Environmental Design for a Total Animal Health Care System

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The need for medical treatment of animals has long been recognized. The need for effective management of environment with respect to its infuence on animal health has been given less attention. Treatment of the animals has often been attempted as a substitute for maintaining a suitable animal environment, but with minimal success.

Livestock buildings can be divided into two broad categories—warm, insulated and mechanically ventilated where the temperature is maintained at about 40° F or above and supplemental heat is supplied as needed; and cold, naturally ventilated where air movement is caused by natural force and little or no insulation is used and the inside temperature approximates the outside temperature.

Mechanical Ventilation

A mechanical ventilation system must be correctly planned to be of maximum benefit to the health and welfare of the animals housed. It must also be properly installed, managed, and maintained to perform properly and to increase the life of the building in which it is installed. When these criteria are met, persons working in the pleasant surroundings of a well-ventilated barn (figures 1 and 2) will in all likelihood be more effective in their jobs. The poorly ventilated barn that is strong smelling and has a damp atmosphere is conducive to high animal disease rates and high labor turnover.

The functions of the ventilation system are: (1) to remove the moisture given off in the breath of the animals housed (about 3 gallons per 1,000 pounds of animal weight per day at 50°F); (2) to dilute the disease organisms that are shed by the cows and always present in the air; (3) to maintain a reasonably uniform temperature in winter (40°-45°F); and (4) to prevent the barn temperature in summer from rising more than about 5 degrees above the outside temperature.

In order to maintain an acceptable inside temperature in winter and to prevent condensation from occurring on even well-insulated walls and ceilings, the barn must be filled to capacity (figure 3). In mechanically ventilated calf barns supplemental heat usually must be provided.

When the outside temperature reaches about -10°F, some condensation or frost can be expected on the surfaces where the cold outside air and the warm stable air meet. These conditions must be tolerated, since a system that would eliminate them would be impractical.

Insulation Necessary

A livestock building that is to be successfully ventilated must be properly insulated. R-values of about 15 for the walls and 25 over flat ceilings are recommended. (The total R-value of a wall or ceiling is a measure of resistance to the passage of heat.) The higher the R-value, the better the insulation. Because windows have a low insulation value compared to walls in which they are installed, their area should be limited. Likewise, the height of the exposed foundation should be kept as low as possible to prevent heat loss. The R-values of various building materials are given in table 1.

A ventilation system consists of two parts: the fresh air inlet system and the exhaust system; each is equally important. Emphasis is often erroneously placed only on installing fans, with little or no thought given to the fresh-air-intake system. Yet, fresh air is just as necessary for satisfactory ventilation as the fan system.

Plan Exhaust System

The determination of a ventilation system's winter capacity for moisture removal and temperature control has commonly been calculated on the basis of weight of the animals housed. However, the exact weight of the animals housed seldom is known, and, in addition, that weight does not remain constant. A simpler method of determining exhaust capacity is on the basis of a *minimal continous* number of air changes needed per hour to remove moisture and to maintain reasonable air purity in cold weather, and a practical maximum to control temperature in summer. On the basis of cooperative research between the University of Minnesota's Department of Agricultural Engineering and

Figure 1. This new single-story, tie-stall dairy barn, 36' x 166', located in Northern Minnesota, has a ventilation system planned from the principles discussed in this paper.

Figure 2. Interior of barn shown in figure 1. A group of three exhaust fans can be seen at the left center. A slot-type inlet is used the full length of both long walls, except directly over the exhaust fans.

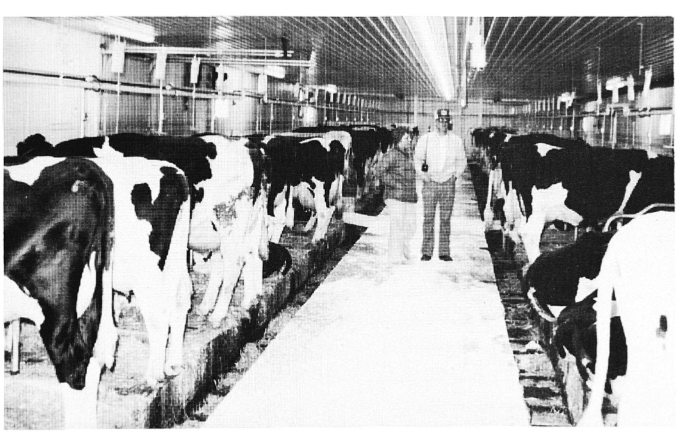


Figure 3. The ceiling in this well-insulated barn is dry over the cow, which is the last one in a row of 28, but wet over the unoccupied stall at the left because there is insufficient heat in this area. Underpopulated buildings require supplemental heat if they are to remain dry in severe winter weather.

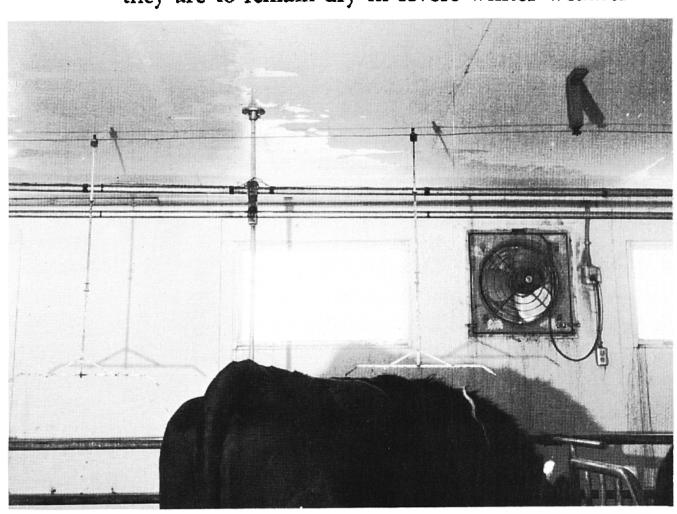


TABLE 1. Insulation Values

From 1981 ASHRAE Handbook of Fundamentals Values do not include surface conditions unless noted otherwise. All values are approximate.

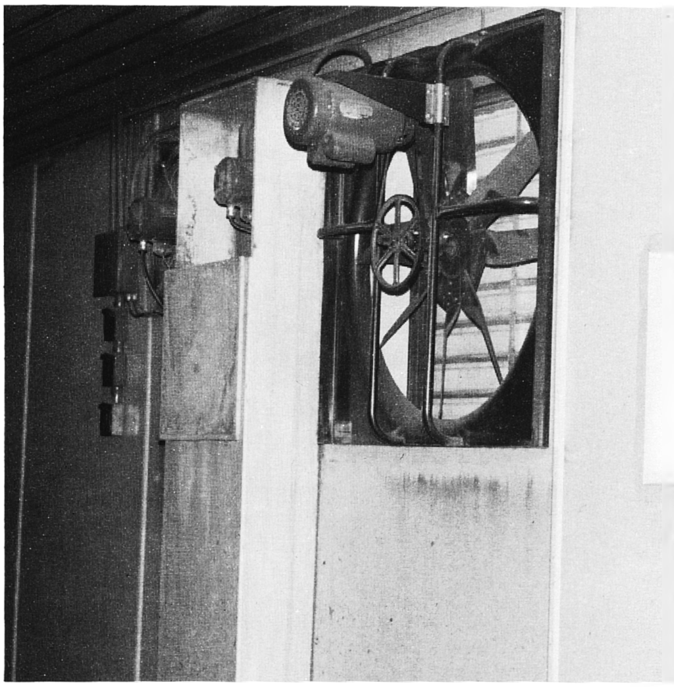
Material	R-value Per inch (approximate)	R-value For thickness listed
Batt and blanket insulation		
Glass or mineral wool fiberglass	3.00-3.80*	
Fill-type insulation		
Cellulose	3.13-3.70	
Glass or mineral wool	2.50-3.00	
Vermiculite	2.20	
Shavings or sawdust	2.22	
Hay or straw, 20"		30+
Rigid insulation		
Exp. polystyrene		
extruded plain	5.00	
molded beads, 1 pcf.	5.00	
molded beads, over 1 pcf.	4.20	
Expanded rubber	4.55	
Expanded polyurethane, aged	6.25	
Glass Fiber	4.00	
Wood or cane fiberboard	2.50	
Polyisocyanurate	7.04	
Foamed-in-place insulation		
Polyurethane	6.00	
Urea formaldehyde	4.00	
Building materials		
Concrete, solid	0.08	
Concrete block, 3 hole, 8"		1.11
lightweight aggregate, 8"		2.00
lightweight, cores insulated		5.03
Metal siding	0.00	
hollow-backed		0.61
insulated-backed, 3/8"		1.82
Lumber, fir and pine	1.25	
Plywood, 3/8"	1.25	0.47
Plywood, 1/2"	1.25	0.62
Particleboard, medium density	1.06	
Hardboard, tempered, 1/4"	1.00	0.25
Insulating sheathing, 25/32"		2.06
Gypsum or plasterboard, 1/2"		0.45
Wood siding, lapped, 1/2"x8"		0.81
Windows (includes surface conditions)		
Single glazed		0.91
with storm windows		2.00
Insulating glass, 1/4" air space		
double pane		1.69
triple pane		2.56
Doors (exterior, includes surface conditions)		
Wood, solid core, 1 1/4"		3.03
Metal, urethane core, 1 1/4"		2.50
Metal, polystyrene core, 1 1/4"		2.13
Floor perimeter (per ft. of exterior wall length)		
Concrete, no perimeter insulation		1.23
with 2"x24" perimeter insulation		2.22
Air space (1/4" to 4")		0.90
Surface conditions		
Inside surface		0.68
Outside surface		0.17

*The R-value of fiberglass varies with batt thickness. Check package label.

the College of Veterinary Medicine, together with field experience, we have established the minimum continuous air exchange rate to be four air changes per hour. Remove this air at a point about 15 inches above the floor, through a duct built around the continuous fan or fans when more than one is used. In summer, an exhaust capacity of 40 air changes per hour is necessary to prevent the temperature in the building from rising more than about five degrees above the outside temperature. The total exhaust capacity is then made up of the continuous fan or fans and a number of thermostatically controlled fans that turn on and off to regulate barn temperature (figure 4). Approximately one-half of the total capacity should be considered the winter, spring, and fall part of the system. The remaining one-half is for summer or mild weather use only (figure 5).

Figure 4. A close view of one group of fans in the barn shown in figures 1 and 2. The duct is built around a minimum capacity fan, which operated continuously during the winter of 1981-82 when outside temperatures fell to —40° or lower. The spring and fall fan at the left is thermostatically controlled. What appears to be a box at the right is an insulated, removable cover for a fan that operates only in summer. This prevents air leakage through and ice formation on the shutters in winter.

Figure 5. The summer fan shown in figure 4 in operating condition, with insulated cover removed. Door at the top of the duct built around the continuous fan is open.



An exhaust rate higher than 40 air change per hour will make little difference in barn temperature and is uneconomical. It will not provide noticeably increased air velocity around the animals or person that may be in the structure. Air within the animal housing area can be effectively mixed if desired by providing strategically placed circulating fans manually controlled by on-off switches when the inside temperature is above 70°F. When winter temperatures decrease to approximately -10°F, the continous air exchange rate may have to be reduced slightly *for short periods* to prevent the inside barn temperature from decreasing below 40°F. This can be done by turning off one fan when there is more than one in continous operation. It can also be accomplished by throttling the airflow through the duct to a single continous fan.

Exhaust Rate Calculation

Minimal fan capacity required for a particular barn in cubic feet per minute (cfm) can be easily determined. Multiply the length of the structure by the width by the height to obtain the volume* (WxLxH/15 = cfm). To calculate the practical maximal capacity of 40 air changes per hour in cfm for summer, multiply the minimal rate already determined by 10.

As an example of ventilation rate calculation, consider a stall barn for 60 cows. A modern barn accommodating this number of cows would likely be 36 feet wide and 160 feet long, including two pens. A common ceiling height is 8 feet. Thus, the volume would be 36′ x 160′ x 8′ $\cong$ 46,000 cubic feet (Note: $\cong$ shows that results are rounded to avoid uneven numbers.) To calculate the needed fan capacity of four air changes per hour in cubic feet per minute (cfm), divide the volume by 15: 46,000/15 $\cong$ 3,000 cfm. The maximal practical summer capacity is 10 times this; 3,000 x 10 = 30,000. This total capacity must be supplied by a number of fans, all of which should be single speed and *rated* to perform against specified static pressures. About one-half of this total, 15,000, should be considered the fall, winter, and spring part of the system. Thus, 15,000 - 3,000 (minimum continuous) = 12,000 cfm remaining. Divide this capacity among three fans of 4,000 cfm each to be controlled by individual thermostats. The minimum 3,000 cfm fan must operate *continuously* and be ducted to within 15 inches of the floor. Select three additional fans of 5,000 cfm for warm weather to provide the total combined fan capacity of 30,000 cfm. Fans of the exact capacities calculated will seldom be available. Except for the minimum continuous fans, choose greater rather than lower fan capacities. Control all fans except the minimum continuous portion of the system with individual thermostats set at 40°, 42°, and 45° F so that each fan will start individually. This lessens the shock effect of sudden cold air entry that would result if all the fans in the winter part of the system were controlled by a single thermostat. Set the thermostats for the summer fans at 50°, 52°, and 55° F. Suggested fan locations are shown in figure 6.

Mount the summer fans on the outside of the barn and close the opening through the wall to them with an insulated panel, or if they are mounted in the wall, cover them in winter with removable insulated boxes fastened to the inside wall (figure 4). Either of these methods prevents the usual buildup of frost and ice on the shutters of fans that do not operate in winter. This also eliminates a possible source of cold air leaks. Some time is required to put the covers in place in the fall and remove them in the spring, but it is a simple and effective way to eliminate a predictable problem.

Use Fans of Known Performance

Fans used for animal shelter ventilation should be designed specifically for that purpose. They should have totally enclosed motors of the split-phase or capacitor type. Each motor should be protected by a time delay fuse or thermal overload device to eliminate risk of motor damage in case of abnormal operating conditions. Thermal overload protection is recommended for all electric motors; regardless of their use.

All fans must have been tested under the standard test code adopted by the Air Moving and Conditioning Association, Inc., or by another standard engineering test procedure and be capable of delivering their required airflow (in cfm) at ⅛-inch static pressure (figure 7). This is approximately

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**In barns with connected manure storage, include that volume when calculating ventilation capacity.*

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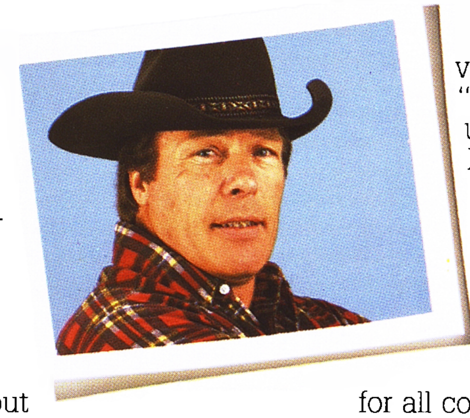

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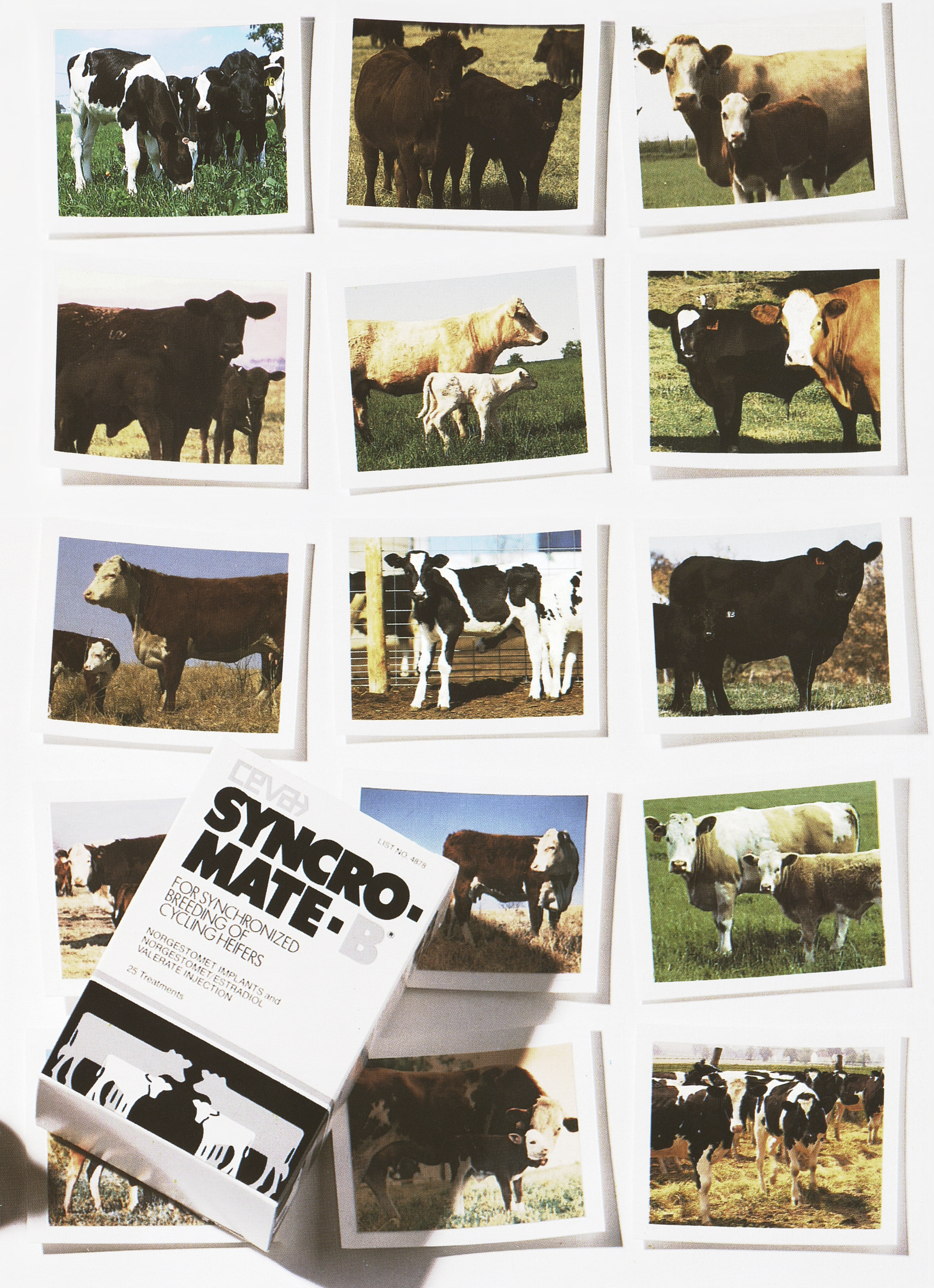
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Figure 6. Schematic drawing showing suggested locations for exhaust fans in a moderate-size dairy barn. Set thermostats controlling winter fans, which includes fall and spring, from 40°-45° F. Set summer fans at 50-55° F. Note that a fixed opening for the slot inlet system is shown along the south wall and an adjustable opening along the north wall.

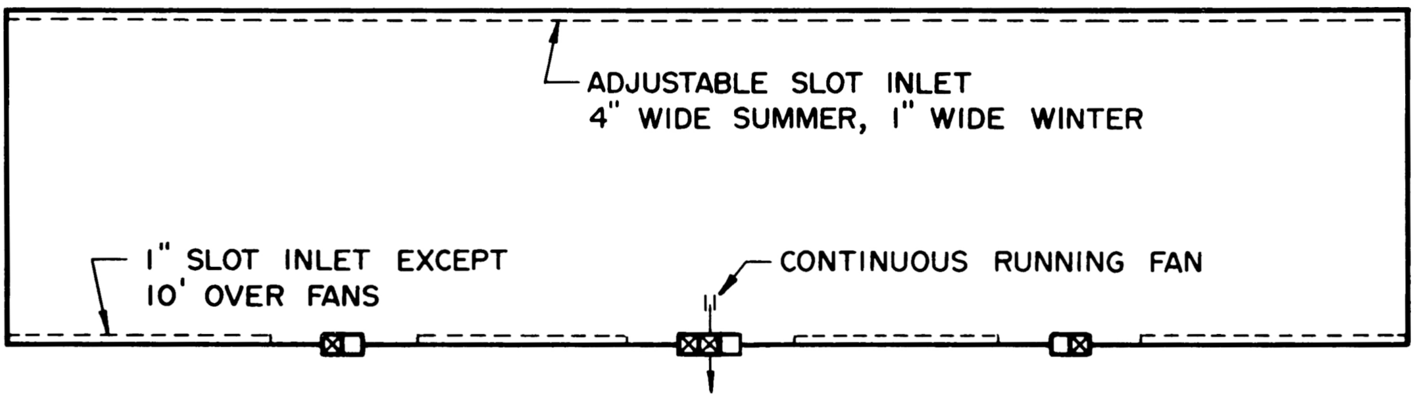


Figure 7. Static pressure is the difference in air pressure between the inside and the outside of the building measured in inches of water. It is a measure of the resistance that fans must overcome to move air through the building. This water column shows schematically a pressure difference of ⅛" (.125) between the atmospheric pressure outside and the negative (lower) pressure inside created by the exhaust fans.

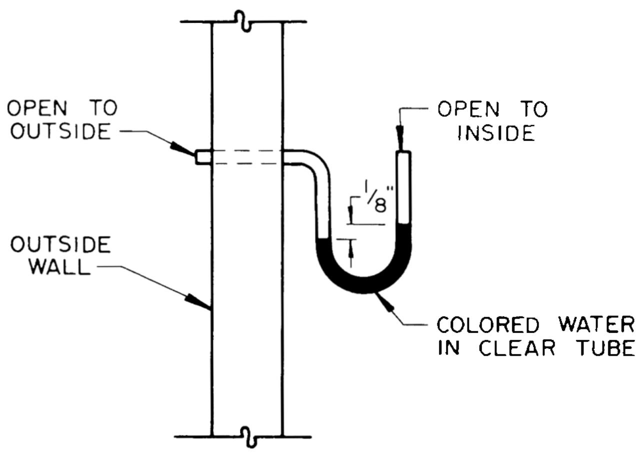


TABLE 2. Typical Rating Tables for Exhaust Fans*

Diam.	RPM	HP	0"	1/10"	1/8"	1/4"	3/8"	1/2"
8"	1650	1/50	400	316	289	—	—	—
10"	1550	1/50	594	457	413	—	—	—
12"	1550	1/30	730	—	—	—	—	—
12"	1600	1/12	1188	1073	1035	827	—	—
16"	1140	1/12	1675	1440	1374	—	—	—
16"	1725	1/3	2534	2392	2353	2142	1890	1635
18"	1140	1/6	2686	2460	2395	—	—	—
18"	1725	5/8	4065	3920	3880	3682	3445	3195
21"	1140	1/4	3812	3599	3540	—	—	—
21"	1725	3/4	4914	4770	4740	4510	4320	3920
24"	855	1/3	4691	4310	4180	—	—	—
24"	1140	7/8	6254	5990	5920	5470	4810	4220
30"	685	1/2	8112	7555	—	—	—	—
30"	855	1	10125	9700	9575	8640	—	—
36"	570	5/8	10596	9560	9220	—	—	—
42"	490	1	15630	14325	13995	—	—	—

*The purpose of this table is to show variation in performance of fans of different sizes. No endorsement of a particular manufacturer is implied or intended.

equivalent to the pressure created by a 15-mile-per-hour wind blowing against an operating fan. Wind substantially affects the output of ventilating fans, as does the resistance to airflow created by an insufficient air intake.

The free-air delivery performance of a fan, which is againt no resistance, give little indication of how it will perform when installed in a barn or other livestock shelter. Then the fan must operate against the resistance of the intake system and the pressure of the wind blowing against it. Likewise, the diameter of a fan is an unreliable measure of its capacity, table 2. Other factors that influence the fan's air delivery include size, shape, pitch and number of blades; turning speed; horsepower of the driving motor; and type of mounting. There is no accurate way to determine the capacity of an in-place fan. This can only be done in a specially designed test duct.

Fans that exhaust air from connected manure storage pits must have performance characteristics equal to or better than those installed in the walls. If they do not have these characteristics, the wall fans may overcome the manure storage area fans and draw air through the manure storage area into the barn. Increased odor and a possible health hazard to humans and animals can result. This very important point is often overlooked.

As a general rule, only properly selected single-speed fans should be used in a ventilation system because of their superior performance characteristics compared to those which can operate at more than one speed. An exception may be for a small building, usually a calf barn, when a good-quality, single-speed fan having the needed low capacity against ⅛-inch static pressure may be used. Variable-speed fans are not recommended because of their general inability to develop the recommended static pressure of ⅛ inch at low speed. Thus, if a wind of about 15 miles per hour is blowing against a variable-speed fan operating at low capacity, the wind may overcome the fan and actually blow air back through it into the building, allowing an operating fan to become an air intake.

Rules for Locating Fans

1) In barns having solid floors and where the animals are housed throughout the year, space the fans uniformly in the south or west wall. Admit winter air uniformly the full length of both long walls, except directly over the exhaust fans. In summer admit most of the fresh air along the wall opposite the fans (figure 6), thus requiring it to flow across the stable before being exhausted.

It is also important that in summer fresh incoming air be directed downward at high velocity, in order that it reach the vicinity of the animals. On a hot summer day the outside temperature is about the same as the inside barn temperature. The weight of indoor and outdoor air is also about the same. Thus, incoming air directed across the ceiling may travel to fans placed at a high level, with very little fresh air reaching the animals. In winter, the cold outside air is heavier than the warm inside air. Fresh air entering the barn at low velocity will thus fall to the floor under the forces of gravity, creating a natural mixing within the barn without high velocity at the air intake.

2) In warm, slat-floor, free-stall barns exhaust one-half of the total fan capacity from the storage area. Part of this capacity must be removed *continuously*. The remainder must be in operation before any of the wall fans are turned on.

3) Locate fans at least 10 feet away from doors and other openings to reduce any entering outside air from moving directly to fans before mixing with air in the building.

4) Locate the thermostats controlling fans at eye level and toward the center of the barn. *Do not locate thermostats on an outside wall.*

In winter, maintain a temperature of 40°-45° F in dairy barns. For calf barns, about 50°-55° F is preferred and supplemental heat is required. Higher inside temperatures should be avoided because it is more difficult to control moisture on the inside shell of the building in cold weather. The cost for heat is also greater.

5) *Do not locate fans in calf pens in an attempt to draw heat to them.* Aerosol contaminants drawn from the cows to the calves often cause disease problems and condensation in the colder area.

Wet corners frequently can be dried up by admitting fresh air. In parts of the stable where only a few animals are housed, such as in calf pens, additional insulation or heat, or both, may be required. *Ideally, calves should be housed in quarters apart from cows.*

6) Install all wall fans near the ceiling (figures 4 and 5). Build a duct around each continuously running fan to draw air from near the floor, which can be as much as 10 degrees cooler in winter than the air near the ceiling. Make the duct at least 12 inches deep and as wide as the fan frame (figure 6). Near the top, provide a door to give access to the fan. Keep the door closed in winter. It may be opened in summer. A damper can be placed near the bottom of the duct to allow reduction of airflow in cold weather. The use of a duct around each continuously operating fan can mean the difference between satisfactory and unsatisfactory performance of the system when heat balance is critical.

7) In barns not filled to capacity, it is usually necessary to add heat if the walls and ceilings of the unoccupied areas, even though well-insulated, are to remain dry in severe winter weather. This is difficult to do and seldom done, to the detriment of the building and animals.

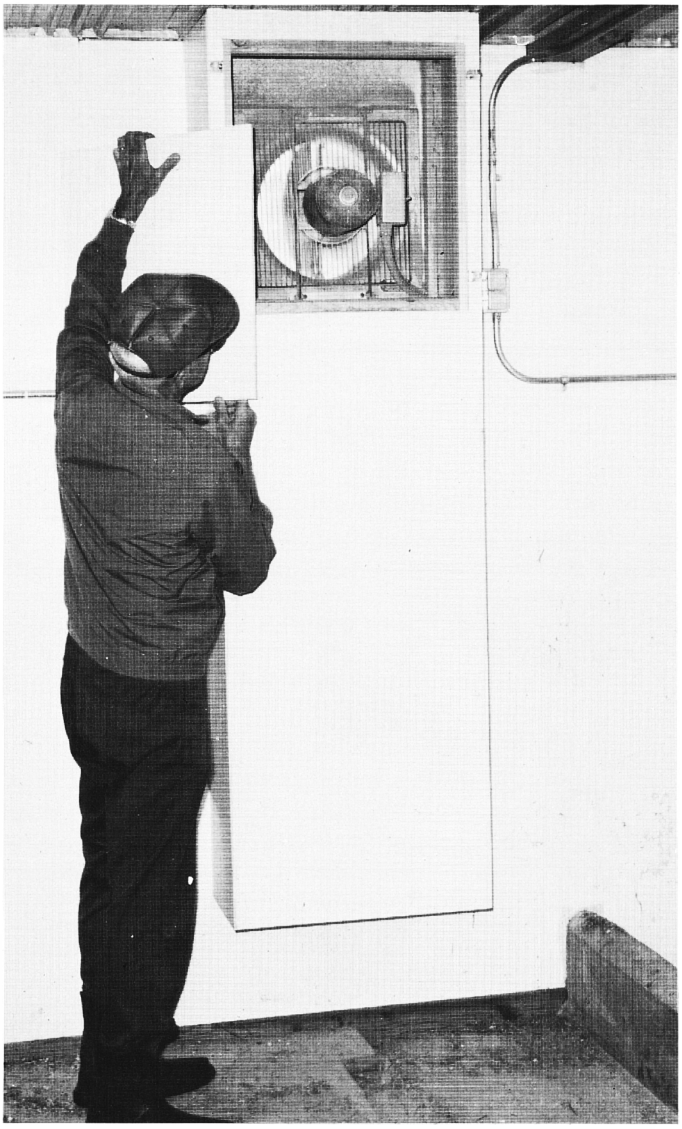
8) In winter, mechanically moving air within the building, through plastic tubes or ducts, in an effort to blend cold outside air with warmer inside air, is not recommended. This technique cannot make up for inadequate building construction, insufficient animal population, or poor ventilation system design. Further, such systems have the disadvantage of redistributing contaminated air through the housing compartment.

Fresh Air Needed

A fresh-air-intake system that will distribute incoming air uniformly is essential. It must have sufficient capacity to prevent the negative static pressure in the building from rising above ⅛ inch of water. High static pressure is an indication of resistance of airflow. It can be measured with a portable inclined column manometer. However, a readily available guide is the barn door. If the door slams shut or if the sound of the fans change when the door is open, there is an inadequate supply of fresh air entering the building.

Poor fresh-air-intake design is one of the most common causes of unsatisfactory ventilation performance. The primary function of a fresh-air-intake system is to distribute incoming air uniformly through the building in a manner that will not cause undue drafts in winter. This is best accomplished by bringing a small amount of air in at many places. At the immediate point of entry, however, cold will be felt regardless of the inlet system design, unless heat is added to the incoming air. When cold incoming air is warmed, its moisture-holding capacity is greatly increased. This enables the air to absorb moisture produced by the animals, thereby allowing the exhaust system to carry it outside. Further, the air replacement process allows for the dilution of disease-causing aerosol contaminants from the animals, preventing a buildup of those organisms and thereby improving air purity. Continuous exhaust is thus mandatory from this standpoint alone, a fact that is often

Figure 8. In winter, air near the floor in a livestock building can be as much as 10 degrees cooler than air near the ceiling. To conserve heat and energy, a duct as shown should always be used around the continuously operating exhaust fan or fans. An equal amount of moisture but less heat is removed than when air is exhausted from the ceiling, making a higher ventilation rate and thus greater dilution of contaminated barn air possible.



unrecognized.

The slot inlet system (figure 9) has proved to be an efficient and economical means of bringing fresh air into any mechanically ventilated livestock housing unit. Because of its low cost and simplicity of construction, it is sometimes disregarded. (Often more expensive equipment is assumed to be of better quality.) Our experience over more than 30 years indicates that there is no system that will outperform the slot inlet.

A slot inlet can best be built into a barn during construction. It is a continuous narrow opening to the attic or hay mow at the junction of the ceiling and the walls, except for a distance of 10 feet above each wall exhaust fan. Air is drawn into the barn through this inlet by the exhaust fans. The amount of air that enters is determined by the amount exhausted. There must be continuous exhaust from the building to prevent back draft of stable air through the slot to the space above it.

The slot intake system for single-story barns should have two capacities—one for winter, spring, and fall, and one for summer. In winter, there should be an opening about 1 inch wide on both sides of the building. This allows nearly uniform air entry throughout the barn. A minimal velocity of about 150 feet per minute (fpm) must be maintained to eliminate back draft through the slot. In summer, a recommended maximal velocity is 800 fpm when the exhaust system is operating at full capacity. The adjustable slot, which is 4 inches wide, must then be fully opened. A velocity of about 800 fpm is obtained when there is an airflow of 800 cfm through an opening 1 inch wide and 12 feet long.

For example, consider the barn 36 feet by 160 feet, previously mentioned. Assume that the building is to have a minimum of 4 and a maximum of 40 air changes per hour. The minimal fan capacity is 3,000 cfm and the maximal capacity is 30,000 cfm. Assume that this capacity is divided among seven fans to be placed in the south wall. The slot should be closed for a distance of 10 feet over each fan. Thus, 70 feet of the south wall would be without a slot, leaving 90 feet of slot. The north side would be unobstructed the full length, or 160 feet. For winter operation, then there would be 250 feet of slot, 1 inch wide.

$$\frac{250 \text{ feet} \times 12 \text{ inches}}{144 \text{ inches}} \cong 21 \text{ square feet}$$

3,000 cfm ≅ 143 feet per minute velocity under minimal conditions, which is adequate.

During the summer, it is essential to prevent the inside barn temperature from rising appreciably above the outside temperature. Thus, it is an obvious advantage to draw the coolest air available into the barn. The north side of the barn is least affected by the sun; next coolest is the east side. For a barn having an east-west orientation for the long dimension, most air should be drawn from the north side. For a barn having a north-south orientation for the long dimension, most air should be drawn in from the east side. Six-inch-wide continuous doors or slide-regulated openings should be built into the underside of boxed-in eaves. These are opened in summer to permit outside air from the shaded area beneath the eaves to enter the slot (figures 9 and 10). Because the incoming air can quickly enter the ceiling slots, there is little opportunity for it to be warmed in the attic. The eave openings may also allow greater natural air movement through the attic as a result of wind action and convection, thereby reducing temperature buildup in that space.

In winter, the eave openings must be closed. Then, all air

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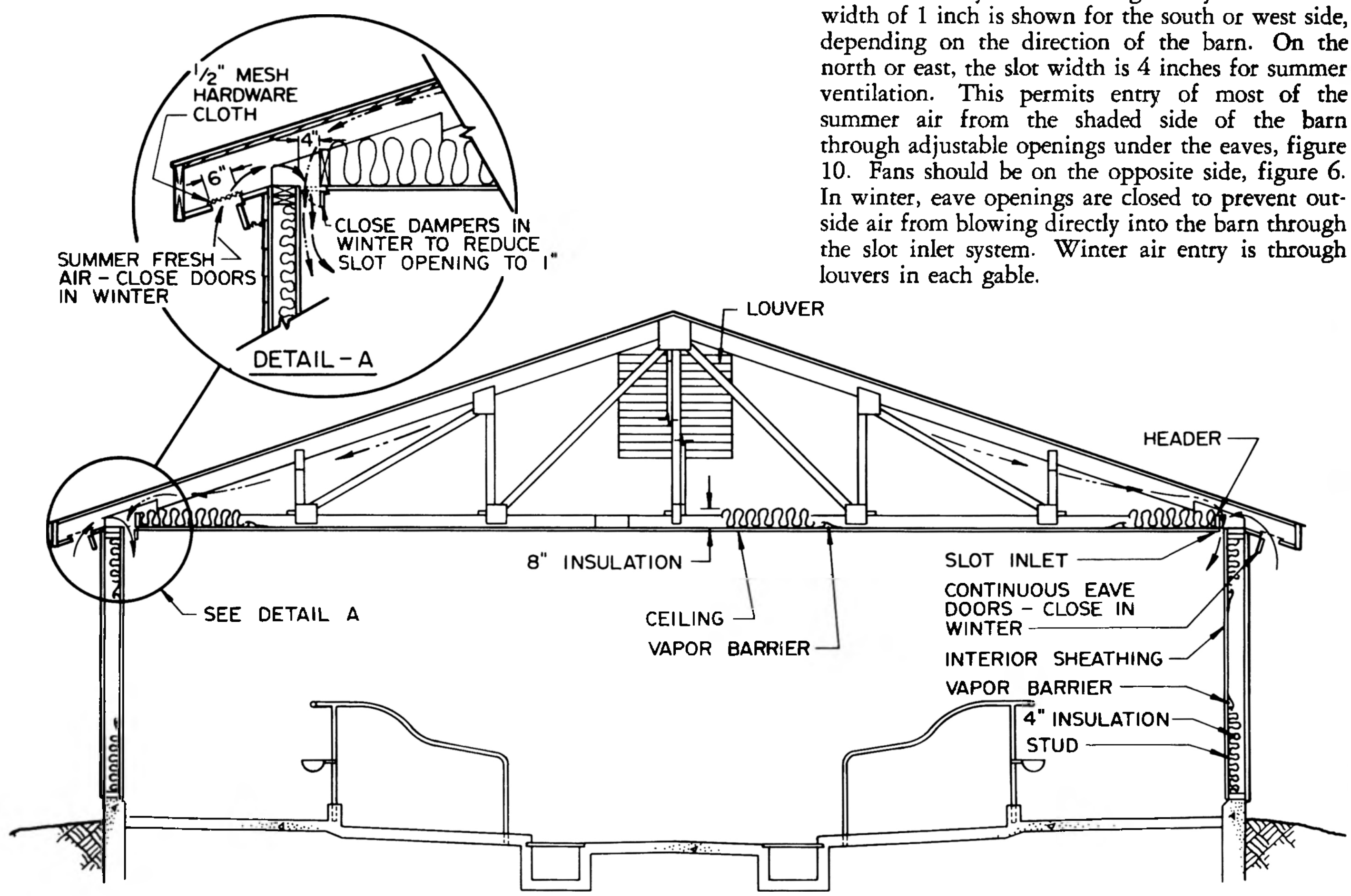
Figure 9. This cross section shows the construction of a slot fresh-air-inlet system for a single-story barn. A slot width of 1 inch is shown for the south or west side, depending on the direction of the barn. On the north or east, the slot width is 4 inches for summer ventilation. This permits entry of most of the summer air from the shaded side of the barn through adjustable openings under the eaves, figure 10. Fans should be on the opposite side, figure 6. In winter, eave openings are closed to prevent outside air from blowing directly into the barn through the slot inlet system. Winter air entry is through louvers in each gable.



entering the barn through the slot inlet is supplied by attic louvers.

By constructing a wider slot opening into the barn along the north or east wall, as the case may be, best advantage can be taken of natural conditions. This slot opening should be 4 inches wide and have a hinged damper (figure 9). It can then be closed to 1 inch in winter. Most of the summer air will come in through the full opening because there is less resistance across the greater width. By placing all exhaust fans on the opposite side of the barn, cross-ventilation results.

In winter, with the damper closed, approximately the same amount of air will enter on both sides. Because the incoming air is cold, and therefore heavier, convective forces cause natural air mixing. Some moisture or frost will form at the edges of the slot during prolonged severe weather (figure 4), but this will take place in any system at the point where cold outside air and warm stable air meet (figure 11). Condensation and frost formation can be eliminated only if the incoming air is warmed to a temperature above the dewpoint of the air in the stable (figure 12). It cannot be eliminated by the so-called tempering process. This is where stable air is blended with outside air in an attempt to raise the temperature of the latter. An interface must occur between the warm and the cold air, with resulting condensation.

For buildings wider than about 42 feet, fresh air also must be admitted near the center of the barn through an additional slot or row of ceiling intakes. Such barns are usually more difficult to ventilate satisfactorily.

During the winter, outside air to supply the slot inlet should be admitted to the attic through large louvers built high in the gable at each end of the barn (figures 1 and 9). As a general rule, build each louver about the size of the calculated winter slot inlet area. Louvers should be screened with ½-inch mesh hardware cloth to prevent the entrace of birds. Window screen should not be used because it will quickly be plugged with airborne debris, thereby greatly reducing airflow. For barns in unprotected locations, it may be necessary to install specially built hoods to prevent snow or rain from blowing through the louvers and into the attic under extreme wind conditions.

With use, even properly designed intake systems may become restricted by debris (figures 13 and 14). Intakes are sometimes deliberately plugged in a misguided attempt to

Figure 10. Under eave opening along the side of the dairy barn for 60 cows shown in figure 1, in summer position. Note the coarse screen to prevent plugging with debris. In addition to providing fresh air for the slot inlet system, eave openings permit increased air movement through the attic in summer.

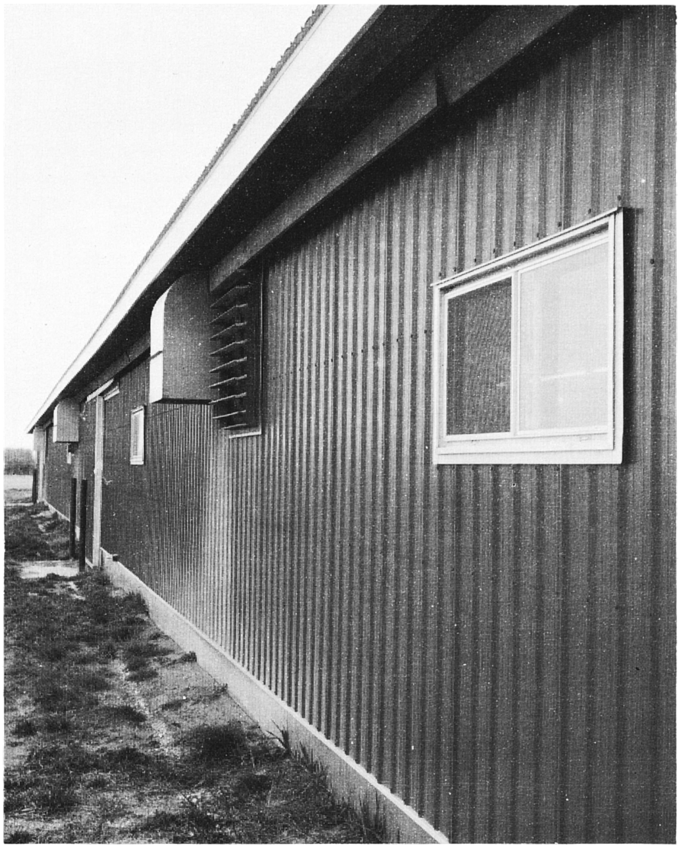
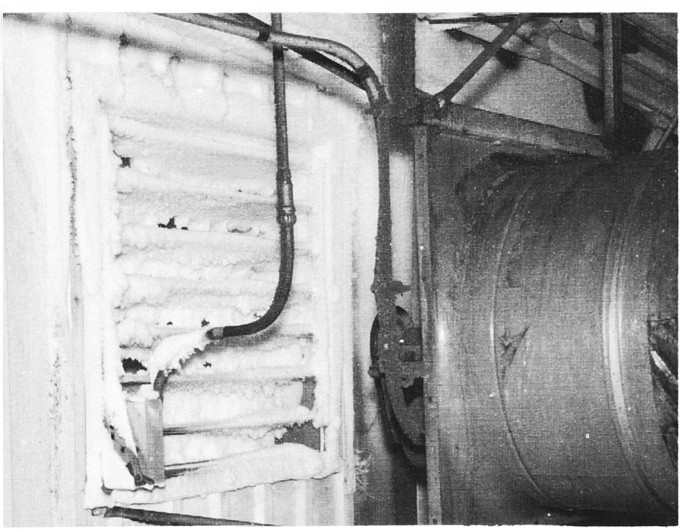


Figure 11. Frost formation on metal parts of a commercial fresh air intake serving a slat-floor young stock barn in Northern Minnesota. Picture was taken on a day when the outside temperature was —20° F.



reduce drafts. A yearly inspection and proper maintenance are essential.

Ventilating the Older Barn

Providing satisfactory ventilation in many older dairy barns is a difficult and sometimes impossible task. These barns are usually poorly insulated, perhaps having stone or concrete block walls, single windows, and loose-fitting doors. One or more fans are often installed in an attempt to improve conditions, with only mediocre results. The degree of improvement will depend on the construction and state of repair of the building. Suitable air inlets are difficult to provide. As a result they are usually not installed. Consequently, air enters through available openings such as the gutter cleaner exit, around loose-fitting sliding doors, and hay chutes. Do not expect to make up for building deficiencies by installing a ventilation system that recirculates stable air, combined with intermittent exhaust fan operation, or one that blends inside and outside air according to weather conditions. Such units cannot provide a healthful environment by distributing contaminated air.

In two-story barns with mow floors and no ceiling on the underside of the joists, a satisfactory inlet system can be installed. This is accomplished by drilling 2-inch holes about 20 inches on center through the floor to the space above. These holes extend the full length of both long walls; except for a distance of 10 feet over each fan. Provide protection in the mow to prevent the holes from becoming plugged (figure 15).

If there is both a mow floor and a ceiling, *do not* drill the holes, because cold air will then circulate in the space between. The ceiling will then become wet because the insulation value of hay or straw stored above it will be lost, and ceiling condensation will occur.

In single-story barns with an insulated ceiling but no air intake system, it is more practical to install commercial or home-built intakes (figure 16) than to attempt installing a slot inlet.

Fan Maintenance

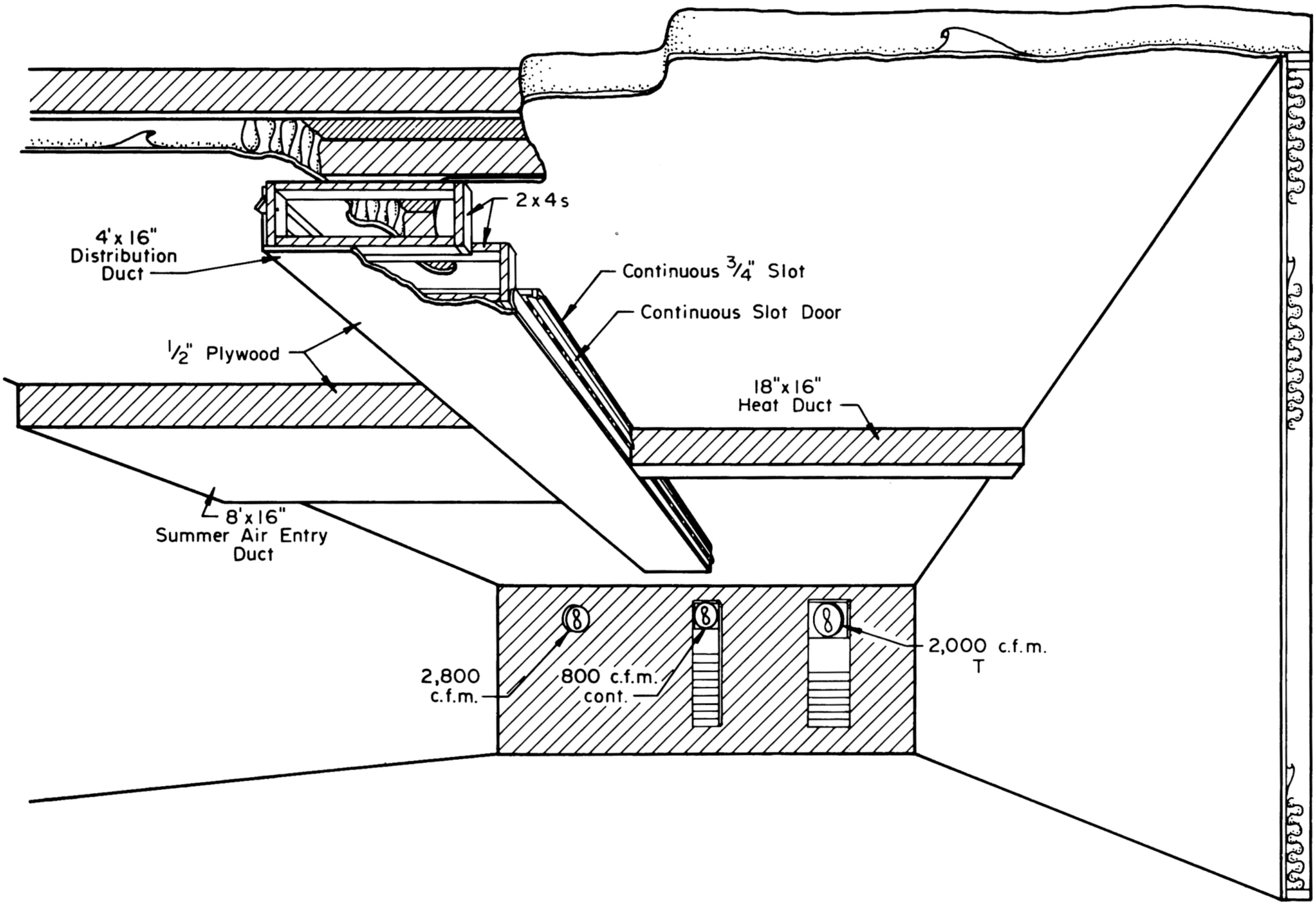
Ventilation fans, like other pieces of mechanical equipment, need periodic maintenance. Usually the bearings are permanently lubricated, but regular inspection and cleaning of the fan blades, and particularly the shutter (figure 17), is essential. Accumulated dirt greatly reduces air output and, as a consequence, there will be insufficient airflow through the building. Inspect all fans at least once a year.

Manure storage fans are constantly exposed to corrosive conditions that cause more rapid deterioration of metal than is the case with wall fans. Thus, earlier replacement may be necessary.

Natural Ventilation

Natural ventilation is accomplished by the forces of

Figure 12. Schematic diagram of distribution system for heated fresh air. Temperd outside air is warmed by a gas-fired heater having a modulating burner mounted on the outside of the building. Burner is controlled by inside thermostat. Fan on heater blower runs continuously supplying warmed air to the duct. Continuously operating fan in building exhausts air from near the floor at a slightly higher rate creating negative pressure in the building. Summer air to meet higher exhaust requirements is supplied through the large duct at the left. Insulated, removable wall panel is opened and closed manually. For uniform air distribution, design the main duct for a maximal air velocity of about 600 fpm (feet per minute) and the duct openings for an air velocity of about 800 fpm.



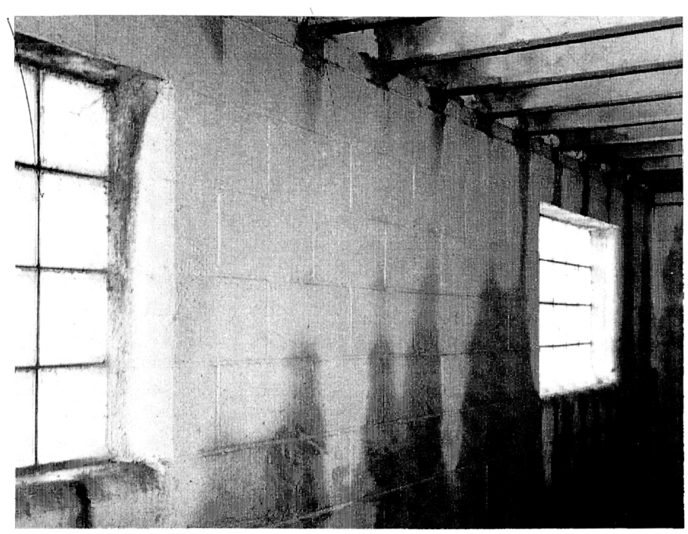


Figure 13. Masonary block walls of a two-story stall dairy barn with a slot inlet built in 1964. Picture was taken on a cold day in 1979. The slot inlet had become partially plugged with hay and chaff. Periodic maintenance is essential. Light-colored areas show effect of fresh air keeping walls dry. Note ice buildup on glass block windows.

Figure 14. Air supply to ceiling intake in stable below must enter through this plugged opening in mow of two-story barn.. Little air can pass through. Results, poor ventilation system performance.

Figure 15. Drawing showing method of providing mow protection for a bored-hole-intake system in a two-story dairy barn. Drill 2-inch diameter holes about 10 inches on center. There must be continuous exhaust from the barn to prevent back draft into the mow.

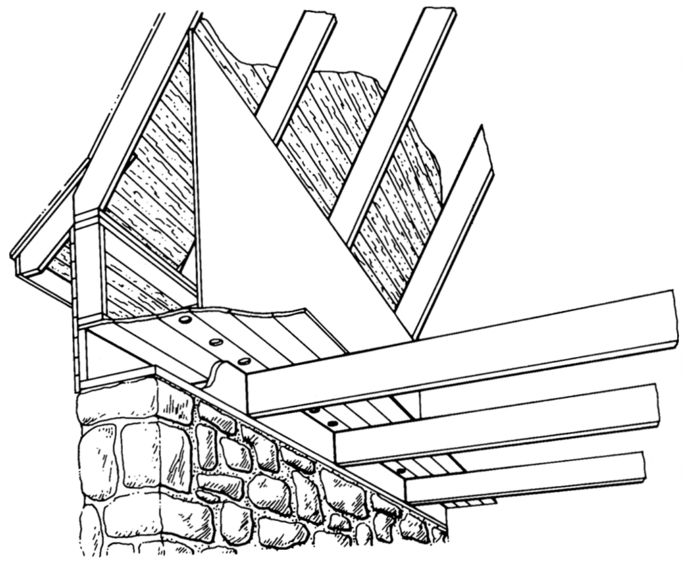


Figure 16. Construction details for a home-built ceiling intake. Headers are placed between ceiling joists with a space between them to give an opening of about 1 square foot. One ceiling intake is equal to a slot inlet 1 inch wide and 12 feet long. Normally two rows of ceiling intakes are placed at intervals of 12 feet down the length of the barn as close to the walls as possible in buildings up to 40 feet wide.

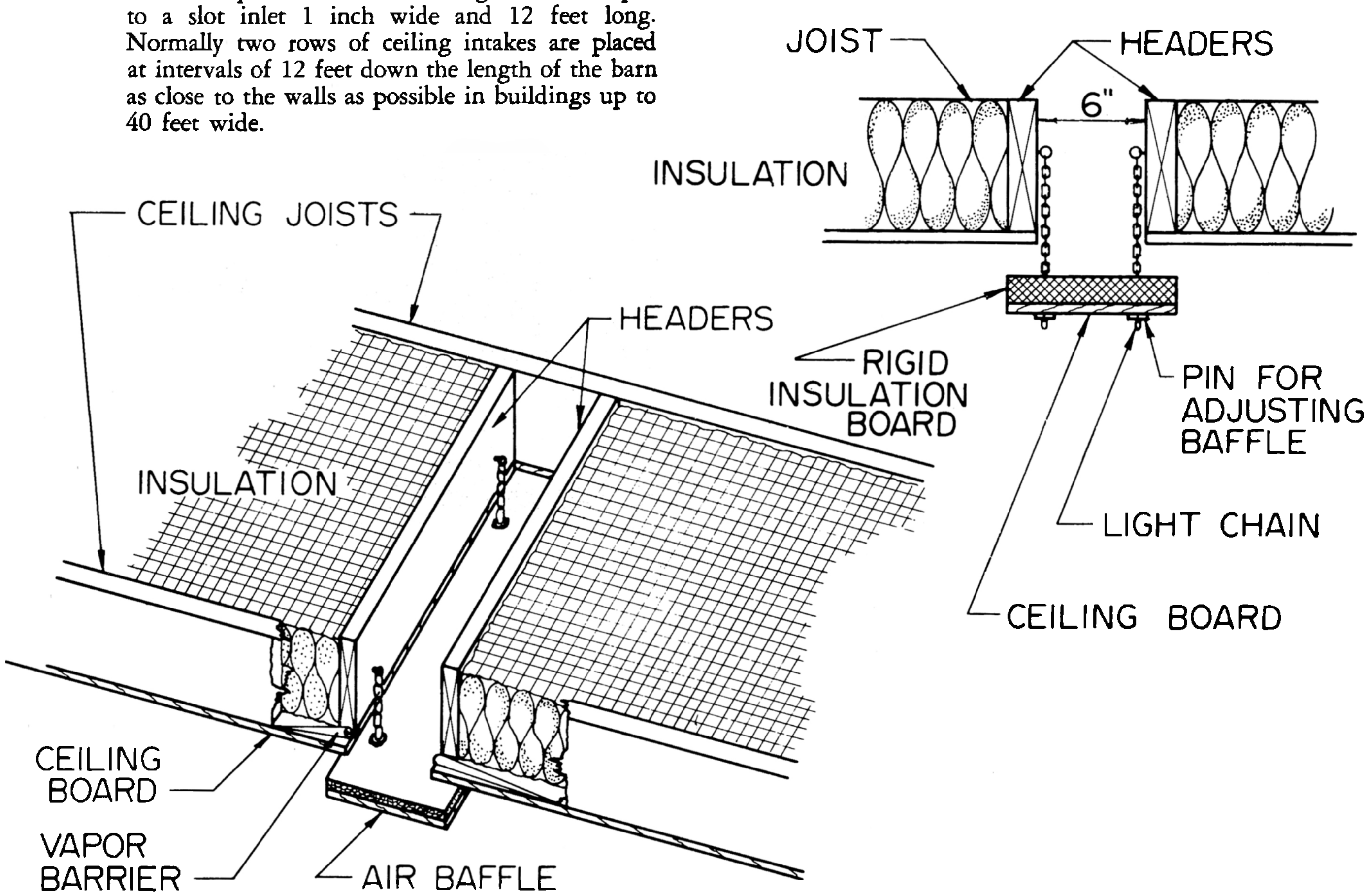
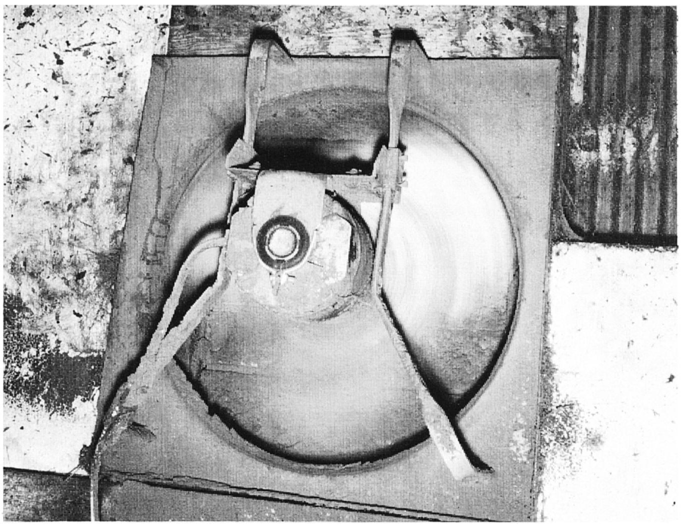


Figure 17. Proper maintenance of exhaust fans is essential. Here the shutters have become so clogged with dirt that they only partially open, greatly reducing the air delivery of the fan.



nature—wind and gravity (stack effect). No mechanical equipment is used, except in rare instances for air circulation in very wide buildings or on hot, still summer days.

Since the force of gravity is a primary mover of air through the building (warm air rises and cold air falls), it is a fundamental principle that in gable roof buildings there be a *continuous, unobstructed* opening the full length of the building at the peak. Such buildings should be oriented on an east-west axis when possible. They may have the south side open (figure 18) with continuous or nearly continuous adjustable ventilation openings in the north wall or they may have both long walls closed with adjustable openings the full length on both sides and at the ends unless large doors are provided (figure 19). In such buildings it is desirable to have permanently fixed openings in one or both walls to permit minimum air entry at all times. This may be done by leaving the space between the top of the plate and the underside of the roof open or by providing a narrow full length opening in both long walls. Where buildings are located in unprotected areas subject to high winds, closure of even these openings on the windward side may be necessary under extremely adverse conditions.

Site Selection

Silos, other structures, and trees disturb airflow around buildings. Locate naturally ventilated buildings at least 50 feet in any direction from other structures and trees. When naturally ventilated buildings must be in a building complex, place them on the west side or south side of mechanically ventilated buildings.

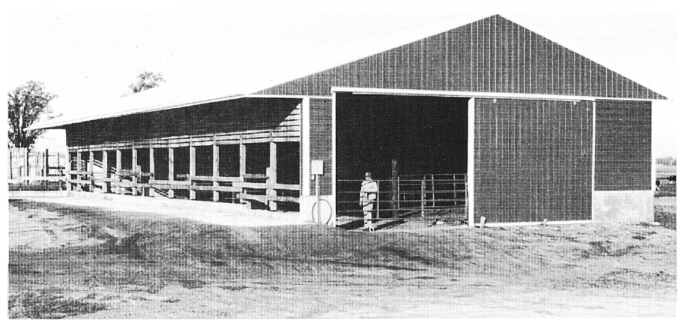
Ridge Openings

Size ridge openings (figure 20) at 2 inches of width for each 10 feet of building width; 16 inches for a building 80 feet wide. Make the ridge opening a minimum of 8 inches wide to prevent closure with frost in cold weather. Open sided buildings narrower than 40 feet are not recommended because of excessive drafts which may develop in them under strong wind conditions.

Air flowing out through a properly sized ridge opening will prevent most rain and snow from entering buildings which are properly located. Nearby obstructions which cause downdrafts must be dealt with individually. Raised ridge caps are not recommended. They reduce airflow and may direct snow into the building. Under prolonged cold conditions ridge caps which have screen or perforated metal openings may become completely closed with frost and ice. Do not cover ridge openings with coarse screen to keep birds out. What this usually does is keep in those birds that enter through the doors.

When possible, locate a feed alley or feed bunk under the open ridge. Cover critical components such as a feed motor or feed belt, or place an internal gutter two to three feet below the open ridge to collect rain water and carry it out of the building.

Figure 18. Open sided young stock building 44' x 96'. Animals are divided by age in four group pens which extend across the building. Feed is supplied by cart to paved manger beneath overhanging roof. Sidewall height is 12 feet. Because of exposed location, upper 4 feet of south wall is partially closed with 1' x 5' boards spaced one inch apart. North wall has continuous 4' x 8' manually adjustable ventilation doors. Uncovered ridge opening is 8 inches wide. There is no insulation beneath the roof.

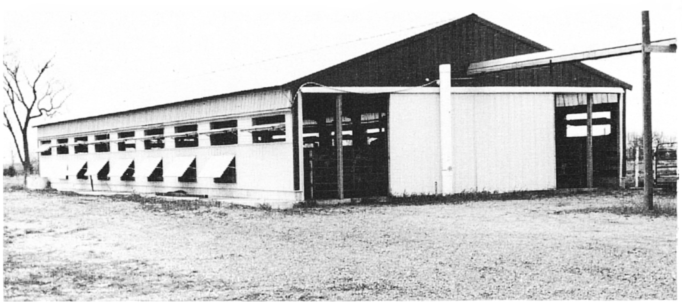


Wall Openings

Sidewalls should have a minimum height of 10 feet. A height greater than 12 feet seems to offer no advantage from the environmental standpoint.

Provide continuous openings along both sides of the building at the eaves, but make provision to close them in case of a severe winter storm. Size each eave opening to have at least ½ as much open area as that of the ridge. Openings can be provided at the spaces between trusses or by placing 2-inch stop blocks on each ventilation door to prevent complete closure.

Figure 19. Totally slatted floor young stock building 40' x 108'. Wall height is 11 feet. Upper row of ventilation doors initially built did not permit sufficient summer air movement for uniform environmental conditions. Lower doors 6' 8" x 3' were added on both sides and have corrected the problem. Continuous, unobstructed ridge opening is 10 inches wide. Roof is built of prefabricated insulated panels smooth on the underside to prevent condensation in winter and heat gain in summer. Inside temperature in summer approximates that of the outside.



Several types of summer vent doors are satisfactory, including pivot doors, top- or bottom-hinged doors, and vertically mounted panels controlled with a winch. Provide continuous openings the full length of both walls. The height may range between 32 and 48 inches depending upon the width and use of the building. For buildings with slat floors, a double row of ventilation doors is desirable to supply adequate summer air movement. Locate a single row of openings so that the bottom is at about cow level. Usually access doors are provided in at least one end of the building. When this is not the case, vent doors similar to those in the sidewalls should be used.

Roof

The steeper and smoother the roof underside, the better the upward airflow. Roof slopes of less than $^4/_{12}$ are not recommended. Exposed purlins deeper than 2 inches should not be used because they impede upward airflow to the open ridge and contribute to condensation formation.

Whether or not to provide roof insulation is a matter of opinion. The purpose of roof insulation is to reduce or eliminate condensation on the undersurface in winter and to reduce solar heat gain in summer. Roof insulation should never be left exposed because it may quickly be damaged by birds and by inside moisture passing through it and condensing on the underside of the roof surface above. This condensation will later fall back on the insulation destroying its thermal properties and often causing it to break loose because of the added weight. Proper construction is thus essential, with ensuing added cost. A tight roof deck with a vapor barrier placed above on which the insulation is laid is recommended. Another method is to construct the roof deck from prefabricated insulated panels placed across the roof support system. These panels are smooth on the underside allowing uninhibited airflow to the open ridge.

An uninsulated roof can be satisfactory for a building left open enough to prevent roof condensation from forming. Many livestock producers are unwilling to do this and as a consequence there is a build-up of roof frost. This later melts and drips back on the animals getting their hair coat wet, increasing stress and promulgating respiratory disease. The same thing can happen however under insulated roofs when the building is kept closed too tightly in an effort to maintain a higher inside temperature. Uninsulated roofs should be white to reduce solar heat gain in summer.

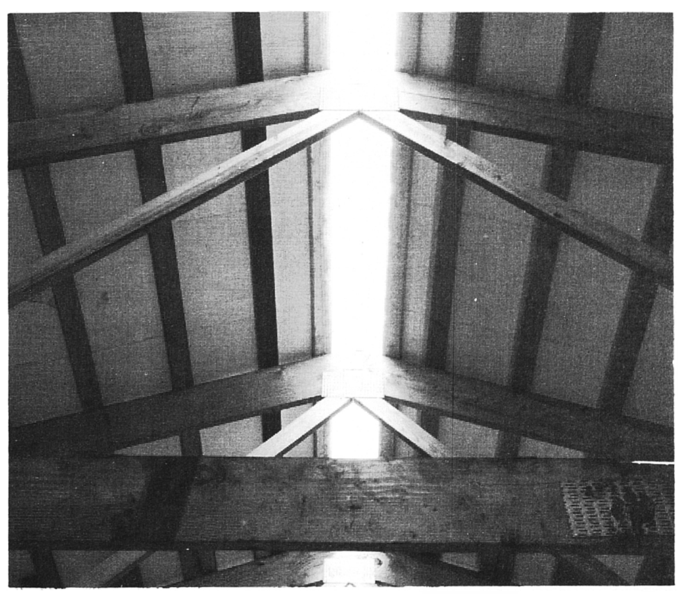
Management

The temperature inside the building should closely follow the outside temperature. Attempting to maintain a higher temperature in winter, usually to prevent manure from freezing, will cause severe moisture and subsequent respiratory and other health problems. Fog, condensation or frost form when the building is not ventilated properly. REGULATE THE VENTILATION SYSTEM TO PREVENT THESE CONDITIONS FROM OCCURING.

A frost-free watering system must be provided.

Hot, muggy, summer weather can cause great environmental stress with consequent reduced animal productivity. It is then that adequate sidewall openings and roof insulation can be an important factor in reducing animal stress. During these times mechanical air movement may be of value. Vertically mounted circulating fans can be located to blow air across the animals. Arrange them to move air in a circular pattern, not to blow air against

Figure 20. View of open ridge from beneath. Unprotected polystyrene insulation was quickly damaged by birds. Open ridge is essential. Insulation should be properly applied or omitted.



themselves. When the roof structure permits, "ice cream parlor"-type fans mounted to blow down on the animals are effective. They should be placed at intervals of 30 to 40 feet.

Carefully planned ventilation, natural or mechanical, based on sound engineering and medical principles is an important key to a profitable livestock operation. When installed and operated within established rules it will function properly; when these rules are violated disappointment is sure to result.

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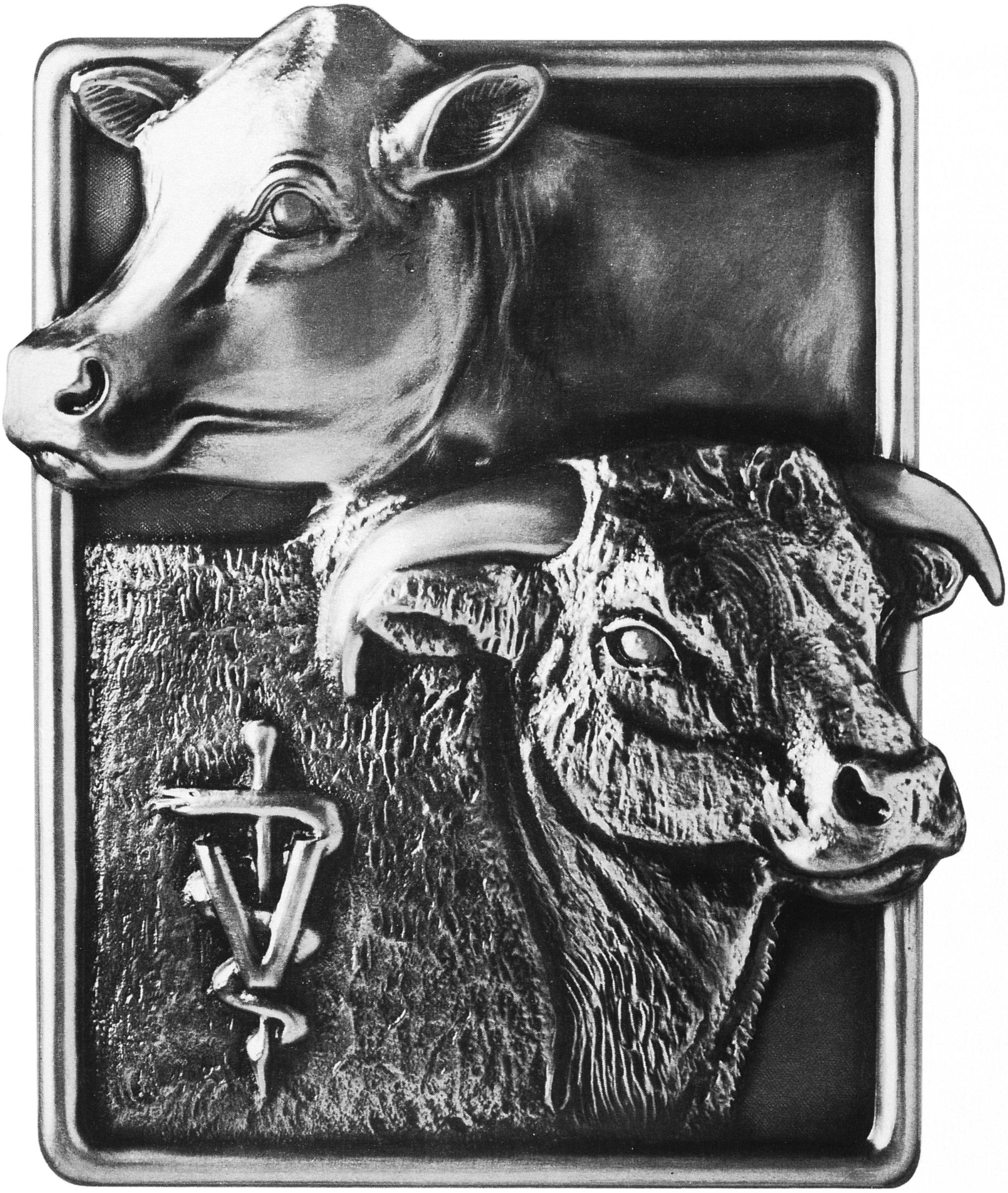

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