POSITIVE-PRESSURE TUBE SUPPLEMENTATION OF NATURALLY VENTILATED CALF BARNS

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INTRODUCTION

Both natural ventilation and negative pressure mechanical ventilation are widely and successfully used in buildings used to house adult cattle. However, field investigations of herds with calf respiratory disease by our clinical service suggest that both natural and negative pressure systems are problematic for calf barns, particularly in cold weather. Calf barns with negative pressure systems have difficulties related to the relatively small air exchange rates used in cold weather, as it is difficult to design inlet systems to distribute small volumes of fresh air throughout a barn. The tiny inlet openings require a sizing tolerance that is rarely found in agricultural buildings. In addition, the proper functioning of negative pressure systems is dependent upon 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, clinical experiences in literally hundreds of calf barns suggest that positive-pressure ventilation systems to supplement natural or negative-pressure ventilation systems can make a substantial improvement in calf respiratory health. This paper will summarize our work with naturally ventilated calf barns and describe some techniques for installing positive-pressure ventilation systems to supplement natural ventilation.

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 as well. The barns usually have the typical open ridge and curtain sidewalls as recommended for adult cow barns [4] and are ventilated by external wind forces and by effects of thermal buoyancy as animals warm the interior air [1]. 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, sometimes a top “hover”, and at the other extreme are pens with mesh panels on three or more sides. 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 [6]. 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 [1]. 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 et al., the average temperature difference was only 1.6º C and one fourth of the barns were colder inside than outside at midday [6]. 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.

PEN FACTORS ASSOCIATED WITH REDUCED RESPIRATORY DISEASE

The field study by Lago et al, 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 [6]. .

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 significant. 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. However, increasing the number of solid sides was associated with higher airborne bacterial counts, a factor adverse to respiratory health. In the later part of this paper, the use of positive pressure ventilation systems to dilute and freshen the air between solid panels will be discussed.

Sufficient Bedding for the Calf to "Nest"

With the thermoneutral zone of a newborn calf is between 50 and 79ºF and between 32 and 73ºC for a 1-month old calf [6], nursing calves are very vulnerable to cold stress. Clearly, young calves are exposed to temperatures below their thermoneutral zone during many days and nights in Upper Midwest winters.

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 [9]. In our clinical work, we assign a nesting score based upon how visible the calf 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. The potential for the calf to nest deeply appears to reduce the risk of chilling and allows better ventilation in cold environments.

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 et al. [8] point out that most airborne bacteria are non-pathogenic, 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.

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 25 ft^2 to 40 ft^2 reduces the airborne bacterial density in the pen by nearly half [6]. The finding that any solid panels increase the airborne bacterial counts, which increases the risk of respiratory disease confounds the finding that a solid panel between each calf reduces the risk of respiratory disease. In practical terms, the expected reduction in the prevalence of respiratory disease by placing a solid panel appears to approximately equal the benefits of reducing airborne bacterial counts. In our clinical work, we have emphasized the use of a solid paned between each calf, open mesh panels on the front and, if possible, rear of the pen, and use of supplemental positive pressure ventilation systems to achieve improve air hygiene between the solid panels.

POSITIVE PRESSURE SYSTEMS TO SUPPLEMENT OTHER VENTILATION SYSTEMS

In contrast, positive pressure mechanical systems appear to be very dependable and consistent for low capacity situations. The advantage is that they can be a self-contained system of a fan forcing air into a distribution duct. It will not be affected by unseen cracks in the walls and windows or doors left ajar. They can complement naturally ventilated calf barns 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, i.e., the positive pressure system can be used at low ventilation winter situations and then be supplemented with larger capacity negative pressure systems that engage as the temperature increases.

DESIGNING A POSITIVE-PRESSURE SYSTEM FOR MINIMAL VENTILATION RATES

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(s) 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 15 ft^3/m per calf to 4 air changes per hour of the building. If the number of calves varies from time to time, the ventilation rate should be based upon 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. With increasing experience, I am tending to ventilate calf barns at the higher rates usually nearer the 4 air changes per hour.

Ventilating at these rates will produce 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 energy needs of cold weather. Consider using the simple, but very effective, calf ration analysis program provided in the last version of Nutrient Requirements of Dairy Cattle [7].

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 will 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 and the air was primarily recycled air from within the building.

If the fan is mounted on an exterior wall, it will need a hood to keep snow and rain from entering the system. In some situations where 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 further away from the roofline. The larger the cross-sectional area of the hood entrance, the slower the velocity of the air entering the hood and the less likely it will be that snow will accumulate within the tube.

There are situations where 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 tube can produce some mixing with the existing air for a distance of perhaps 10-20 feet depending on internal static pressure and exit hole size. These factors are discussed below. With air exiting from two sides of a centrally located duct, one duct can suffice for every 20-40 ft of building width. Experience suggests that the most satisfactory systems in wide barns are spaced approximately every 25-30 feet.

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 800-1,020 ft/m [5], although several commercial manufacturers of tube systems make recommendation for air speed in the proximal end of the tube to be less than 1,200 ft/m [2]. This usually requires that the diameter of the tube is 1.3 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. This usually results in very high air velocity and very low static pressure in the proximal end of the tube, resulting in very little air discharge through the holes in the first portion of the tube. In many installations, this results in no ventilation benefits to as many as 8-14 calf pens.

The tube diameter discussion above represents “thumb rules” for tube sizing and avoids a discussion of static pressure within the tube, which is beyond the scope of this paper. Static pressure calculations become quite critical for tubes that extend greater than 100 ft in total length.

While larger diameter tubes are commonly mounted on a fan housing using “worm” gears, the connection may sometimes require construction of an expander junction. In some installations, the larger diameter tube is mounted on various pieces of plastic cut from barrels or pails, which in turn is 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 1,200-1,800 ft/m so that it travels some distance toward the pens and mixes well with the existing interior air [5]. Because of a phenomena called “vena contracta” when air exits a hole through an orifice in a flat surface, the air flow gets reduced to a net area that is typically about 60-70% of the measured area of the hole [3]. This has the effect of substantially increasing the speed of the air jet exiting the tube.

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

“Throw Distance” of Air From the Tube

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 50 ft/m [8]. Do not expect to squat in the calf pen and feel a cooling breeze; 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. The holes are usually custom punched and you must specify the diameter of the holes, the intervals between holes, and the location on the tube in terms of clock positions, i.e., 5:00 and 7:00 o’clock.

If air exits two holes of different diameters at precisely the same speed, the air emerging from the larger diameter hole will have the greater “throw” distance [9]. In general, options for precut holes range from about 1 to 3 inches. However, manufacturers of higher quality tubes cut holes with lasers and the diameters can be cut to any dimension. For typical installations in calf barns, the holes range between 1.0-2.5 inches in diameter.

Equations to calculate throw distance from the tube can be found in agricultural engineering textbooks [10}. If the total exit area is sized to produce an air exit speed of 1,200 ft/m, a 1” hole should yield a “throw distance” to still air of 7 feet, a 1.5” hole yields a 10 ft throw, a 2.0” hole yields 14 ft throw, a 2.5” hole yields 17 ft throw, and a 3.0” hole yields a 20 ft throw. If the exit speed is greater or less than 1,200 ft/m, throw distances will also change.

The total number of punched holes is determined by dividing the total area needed to achieve an air exit speed of about 1,200 ft/m by the area of the chosen diameter hole increased by about 35% to allow for the vena contracture effect. The holes are distributed evenly along the length of the tube. If the holes are located in pairs with one on each side of the tube, the total length of the tube is 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 wider and more slowly. However, the holes can become too widely spaced and the holes should be spaced no further that the width of two pens.

The clock position of the holes on the tube controls the direction of the airflow 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 further 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 10 ft high, 5:00 and 7:00 o’clock sites may be preferred. If the bottom of the tube is 8 ft above the floor, the 4:00 and 8:00 o’clock locations might be preferred.

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 sometimes are sometimes buffeted by winds in the summer when sidewall curtains are down. There are several approaches to address this problem. First, manufacturers of higher quality tubes supply more durable fabrics and also offer suspension systems using two cables and durable clips to the cables. Alternatively, supplemental support can be provided with “freezer strips” or bands of heavy plastic spaced approximately every 6 ft to cradle the plastic tube. Third, the ducts can be installed up within the truss structure, which helps to shelter the tube from the direct force of prevailing winds. Finally, some installations of larger diameter polyvinylchloride pipe have been completed. While these materials are more expensive than flexible polyethylene tubing, they will withstand wind forces better. When using pipe ducts, the holes need to be drilled manually into the pipe.

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 very small amounts of air to each pen. Implementation of these recommendations can produce calf barns that appear to equal calf hutches in terms of minimizing disease and provide better working conditions for the caregivers.

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