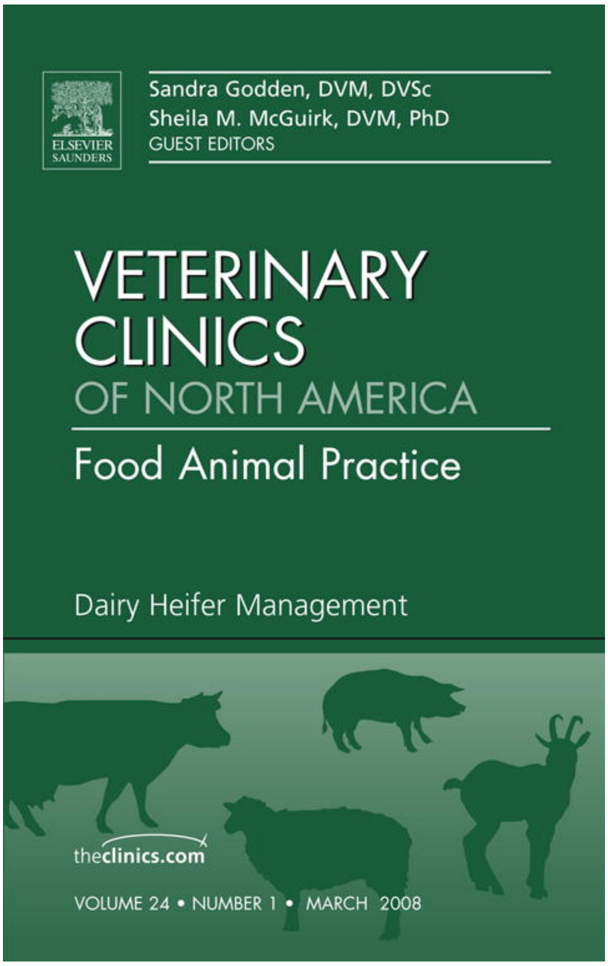

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Practical Considerations for Ventilating Calf Barns in Winter

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Portable air sampling devices have made it clinically feasible to evaluate air hygiene in livestock buildings. By determining the concentration of bacterial colony-forming units per cubic meter of air (cfu/m^3) in different areas within a barn, microenvironments of polluted air within buildings can be identified. Air-sampling devices have facilitated a reconsideration of traditional assumptions about ventilation of calf barns.

Natural ventilation and mechanical ventilation using negative-pressure systems are widely and successfully used in buildings used to house adult cattle. Field investigations of herds with calf respiratory disease by our clinical service suggest that both methods are problematic for calf barns, however, particularly in cold weather. Barns ventilated with negative-pressure mechanical systems present their own set of practical problems. Because of the relatively small air exchange rates used in cold weather, it is difficult to design inlet systems to distribute small volumes of fresh air throughout a barn. In addition, the proper functioning of negative-pressure systems depends on a level of maintenance and management that is not commonly provided by calf barn personnel. In contrast, naturally ventilated calf barns present a different set of problems that include draft-free pens that prevent ventilation of the pen itself, resulting in highly polluted microenvironments within well-ventilated barns. In contrast, positive-pressure ventilation systems to supplement natural or negative-pressure ventilation systems seem to be effective in overcoming these problems.

This article reviews some of the basic principles of aerobiology, discusses common problems of natural and negative-pressure mechanical ventilation systems in calf barns, and describes some techniques for installing supplemental positive-pressure ventilation systems.

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Airborne bacteria concentration as a marker of air hygiene

Airborne bacteria sampling devices based on impaction on agar plates have been developed for quality control programs in sterile room manufacturing facilities, surgical suites, and for other purposes. A programmed quantity of air is drawn through the sampling device at precise speeds where the mass of the airborne organism impacts the media in a Petri dish [1]. After incubation, the colonies are counted, allowing the user to estimate the quantity of colony-forming units per cubic meter of air.

Because the sampling devices being manufactured are designed for very clean spaces, collections of even minimal volumes of air frequently result in overgrown plates. In our clinical program, the standard collection through the air sampler (airIDEAL, bioMerieux, Inc., Hazelwood, Missouri) is 5 L of air onto blood agar plates (BAPs) where the maximum accurate count is 326,418 cfu/m^3.

In the most general terms, outdoor air collected onto BAPs contains about 100 to 1000 cfu/m^3, although we have collected samples as high as 20,000 in some situations. In well-ventilated livestock buildings, we expect to recover from 5,000 to 30,000 cfu/m^3. Generally, bacterial counts exceed 100,000 cfu/m^3 in poorly ventilated calf housing associated with enzootic calf pneumonia. Gross observation of plates, however, suggests that many calf barns have counts that exceed several million live organisms per cubic meter of air.

There is a mixed growth of bacteria recovered on the plates, usually dominated by various staphylococci, streptococci, bacillus, and *E coli*. Rather than attempt to isolate and count specific respiratory pathogens, we have used the total count on BAP as a marker of air hygiene. Although the total count should not be viewed as causative, a field study by Lago and colleagues [2] showed an association between total cfu/m^3 and the prevalence of calves with respiratory disease.

Factors that determine bacterial counts in air

A conceptual formula has been developed to describe bacterial density in air [3].

$$C = \frac{N}{V} x \frac{R}{(qr + qs + qd + qv)}$$

The symbol C is the concentration of bacterial colony-forming particles per cubic meter of air, N is the number of animals, V is the volume of building space, R is the release of organisms per animal, and q describes the clearance of bacteria from air by ventilation (v), sedimentation (s), inspiration into respiratory tracts (r), and desiccation and UV light (d).

Stocking density is the most significant determinant of air bacterial counts. Using mathematical models to calculate airborne bacterial densities, an approximate tenfold increase in ventilation rate (example, from 4 to 40 air changes per hour) does not fully compensate for a doubling of stocking density [3].

Airborne bacteria are released primarily from skin, feces, and bedding, but cattle that have respiratory disease can exhale and cough pathogens into the air [3]. Clearances of organisms by inspiration (q_r) into lungs and sedimentation (q_s) to the floor are minor factors. The primary clearance mechanisms are through desiccation (q_d) and ventilation (q_v). Most bacteria die within seconds after becoming airborne because of dehydration. As relative humidity increases to greater than approximately 80%, bacterial survival time (which varies with species) generally increases into minutes, resulting in dramatic increases in bacterial density [3]. Floors that allow urine and water to accumulate are associated with higher humidity levels. Careless water use practices from hoses and power washers can increase humidity greatly and increase the bacterial load in air. Warm air can hold more water than cold air; therefore heating air reduces the relative humidity although the absolute water in the air remains the same. Heating air reduces relative humidity, which may reduce bacterial loads because of increased clearance through desiccation. Ventilation removes organisms directly in the airstream leaving the building, and also reduces relative humidity, which again may reduce the numbers of live airborne bacteria in the building.

The issue with calf hutches

The traditional single calf hutch remains the preferred standard for calf housing and is associated with reduced morbidity and mortality [4,5]. Hutch housing offers several advantages for calf respiratory health, including isolation and spatial separation from other calves [6]. Unpublished data summarizing air samples collected deep inside hutches as a part of our clinical investigations shows typical total counts of about 20,000 cfu/m^3, but counts exceed 100,000 cfu/m^3 if the bedding is disturbed by an active calf (Alfonso Lago and Ken Nordlund, DVM, unpublished data, 2004). Compared with most other housing types, hutches offer the calf considerable choice to move between different thermal environments in the rear of the hutch, the front of the hutch, and an outdoor pen [7]. However successful hutches may be for calves, they present uncomfortable working conditions for calf caregivers in adverse weather. Delivering milk to 4 or 6 calves during a snowstorm may be viewed as a challenge, but delivery to 100 calves is a hardship. As dairy herds in the Midwest have increased in size, there has been a renewed interest in moving calves and caregivers out of the weather and into various calf barns.

Individual calf pens in naturally ventilated barns

Because natural ventilation systems have been successfully used in the new cow barns in expanded herds, many dairy owners have constructed naturally ventilated barns for calves also. The barns usually have the typical open ridge and curtain sidewalls as recommended for adult cow barns [8] and are ventilated by external wind forces and by effects of thermal buoyancy as animals warm the interior air [9]. In warm weather, the curtain walls are lowered and the barn is ventilated by prevailing winds that move directly through the building. In cold weather, the curtain sidewalls are raised and the building is ventilated by wind entering the open eave on the windward side and potentially by thermal buoyancy of warmed air rising toward the open ridge.

The pen structure within the barns varies considerably. Some pens have three or four solid sides as shown in Fig. 1, sometimes there is a top "hover," and at the other extreme there are pens with mesh panels on three or more sides as shown in Fig. 2. The fully enclosed pens seem to have evolved because of concerns about drafts of cold air on young calves.

Because our clinical investigations of problem herds suggested that endemic calf pneumonia is common in these new barns, we conducted a field trial to explore risk factors for calf respiratory disease in winter conditions [2]. In comparing the alley and pens within barns, the airborne bacterial concentrations in the alleys were associated with the estimated barn ventilation rate, but the air hygiene within the pens was independent of barn ventilation rate. Albright indicates that incoming air from prevailing winds generally enters the barns through eaves at too slow a speed to allow for good mixing, particularly when there are solid obstructions within the barn [9]. Ventilation by thermal buoyancy is also limited in calf barns in winter because of the minimal difference between the interior and exterior temperatures. In the temperature data collected by Lago and colleagues [2], the average temperature difference was only 1.6°C and one fourth of the barns were colder

Fig. 1. Interior view of a naturally ventilated calf barn with four rows of pens. There is a ridge opening above the translucent-panel roof to the south, adjustable curtain sidewalls, and individual calf pens surrounded by solid panels and a feeding opening in the front.

Fig. 2. Interior view of a naturally ventilated calf barn. The pens on the left are constructed of wire mesh panels, and the pens on the right side have been removed for cleaning.

inside than outside at midday. Because both of the forces essential for natural ventilation are compromised in winter operation of calf barns, most of the pens are poorly ventilated microenvironments within well-ventilated barns.

Although ventilation of barns and pens is the focus of this article, the field study by Lago identified three factors as significantly associated with reductions in the prevalence of respiratory disease within the barns: a solid panel between each calf, sufficient bedding to nest, and lower airborne bacterial counts [2]. The findings are summarized graphically in Fig. 3.

Solid panel between calves

The difference in prevalence of respiratory disease in pens with a wire mesh or a solid panel between each pen was substantial. A solid panel between each calf is a traditional recommendation from veterinarians and perhaps helps to limit movement of pathogens from one calf to another. Increasing the number of solid sides was associated with higher airborne bacterial counts, however, a factor adverse to respiratory health. The use of positive-pressure ventilation systems to dilute and freshen the air between solid panels is discussed later in this article.

Sufficient bedding for the calf to nest

With the thermoneutral zone of a newborn calf between 10°C and 26°C and between 0°C and 23°C for a 1-month-old calf [10], nursing calves are vulnerable to cold stress. In the field study by Lago and colleagues [2], the average midday temperature in the barns was 3.9°C and ranged from −6.7°C to 12.2°C. Overnight temperatures were lower. Clearly, the young calves were exposed to temperatures below their thermoneutral zone during many days and nights through the period in which the trial was conducted.

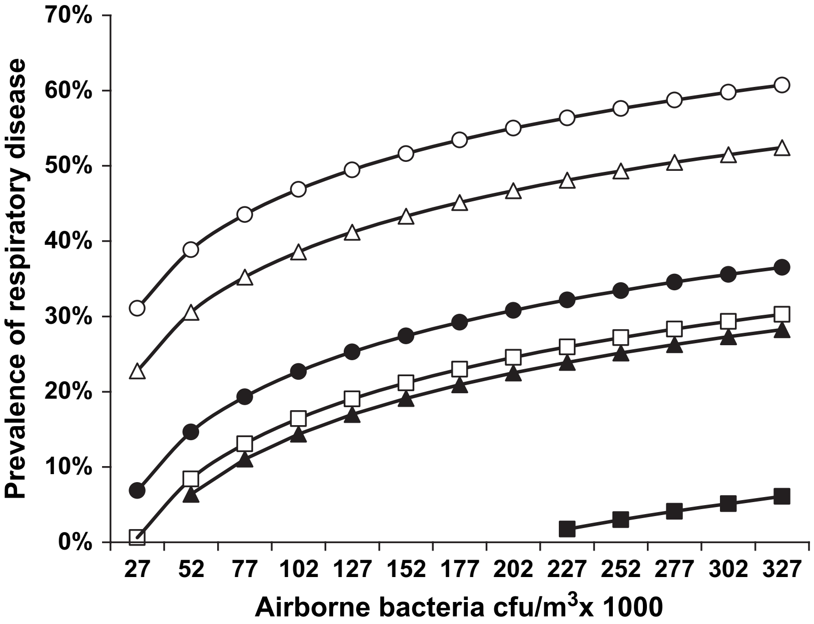


Fig. 3. Graphic model of the associations between airborne bacterial concentration and prevalence of calf respiratory disease with different degrees of nesting and the presence or absence of a solid barrier between each pen. Deep nesting and presence of a solid barrier (■); deep nesting and absence of a solid barrier (□); moderate nesting and presence of a solid barrier (▲); moderate nesting and absence of a solid barrier (△); minimal nesting and presence of a solid barrier (●); and minimal nesting and absence of a solid barrier (○).

Bedding provides a potentially effective mechanism for calves to reduce heat loss. If the bedding is sufficiently deep, the calf can nest and trap a boundary layer of warm air around itself, which reduces the lower critical temperature of the calf [3]. In our clinical work, we assign a nesting score based on how visible the calf's legs are when the calf is lying down. A score of minimal nesting is assigned when the calf lies on top of the bedding with its legs exposed. A score of moderate is assigned when calves nestle slightly into the bedding but parts of the legs are visible above the bedding. An excellent score is assigned when the calf appears to nestle deeply with its legs completely obscured by the bedding Fig. 4. The potential for the calf to nest deeply seems to reduce the risk for chilling and allows for colder and better-ventilated spaces.

Low total airborne bacterial counts within the pens

Lower total airborne bacterial counts were associated with reduced prevalence of respiratory disease in the barns. The total airborne bacterial counts should not be viewed as the cause of respiratory disease, but rather as a marker of poorly ventilated spaces. Wathes and colleagues [10] point out that most airborne bacteria are nonpathogenic, but that even dead airborne bacteria can be a burden to respiratory tract defenses. Because calves spend 100% of their time in the pens and cannot leave for even short periods of time, the exposure to the air within the microenvironment is continuous and chronic.

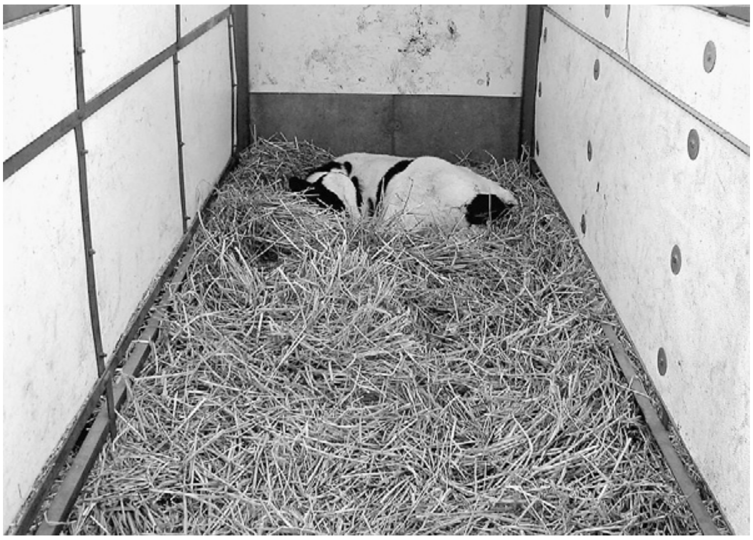


Fig. 4. An example of deep nesting; the legs of this calf are completely obscured by bedding.

Factors associated with lowered airborne bacterial loads include larger area pens and fewer solid sides around the pen. Increasing the area of the pen from 2.3 m^2 (25 ft^2) to 3.7 m^2 (40 ft^2) reduces the airborne bacterial density in the pen by nearly half [2]. The finding that any solid panels increased the airborne bacterial counts, which increases the risk for respiratory disease, confounds the finding that a solid panel between each calf reduces the risk for respiratory disease. In practical terms, the expected reduction in the prevalence of respiratory disease by placing a solid panel between each calf is greater than the expected effect of the improved air hygiene without them. In our clinical work, we have emphasized the use of a solid panel between each calf, open mesh panels on the front and if possible the rear of the pen, and use of supplemental positive-pressure ventilation systems to achieve improve air hygiene between the solid panels.

Negative-pressure ventilation in calf barns in winter

Negative-pressure mechanical ventilation systems are commonly recommended for livestock buildings because passive inlet systems are usually cheaper to construct than ductwork associated with positive-pressure systems. Although negative-pressure systems can be successful in many housing systems, they present special problems in calf barns. In winter, the recommended ventilation rates result in small-capacity systems that are difficult to design and maintain. For example, Midwest Plan Service guidelines suggest a minimal cold weather ventilation rate of 25 m^3/h or 15 ft^3/min of air per calf [11].

Some of the difficulties are best understood by working through the design parameters of an example barn housing 50 calves. A cold weather ventilation system would provide 1275 m^3/h (750 ft^3/min) of fresh air to be distributed throughout the building. To mix with the air already in the barn, inlets should be designed so that the incoming air enters at about 4.2 m/s or 800 ft/min [11]. To achieve this velocity, the total air inlet area would need to approximately 0.086 m^2 (0.93 ft^2), a small area. If the barn were configured with two rows of 25 pens on each side of a central alley, and each pen were 1.2 m (4 ft) wide, the barn might be 30 meters (100 ft) long. If a single continuous slot inlet is designed along one side of the barn, the required width of the slot would be 0.27 cm (0.009 ft) wide, or 0.14 cm (0.0045 ft) wide if it ran along both sides. Slots of this width cannot be constructed with any accuracy with standard farm building construction practices. An alternative would be to drill inlet holes into an attic to yield the appropriate area. If one inlet hole were to be drilled above each pen, each of the 100 holes would need to be just larger than 2.54 cm (1 in) in diameter. This solution is more feasible, but holes this size in an attic are easily plugged with insulation, leaves, and other refuse that enters attics of livestock buildings.

In addition to the difficulty of inlet sizing is the risk for other inlet openings. If there are undetected openings in the walls or around windows, air also enters through those openings, becoming part of the cumulative inlet area and reducing the incoming air speed. In a calf barn of this size, it would be almost impossible to not have at least a square foot of unrecognized openings. Because of these openings, the air coming into the barn usually enters too slowly to mix well and is frequently poorly distributed within the barn. Finally, if a worker should leave a door slightly ajar or break a window, the area of such an opening essentially renders the distribution system nonfunctional.

Clinical experience using the air sampling device during the winter has demonstrated that poor distribution of fresh air is almost standard in negative-pressure mechanically ventilated barns. These experiences have led the author to the conclusion that low-volume negative-pressure systems for winter calf barn use are not reliable enough to be recommended.

Positive-pressure systems to supplement other ventilation systems

Positive-pressure mechanical systems seem to be dependable and consistent for low-capacity situations. The advantage is that they can be self-contained systems of a fan forcing air into a distribution duct. The system is not affected by unseen cracks in the walls or windows or doors left ajar. Positive-pressure mechanical systems can complement naturally ventilated calf barns as shown in Fig. 5 and deliver minimal volumes of fresh air to dilute polluted air within the pens. As weather warms, the sidewall curtains are lowered and the positive-pressure system continues to operate. Positive-pressure systems can also be used to complement negative-pressure systems (ie, the positive-pressure system can be used in low-ventilation winter situations and then be supplemented with larger capacity negative-pressure systems that engage as the temperature increases).

Fig. 5. A positive-pressure distribution duct installed in a naturally ventilated calf barn. The fan that powers the system is installed in an outside wall and forces air into the tube. Holes are punched at 4 o'clock and 8 o'clock positions in this barn and sized so that air exits the holes at about 800 ft/min. The small volumes of air are driven into the pens between the solid panels. In this barn, the airborne bacterial counts in the pens dropped from 170,000 cfu/m^3 to approximately 40,000 cfu/m^3 and the annual number of calves treated for respiratory disease was reduced by approximately 75% following the installation of the supplemental system.

Designing a positive-pressure system for winter use

The general approach to designing a positive-pressure supplemental system for winter is to (1) determine the total minimal winter ventilation rate for the building, (2) decide how many distribution ducts are required, (3) calculate the minimal cross-sectional area of the duct so that it can carry the required volume of air at moderate speeds, (4) specify the area required for air to leave the duct at high speeds, and (5) distribute that air inlet area along the entire length of the duct.

Minimal ventilation rate for cold calf barns

Current recommendations for a minimal winter ventilation rate in calf barns range from 25 m^3/h (15 ft^3/min) per calf to four air changes of the building per hour. If the number of calves varies from time to time, the ventilation rate should be based on the maximal number of calves. It is often practical to calculate the ventilation capacity using both approaches and then purchase a fan to move a volume of air somewhere intermediate to the two rates.

Ventilating at these rates produces freezing temperatures in very cold weather. It is critical that the calves have deep straw in which to nest and that they are fed adequately to meet the energy needs of cold weather. Consider using the simple, but effective, calf ration analysis program provided in the last version of Nutrient Requirements of Dairy Cattle to determine the energy intake of the calves [12].

The fan should be mounted in an exterior wall and the distribution tube attached directly to the fan. The tube should carry only exterior air. Many people recall these same systems used as recirculation systems about 30 years ago. In those installations, the fan was installed a foot or two inside the barn relatively close to a louvered inlet.

If the fan is mounted on an exterior wall, it needs a hood to keep snow and rain from entering the system. In some situations in which the fan is close to the roofline, snow can drift off the roof and get picked up in the flow of air entering the hood to the fan. To reduce the likelihood of this happening, install an oversized hood and extend it farther away from the roofline. The larger the cross-sectional area of the hood entrance, the slower the velocity of the entering air and the less likely it is that snow will accumulate within the tube.

There are situations in which there are rooms for other purposes between the outside wall and the calf room, usually utility or feed storage sites. In some cases, ducts need to be constructed from the sidewall into the room and the fan and tube attached to the duct. The cross-sectional area of the supply duct to the side should be approximately double the cross-sectional area of the distribution tube.

Number of distribution ducts

In still conditions, air exiting a duct at 4.2 m/s (800 ft/min) produces some mixing with the existing air for a distance of perhaps 3 to 5 meters (10–15 ft). With air exiting from two sides of a centrally located duct, one duct suffices for an 8-m (25-ft) wide building. If the building is wider than this, additional distribution ducts of reduced capacity should be installed.

Cross-sectional area of the duct

The cross-sectional area of the duct should be large enough to carry the desired volume of air at moderate speeds. For common flexible tube ducts, the cross-sectional area of the duct should be sized so that the calculated air speed through the duct nearest the fan is within a range of approximately 4 to 5.2 m/s (800–1020 ft/min) [11]. This specification usually requires that the diameter of the tube is 1.25 to 1.5 times the diameter of the fan. Sometimes the sales representatives of the fan and tube suppliers recommend that the tube and the fan be the same diameter. If the fan and tube are the same diameter, the air speed in the proximal end of the tube is so fast that little air exits the holes in the proximal 5 to 8 m of the tube. In many barns, this results in no ventilation benefits to as many as 8 to 14 calf pens.

Connecting the larger diameter tube to a smaller diameter fan requires some improvisation. In some installations, the larger diameter tube is mounted on various pieces of plastic cut from barrels or pails, which in turn are mounted to surround the fan.

Total area of inlet holes in the duct

The air forced into the distribution duct should exit the holes at a speed of 3.5 to 4 m/s (600–800 ft/min) so that it travels some distance toward the pens and mixes well with the existing interior air [11].

For every quantity of air forced into the building, an equal quantity of air must leave the building. In naturally ventilated buildings, this air exits through the open ridge and eaves. In mechanically ventilated buildings, make sure that there are openings from the building at least equal in area to the calculated inlet area.

Uniform distribution of the incoming air

The goal of these systems is to deliver a small volume of fresh air to the microenvironment of the calf without creating a draft. Technically, a draft is defined as air movement at a speed greater than 0.5 m/s (50 ft/min) [10]. Do not expect to feel a cooling breeze within the calf pen; the air movement should be imperceptible except that it should not feel stale.

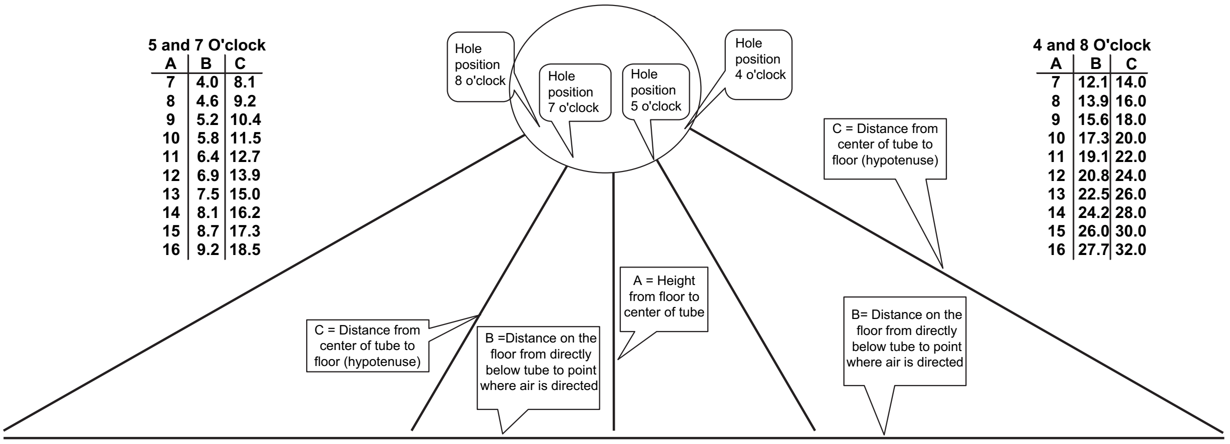
The openings from the distribution duct should distribute the air evenly throughout the area in which calves are housed. With the polyethylene tubes, this is done by punching holes along the length of the tube. The holes are usually custom punched to a specified diameter, interval between holes, and position around the circumference of the tube (ie, 5 o'clock and 7 o'clock positions when viewing the tube as a clock face).

If air exits two holes of different diameters at precisely the same speed, the air emerging from the larger diameter hole has the greater "throw" distance [13]. In general, options for precut holes range from about 2.5 to 7.5 cm (1–3 in). For typical installations in calf barns, the holes should be 5 to 7.5 cm in diameter.

The total number of punched holes is determined by dividing the total area needed to achieve an air exit speed of about 4 m/s (800 ft/min) by the area of the chosen diameter hole. The spacing between holes is determined by the length of the tube. The custom punched holes are normally done in pairs because the punch goes through two layers of the tube. The total length of the tube is then divided by half the total number of holes to yield the interval between each pair of holes.

There is no need to have a hole punched for each stall. As the air exits the tube, it begins to slow and disperse more widely and slowly. The holes can become too widely spaced, however, and the holes should be spaced no farther that the width of two pens.

The clock position of the holes on the tube controls the direction of the air flow toward the pens. The goal is to force a small amount of air into the environment of the calf, yet not create a draft. In general, the farther the tube is mounted above the floor, the more nearly vertical the hole position should be. For example, if the bottom of the tube is more than 3 m (10 ft) high, 5 o'clock and 7 o'clock sites may be preferred. If the bottom of the



5 and 7 O'clock

A	B	C
7	4.0	8.1
8	4.6	9.2
9	5.2	10.4
10	5.8	11.5
11	6.4	12.7
12	6.9	13.9
13	7.5	15.0
14	8.1	16.2
15	8.7	17.3
16	9.2	18.5

4 and 8 O'clock

A	B	C
7	12.1	14.0
8	13.9	16.0
9	15.6	18.0
10	17.3	20.0
11	19.1	22.0
12	20.8	24.0
13	22.5	26.0
14	24.2	28.0
15	26.0	30.0
16	27.7	32.0

Fig. 6. Illustration and tables showing the effect of hole position in the distribution tube on the direction of airflow and the resulting distance from the tube to the floor. A represents the vertical height from the floor to the center of the distribution tube, B represents the distance on the floor as measured from directly below the tube to the point that the airstream would be directed, and C represents the total distance that the airstream would need to travel from the tube to reach the floor. All distances are given in feet.

tube is 2.5 m (8 ft) above the floor, the 4 o'clock and 8 o'clock locations are preferred.

Using Fig. 6, throw directions can be estimated. If the center of a tube is 3.6 m (12 ft) above the floor (A), the center of the air stream would theoretically be directed toward a point on the floor 2.1 m (6.9 ft) to the side if the holes are punched at 5 o'clock and 7 o'clock. If punched at 4 o'clock and 8 o'clock, however, the air stream would be directed at a location on the floor 6.4 m (21 ft) to each side.

These positive-pressure systems are complementary to natural and negative-pressure systems that may become predominant as the temperature increases. Curtains should be opened normally, or if negative-pressure systems are present, the fans should be activated with thermostats and additional inlets opened as normal.

Supporting the tubes for protection from wind damage

The tubes are usually clipped to a cable stretched between the end walls of the building. The tubes are sometimes buffeted by winds in the summer when sidewall curtains are down. Three techniques have been used to minimize the exposure to wind damage. First, supplemental support can be provided with ''freezer strips'' or bands of heavy plastic spaced approximately every 2 m to cradle the plastic tube. Second, the ducts can be installed within the truss structure, which removes the tube from the direct force of prevailing winds. We do not have long-term experience to indicate whether friction between the tube and the truss causes premature wear or tear on the tube. Finally, some installations of larger diameter polyvinylchloride pipe have been completed. Although these materials are more expensive than flexible polyethylene tubing, they withstand wind forces better. When using pipe ducts, the holes need to be drilled manually into the pipe, which allows the builder to install either single or multiple rows of holes.

Summary

The last several years of research and clinical experience in calf barns have suggested that traditional systems of ventilation, both natural and negative-pressure mechanical systems, are problematic in cold weather. Individual pen designs should have two solid sides, but the front and rear should be as open as possible. Thermal stress should be managed by providing deep, long straw bedding and not by enclosing the pen. Air hygiene can be improved in most situations by supplemental positive-pressure ventilation systems to deliver small amounts of air to each pen. Implementation of these recommendations can produce calf barns that seem to equal calf hutches in minimizing disease and provide better working conditions for the caregivers.

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