CSAE SCGR

Paper No. 86-114

NATURAL VENTILATION IN MODERATE CLIMATES

J.A. Munroe
Engineering & Statistical Research Centre
Research Branch, Agriculture Canada
Ottawa, Ontario
K1A 0C6

and

Y. Choinière
Alfred College of Agriculture and Food Technology
Ontario Ministry of Agriculture and Food
Alfred, Ontario
K0B 1A0

For presentation at the 1986 Annual AIC Conference
CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING
University of Saskatchewan, Saskatoon, Saskatchewan
July 6-10, 1986

ABSTRACT

There are more and more livestock buildings using natural ventilation (i.e., ventilation without fans). This paper describes the principles, benefits and limitations of natural ventilation. Emphasis is placed on the use of naturally ventilated barns in areas such as southern Ontario and Quebec. Alternative air inlet/outlet systems, building shapes and control requirements are described.

INTRODUCTION

A naturally ventilated building is ventilated by the natural forces of the wind outside and thermal buoyancy of the air inside, rather than fans. A naturally ventilated building requires at least as much insulation and supplemental heat to function properly as does a fan ventilated building in the same situation. Typically insulation values of RSI 3.5 or more are recommended. The minimum recommended ventilation rates depend on animal heat and moisture production and thus will be the same for both buildings. Initial capital costs for the two types of buildings are therefore about the same, although operating costs of the naturally ventilated building should be less since fans are not required. The type of control system used in naturally ventilated barns varies from simple manual adjustments to fully automatic controls. As with fan ventilated barns, thermostats are normally used in automatic control systems.

As requested by the planners of this session of the conference, this paper has been prepared as a 'statement of currently understood principles, presented in a language suitable for animal producers'. It is intended that the text, with a minimum of revision, can subsequently be published as an extension leaflet or part of a bulletin. Thus comments would be appreciated.

PRINCIPLES OF OPERATION

Wind Effect

Wind blowing against a building exerts pressure on all surfaces of the building both inside and outside. Outside surfaces facing the wind are subject to positive pressure while surfaces facing downwind (leeward) are normally subject to negative pressure or suction. Interior pressures vary depending upon the location of any openings in the walls or roof. For walls parallel to the wind, exterior pressures are generally negative. The ridge on a building with a gable roof perpendicular to the wind is normally subject to a negative pressure.

Contribution No. I-847, from Engineering and Statistical Research Centre, Research Branch, Agriculture Canada, Ottawa, Canada K1A 0C6.

If openings are built into the walls or ridge, air will move into the building at areas where the difference between the exterior and interior pressure is positive, or out of the building at areas where the difference is negative. Figure 1A shows how wind pressures cause air to move into the building at the windward wall and out of the building at the ridge and leeward wall. This would be typical for summer operation. In winter, the windward wall openings are sometimes closed, as shown in Figure 1B. Air then leaves the building at the ridge and enters at the leeward wall openings. When the wind blows parallel, or at some other angle except perpendicular, to a building the pressure patterns can be more complex. Examples of other wind pressure patterns are shown in Figure 2.

The quantity of air that moves through a building due to wind depends essentially on the size of the openings (inlets and outlets) and the difference in pressure at the inlets and outlets. A simplified relationship is often used as follows:

$$Q = EAV \qquad [1]$$

where
Q = air flow (m^3/min)
A = free area of inlet openings (m^2)
V = wind velocity (m/min)
E = effectiveness of the openings.

The effectiveness E of the opening varies from 0.5 to 0.6 for wind perpendicular to the opening and from 0.25 to 0.35 for wind diagonal to the opening. For design purposes, a value of 0.35 is often assumed (Hellickson and Walker, 1983). The value used for V is somewhat arbitrary although half the seasonal average wind velocity is sometimes suggested for design purposes.

Chimney Effect

Warm air rises and this action is referred to as the thermal buoyancy or chimney effect. In a livestock building, when the air is much warmer inside than outside, and in the absence of wind, air will tend to rise and leave at high openings, and be replaced by cool air entering at low openings (Bruce, 1977, 1978; Hellickson et al. 1983). This is similar to warm air moving up a chimney. Air flow through a building due to the chimney effect alone varies with the area of inlets and outlets, and the square root of both the height difference between inlets and outlets and the temperature difference between inside and outside. The relationships between these parameters are not simple and will not be discussed in detail here.

It should be noted that the chimney effect can be quite significant in calm winter weather when the difference between inside and outside temperature is large. However in summer, the difference between inside and outside temperature is small and as a result so is the chimney effect.

Combination of Wind and Chimney Effects

In cold winter weather, air movement through a naturally ventilated building will usually be caused by a combination of wind forces and chimney effect. All factors mentioned above in connection with each of these forces will be involved. Their relative effects are difficult to determine, however with most livestock buildings, as airspeed increases the wind effect quickly outweighs the chimney effect (Smith, 1972).

Openings that were inlets when considering chimney effect can become outlets when the wind is blowing. For example, with the wind perpendicular to a gable building with openings at both the leeward eave and the ridge, the eave opening becomes an inlet while the ridge opening remains an outlet (Figure 1B). Although the wind pressure at the leeward wall is negative, the pressure in the building is more negative.

Controls

Control systems vary from simple manual adjustments to automatic adjustments responding to a thermostat. The adjustments are made to control the size of inlet and/or outlet openings thereby varying the ventilation rate. More details on controls will be given later.

INLETS/OUTLETS

Sidewall

Openings in the sidewalls can be fitted with panels that are hinged at the bottom and tilt in, or with panels that are hinged at the top and tilt out. In buildings where temperature control is less critical, a simple plastic curtain that can be raised and lowered has been used effectively to adjust the wall opening size. Panels can also be fitted to rotate about a horizontal axis at or near their mid-height. As well, a curtain or panel hanging outside slightly beyond the air inlet can be installed to alter the effects of the wind. These various types of inlets are shown in Figure 3. In recent studies (Choinière et al. 1986), the use of a small windbreak in front of a horizontal slot air inlet (Figure 3D) gave the best winter performance of several types of inlets tested. The windbreak reduced the throw of the air entering, by creating more turbulence and thus better mixing. As a result there was less temperature fluctuation in the animal zone.

Ridge

Two arrangements for adjusting the size of the ridge opening are shown in Figure 4. The hinged baffle shown in Figure 4B is impractical to fit between trusses at 1.2 m or less on center, but can be readily installed in steel frame structures where the frames are 3.6-7 m on centre. The hinged baffles shown in Figure 4A are typical of some commercial systems.

Winter condensation can be a problem with almost any ridge opening and baffle arrangement. Warm moist air is normally exhausted through the ridge and the moisture will condense if it comes in contact with a colder surface. If the steel flashing is continuous from the outside to the inside of the throat of the ridge opening, it forms a cold thermal bridge in winter. Any condensation on this flashing can then continually drip into the building. This would certainly be a problem if, for example, cattle stalls were directly below. Avoid thermal bridges from outside to the throat area of the ridge opening. If condensation is still a problem, install a trough of translucent fiberglass or steel roofing panels underneath to catch the drip and slope the trough to drain.

Birds entering the building through the open ridge can be a problem in winter. The addition of galvanized wire or plastic mesh is recommended. The mesh size should not be too small, otherwise it could plug with frost.

Chimney

Another type of roof outlet is a large chimney. These can be spaced along the centre of the building at intervals depending on throat area. They are normally fitted with a rain cover and an interior baffle to adjust the size of the outlet. Such baffles as well as the chimney walls should be well insulated to reduce condensation. The chimney type of outlet is well adapted for retrofitting a natural ventilation system to an existing building. As well, it is very practical as an outlet in two-storey dairy barns. A chimney type outlet is shown in Figure 5.

CONTROLS

The simplest and least costly control system involves manually adjusting the size of inlet and/or outlet area. This can be done by a cable and pulley system attached to the curtains or baffles controlling the inlet and outlet areas. Movement of the cable is readily controlled by a small boat winch. Alternatively, a system of pipes and lever arms can be used, similar to that used for openings in greenhouses. The operator decides from his experience when and how much to open or close an inlet or outlet. As adjustments are normally made at most a few times per day, building temperature and humidity can be expected to vary. Although not quantified, the degree of variation experienced in moderate climates has not been a concern for dairy producers, but has been very much a concern for swine producers.

The sensor for automatic systems is usually a thermostat. Some earlier automatic systems had pneumatic cylinders that opened or closed the baffles in response to the thermostat. The baffles stopped at either 'fully open' or 'fully closed' with the degree of rotation for 'fully open' being manually preadjusted to suit the season.

Newer controls incorporate a time delay to produce an incremental opening and closing of the baffles. At given time intervals, say every three minutes, the control system checks the thermostat to see whether the baffles should open, close or remain the same. For example, if the thermostat calls for the baffles to open a gear motor can be energized for a short time (say 3 s) to operate a crank or winch which controls the position of the baffles. There is no further action until the end of the time interval (3 min) when the procedure repeats. The time interval for checking the thermostat as well as the time period during which the gear motor is energized can be manually adjusted by the operator. The end result is a system that responds in smaller increments leading to smaller and less rapid fluctuations in environmental conditions in the barn.

Most automatic control systems now have an override allowing an operator to manually select the position of baffles.

PERFORMANCE

Air Distribution

Air flow patterns within buildings can vary greatly from site to site because of their orientation and the effect of adjacent buildings, as well as from day to day at the same site because of changing wind direction. Typical air flow patterns expected in a swine barn in summer and winter are shown in Figure 6. Here it is assumed that the wind is perpendicular to the building, and that there are no large buildings, silos or other obstructions close by.

Problems can occur when the wind hits a building at some other angle. Figure 2 for example shows how a diagonal wind can produce both positive and negative pressures along a ridge. In this situation, air could be leaving the open ridge in the region of negative pressure and entering the same opening in the region of positive pressure. This also applies to openings in the leeward sidewall with diagonal winds. Cool, drafty areas could result in regions of the barn where most of the air is entering.

Temperature Distribution

As with any ventilation system, the degree of temperature variation within the animal space and air movement is most important. Cold drafts in the animal area are undesirable, particularily for animals without long hair such as young pigs. Although the acceptable range of temperature is known for several classes of animals, the effects of temperature fluctuation (hourly or diurnally) on performance or production are not well documented. Considerable research has been carried out monitoring temperature in naturally ventilated barns using different inlet/outlet systems and controls. Work reported by Choinière (1985) and Choinière et al. (1986) indicates very good temperature control during winter using thermostatically controlled rotating side panels. The degree of temperature control was improved when the 'full open - full closed' pneumatic control system was replaced with an electric motor driven 'step open - step close' control system.

In summer, high indoor temperatures are a concern in all buildings. Naturally ventilated barns, with suitable inlet design, can provide higher air velocities due to wind, thereby reducing the effective temperature in the animal space. Siting buildings in the open, and perpendicular to prevailing summer winds help improve the effectiveness of wind induced ventilation.

ANIMAL RESPONSE

Cattle

Beef cattle don't appear to be greatly affected by moderate changes in temperature, or by drafty conditions, provided they are not tied in one spot. As a result, naturally ventilated buildings have been found quite suitable for beef. Little if any adjustment of inlets and outlets is required over the winter period, however large wall openings are generally recommended in the summer to ensure adequate ventilation.

Dairy animals appear to be more affected by drafty conditions, likely because of their shorter hair coat. This would be particularly true of young calves and milking cows. As a result, at least manual adjustment of inlet and/or outlet baffles should be provided. Satisfactory conditions can be achieved with such a system even in tie-stall barns (Milne, 1985). However, use of automatic controls could be beneficial, particularly in spring, summer and fall when daily temperature fluctuations are large. In addition, with automatic control the operator does not have to be there all the time to make adjustments. This is definitely an advantage if the operator is away temporarily and other staff are looking after daily chores. Although not proven, automatic controls could be a benefit particularly to high producing herds. With these herds, minor stress can cause significant drops in production.

Swine

There is considerable controversy over the suitability of naturally ventilated barns for the various phases of swine production. Both modified open front (MOF) barns and gable barns with openable sidewall panels and open ridge have been successfully used for growing and finishing. Some studies (MacDonald et al. 1985; Choinière 1985) show no significant difference in feed conversion or daily gain between hogs raised in a conventional fan ventilated building versus hogs raised in a naturally ventilated building.

At this time natural ventilation for swine in moderate climates is recommended only for gestation, growing, and finishing.

Poultry

Due to the difficulty in controlling light level and duration in natural ventilation systems, they are not recommended for laying hens. Similarly suitability for broiler production has yet to be shown.

Sheep and Goats

Natural ventilation is suitable for sheep and goats in moderate climates. As with dairy cattle, manual control is satisfactory but automatic control should provide more uniform conditions and relieve the operator of one more function.

ADVANTAGES AND DISADVANTAGES

Advantages

° no fan noise
° ventilatiion is more reliable in case of power failure; all openings can remain at current settings or be manually adjusted
  considerable daylight enters by wall and ridge openings
° lower operating costs

Disadvantages

- condensation dripping from ridge and/or wall openings may be a problem
- birds enter ridge opening in winter unless screened
- may be more temperature variation in the barn than with fan ventilation
- orientation of building, and its location relative to other buildings greatly influences wind effects

REFERENCES

BRUCE, J.M. 1978. Natural convection through openings and its application to cattle building ventilation. J. of Agric. Eng. Res., 23: 151-167.

BRUCE, J.M. 1977. Natural ventilation - its role and application in the bio-climatic system. Farm Building R&D Studies, (8). Feb.

CHOINIERE, Y., F. BLAIS, J.A. MUNROE and J.-M. LECLERC. 1986. Winter preformance of different types of inlets in naturally ventilated swine barns. Paper No. 86-121, Can. Soc. Agric. Eng., Ottawa, ON.

CHOINIERE, Y. 1985. Natural ventilation versus mechanical ventilation for swine housing. Preliminary Report, Alfred College of Agric. and Food Technology, Alfred, ON.

HELLICKSON, M.A. and J.N. WALKER. 1983. Ventilation of agricultural structures. Monograph No. 6, Am Soc. of Agric. Eng., St. Joseph, MI.

MacDONALD, R.D., G. HOUGHTON AND F.A. KAINS. 1985. Comparison of a naturally ventilated to a mechanically ventilated hog finishing barn. Paper No. 85-402, Can. Soc. of Agric. Eng., Ottawa, ON.

MILNE, R.J. 1985. Natural ventilation of tie stall dairy barns. Paper No. 85-412, Can. Soc. of Agric. Eng., Ottawa, ON.

SMITH, C.V. 1972. Some environmental problems of livestock housing. Technical Note No. 122. World Meteorological Organization, Geneva.

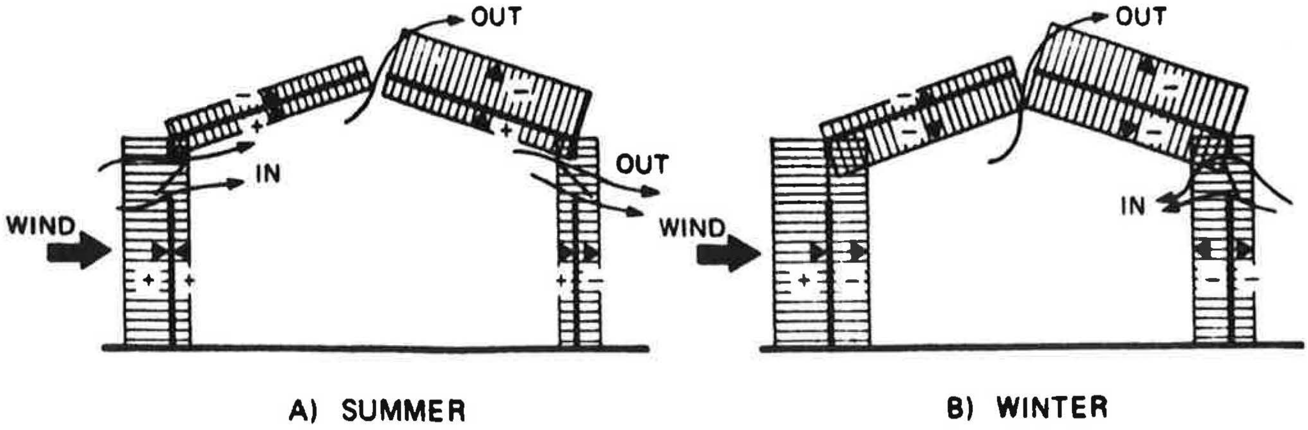


Figure 1. Airflow due to difference in pressures on internal and external building surfaces caused by wind

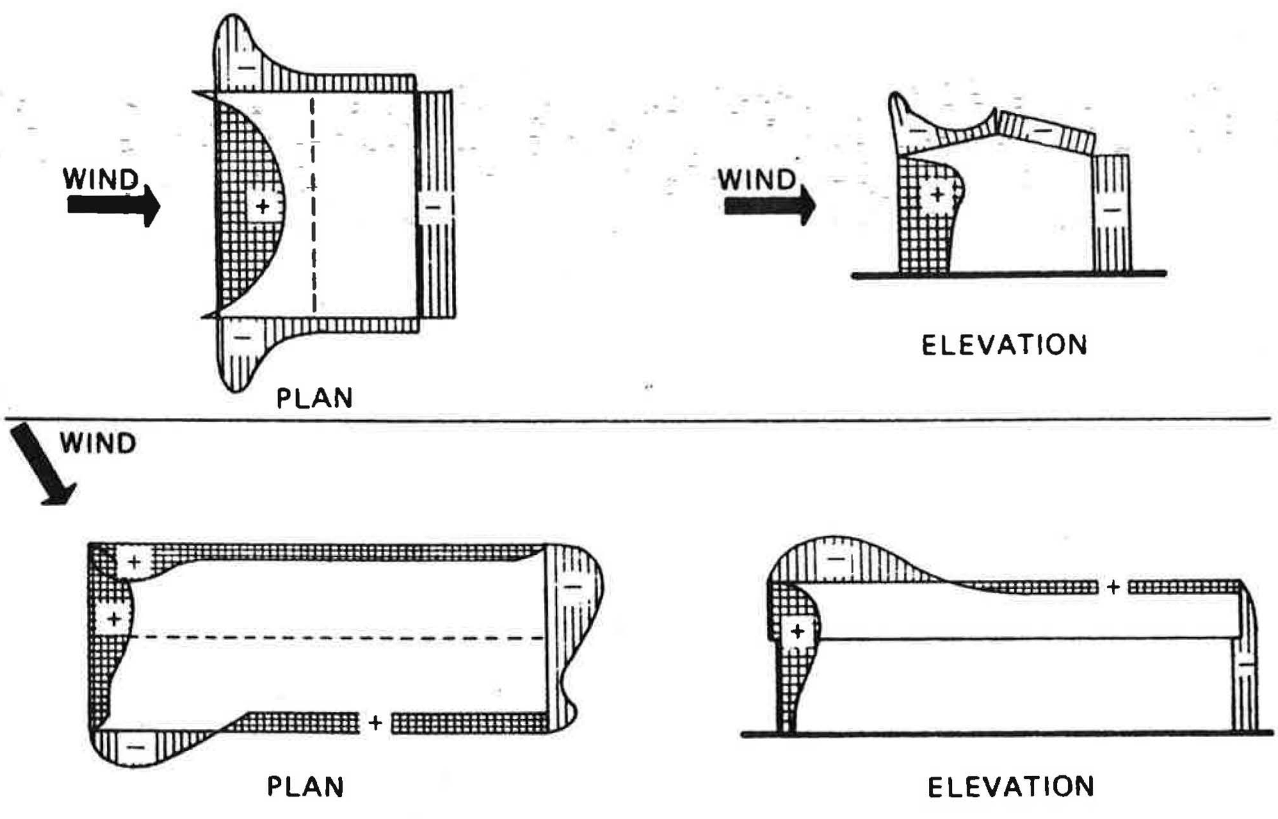
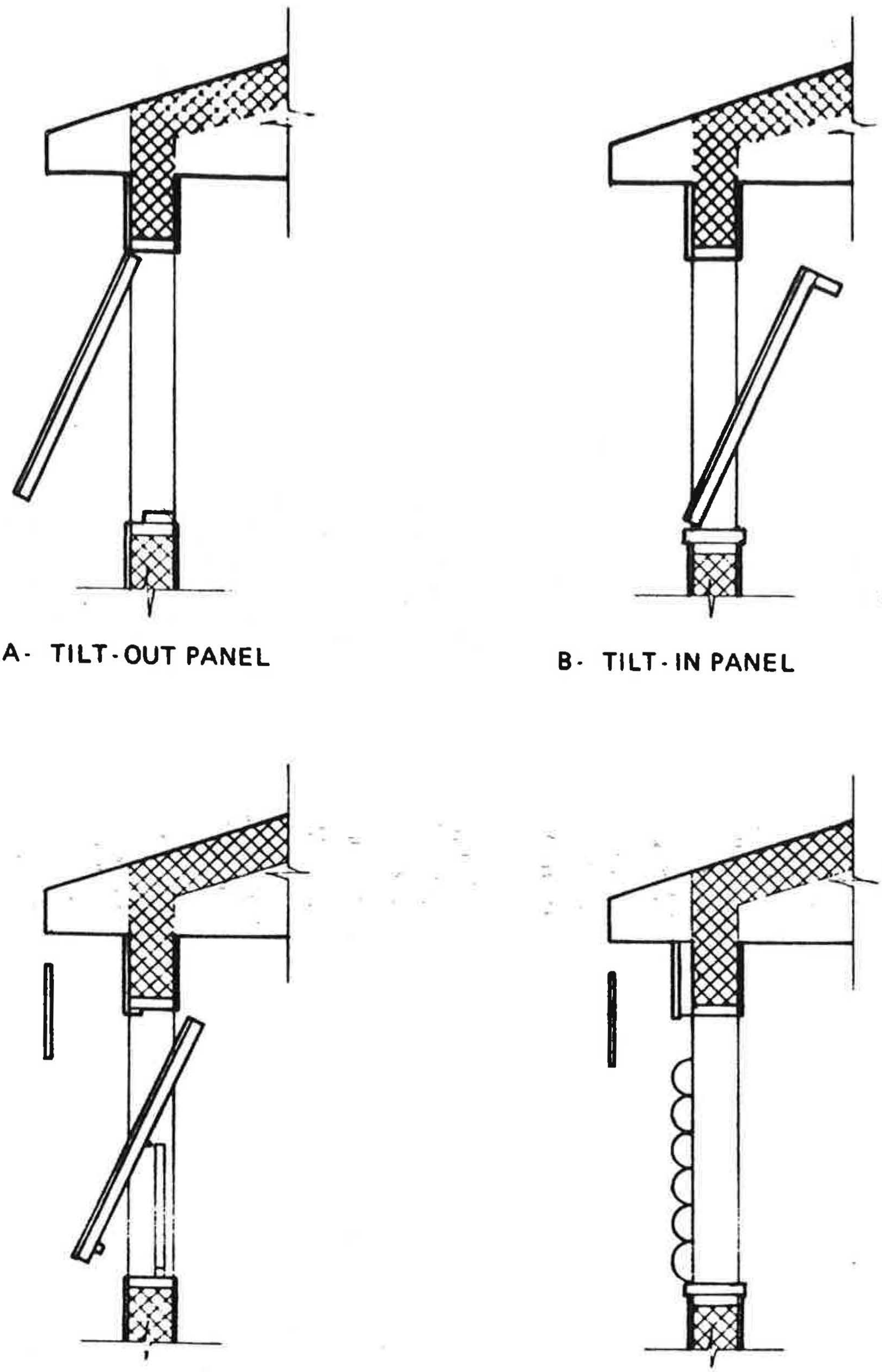


Figure 2. Examples of wind pressure distributions on building surfaces



A- TILT-OUT PANEL

B- TILT-IN PANEL

C- ROTATING PANEL WITH EXTERIOR AND INTERIOR WIND BREAK PANELS

D- PLASTIC CURTAIN WITH WIND BREAK PANEL

Figure 3. Several styles of side wall inlets

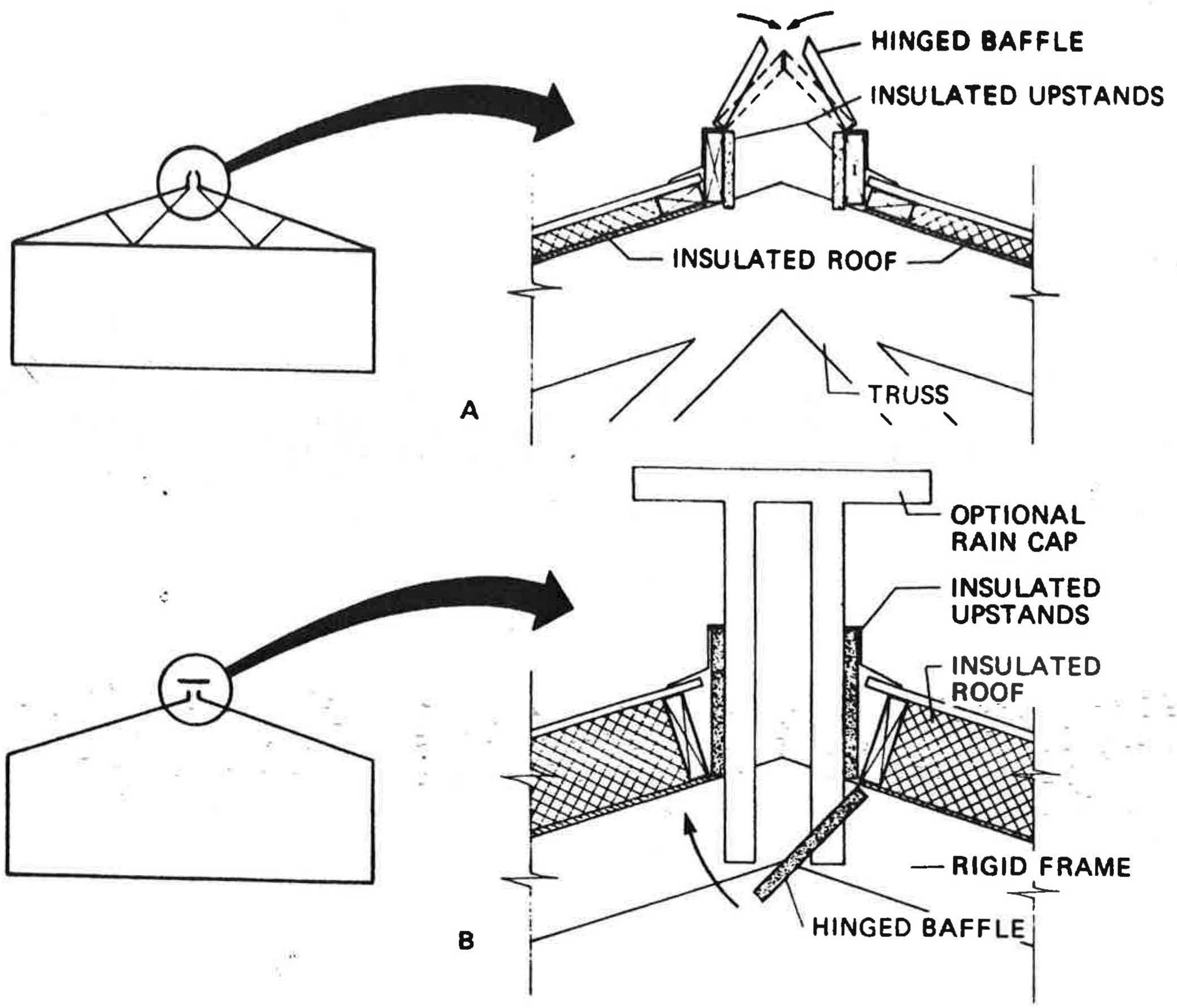


Figure 4. Two types of adjustable ridge outlets:
(a) exterior hinged baffle, b) interior hinged baffle

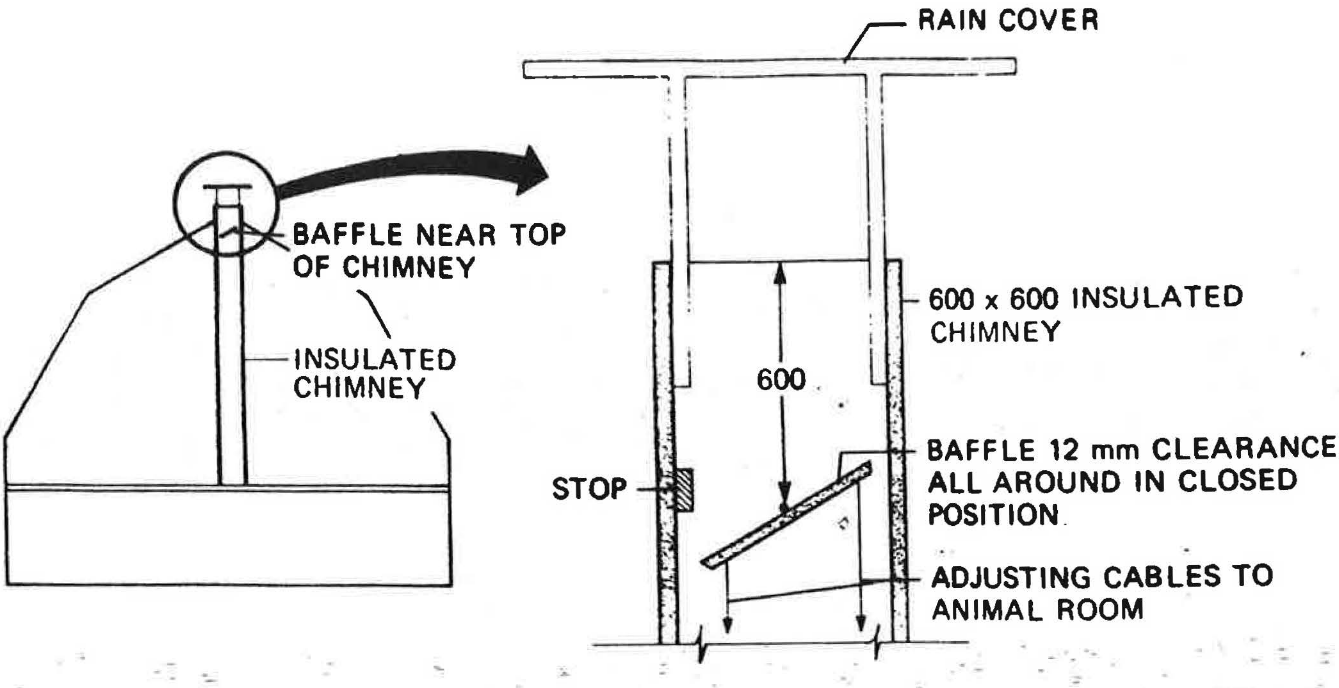
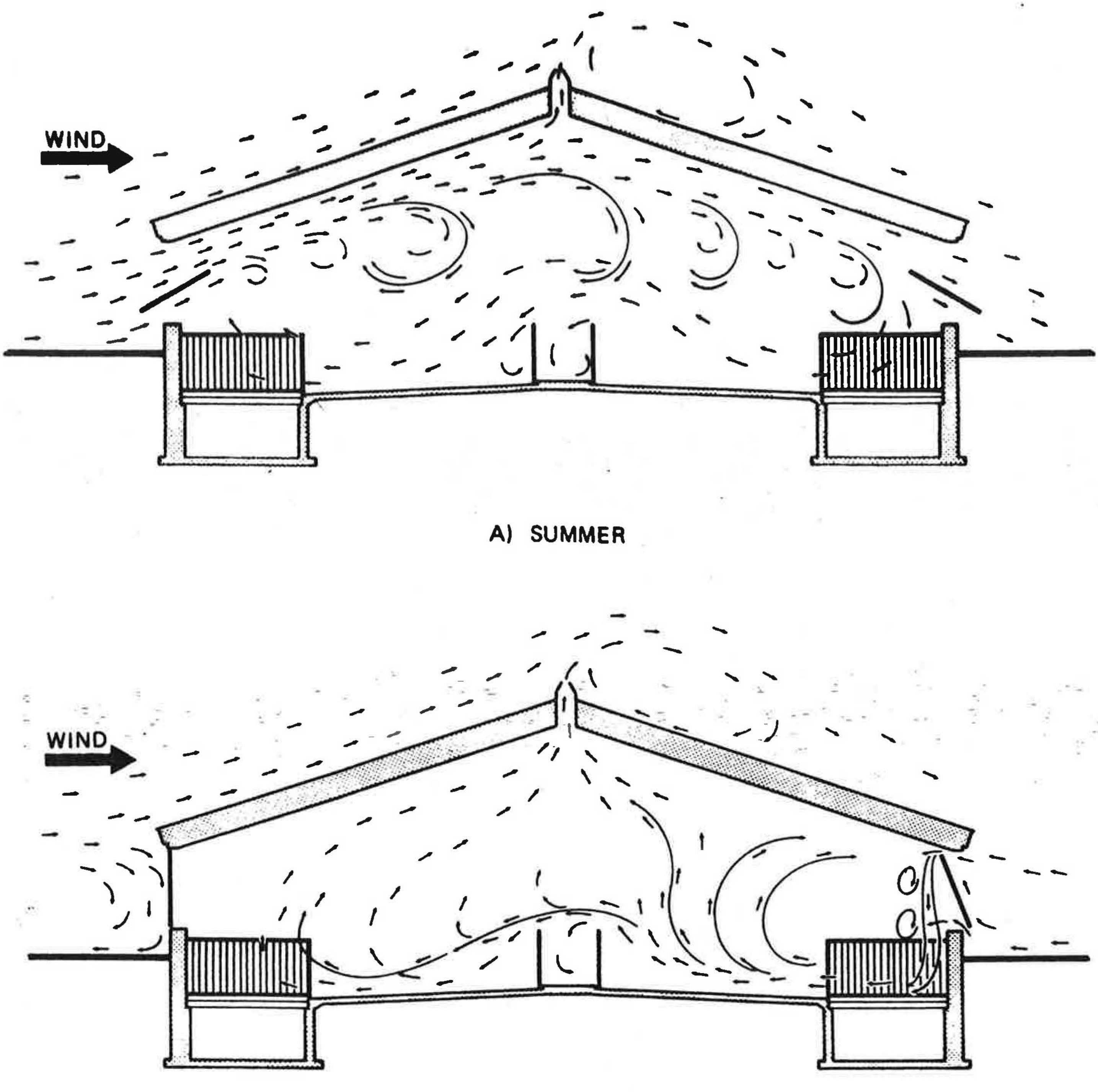


Figure 5. Chimney outlet with rotating baffle



A) SUMMER

B) WINTER

Figure 6. Typical air flow patterns for summer and winter in a naturally ventilated hog barn