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CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING

SOCIÉTÉ CANADIENNE DE GÉNIE RURAL

Paper No. 92 - 211

WIDE NATURALLY VENTILATED BREEDING-GESTATION UNITS AND NEW RIDGE AIR INLET DESIGN FOR 26 M WIDE FARROWING-NURSERY UNITS FOR A 700 SOW COMPLEX

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For presentation to the
CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING
at the **Agricultural Institute of Canada Annual Conference**
July 5 - 9, 1992 - Brandon, Manitoba

ABSTRACT:

This new 700 sow complex incorporates two major innovative technologies. The 19 m x 73 m breeding-gestation unit is naturally ventilated using intermittent chimneys and continuous vertical sidewall panels complete with windbreaks. A new digital, automatic control system is used to activate the sidewall openings.

The farrowing and nursery units are contained in a 26 m x 64 m building. A newly developed ventilation system draws air through a wide continuous ridge opening into a central attic duct. Lateral distribution ducts in the attic then feed each room independently. This paper describes advantages of this ventilation system, as well as presents laboratory results relating air flow characteristics to ridge design.

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RÉSUMÉ

Un nouveau complexe pour 700 truies utilise deux innovations technologiques majeures. L'unité d'accouplement gestation (19 m x 73 m) est ventilée naturellement avec des cheminées intermittentes, des panneaux verticaux continus dans les murs avec les nouveaux panneaux pare-vents. Les panneaux verticaux sont activés par un nouveau système de contrôle digital.

Les maternités et les pouponnières sont situées dans un bâtiment de 26 m x 64 m. L'air pour la ventilation estivale entre dans un conduit d'air central dans l'entretoît par une nouvelle prise d'air située au faîte du toit. Subséquemment, des conduits latéraux distribuent l'air pour chaque chambre. Le présent document décrit les avantages de ce système de prise d'air ainsi que les résultats expérimentaux des mesures des coefficients de pression et des essais de visualisation de la circulation de l'air au-dessus des différents prototypes de prises d'air au faîte du toit.

INTRODUCTION

Traditionally, most swine buildings for breeding-gestation and farrowing-nursery units have been 12 to 14 m wide. For herds in the order of 700 to 1000 sows, this means a very long barn. This paper discusses the design of a recently constructed wider building for 700 sows and in particular, innovative methods of ventilating such a facility.

This paper is divided into two parts. Part I describes the ventilation systems - natural ventilation in the 19 m wide breeding-gestation unit, and ridge inlet and pre-warming attic duct for the 26 m wide fan ventilated farrowing-nursery unit. Part II presents and discusses the results of full-scale laboratory tests carried out to study the effects of ridge opening details and modifications on pressures developed in the attic duct due to wind.

PART I: BUILDINGS AND VENTILATION SYSTEM

This 700 sow complex is located in St-Dominique, Province of Québec, Canada. It is owned by Pauniporc Inc. and the stock is supplied by F. Ménard Inc. of L'Ange-Gardien de Rouville, Québec. This complex is composed of two different types of buildings. As shown on Photo 1, there is a wide, naturally ventilated breeding-gestation unit adjoining a wide fan ventilated farrowing-nursery unit. Construction started in August 1990 and was completed in May 1991.

This sow complex incorporates two major innovative technologies:

1 - a new automatically controlled natural ventilation system for a 19 m wide breeding-gestation unit;

2 - a unique ridge air inlet system to ventilate the farrowing and nursery units.

NATURALLY VENTILATED BREEDING-GESTATION UNIT

In most parts of Canada, the breeding-gestation units are 12 to 14 m wide with two rows of stalls and one row of breeding and/or boar pens. In order to save on building construction costs, an attempt was made to enlargen the building to 19 m wide. For this particular case, this producer wanted to have 4 rows of sows with a central row of pens for breeding and for boars. Also, this design can accommodate 6 rows of gestating stalls and boar stalls. Figure 1 and Photo 2 present the general profile of the building.

Building description

The unit is 19 m wide and 73 m long. The walls and ceiling are insulated for RSI-3.5 value. As shown on Photo 2, this building has a cathedral ceiling with a 4:12 slope.

Environmental control for sows

Since the gestating sows are housed in individual stalls, the main concern for using natural ventilation for this gestation unit was the cold zones which could occur along the air inlet zones along the sidewalls. The "Lower Critical Temperature" of gestating sows and the relative comfort zone depend on the weight of the sow, the feed intake, the type of floor, the group size, and the expected air speed. The weight of these sows can vary from 120 kg for young gilts up to 230-250 kg for mature sows. The sow's weight is related to the food intake, which varies from 2 to 2.3 kg of feed/d. The thermostat should be set at 17°C for 230 kg sows and 19.5°C for 120 kg sows. It was decided to use the typical Canadian compromise and use the middle target temperature, 18.5°C.

Description of natural ventilation system

A new automatic control system manufactured by Sun-North Systems Ltd., Seaforth, Ontario, was installed. This system consists of:

1 - six electronic thermostats with temperature sensors equally spaced along the length of the barn; three sensors located on either side of the barn;
2 - six independent interlock heating units, 7560 kJ/h propane burners on separate thermostats, equally spaced along the building;
3 - three independent 23 m long x 90 cm high sections of insulated vertical panels, on both sidewalls;
4 - continuous wind break panels for draft protection in winter on both sidewalls;
5 - intermittent 0.6 x 0.6 m chimneys spaced 3.7 m apart (see Photo 3);
6 - two 1.2 x 2.4 m openings for summer use in the North end wall.

The control strategy is the following:

on inside temperature rise, T° = 19°C, open the panels
on inside temperature fall, T° = 18°C, close the panels
on inside temperature fall, T° = 16.5°C, start heating unit

The temperature sensors are located 3 m from the sidewall, just above the first row of stalls. The chimneys are manually controlled. With the use of an automatic control system, the need for chimney adjustment is minimal. Current recommendations are to close them when external temperatures remain steadily below -1° to 2°C (November-December) and re-open them gradually during spring (April-May). This way, there is no need for chimney automation.

After one year of observation, the sows along the sidewall seemed to have performed very well. They exhibited normal lying behaviour and did not show any signs of thermal stress.

During the summer, the "Upper Critical Temperature" for these sows may vary between 32°C and 33°C for air speeds between 0.3 and 0.5 m/s. It is therefore important to have sufficiently large sidewall openings to generate these interior air velocities. This design was produced after analyzing the local summer climatic conditions. According to the prevailing winds, the complex had to be built on a NNW-SSE orientation to provide the best ventilation performance. From the wind speed and direction frequency curves, it was decided to use 90 cm high continuous sidewall openings.

Operator's comments

The operators enjoy the overall improved air quality, the sunlight and the quietness within the building since there are no fans. The system is also power-failure safe.

FARROWING AND NURSERY UNITS

The near building shown on Photo 1 contains the farrowing and nursery units, as well as the shipping and office areas. This building is 26 m wide and 64 m long. One side of the building contains 4 farrowing rooms (Fig. 2) 12 m wide by 14 m deep with 32 farrowing crates. Provisions were made for a possible overflow with the addition of a 6 x 12 m farrowing room. The other side of this building, separated by a 1.5 m wide corridor, has 5 nurseries measuring 10.4 m wide by 9.8 m deep and one half-size nursery room 5.2 m wide by 9.8 m deep. The flow of hogs is based on a 3 week weaning cycle in the farrowing rooms and a 4-5 week growing period in the nurseries (from an average of 5.5 to 16 - 18 kg).

Design of the ventilation system

The design of the ventilation system depends entirely on the desired air quality inside each room. In this complex, farrowing rooms require a temperature of 20°C prior to farrowing, and 22°C for 3-4 days after farrowing. The temperature can then be lowered to 20°C again. Adding to the design complexity is the fact that a lactating sow with her litter produces about 4 times more moisture and only 1.5 times more sensible heat than a pregnant sow. Consequently, the ventilation system has to be very flexible, especially during the winter. At this time, the building is heat deficient and extra heating is required.

In the nurseries, the temperature is adjusted according to the age and weight of the piglets. Initially 5.5-6.8 kg weaners require a room temperature of about 27°C, which is usually provided with extra heat lamps. This temperature is gradually dropped to 22°C after 4 weeks. In all cases, the ventilation system has to be extremely flexible during the winter because the 18 kg weaners produce about 4 times more moisture and 4.5 times more sensible heat than the 5.5 kg piglets.

Pre-heated hallways

The use of pre-heated hallways has been promoted in Ontario and Québec. The intent is to pre-warm the incoming air before it reaches the farrowing or nursery rooms. It has been successful, but most operators realize that these corridors have to be maintained quite cold to prevent high heating bills. Since the ventilation rate depends on the heat balance and self-adjusts according to the temperature of the incoming air, then, if the corridor is maintained at 16°C, the fans will run the same amount as during the summer. This will provide good air quality but also give high heating bills.

Central pre-heating duct in the attic

When the heat deficit temperatures are calculated for this particular complex's farrowing and nursery rooms, the results show that the air should be pre-warmed to between -12 and -6°C. With this pre-warming, only the rooms with young weaners and newborn piglets require extra heating.

Since this building is 26 m wide, there is lot of space in the attic to create a central heating chamber to maintain the attic duct temperature at -6°C.

These are the advantages when using this type of system:

1 - more efficient use of building space;
2 - control of the minimum winter ventilation rate based on a steady inflow of air entering at -6°C;
3 - reduction of odours and gas levels because of higher winter ventilation rates;
4 - able to maintain a warm working corridor;
5 - reduction of heating costs;
6 - reduction of the investment for individual room heating equipment;
7 - less air inlet freezing problems in each room due to air pre-warming to -6°C.

Heating Requirement

A central heating unit has to be sized according to the local climate in order to supply enough heat in cases of extreme cold periods. It is recommended that the central heating unit have at least two stages. For this particular complex, the system is designed to maintain the duct temperature at -6°C. If the exterior temperature is between -13 to -6°C, the central heating unit supplies about 63,000 kJ/h. However if the exterior temperature drops below -13°C, the second stage goes on providing 126,000 kJ/h. The two stage concept prevents excessive temperature jumps inside the heating duct between the "on" and "off" cycles.

Summer air supply by a ridge opening

As shown in Photo 4 and Fig. 2, the air enters each room by way of a continuous self-adjusting air inlet. This air inlet is located in the middle of each room to obtain even air distribution. A small recirculation duct is used for the autumn-winter-spring period to provide excellent airflow pattern stability and prevent cold air from falling on sows or piglets.

For a conventional 13 m wide barn, there is no problem in taking summer air from a sidewall corridor, but this layout is impossible in this building. Many producers take the hot summer air directly from the attic, but then the rooms' temperature increases. Another option is to take air directly from outside using an opening at ridge level.

Traditionally, ridge openings act as air exhausts due to the negative pressures at the peak generated by the wind. A wind tunnel study was performed at Alfred College of Agriculture and Food Technology on a full scale section of a roof deflector, and on a scale model of a complete barn to see if alterations to the ridge design would cause this location to be an air inlet instead of an exhaust.

With the final design, air is forced into the distribution duct from outside for any wind direction, but strong positive pressures due to high winds, which might damage the self-adjusting air inlets, are avoided.

The following are advantages of this ridge air inlet system:

1 - it satisfies the total summer ventilation rate requirements;
2 - no air warming in the attic during the summer;
3 - air inlet independent of wind direction;
4 - minimal airflow resistance for the fans.

Winter Air Inlet

Soffit openings should be used for air intake during the winter, and baffles have to be installed in the ridge inlet to prevent snow infiltration. In Eastern Ontario, the ridge air inlet would be used from April to November. For summer ventilation in this particular building, a 30 cm continuous opening was employed on each side of the vertical baffles shown in Fig. 2.

Design of exhaust fans

During the winter, the minimum ventilation rate of any farrowing room varies from 142 L/s just before farrowing to 390 L/s after 2 weeks. During this time in the nursery rooms, the 5.5 kg piglets need about 153 L/s with the help of extra heat from propane burners and about 354 L/s only 3 weeks later. Also, during the summer, the desired summer ventilation rate is about 6135 L/s in the farrowing rooms and 5663 L/s in the nurseries.

The use of variable speed fans is strongly suggested for up to 2800 to 4000 L/s. During the winter, a 30 cm diameter variable speed fan is used in each farrowing and nursery room.

For the autumn-summer-spring, three 46 cm diameter variable speed fans are used.

Self-adjusting air inlet design

Continuous self-adjusting centre air inlets 9.8 m long in the farrowing rooms and 7.3 m long in the nursery rooms were installed. As shown on Photo 4, a small recirculation duct was added below the air inlet.

Management

Basically, the self-adjusting air inlets have to be re-adjusted twice per year. The counter-weight should be moved inside the duct to generate a higher room negative pressure during the winter and moved back out to generate a lower pressure during the summer. A lower room pressure during the summer allows the fans to exhaust more air.

Operators' comments

The operators are enthusiastic about this farrowing-nursery complex. Putting the pre-warming duct in the attic allows the working corridor to be kept warm and comfortable. Heating bills are low, the walking distance from room to room is reduced and the work required to control the ventilation rates and air inlets is minimal.

Design considerations for the future

Using a ridge air intake and pre-warming attic duct, the building width is no longer an obstacle. The construction cost is lower with these types of buildings when compared to conventional ones and the convenience for the operators is enhanced.

In order to use this concept with farrowing units as well as with hot and cold nurseries, two sections would be required in the pre-warming duct. Basically, the farrowing rooms and hot nurseries require the air to be pre-warmed to between -9 and -4°C while the cold nurseries need only -12°C. The heating systems for these two sections of duct should be separate.

The design of these ventilation and heating systems have to be based on the local weather conditions with knowledge of the extremes of winter and summer temperatures. Also, differences in building layouts will influence the number of external walls and the heating requirements. Finally, the ventilation system and the pre-warming duct temperatures have to be calculated according to the number of sows or piglets per room, the production phase and the air quality level desired inside each individual room.

PART II: WIND LOADING TESTS ON 12 FULL-SCALE PROTOTYPES OF RIDGE AIR INLETS

LITERATURE REVIEW

Aynsley *et al.* (1977) described the early use in China and India of roof air inlets for natural ventilation and cooling of occupants. Karakatsanis *et al.* (1986) studied the ventilation performances of wind towers used in the Middle East. Bauman *et al.* (1988) developed a new ridge air inlet design for long building rows in urban surroundings to be used in Asia. They were proposing a flexible deflector which would force the air to enter the opening independently of wind direction.

OBJECTIVE

The main purpose of this study was to develop a ridge air inlet system which would force the air to enter the building without creating too high a pressure on the individual room air inlets.

PROCEDURE AND METHOD

Figure 3 shows the experimental setup. Two sections of a 2.4 m wide roof were installed on the floor of the Pavillon de Génie Rural du Collège d'Alfred. Twelve full scale prototypes of ridge air inlets were tested, as illustrated in Figs. 4 to 15.

The wind was generated by a 1.2 m propeller fan equipped with a 5.6 kW motor. For each prototype, three tests were carried out with wind speeds varying from 4 to 11 m/s. As shown in Fig. 3, the reference wind speed was measured at 3.3 m upstream of the ridge air inlet. The tests were carried out only for wind perpendicular to the length of the prototype.

Three pressure measurements were taken for each test at each location. These locations are shown in Figs. 4 to 14.

Pressure coefficients were calculated using the following equation:

$$C_p = \frac{P}{.5\rho V^2} \qquad [1]$$

where C_p = pressure coefficient
P = pressure measurement (Pa)
ρ = air density (typically 1.2 kg/m^3)
V = reference wind speed (m/s)

An average pressure coefficient was calculated for each location. Drager smoke tubes and a large smoke generator were used to visualize the airflow patterns.

RESULTS AND DISCUSSION

Figure 4 presents the pressure coefficients for a conventional roof. The negative pressure coefficients indicate a suction above the ridge line. Values of -0.28 and -0.74 are close to the pressure coefficients for conventional roofs, as reported by Choinière (1991).

The prototype shown in Fig. 5 is very similar to a continuous open ridge. It generates a suction inside the cavity. Also, a positive pressure is measured on the upwind baffle.

The addition of a sloped ridge inlet cap (Fig. 6) and some vertical sides on the ridge inlet cap (Fig. 7) caused a reduction of the suction in the cavity and some changes in the upwind and downwind pressures. However, negative pressure inside the cavity is not desirable; a positive pressure coefficient would indicate that the air is forced into the inlet.

The addition of a solid vertical deflector at the centre of the prototype created the desired positive pressure coefficient (Fig. 8). As shown in Fig. 9, the addition of an extra 600 mm of solid deflector inside the cavity did not change the positive pressure coefficients generated.

The use of a flat roof over the ridge air inlet was also investigated. The prototype presented in Fig. 10 would be similar to a continuous ridge opening with a flat roof but it generated a suction inside the cavity. As illustrated in Fig. 11, three solid vertical deflectors of various lengths: 75, 150 and 200 mm were tested. Surprisingly, all three generated a positive pressure inside the cavity. With pressure coefficients of 0.26 and 0.35, it would have generated a strong positive pressure inside the building when strong winds would blow.

Vertical sides were added to the flat roof prototypes (Fig. 12). However, this design caused a suction inside the cavity. With this prototype, the addition of a solid vertical deflector (Fig. 13) produced a positive pressure coefficient of 0.19.

As used by Bauman *et al.* (1988), a flexible deflector was made of plastic with a steel bar weight. When the wind blows, this plastic deflector moves, forcing the air to enter the cavity from the windward direction. However, the results presented in Fig. 14 show that very high positive pressure coefficients are generated, especially with the 450 mm deflector. Although this method would be extremely efficient as an air inlet, the very high pressure coefficients may present a problem of over-pressurization inside the attic duct at the rooms' air inlets during high winds.

RECOMMENDATIONS

The prototypes presented in Figs. 8 and 13 are recommended as ridge air inlets for wide livestock buildings. Install bird screen over the openings and use a tight trap to close the opening during the winter in order to prevent snow infiltration. During the winter, the soffit openings will provide sufficient air for ventilation requirements.

SUMMARY AND CONCLUSIONS

The design and operation of the ventilation systems in a recently constructed very wide breeding-gestation, farrowing-nursery complex has been discussed. The 19 m wide breeding-gestation unit was naturally ventilated with automatic controls, while the 26 m wide fan ventilated farrowing-nursery unit incorporated an innovative ridge air inlet and pre-warming attic duct. Laboratory test results relating to the ridge inlet design and its effect on pressures developed in the duct due to wind have also been discussed.

For summer ventilation of the wide farrowing-nursery unit, either of two ridge air inlet designs with sloped or flat roofs can be recommended. The key to success is the addition of a solid vertical deflector at the centre of the ridge air inlet to force the air to enter the duct.

RÉSUMÉ ET CONCLUSION

Les détails de conception et d'opération pour les systèmes de ventilation d'un complexe porcin de 700 truies (gestation, accouplement, maternité et pouponnière) ont été présentés. L'unité de gestation-reproduction (19 m de large) utilise un nouveau système de contrôle de ventilation naturelle automatisé. Un nouveau système de prise d'air au faîte du toit a été développé pour les unités de maternité et pouponnière (26 m de large). Les coefficients de pression générés par le vent sur les différents prototypes de prise d'air au faîte on été discutés.

Pour la ventilation estivale de larges bâtiments agricoles, deux types de prise d'air au faîte avec un toit plat ou en pente peuvent être utilisés. La clé du succès pour forcer l'entrée de l'air dans l'étable est d'ajouter un déflecteur au centre de la prise d'air.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge C. Weil, P.Eng., Head of the Agricultural Engineering Department and M. Paulhus, P.Ag., Principal, Collège de technologie agricole et alimentaire d'Alfred, Alfred, Ontario; G. Garland, P.Eng., Head of the Engineering Resources Unit, J. Johnston, P.Eng. Manager and V. Spencer of the Resources Management Branch, Guelph, Ontario, for their support.

Special thanks are addressed to the barn owner, Paul Cloutier, St-Dominique, Québec and Guy Ménard from F. Ménard Inc. for the full scale testing of the wide ridge prototypes.

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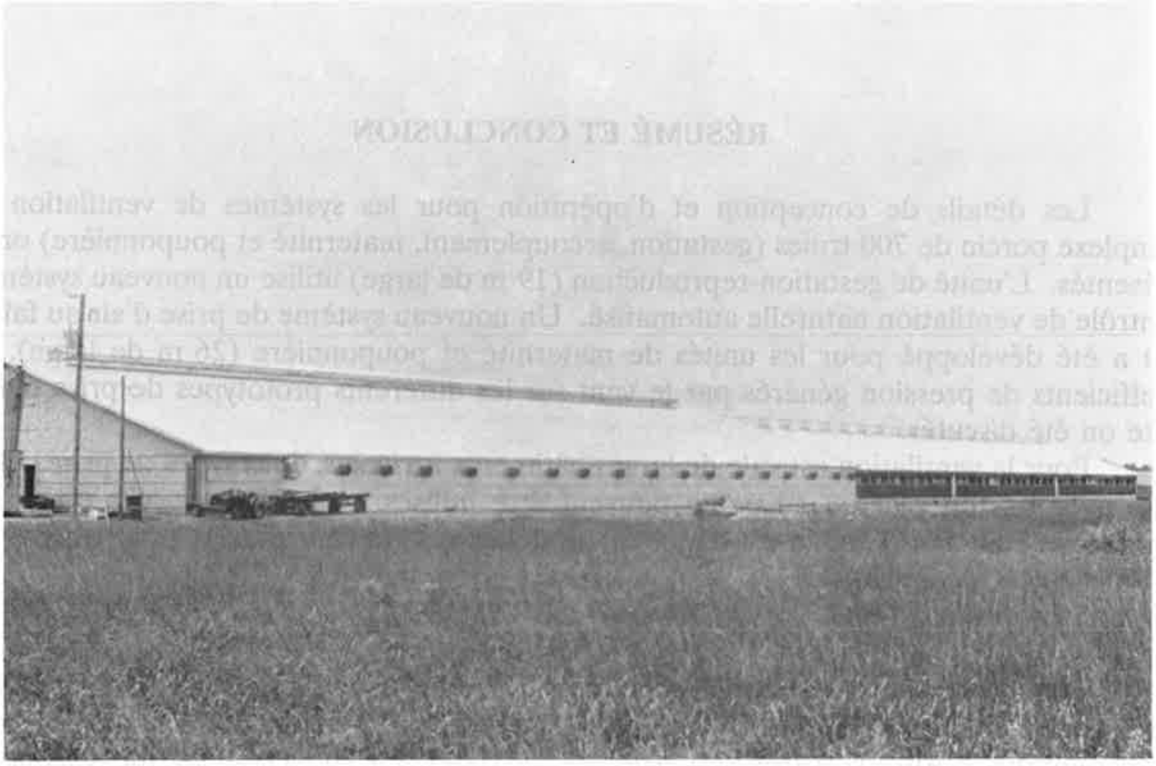


Photo 1. 700 sow complex with a 26 m wide fan ventilated farrowing-nursery unit and a 19 m wide naturally ventilated breeding-gestation unit.

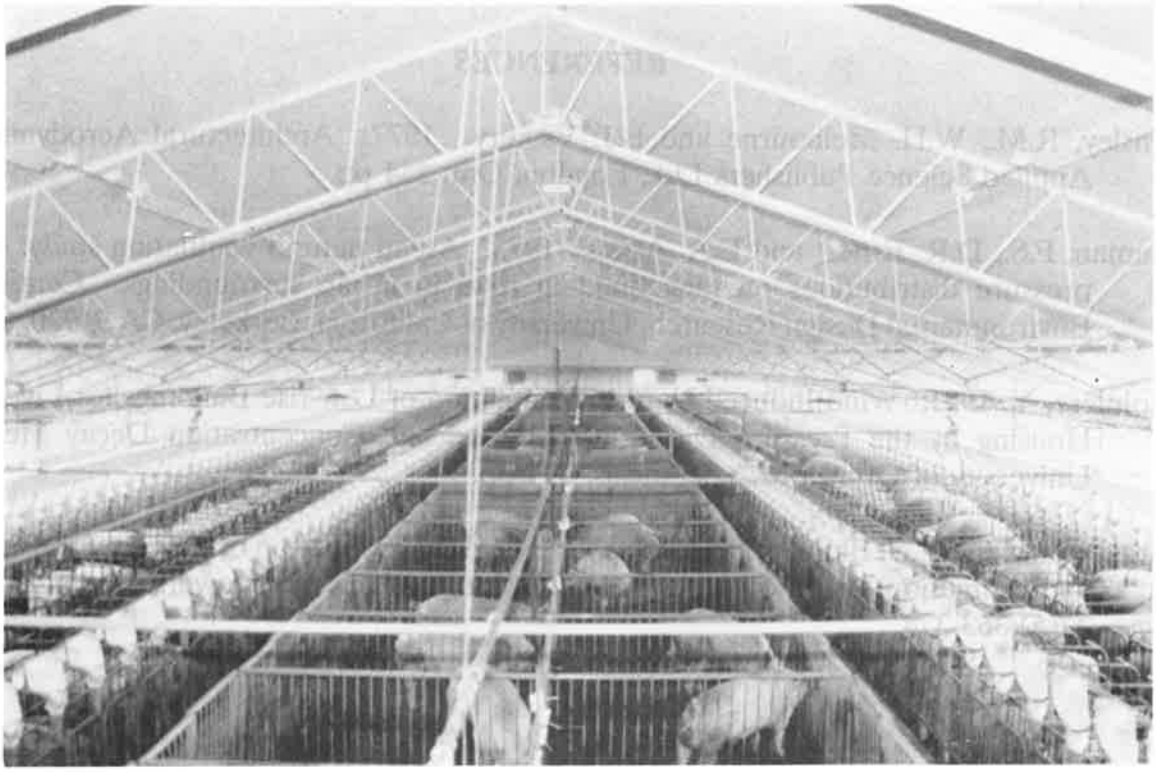


Photo 2. 19 m wide naturally ventilated breeding-gestation unit with sloped ceiling.

Photo 3. Naturally ventilated breeding-gestation unit with insulated vertical sidewall panels complete with windbreaks and intermittent chimneys.

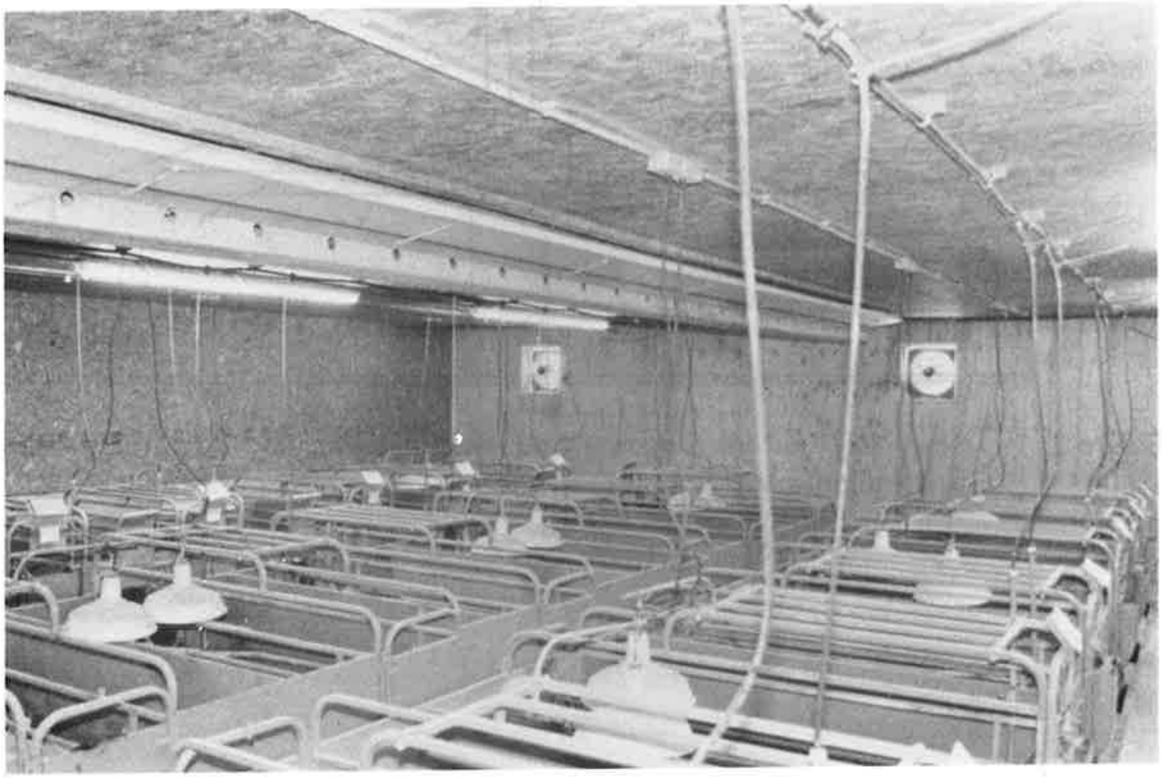


Photo 4. Fan ventilated farrowing room with self-adjusting centre air inlet and recirculation duct.

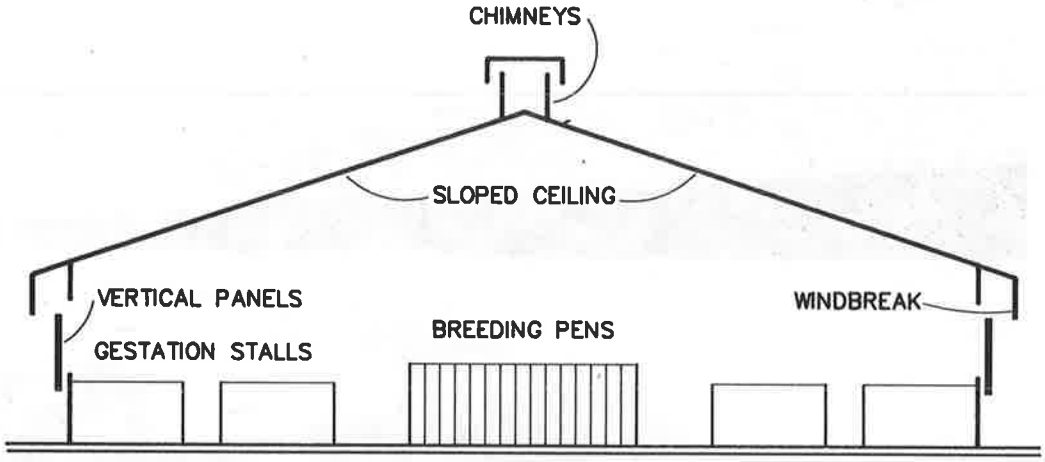


Figure 1. Profile of a 19 m wide naturally ventilated breeding-gestation unit.

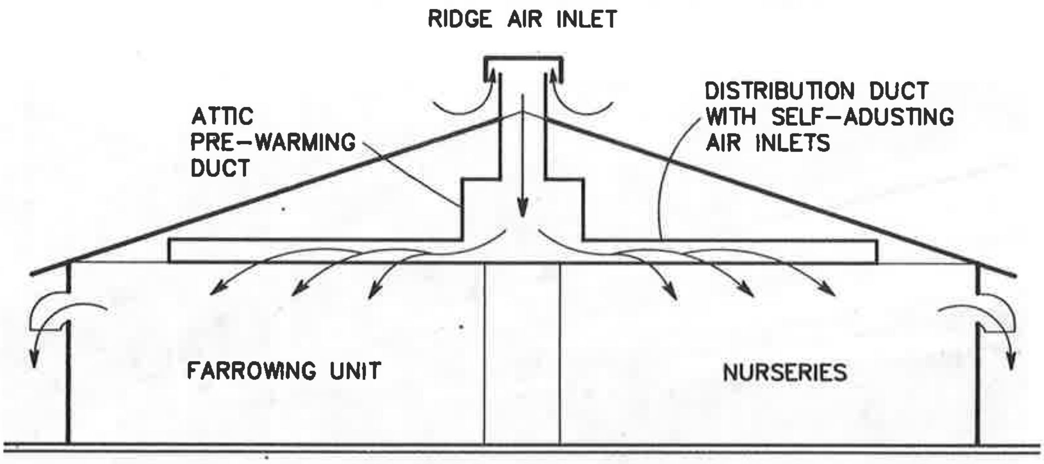


Figure 2. New ridge air inlet system and attic pre-warming duct for a 26 m wide farrowing-nursery complex.

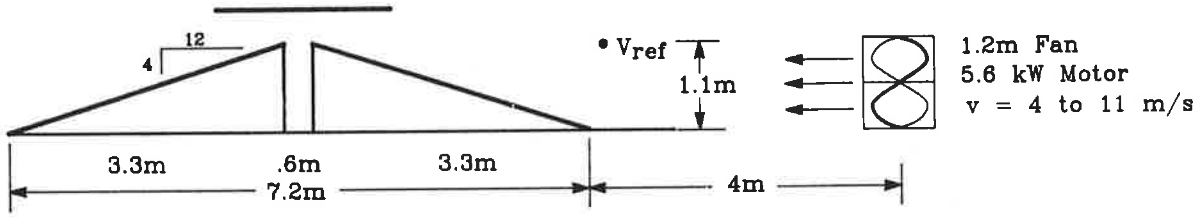


Figure 3. Full scale testing of the ridge air inlet models.

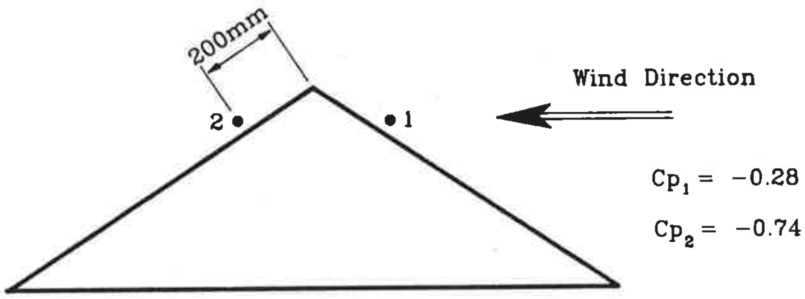


Figure 4. Pressure coefficients for closed ridge (standard roof).

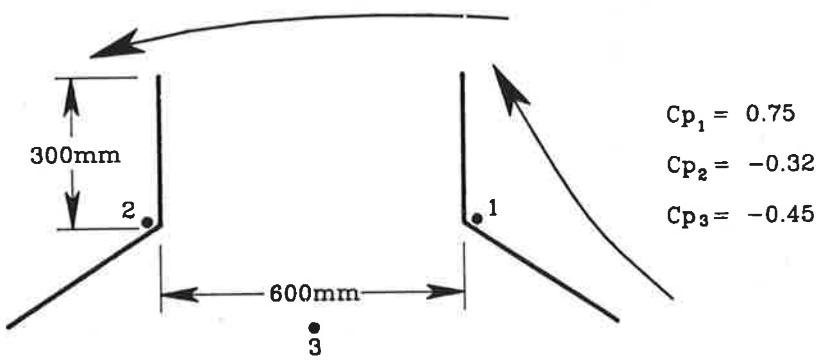


Figure 5. Pressure coefficients with vertical baffles.

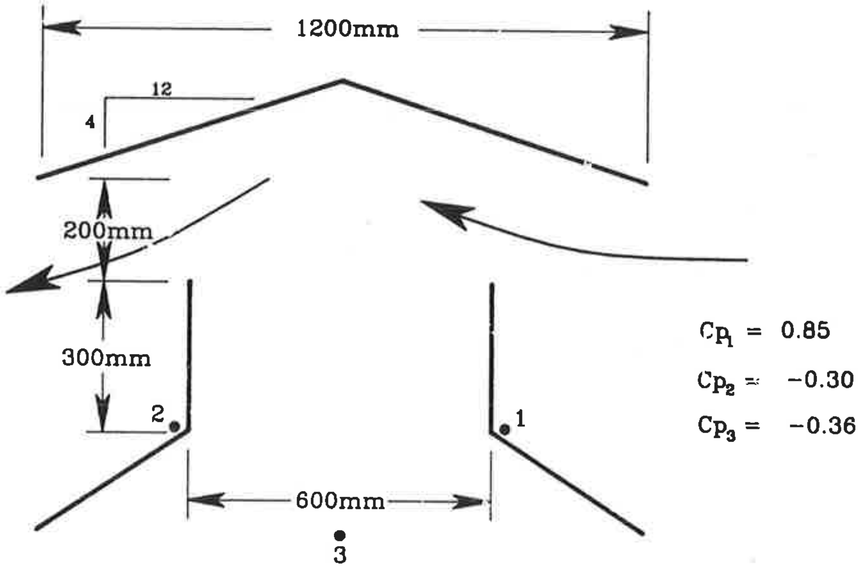


Figure 6. Pressure coefficients for sloped roof with open sides.

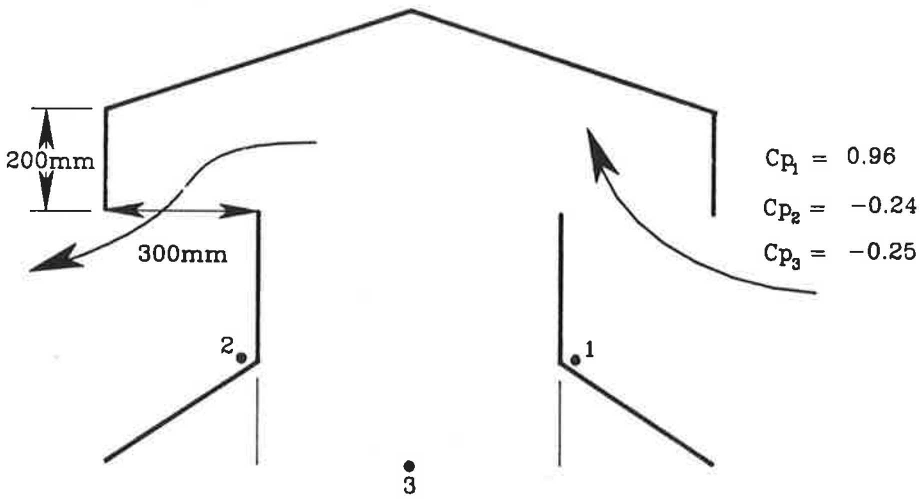


Figure 7. Pressure coefficients for sloped roof with vertical and open bottom, with or without plastic bird screen.

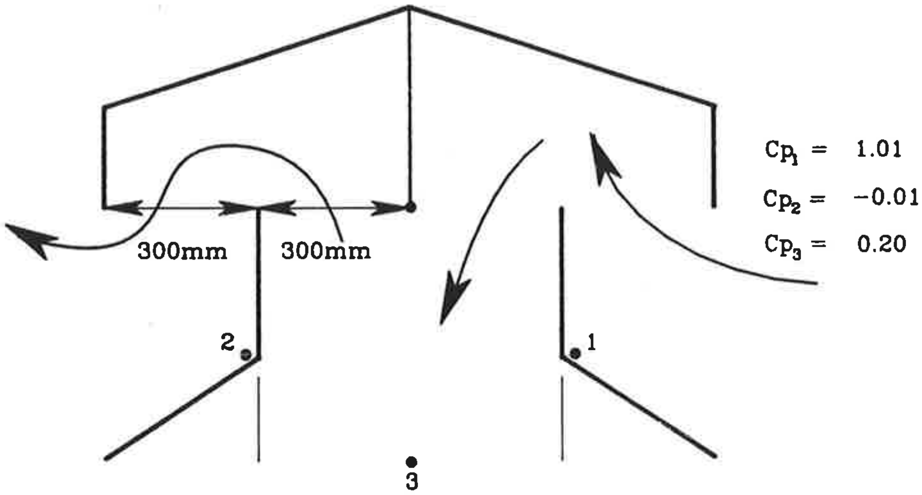


Figure 8. Pressure coefficients for the sloped roof with vertical sides, open bottom and a solid vertical pannel at the centre, with or without bird screen.

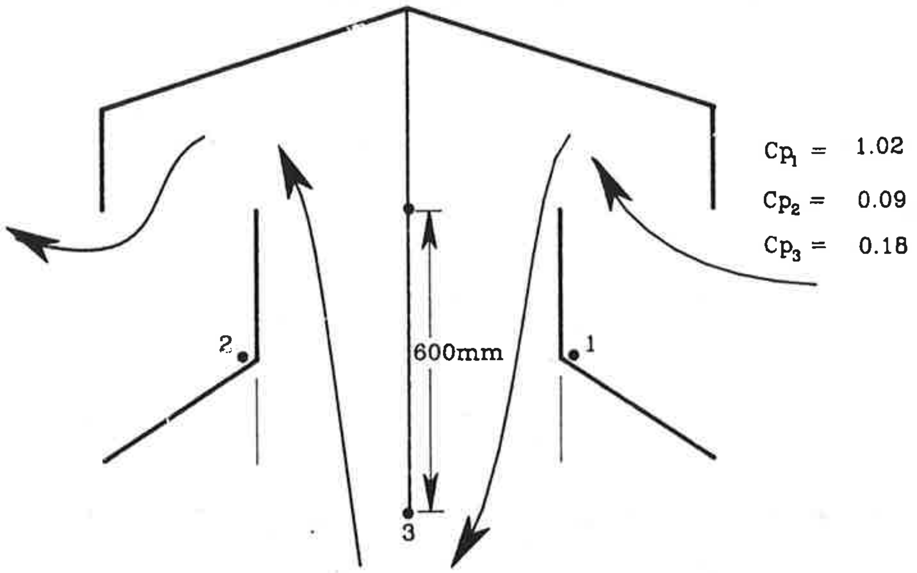


Figure 9. Pressure coefficients for the sloped roof with an extra 600 mm central pannel.

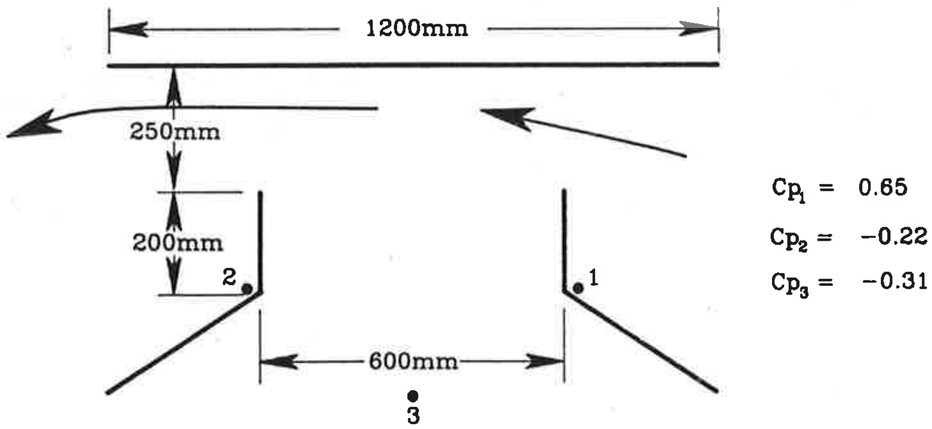
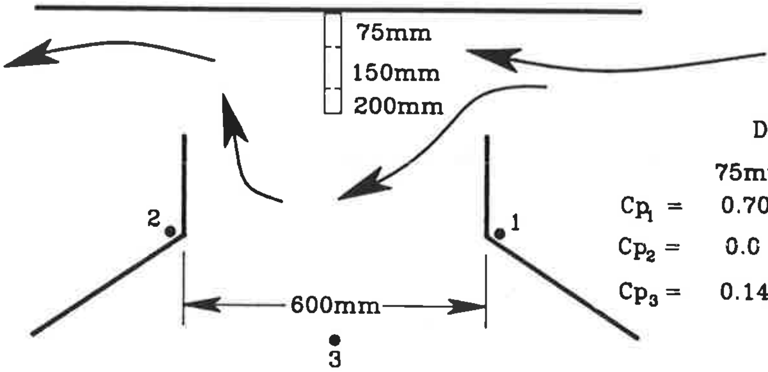
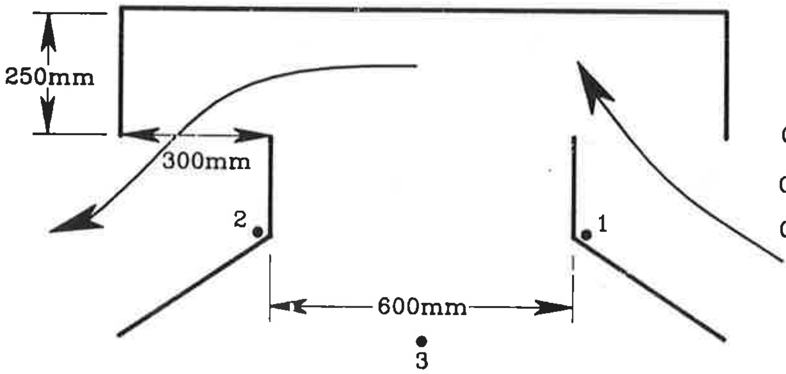


Figure 10. Flat roof design.



	Deflector Depths		
	75mm	150mm	200mm
Cp_1 =	0.70	0.70	0.70
Cp_2 =	0.0	−0.08	−0.08
Cp_3 =	0.14	0.26	0.35

Figure 11. Flat roof with a solid central deflector.

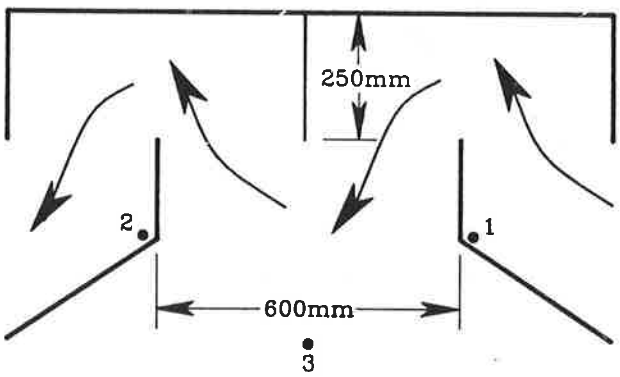


Cp_1 = 0.94

Cp_2 = −0.12

Cp_3 = −0.14

Figure 12. Flat roof with closed sides.



Cp_1 = 1.01

Cp_2 = -0.01

Cp_3 = 0.19

Figure 13. Flat roof with central solid deflector.

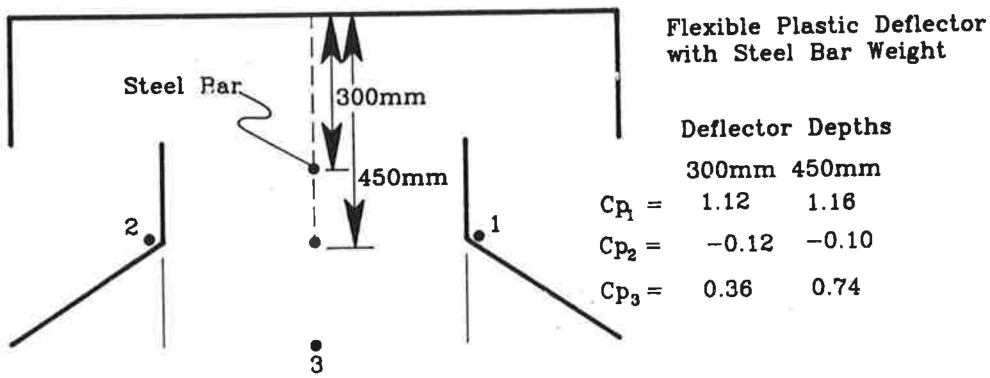


Figure 14. Flat roof design with flexible plastic deflectors 300 or 400 mm deep.

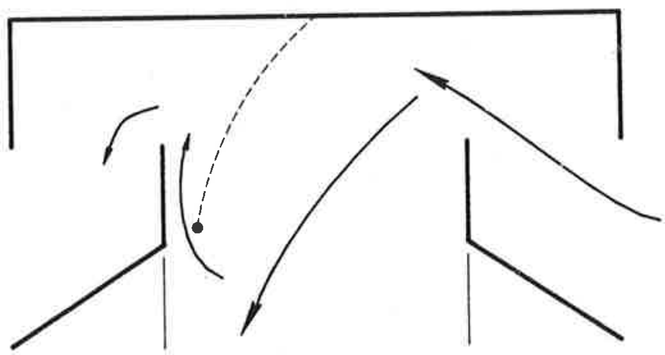


Figure 15. Movement of the flexible plastic deflector with the wind pressure forcing the air inside the opening.