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PRINCIPLES AND GUIDELINES FOR NATURAL VENTILATION OF WARM DAIRY HOUSING

by

Y. Choinière[1],
Farmstead Planning,
Health and Safety Specialist

J.A. Munroe[2]
Research Scientist

1. Engineering Research Unit, Alfred College of Agriculture and Food Technology, Alfred, Ont. KOB 1AO.
2. Animal Research Centre, Research Branch, Agriculture Canada, Ottawa, Ont. K1A OC6.

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SUMMARY:

This paper discusses the design and management of natural ventilation for warm dairy housing. Including are basic principles of air movement according to season, the use of chimneys versus a continuous ridge opening, types of sidewall openings, and thermostat location. Other factors considered are wind direction, building length, and ceiling slope.

KEYWORDS:

ventilation, natural, warm, dairy

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INTRODUCTION

Naturally ventilated buildings depend upon the natural forces of wind and temperature difference (chimney effect) to move air. Wind can blow air through openings in the wall on the windward side of the building, and suck air out of openings on the leeward side and the roof. Temperature differences between warm inside air and cold outside air can cause the air in the room to rise and exit at the ceiling or ridge, and enter via lower openings in the wall. Overall ventilation is due to the combination of the wind and chimney effects.

This paper presents guidelines for the use and management of natural ventilation for warm dairy housing. It covers many aspects of natural ventilation including basic principles of air movement and changes thereof due to season, the use of chimneys versus a continuous ridge opening, the performance of different types of sidewall openings, and preferred thermostat location. It also considers other factors such as wind direction, building length, and ceiling slope. It is intentionally written in a style and format such that it can be readily transformed into an extension leaflet. Such a leaflet entitled Natural Ventilation For Warm Housing, M-9760, has recently been published within the Canada Plan Service system. For this reason, individual references are not cited here but can be found in several related articles by us upon which this paper is based. These related articles are listed at the end of this paper.

This paper concentrates on natural ventilation as it applies to warm housing. This means buildings that are temperature controlled in cold weather. It does not cover cold or modified environment barns where inside temperature follows at or slightly above outside temperature.

During the summer, natural ventilation depends primarily upon wind forces since inside-to-outside temperature differences are small. Successful design of sidewall and ridge openings as well as proper use of control systems therefore require a good understanding particularly of the wind effects.

The ventilation requirements of livestock buildings are the same for either naturally or fan ventilated buildings. Sufficient ventilation is needed in the summer to prevent excessive temperature rise in the room, and in the winter to prevent build up of moisture or gases. These requirements are determined by the heat and moisture production of the animals housed.

During warm summer weather, the ventilation rate in fan ventilated barns is limited by the number and size of fans; while in naturally ventilated barns, the ventilation rate depends upon the size of wall openings, and the speed and direction of the wind.

During cold weather, the inside temperature in fan ventilated barns can be automatically controlled by using thermostats to turn fans 'on' or 'off', thereby changing the ventilation rate as required. In a similar manner, the ventilation rate can be varied in naturally ventilated barns by using thermostats to automatically adjust the size of openings in the sidewalls.

As with fan ventilated barns, in colder climatic regions warm naturally ventilated barns have the same requirement to be insulated and sometimes be provided with supplemental heat.

ADVANTAGES

Some advantages of natural ventilation include:

1. **Reduced operating costs.** Since fans are not used, maintenance and electricity costs are virtually eliminated.
2. **Reduced noise levels.** Stress levels are lower for both the livestock and the workers. Any unusual animal sounds as well as conversations between workers are easily heard making working conditions safer.
3. **Improved odour and humidity control.** Both the barn and control systems must be properly designed, otherwise poor air quality may develop.
4. **Ventilation still functions in the event of a power failure.** All openings will remain at their settings if the power fails. The doors can be operated manually or, if electrically driven, can be operated with standby power.
5. **Daylight makes these buildings brighter.** This makes them more comfortable to work in.
6. **Summer ventilation rates are high.** During the summer, with any amount of breeze, the ventilation rates obtained in naturally ventilated buildings can easily be above one air change per minute due to the size of the large sidewall openings.

DISADVANTAGES

1. **Birds.** They can be a nuisance if no bird screens are used.
2. **Dripping beneath open ridge.** No animals should be housed below ridge openings or chimneys since some rain infiltration and/or water dripping can occur.

TYPES OF PRODUCTION THAT CAN USE NATURAL VENTILATION

Research to date indicates that natural ventilation can be recommended for many production facilities where high ventilation rates are necessary during warm summer weather and good temperature control is needed during the winter.

With swine, natural ventilation can be used for growing/finishing units as well as gestation units. With dairy, tie stall or free stall barns as well as barns for replacement heifers and calves are good candidates for natural ventilation. It can also be used successfully by beef and sheep producers, and in moderate and warm climates by broiler and turkey producers.

Natural ventilation is not recommended for production units where light control is a must; e.g., for laying hens or rabbits.

MINIMUM LENGTH OF BUILDING

For warm buildings less than 12-18 m (40-60 ft) long, it may be more economical to use mechanical instead of natural ventilation. The initial capital cost for sidewall openings and chimneys for natural ventilation is small but when the cost of an automatic control system is added, the total may be more than the cost for a mechanical ventilation system with fans, air inlets and thermostats.

BUILDING OPENINGS USED FOR VENTILATION

A variety of inlets and outlets can be installed in naturally ventilated buildings. Openings in the sidewalls may function as air inlets or outlets depending on wind direction and the exterior temperature.

Generally, ridge openings or chimneys in the roof act as an outlet only. But during the coldest days of the year, when the sidewall openings are likely completely closed, a minimum ridge opening should be maintained. The ridge or chimneys will then act simultaneously as an inlet and outlet.

Sidewall Openings

There are basically two types of sidewall openings (Fig.1) used with automatically controlled naturally ventilated warm buildings: either panels that slide vertically or doors that rotate. These doors typically run the full length of both sides of the barn, and may be up to 1200 mm (4 ft) high depending on the building, the door or panel style, the local climate, and the livestock housed. Further details will be given in other leaflets relating specifically to sidewall opening design.

For warm housing, research has proven that excellent environmental control can be achieved using either type.

Rotating doors These doors are hinged slightly above centre and rotate about a horizontal axis. The air enters/exits at both the top and the bottom of the door. But rotating doors have two major disadvantages. First, in winter, cold air can enter through the lower opening and drop directly to the floor, creating cold zones in any stalls against the wall. Second, rotating doors may experience freezing problems around the edges particularly in very cold climates.

It may be possible to prevent air from entering at the bottom of the rotating door by placing an insulated panel (Fig. 1) in the lower portion of the doorway. This is especially important for animals that are sensitive to drafts. The insertion of such an insulated panel also promotes better air mixing above the floor.

Vertically sliding panels Research shows that vertical panels with added windbreaks (Fig. 1) tend to minimize temperature fluctuations and provide good air distribution and mixing patterns within the animal room. These panels are easily controlled and less susceptible to freezing. Since cold air comes in at the top of the opening, it has time to warm before reaching the livestock.

The vertical panels can consist of a plastic envelope inside of which are placed rigid faom insulation panels. Such an arrangement can be seen in Photo 1. The vertical panels are moved up or down using a steel cable and pulley arrangement, and an electric actuator.

A 300 mm (12-in.) wide plastic windbreak panel (Fig. 1) can be added to encourage better mixing of the incoming air. The windbreak is fastened to the eave in front of the inlet slot. This windbreak causes air turbulence and reduces the air speed as it enters the barn. The addition of a windbreak improves the mixing action and reduces the temperature fluctuations in the barn. It can be left in place year round.

End Wall Openings

It is highly recommended to have adjustable openings in both end walls of the building. When the wind is blowing parallel to the building, zones of poor circulation or stagnation can develop near the ends of the barn. End wall openings can improve air circulation in these areas. In typical dairy barns, such openings can be the doors at the ends of the cattle alleys as well as the large doors at the end of a drive-through feed alley (Photo 2).

End wall openings are adjusted manually during the summer and closed during the remainder of the year.

Minimum Ridge Concept and Operation

Research has demonstrated that the use of a large ridge opening does not present any advantage over a small ridge opening provided sufficient sidewall opening area is available for warm summer conditions. Instead of a continuous ridge, the use of intermittent chimneys, like those shown in Photo 1, is now recommended. For dairy barns, this can typically be 600 x 600 mm (2 x 2 ft) chimneys 7.2 m (24 ft) apart.

An adjustable baffle (Fig. 2, Photo 3) can be installed in the chimney to reduce the opening area. However, it should be designed such that even in the fully closed position, there is still a gap of about 25 mm (1 in) left around the baffle which is sufficient to allow the minimum ventilation rate required in winter.

The use of chimneys presents many advantages over the continuous ridge opening. It reduces material and construction costs and reduces or eliminates exposure of wood members and deterioration in the ridge opening since failure of truss joints and corrosion of truss plates has proven to be a problem. Chimneys are also more convenient for restricting bird entry to the building. If installing bird screens, use plastic instead of metal to avoid frosting in cold weather. The rain hood or cap eliminates most of the rain and snow infiltration.

The chimneys should be fully open during warm weather and closed when the average daily temperatures are below the 0 - 5°C range. In Ontario for example, this would typically involve opening the chimneys in April and closing them in late October, however this may vary depending upon local climatic conditions. Throughout the year, the automatic control system will take care of opening or closing the large sidewall openings in order to maintain an ideal temperature inside the barn.

As an alternative, a continuous adjustable ridge slot opening can be used that runs almost the entire length of the building. A continuous ridge slot should not be over 150 mm (6 in) wide. The ridge slot should be adjusted to be fully open during the summer, but closed to a narrow 6-12 mm (1/4-1/2 in) slot during the winter, leaving the automatic temperature control system to adjust the sidewall openings. Manual control of the continuous ridge opening is recommended.

To keep birds out, install a plastic screen in the ridge. Condensation may form in the ridge during the winter, so it is recommended to use preservative treated wood for any supporting members. Also, soak the ridge area of trusses with preservative.

SEASONAL CHANGES IN AIRFLOW PATTERNS

In many parts of Canada, the weather can be divided into four basic temperature ranges: hot, cool, cold, very cold. The interior airflow patterns will change completely over these ranges since the size of openings changes due to changes in required ventilation rate and temperature of the incoming air. Typical air flow patterns and temperature distributions within the barn during each of these four seasons are shown in Fig. 3.

Hot (Summer) - Exterior Temperature Above 20°C

When the outside temperature is higher than the indoor thermostat setting, the sidewall doors are opened to their maximum by the automatic control system. Large volumes of air enter the windward openings due simply to the wind forces. Thermal buoyancy effects are negligible since there is little difference between inside and outside temperatures during these periods. The incoming air flows across the ceiling, mixing with the inside air, and recirculates towards the windward side near floor level.

Wind direction also has an effect on airflow patterns particularly during the summer, when sidewall vents are fully open. These effects are illustrated in Fig. 4. When wind is perpendicular to the side wall, airflow across the barn is uniform from one end to the other. However when wind is blowing at some other angle, say 45°, a rotational pattern develops in the building. In this case, the effective ventilation rate is slightly higher in the downwind end of the building, and lower in the upwind end. As a result, the upwind end can be warmer. In a similar way, when wind is parallel to the building, air circulation in the upwind end of the building can be lower, and temperatures slightly higher than in other parts of the barn. It is in conditions such as this, that openings in the end of the building are a big help in promoting good air circulation and more uniform temperatures throughout the length of the barn.

Cool (Spring, Fall) - Exterior Temperature 5-20°C

In warm dairy housing, operators,livestock and equipment seem to perform well in the 5-10°C range. If the thermostat is set at, for example, 8°C, and the outside temperature drops below this, the automatic control system will react by partially closing the sidewall doors. The volume of air entering is reduced and the airflow patterns developed are not as strong as those noted under summer (hot) conditions (Fig. 3). The incoming air does not travel completely across the barn at ceiling level but rather tends to fall and recirculate partway across, eventually exhausting through the ridge and leeward openings. The temperature of the incoming air during this period is slightly cooler than inside, but not so cold as to drop immediately upon entering as will be discussed later for cold weather. The conditions and airflow patterns noted during this cool period are sometimes called intermediate; i.e., between summer and winter.

Cold (Winter) - Exterior Temperature -15-5°C

As the weather gets colder, the automatic control system continues to reduce the size of the sidewall openings. The wind will have less effect now since the volume of air coming in is greatly reduced. At the same time, the "thermal effect" becomes evident as the inside to outside temperature difference increases. Immediately upon entering, the cold air falls to the floor, but because of turbulence, it mixes with inside air and warms within 2-3 m (7-10 ft) of the wall. It then rises slowly and recirculates moving slowly towards openings in the ridge or leeward wall.

Very Cold (Winter) - Exterior Temperature Below -15°C

In very cold weather, the sidewall doors shut completely on both sides of the barn. Fresh air enters and leaves through openings in the ridge. Airflow rates are low and an opening can be an air entrance one moment and an exit the next depending upon slight differences in wind outside or thermal effects inside. Most likely some air leakage also enters through small openings or cracks around the building and the sidewall panels. Air movement within the building is more varied and depends upon the thermal effects caused by the warm animals as well as the incoming cold air.

CONTROL SYSTEMS

The natural ventilation control system adjusts the ventilation rate by opening or closing the inlets and outlets. Three types of systems are currently used: manual, automatic non-modulated, and automatic modulated.

Manual Control

Manual control is not recommended for warm housing except for the ridge or chimney openings. This system often requires frequent manual adjustment of the doors and ridge as the weather changes. In the spring and fall, daily fluctuations of wind and temperature conditions demand many adjustments to the sidewall openings -- very inconvenient for the operator. Typically, environmental control with this system is unreliable and inconvenient.

Automatic Non-modulated Control

This system uses thermostats to activate the opening and closing of the sidewall doors. The doors, however, are either fully open or fully closed. The operator must preset the maximum-minimum opening width. Again, this type of control system is not highly recommended since it can result in large, rapid temperature fluctuations in the building. Also, in winter, condensation can form and freeze around the door edges sealing the door shut. As a result, ventilation will suffer and air quality will deteriorate.

Automatic Modulated Control System

This system consists of: 1) temperature sensing elements (thermostats), 2) a control unit with timer, and 3) electric actuators. The timer determines how often and for how long the actuators can operate. If the doors move too frequently or too far, the abrupt large changes in ventilation rate can cause temperature fluctuations in the room; likewise, if operation is too slow or opening increments too small, it is difficult for the system to respond fast enough to changing weather conditions. Results indicate that good temperature control can be achieved when the timer is set to operate every 3-4 minutes and when operating, remains active long enough to allow the doors to move 12-18 mm (1/2-3/4 in).

For winter operation, install a limit switch or mechanical stop to prevent the ventilation doors from opening more than a third to a half of maximum. This will guard against the doors moving fully open due possibly to some control system malfunction during cold weather.

Thermostat Location and Adjustment

Proper location of the thermostats is essential to maximize the comfort zone of the animals. In tie stall dairy barns, the thermostats should be located 3-4 m (10-12 ft) from the sidewall,over a stall divider, but out of the reach of the cattle (Fig. 5). In free stall barns, in the first alley from the wall, out of the reach of the cattle is good (Photo 4). To avoid mechanical damage, the thermostats should be hung from the ceiling and be free to swing in case they are hit by the operator or the animals.

Be careful to adjust all the thermostats to the same temperature throughout the barn. For example for dairy cattle, a particular temperature in the 6-10°C should be set on all thermostats. As with fan ventilated buildings, lowering the thermostat a few degrees in cold weather reduces the need for supplemental heat by effectively lowering the outside temperature at which the building reaches a heat deficit.

For short buildings, thermostats should be installed at the midlength of the building. As the building length increases, more strain is placed on the mechanical hardware operating the sidewall doors or panels, particularly if any freezing problems occur. As well, there is more potential for temperature gradients to occur along the length of the barn. For these reasons, sidewall opening units should be limited to about 36 m (120 ft). For longer buildings, use two units with a separate set of thermostats for each (Fig. 6). Locate thermostats at the midlength of the unit they control. All thermostats should be set at exactly the same temperature so that they can work in harmony and provide uniform temperature throughout the barn.

BUILDING ORIENTATION

Building orientation is critical to the success of a natural ventilation system. Locate the length of the building perpendicular to the prevailing winds. A NNW-SSE orientation is usually recommended for most areas in Ontario.

This reduces to a minimum the periods when little or no wind is blowing against the sidewall. As well, when wind is blowing, this orientation maximizes the ventilation rate. Other orientations can be used but thermal performance in the barn may be reduced.

OTHER FACTORS THAT AFFECT PERFORMANCE

Ceiling Slope

Flat ceilings can be used successfully but a sloped ceiling promotes better air circulation patterns (Fig. 7) during the summer which helps cool the animals, and gives more room volume per animal.

Upwind interference

Naturally ventilated buildings are most effective when the wind is free to hit the building from all directions. It is not recommended to use natural ventilation if the proposed building will have major obstructions nearby, particularly upwind in the predominant summer wind direction. Such obstructions act like wind breaks and reduce the effective wind velocity.

Multi-room buildings

When a naturally ventilated building has two or more rooms or sections along its length, the room at the upwind end of the building appears to have a higher ventilation rate for a given sidewall opening (Fig. 8). For farmstead planning purposes, it is recommended that the rooms or sections requiring the higher summer ventilation rates (e.g. the main dairy barn area versus a calf nursery) be located at the upwind end. For example, if predominant summer winds are from the southwest and the building is oriented north-south, locate the main dairy section at the south end.

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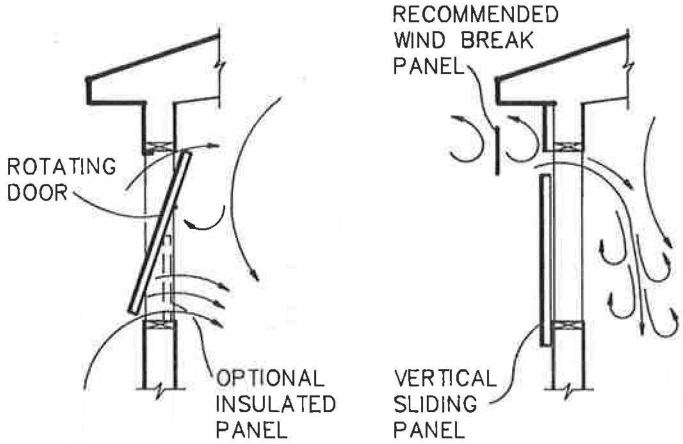

Fig. 1 Two common methods of adjusting wall opening size. Airflow patterns shown are for winter conditions.

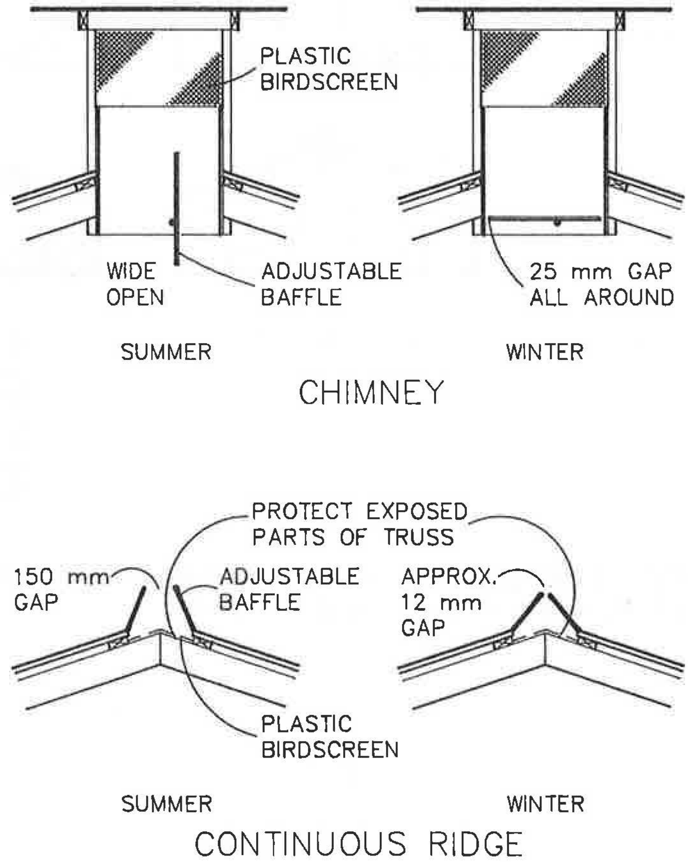

Fig. 2 A minimum ridge opening can be achieved using either chimneys or a continuous ridge slot.

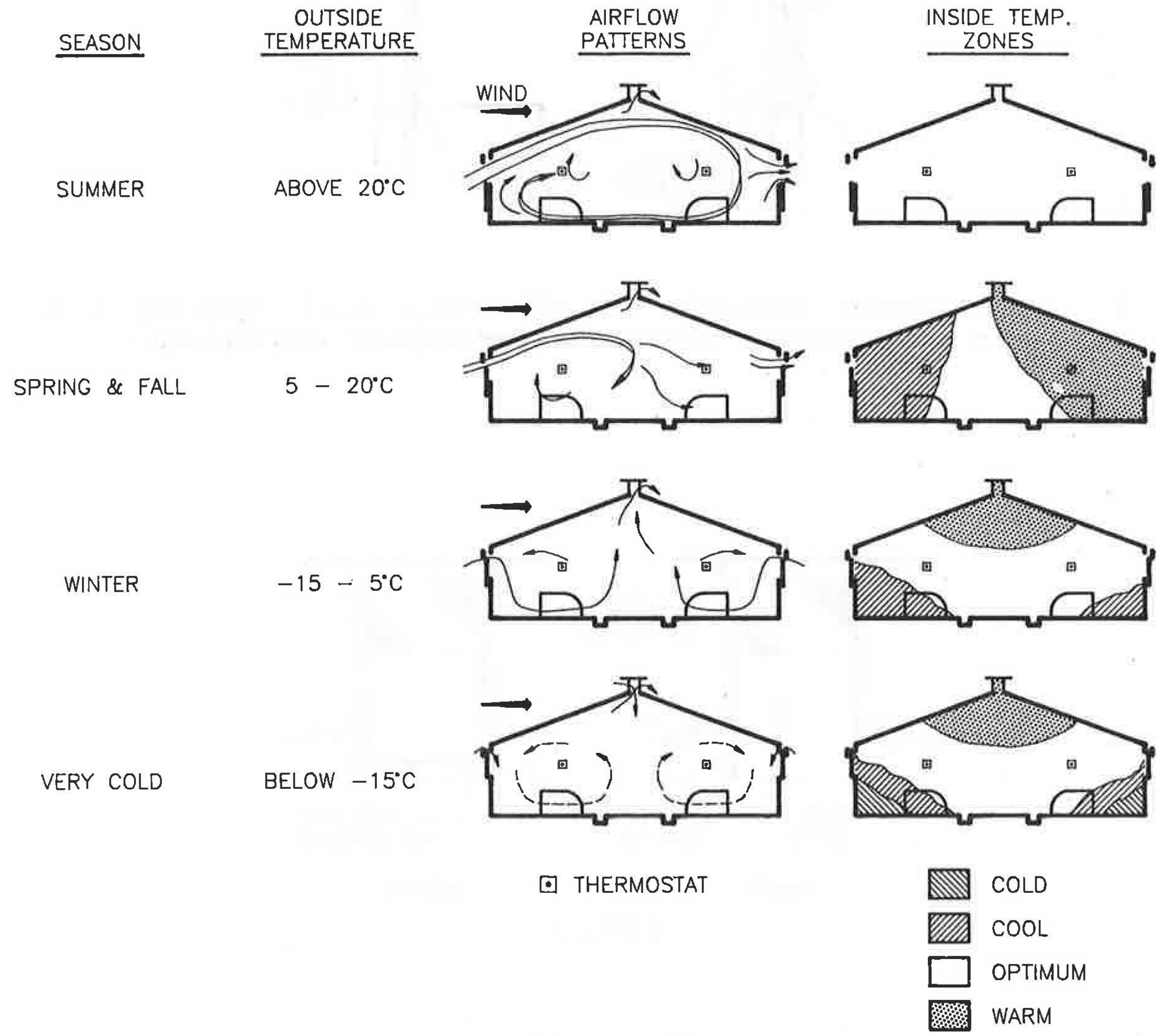

Fig. 3 Seasonal changes in airflow patterns and temperature distributions in the animal room.

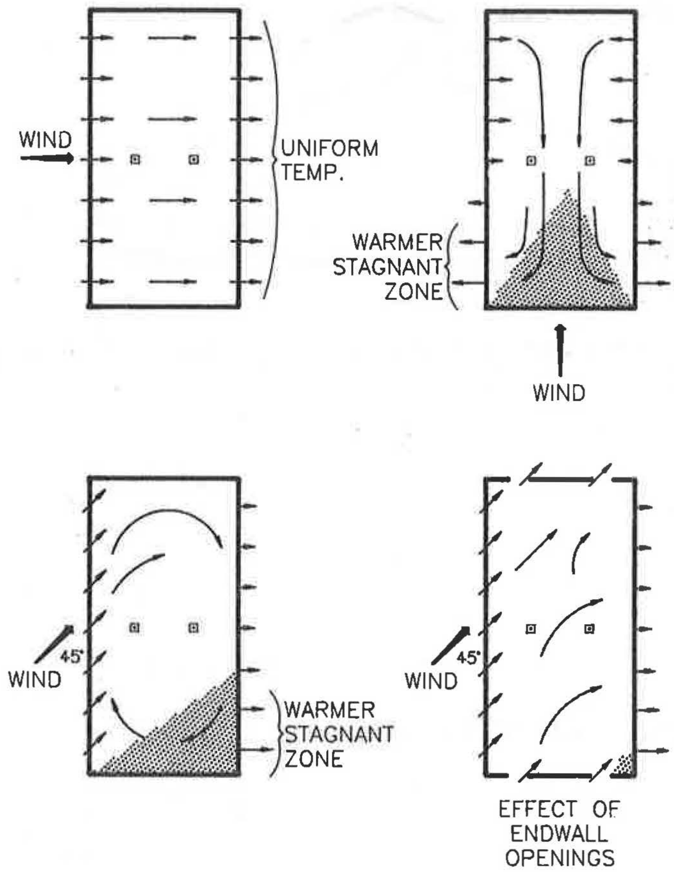

Fig. 4 Wind direction effects on airflow patterns during summer conditions (plan view).

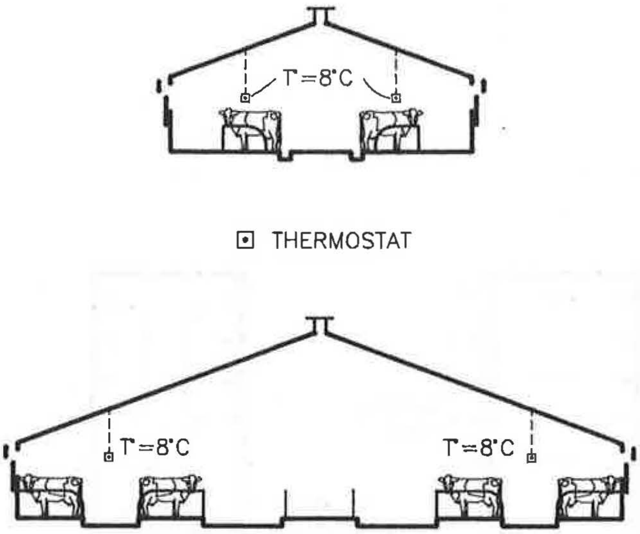

Fig. 5 Suggested thermostat location in dairy tie stall or free stall barns.

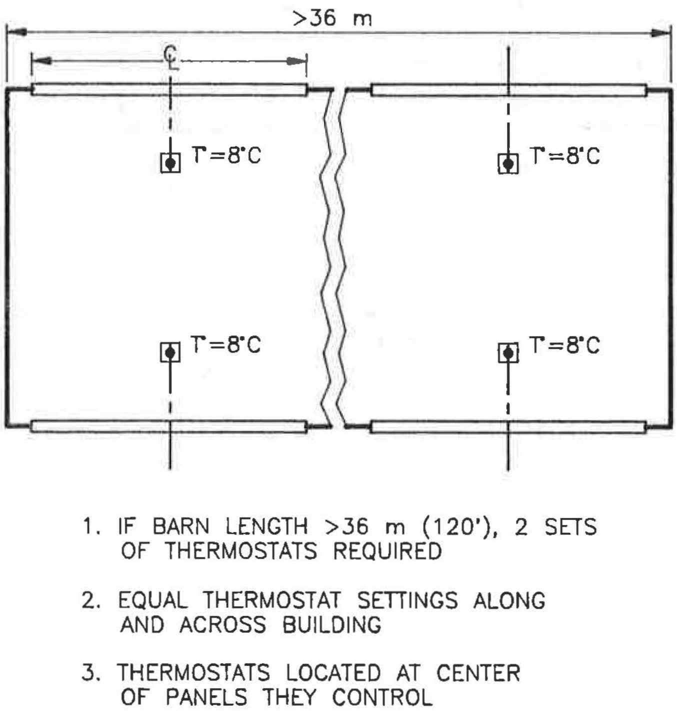

Fig. 6 Thermostat location along the barn and adjustment.

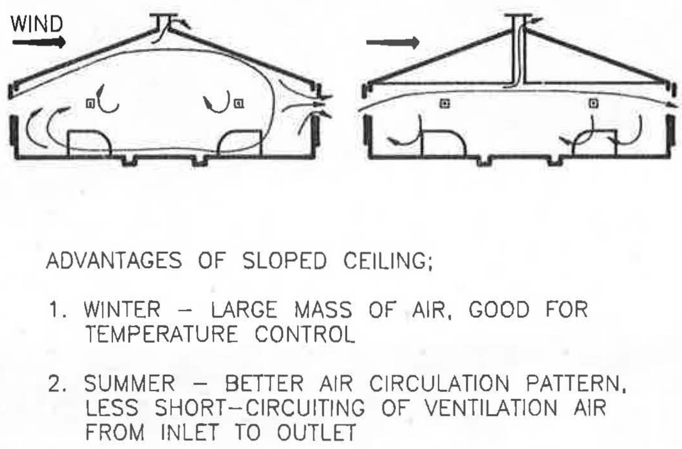

Fig. 7 Advantages of a sloped ceiling.

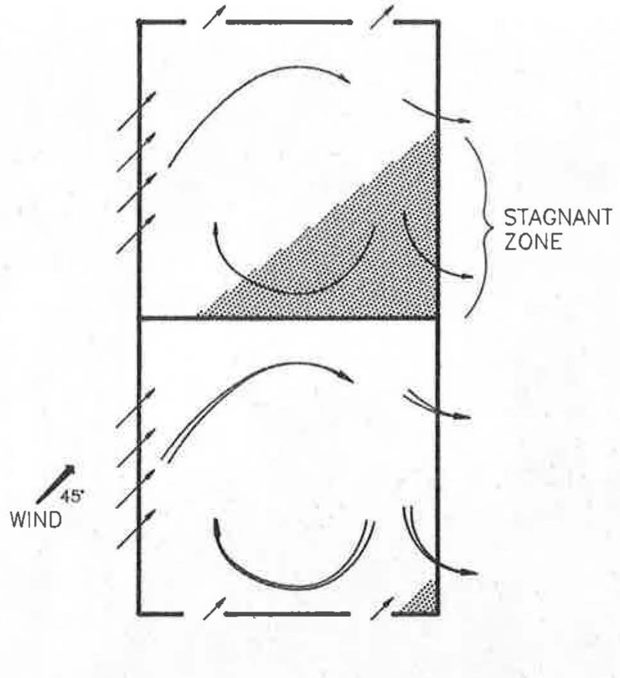

Fig. 8 In a multi-room building, the upwind room has a slightly higher ventilation rate.

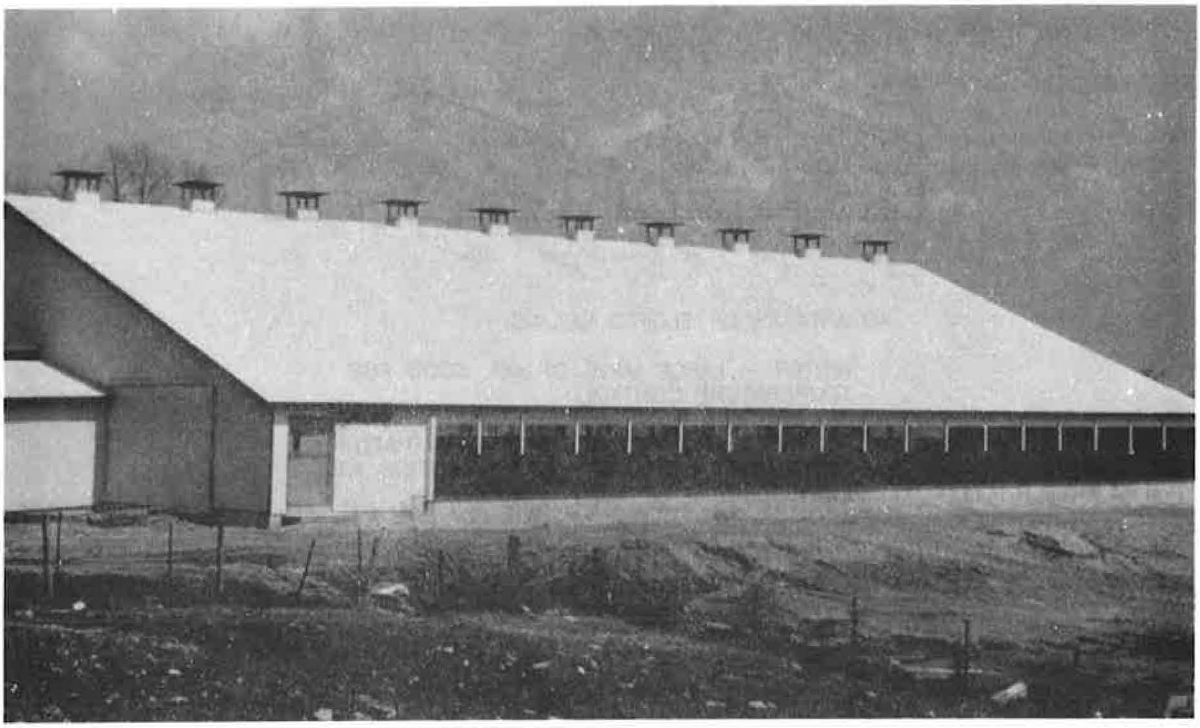

Photo 1 An automatically controlled, warm, naturally ventilated dairy barn using vertically sliding sidewall panels, chimneys, and manually operated doors as the endwall openings.

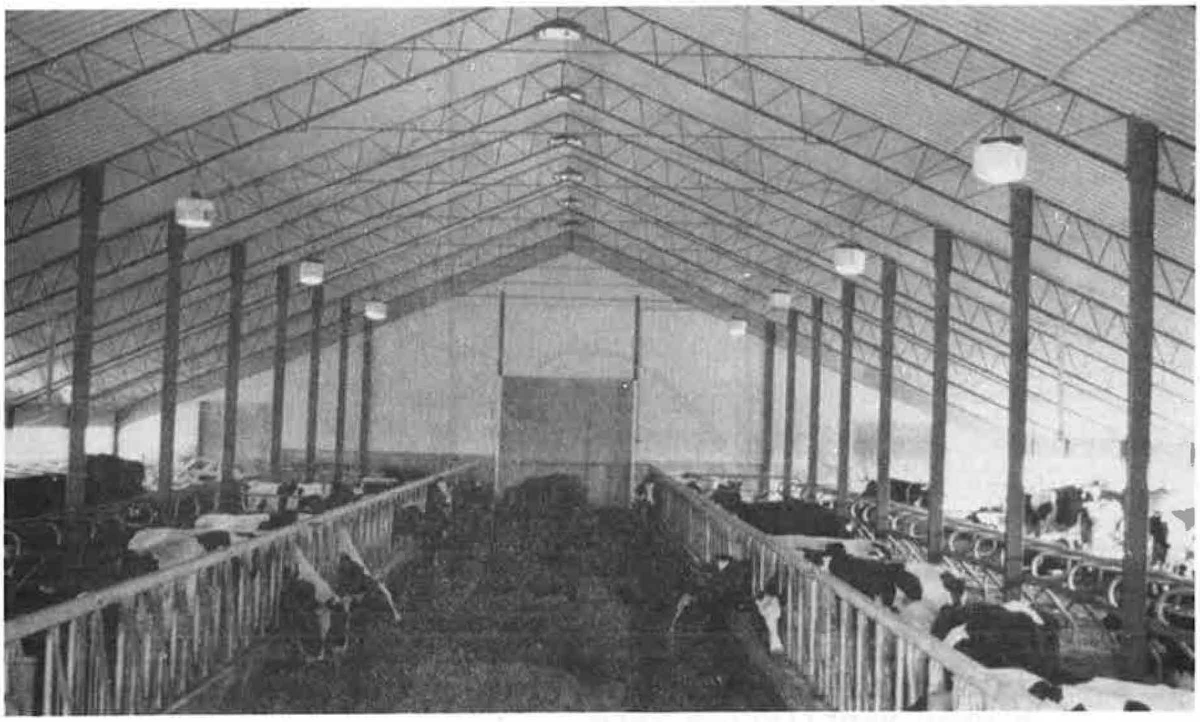

Photo 2 Natural ventilation will provide an excellent environment in this warm insulated steel-truss building with a sloped ceiling.

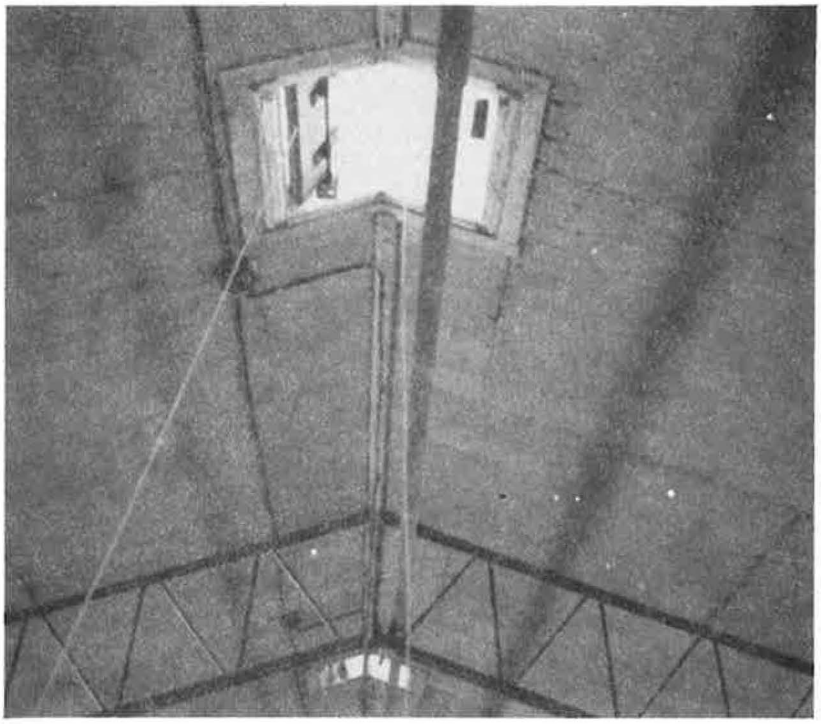

Photo 3 Chimneys with baffle and manual control cable as seen from below. The baffle is in the fully open (summer) position.

Photo 4 Thermostats (or temperature sensors) located at 3-4 m (10-12 ft) from the sidewall, and about 2.4m (8 ft) high out of the reach of the cattle; adjust all thermostats to the same set point.