, as well as on the angle of incidence of the wind. Choinière (1989) determined a $C_Q$ versus wind direction relationship for a naturally ventilated building with a minimum ridge opening. For wind parallel or perpendicular to the building, $C_Q$ was equal to 0.2 or 0.4 respectively.

Based on data from Environment Canada (1982), the average wind speed in the Ottawa area during the months of October through April is 4.5 m/s. According to Aynsley et al. (1977) the wind speed distribution for all directions follows a Weibull frequency distribution and on this basis the actual wind speed is below 1/2 the average wind speed 2.25 m/s only 20% of the time, and above 3/2 the average wind speed (6.75 m/s) only 20% of the time. These wind speeds were considered when determining the sidewall areas required to achieve the minimum ventilation rates.

As a result, an average value of $C_Q$ equal to 0.3 with a wind speed of 4.5 m/s will be assumed in this paper to determine the permanent sidewall opening required. But in addition, a value of $C_Q$ equal to 0.2 with a wind speed of 2.25 m/s, and a $C_Q$ equal to 0.4 with a wind speed of 6.75 m/s will be used to determine respectively the minimum and maximum sizes that this permanent opening should be able to achieve according to weather conditions.

The airflow through the sidewall openings is assumed to be

$$Q_W = Q_T - Q_C - Q_I$$

where $Q_W$ = air exchange via the sidewall openings ($m^3/s$)
$Q_T$ = total air exchange ($m^3/s$)
$Q_C$ = air exchange via the chimneys ($m^3/s$)
$Q_I$ = air exchange via infiltration ($m^3/s$)

The continuous sidewall opening width H can then be calculated as

$$H = Q_W / (C_Q \cdot V \cdot L)$$

where H = sidewall opening width (m)
L = sidewall opening length (m)

## RESULTS AND DISCUSSION

Table 1 is based on results of the VENT program for the two inside target temperatures of 2 and 7°C. For the warm building, given a target temperature of 7°C the exterior temperature $T_o$ has to fall to -22°C before a heat deficit occurs. At this time, the calculated ventilation rate is approximately 4770 L/s, and the relative humidity 80%. This represents 24 L/s per cow. The barn is able to maintain a $\Delta T_{in\text{-}out}$ of up to 29°C. Operators of actual barns similar to this indicated that the curtains would be completely closed when $T_o$ dropped to the -15 to -20°C range although this could depend somewhat on wind speed and direction.

For the warm building, it can be seen from Table 2 that assuming air infiltration to be 1.1 ac/h and air exchange per chimney to be 200 L/s, then the minimum winter ventilation rate of 4770 L/s is slightly exceeded with 10 chimneys spaced 7.2 m apart. No extra sidewall openings are necessary.

Many warm dairy barns have been built in Eastern Ontario following this rationale and all operators have expressed a high degree of satisfaction.

The modified environment barns are generally operated at lower inside temperatures. For example, if the desired inside temperature is 2°C, the exterior temperature has to fall to below -14°C before a heat deficit occurs. The observations by Kammel et al. (1982) and Crammer and Converse (1985) of naturally ventilated dairy barns indicate a $\Delta T_{in\text{-}out}$ of approximately that order. Assuming an average infiltration rate of 1.5 ac/h and 200 L/s per chimney, 22 chimneys spaced 3.3 m apart could make up the remainder of the ventilation required at this time. The other option is to minimize the number of chimneys and leave a permanent sidewall opening. As shown in Table 2, if 10 chimneys were retained the additional 2370 L/s required could be provided by a continuous sidewall or soffit opening about 25 mm wide. During extreme weather conditions, this permanent opening might have to be reduced to 13 mm especially with high winds perpendicular to the building, and increased to 70 mm when the wind is light and parallel to the building.

These approximations do not take into account any ventilation due to the thermal buoyancy effect, nor do they consider variation of the infiltration rates according to the wind speed and direction. Generally, the operators with modified environment barns have ridge openings larger than necessary and as a result are maintaining their soffit openings or curtains mostly closed. Some buildings visited showed wood deterioration and some corrosion of the metal truss gusset plates. This appears due to excessive moisture during cold weather. Figure 1 shows a possible arrangement of the vertical panel with a minimum continuous opening that would be suitable for the Ottawa area. The wind break (Photo 1) developed by Choinière et al. (1989) prevents air blowing directly into the building and reduces the draft over the animals. The quantitative effect of the wind break on pressure reduction at the opening and on airflow control are still unknown, but operators who have installed such a panel feel positive concerning this draft reduction aspect.

If an automatic control system is used, some provision for a manual override should be made to allow the operator to adjust the sidewall panel according to wind by closing the opening to 13 mm or opening it to 70 mm when the external temperature is below the heat deficit temperature. At this time the inside temperature will be low enough such that the thermostat will always be calling for the panels to be in the closed position.

The cold building can maintain a temperature differential of 6.5 to 7°C which is close to the 4°C value noted by Kammel et al. (1982). A heat deficit will occur at -4.5°C even if the inside target temperature is only 2°C. Even with 2.2 ac/h due to air infiltration, 34 chimneys (2.1 m apart) will be required if no minimum sidewall openings are available. If only 10 chimneys are installed at 7.2 m apart, then a permanent continuous opening of 50 mm will have to be retained (see Fig. 1). Depending on wind speed and direction, the permanent opening required could vary from 25 mm to 140 mm wide. Coincidentally, these values are very close to those achieved with the adjustable flap and soffit opening now shown in the existing Canada Plan Service free stall dairy plan 2106.

To avoid the inconvenience of frequently adjusting the soffits openings, most operators leave the soffits open about 150 mm wide and reduce their ridge opening to about half (75 mm to 100 mm wide). The $\Delta T_{in-out}$ with this arrangement is less than the calculated 6.5 to 7.0°C which could occur if the ventilation rate was restricted to the calculated minimum necessary.

<u>Potential for use of an automatic control system</u>

An automatic control system based on a thermostat regulates the inside temperature by opening or closing the sidewall panels according to a selected (target) temperature. For example, during the winter in a warm barn with a target temperature of 8°C, and assuming a dead band of 2°C, the thermostats open the panels if the inside temperature rises above 8°C and close them if the temperature drops below 6°C. Most control systems use a timer and time delay to readjust according to temperature every 3 to 4 minutes and remain active long enough each time to move the vertical panels 12 to 20 mm if adjustment is necessary.

The authors observed with various control systems that the panels would be closed completely when the exterior temperature fell to a few degrees above the predicted heat deficit temperature. An approximation of the period of time when the automatic control system would be operational can be determined from local weather data. The range of exterior temperature above which the automatic control system would be operational was approximated by adding and subtracting a few degrees from the predicted heat deficit temperatures. These ranges are presented in Table 3.

In the Ottawa area, there is about 181 h during the year when the exterior temperatures are below -20°C and the automatic control system in warm naturally ventilated barns would not operate (Agri. Env. Centre, 1988). In addition, inspection of the average daily minimum and maximum temperatures for the months of November to April shows that the control system would operate by adjusting the sidewall openings likely every day during the winter.

With the modified environment barns, the panel control system would be inoperative in the order of 528-1073 h which is the average time that the outside temperatures are below -15 or -10°C respectively. During such time, the vertical sidewall panels would be closed down to a minimum permanent opening of 25 mm. Based on average temperatures, this would be for about 12 to 25% of the time from November to April. Inspection of the daily minimum/maximum, and average temperatures show that the automatic control system would activate the sidewall openings almost every day of the year.

In a cold dairy barn, the automatic control system would be largely inactive during January, but it would likely operate occasionally during December and February. The control system would likely be activated almost every day in November, and March and April.

Control strategy

Table 4 presents a possible control strategy for cold, modified, or warm, naturally ventilated dairy barns. The operation is subdivided into four weather conditions being the extremely cold period ($T_o$<-15°C), the cold period (-15°C<$T_o$<5°C), the intermediate period (5°C<$T_o$>20°C) and the warm season ($T_o$>20°C). For simplicity, the extremely cold and cold periods can be associated with winter, the intermediate period with autumn/spring, and the warm period with summer. The control strategy includes: (1) adjustment of the thermostat, (2) opening or closing of the chimneys or ridge, and (3) allowance for a minimum opening during the cold and extremely cold period.

It is generally accepted that the maximum opening of the sidewall panels should be restricted during the cold and extremely cold periods to 30-50% of full to prevent excessive draft over the animals and to give a measure of security against controller failure. This is easily accomplished by adjusting the stroke on the cable actuator.

Basically the chimneys require two manual adjustments per year; they are closed toward the end of October and reopened in April when the average outside temperatures are above 5°C. Automatic control of the chimneys is not recommended.

The target temperature set on the thermostats can be lowered during the cold period as compared to the intermediate and the warm periods. This will increase the number of days or times that the control system will be activated. Although lower, the barn temperature should remain more stable.

## SUMMARY AND CONCLUSIONS

Three variations of a 200-cow free stall dairy barn - a fully insulated warm environment, a lightly insulated modified environment, and an uninsulated cold environment - were simulated using a computer program for ventilation. Air exchange was considered through a series of chimneys, via air infiltration, and through sidewall openings due to wind effects. Minimum required sidewall openings were determined for each type of building based on ventilation rates required at the respective heat deficit temperatures.

A control strategy for the adjustment of the ventilation components of these barns, including the possible use of an automatic control system, is presented. Based on the climate of the Ottawa area, the following conclusions can be drawn:

1. Permanent minimum continuous sidewall openings of 50 mm and 25 mm should be left for the cold and modified environment buildings respectively; no permanent minimum sidewall opening is required for the warm building.

2. An automatic control system would likely activate the sidewall openings every day of the winter in a warm barn and almost every day in a modified environment barn. With the cold barns, an automatic control system would likely be inactive during the month of January, but active most other days during the winter.

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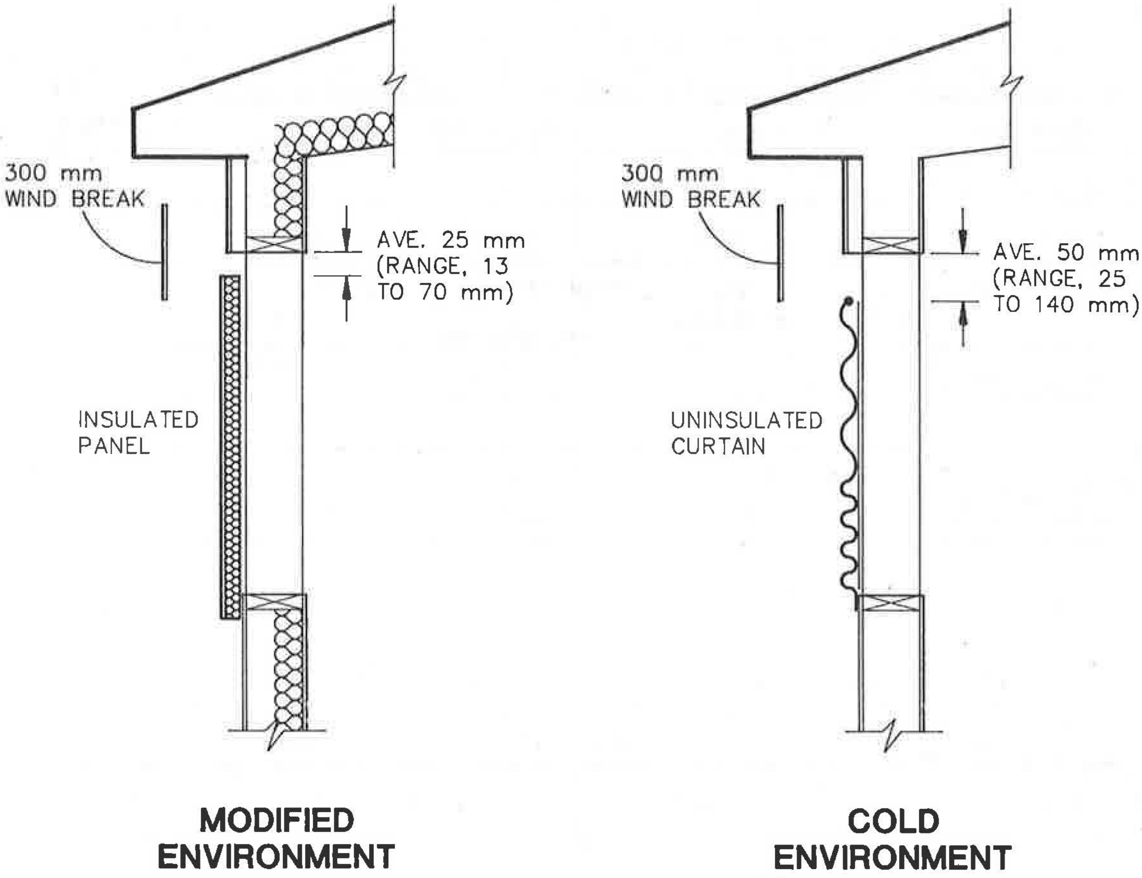


Fig. 1 Permanent continuous sidewall openings for cold and modified environment dairy barns

Table 1. Results based on the VENT program for cold, modified, and warm versions of a free stall dairy barn

| Barn type<br>Insulation | Warm<br>RSI 3.5 | | Modified<br>RSI 0.9 | | Cold<br>RSI 0.2 | |
|---|---|---|---|---|---|---|
| Inside target temp. | 2°C | 7°C | 2°C | 7°C | 2°C | 7°C |
| Heat deficit temp., ($T_o$) | -24°C | -22°C | -14°C | -12°C | -4.5°C | 0°C |
| Temp. differential, ($\Delta T_{in-out}$) | 26°C | 29°C | 16°C | 19°C | 6.5°C | 7.0°C |
| Min. total vent. rate (L/s) | 6530 | 4770 | 8220 | 6100 | 12480 | 9560 |

Table 2. Various components of minimum total air exchange rate, assuming 10 chimneys spaced 7.2 m apart

| Building type | Warm | Modified | Cold |
|---|---|---|---|
| Total flow, (L/s) | 4770 | 8220 | 12480 |
| Chimneys, (L/s) | 2000 | 2000 | 2000 |
| Infiltration, (L/s)<br>(ac/h) | 2820<br>1.1 | 3850<br>1.5 | 5650<br>2.2 |
| Sidewall vent, (L/s) | -50 | 2370 | 4830 |
| | | | |
| Sidewall opening (mm)<br>range (min-max) | negl.<br>negl. | 25<br>13 to 70 | 50<br>25 to 140 |

Table 3. Weather data for Ottawa area used to determine the potential for use of an automatic control system for warm, modified environment, or cold dairy barns.

| Barn type<br>Inside temp. (°C) | warm<br>6-8 | modified<br>4-6 | cold<br>2-4 |
|---|---|---|---|
| Ext. temp. range[a] | $T_o$<-20°C | -15°<T°<-10°C | -5°<$T_o$<0°C |

Historical weather data

| Ext. temp. $T_o$ (°C) | | | | | |
|---|---|---|---|---|---|
| Avg. no. of hours below $T_o$ per year[b] | 181 | 528 | 1073 | 1831 | 2868 |

| Month | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. |
|---|---|---|---|---|---|---|
| Avg. daily min. $T_o$ | -2.5 | -11.7 | -15.4 | -14.1 | -7.3 | 0.3 |
| Avg. daily $T_o$ | 1.2 | - 7.7 | -10.9 | - 9.5 | -3.0 | 0.6 |
| Avg. daily max. $T_o$ | 4.9 | - 3.7 | - 6.4 | - 4.8 | -1.3 | 10.7 |

[a]Exterior temperature range below which the automatic control system would be inactive.
[b]From Agric. Energy Centre (1988)
[c]From Env. Can. (1982,b)

Table 4. Control strategy for a free stall dairy barn using a series of chimneys, and an automatic control system for the sidewall openings.

| Weather conditions temperature range | | Extremely cold $T_o<-15°C$ | Cold $-15°<T_o<5°C$ | Intermediate $5°<T_o<20°C$ | Warm $20°C\ T_o$ |
|---|---|---|---|---|---|
| Sidewall opening (max. allowable) | | half | half | full | full |
| Chimney | | closed* | closed* | open | open |
| | | Temperatures at which sidewall panels open or close** | | | |
| warm barn | - close | 6 | 6 | 10 | 10 |
| | - open | 8 | 8 | 12 | 12 |
| modified barn | - close | 4 | 4 | 10 | 10 |
| | - open | 6 | 6 | 12 | 12 |
| cold barn | - close | 2 | 4 | 10 | 10 |
| | - open | 4 | 6 | 12 | 12 |

* in the closed position, a minimum opening around the chimney baffle is still maintained; this allows an assumed air exchange of 200 L/s per chimney
** it is assumed that the desired temperature is the thermostat target temperature and the temperature above which the sidewall panels will open.

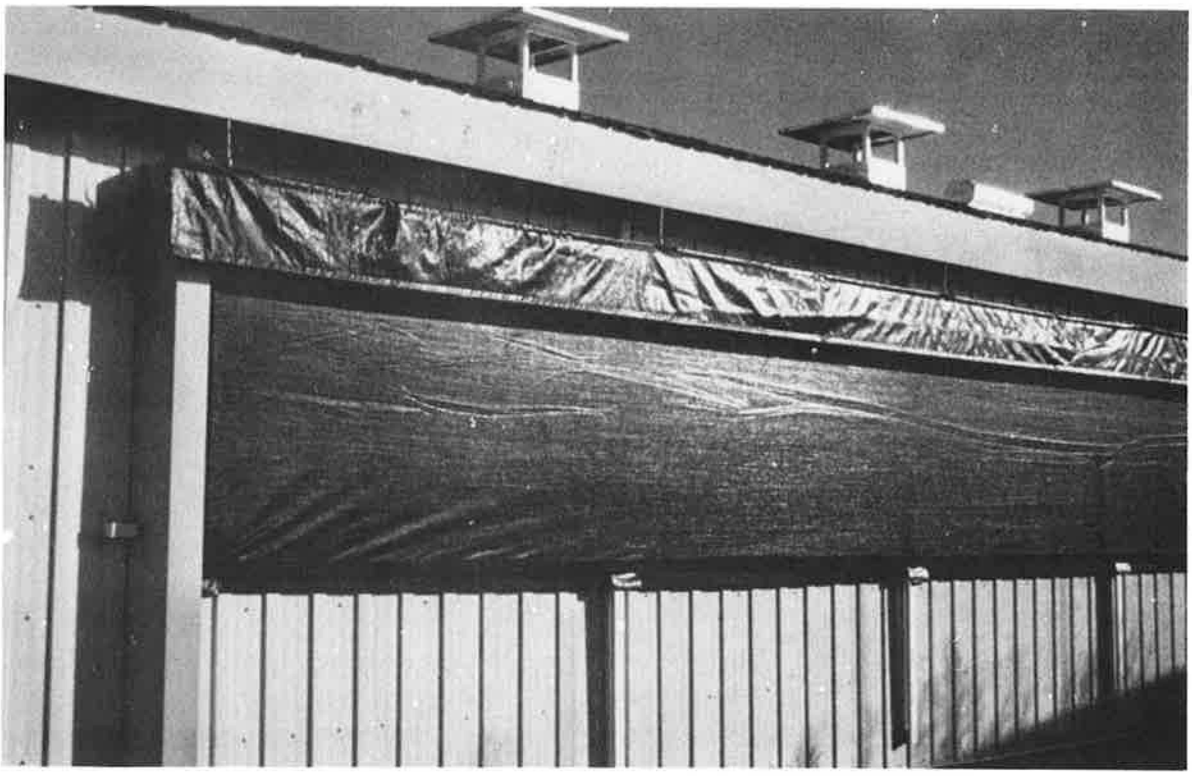

Photo 1. Windbreak panel shown protecting the permanent opening at the top of the sidewall panels in an automatically controlled warm naturally ventilated dairy barn; also visible are intermittent chimneys along the ridge.