*Ventilating Farm Buildings for Animal Health

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Summary

Fundamental to maintaining a healthy animal environment in a warm confinement building is **continuous** air exchange at the rate of 4 changes per hour for removal of aerosol contaminants and moisture. Maximum summer rate should be 30 changes or more. A correctly designed fresh air intake system is **mandatory**. Proper insulation is essential–walls R=15, flat ceiling R=23. Supplemental heat is necessary in calf barns to maintain desired temperature at minimum exhaust rate.

The veterinarian is usually the only professional person the farmer consults regarding his livestock operation for whose services he is willing to pay. He looks to the "vet" as an authority not only on medicine for which he is trained, but also on environmental control and related housing problems for which he may not be trained. Also, in years past, there has sometimes been the feeling among members of the medical fraternity that if enviornment were a causative factor, resulting ills could usually be cured with pills and shots, so why get overly concerned about it.

In recent years, more attention has been given to the role of environment in animal health, particularly with respect to dairy calves. Through our association over many years with Dr. D. W. Johnson and other members of the College of Veterinary Medicine at the University of Minnesota, we have gained an insight into the effect of environment on lung damage and other health problems of bovines from the medical standpoint. We have worked together in many field circumstances where medicine alone could not maintain the health of the animals. In addition, frequent inquiries from practicing veterinarians give evidence of the importance of the engineer's contributions to alleviating animal health problems, where environment is a causative factor.

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Generally, ventilation systems have been designed to control moisture within the housing unit they serve. Although such control is fundamental, some engineers have tended to look at the condition of the structure and presume that animal health and comfort come automatically. This is not necessarily the case. Just because a building is dry does not insure that it is either comfortable or healthful for the animals housed in it. Seldom has the need for ventilation to reduce aerosol contamination been mentioned. Sometimes a few gimmicks are used in the hope of making up for fundamental deficiencies in the design of the building or the ventilation system, or both–specifically in commercial ventilation systems which the farmer may purchase.

A joint approach to the solution of environmental problems by veterinarians and engineers is bound to be of ultimate benefit to the livestock producer and we are pleased to have an opportunity to share with you our views and those of our colleagues in the Agricultural Engineering Department at the University of Minnesota. We consider the following to be essential requirements for maintaining a healthy environment in mechanically ventilated livestock structures:

1. Adequate insulation protected by a vapor barrier, walls R=15, **flat** ceiling R=23. Generally these values will be met with 4 and 6 inches of mineral wool insulation plus the structural materials.
2. **Continuous** exhaust from the structure to provide a minimum of 4 air changes per hour for controlling moisture in cold weather and for reducing aerosol contamination. In heat deficient buildings or those having supplemental heat, remove this air about 15 inches above the floor through a duct built around the fan. Intermittent operation of a higher capacity using an interval timer or thermostat to substitute for the lower continuous capacity is **not** recommended. While intermittent operation may sound like a good idea because it permits the use of fewer but larger fans, it brings about a wider variation in conditions within the building which may cause undue stress on the

animals housed. Only when the animals in the building begin breathing in response to a time clock or theremostat would it seem logical to use such devices to control the minimum part of any livestock ventilation system.

A maximum exhaust of 30 or more air changes is required in summer. For swine finishing buildings, 60 air changes per hour is recommended. When there is manure storage beneath, as in slat-floor units, exhaust continuously from the storage pits and provide for additional thermostatically controlled exhaust up to about 1/2 of the total system capacity. All pit fans should be in operation before any wall fans start.

3. A fresh air intake system that will distribute incoming air uniformly and have sufficient capacity to prevent the negative pressure in the building from rising about 0.125 inches of water. A minimum velocity of 100 feet per minute and a maximum velocity of 800 feet per minute in the intake system is recommended.

   The same general principles apply to positive pressure systems, but in reverse.
4. Buildings which rely on animal heat as the only heat source must be filled to capacity or moisture problems will develop in unoccupied areas during cold weather regardless of how the air is moved.
5. In heat deficient buildings such as calf barns and farrowing houses, supplemental heat must be provided. Ideally, supplemental heat should be added to the incoming air, distributed through the building in correctly designed duct work and exhausted with no provision for recirculation of contaminated air from within the building over the heat soruce. The amount of supplemental heat required is that necessary to provide **continuous** exhaust at the minimum rate. Thermostatic control should be on the heat source.

   In small buildings, particularly calf barns, electric heaters specifically designed for use in livestock buildings are practical. These are used in conjunction with the planned intake system when it is not practical to add the heat directly to the incoming air. Likewise, hot water systems may be used on the same basis.
6. Mechanical movement of air within the building through various devices in an effort to blend cold outside air with warmer inside aira cannot make up for inadequate building construction or inadequate animal population.
7. There is no substitute for common sense in operating the ventilation system.

Determining fan capacity . . .

Since the weight of the animals is seldom known, a practical way to determine exhaust capacity is on the basis of the minimum number of air changes per hour necessary to maintain reasonable air purity and to remove moisture in cold weather. In addition a practical maximum capacity to control temperature in hot weather is needed. The minimum has been arbitrarily set at 4 on the basis of field observations in cooperative work with members of the College of Veterinary Medicine. It is the easiest way that we know of to determine fan capacity. For example, consider a stall barn for 60 cows. A modern barn to house this many cows would likely be about 36' x 150' including two pens. A common ceiling height is 8 feet. 36 x 150 x 8 = 43,200 cubic feet of volume. Dividing 60 minutes by the required air change per hour, 4, will give the number of minutes needed for one air change, 15. 43,200 ÷ 15 = 2,800 cfm. This then is the minimum fan capacity needed. A practical maximum summer ventilation rate is one air change every 2 minutes, or 30 air changes per hour, thus, 43,200 ÷ 2 = 21,600 cfm total capacity needed in the barn. Remember that about 1/2 of this total should be considered the winter part of the system and be furnished by several fans controlled by thermostats having different settings. In barns with connected manure storage, about 1/2 of the total capacity must be exhausted from the manure pits.

Fans which exhaust air from the manure pits must have characteristics equal to or better than those in the walls. Otherwise, the wall fans may overcome the pit fans and draw air through these fans, even when in operation, should there be insufficient fresh air intake area. Then manure gases will be drawn into the barn, increasing odor and possibly creating a health hazard. Somehow this very important point is overlooked and fans of low quality are used in the pit compared to those in the walls. Only **single** speed fans are recommended for use in manure pits.

It must be recognized that a precise calculation of the ventilation capacity for a specific barn can be made only when all the design factors such as the exact amount of insulation, the size of the animals, the number of doors and windows and the minimum and maximum outside temperatures and the desired inside temperature are known. Usually, all of this information is not available. However, if the principles described are followed, the ventilation system will perform satisfactorily. Should the barn be poorly insulated or only partially full of animals, no amount of ventilation equipment will keep it dry without the addition of heat. Remember that there is no substitute for common sense.

Use fans of known performance . . .

To insure suitable performance, fans to be used must have been tested under the Standard Test Code adopted by the Air Moving and Conditioning Association, Inc. (AMCA) or some other recognized test procedure. All fans should be capable of removing their design capacity against 1/8" static pressure. This is approximately equivalent to the pressure created by a 15-mile-per-hour wind.

The free air delivery rating of a fan gives little indication of how it will perform when installed in a barn or other livestock shelter where it must operate against the resistance of the intake system and the wind pressure. Likewise, the diameter of a fan is an unreliable measure of its capacity, see Table 1. Other factors which can determine how much air a fan will move are size, shape, pitch, number of blades, the speed at which it turns, type of mounting and the horsepower of the motor.

Fans used for animal shelter ventilation should be specifically designed 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.

A two-speed fan may be used as a thermostatically controlled high capacity fan. One two-speed fan **should not** be used to replace two single-speed fans, however, because the drop in capacity between the high and low speed is not great enough. This means that a single two-speed fan will have to be shut off entirely in cold weather or that it will be of insufficient capacity in warm weather. Variable speed fans which have a large range in capacity, but also considerable range in performance between their low and high range, are in common use. Their price is much higher than single speed fans.

As a general rule, properly selected, single speed fans will serve well, and at less cost, to remove a comparable volume of air.

Reversible fans which can blow air into, as well as exhaust air from, the building are used in an attempt to add more flexibility to the system in hot weather. They provide great air turbulence at the point of entry when blowing in and may add to the comfort of the animals directly in the air stream under some conditions. Reversible fans have reduced capacity when running "backward." The blades are less efficient when turning in the direction opposite the one they were designed for. Generally it is best to plan the system only for exhaust. Where additional air turbulence is desired in summer, beyond that provided by the exhaust system operating at full capacity, supply this with one or more inexpensive circulating fans within the building.

Rules for locating fans . . .

1. In barns having solid floors where the animals are left in throughout the year, space the fans uniformly in the south or west wall to provide for best air flow across the stable in summer.
2. In slat-floor free stall barns or stall barns with open gutters and manure storage beneath, exhaust 1/2 of the total capacity from the manure pits. Part of this amount must be removed **continuously.**
3. Locate fans at least 10 feet away from doors or other openings.
4. Locate the thermostats controlling the high capacity part of the system at about the level of the cows' backs and toward the center of the stable. **Do not** locate thermostats on an outside wall.

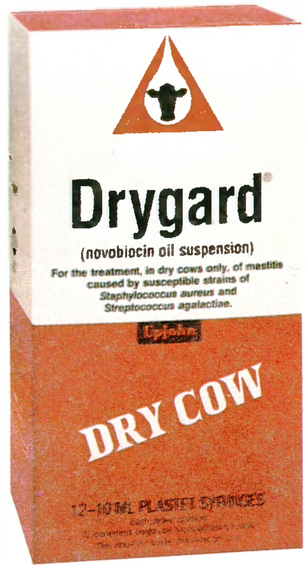
   In winter, maintain a stable temperature of 40-45° F. Remember that the higher the inside temperature the more difficult it is to control moisture in cold weather.
5. Do not locate fans in calf pens in an attempt to draw heat to this area. Aerosol contaminants drawn from the cows to the calves may cause disease problems and condensation in the colder area.

   Wet corners often can be dried up by admitting fresh air. In parts of the stable where few animals are housed, such as in calf pens, additional insulation may be required and possibly heat. Calves

Table 1. Typical Rating Tables for Exhaust Fans*

			Air Delivery in Cubic Ft./Min. (CFM) at Indicated Static Pressure					
Diameter	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.



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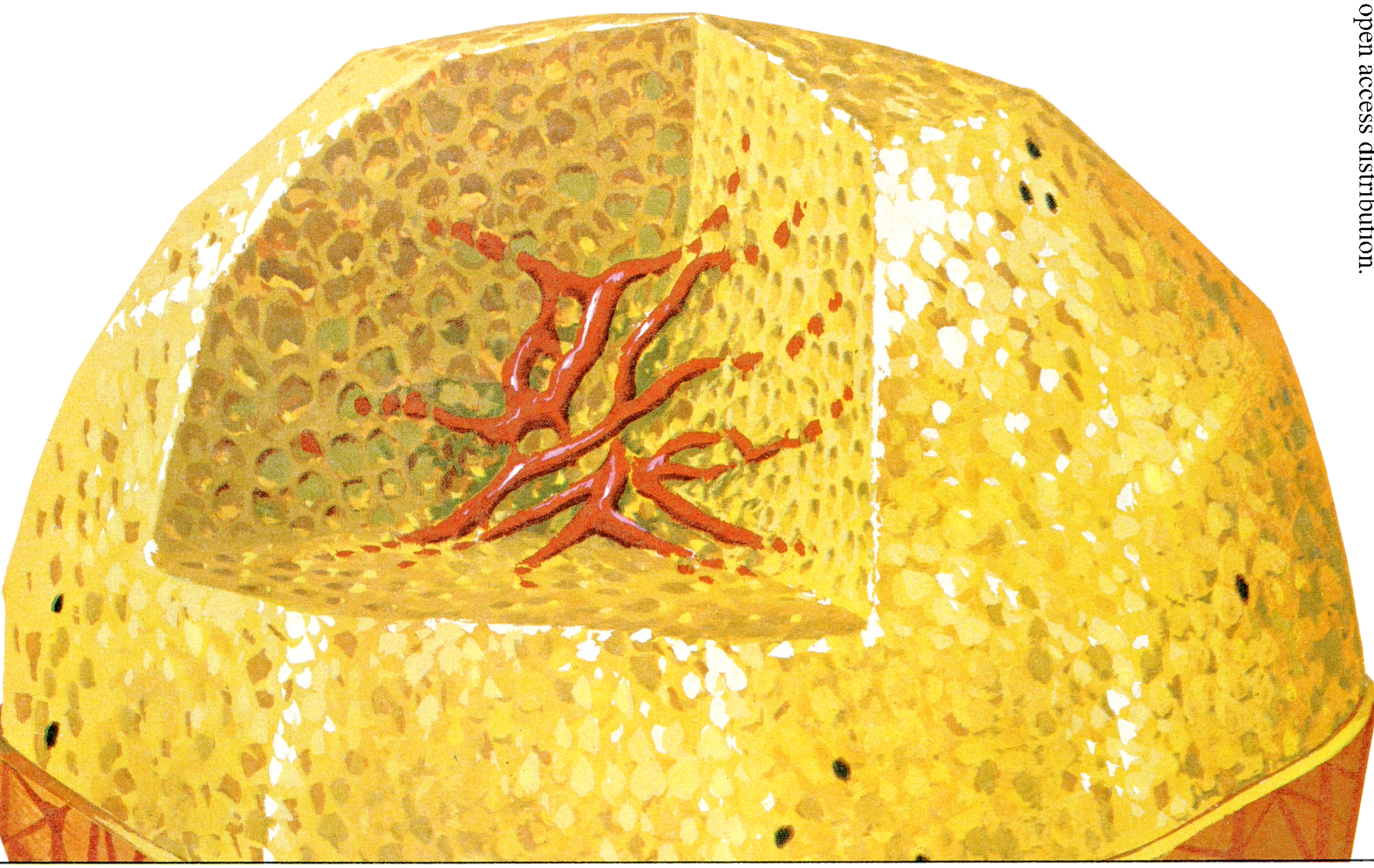

from the strong red line of **Upjohn** *Veterinary Products, Kalamazoo, Michigan 49001* should be housed in quarters other than with the cows.

6. Install all fans near the ceiling. In older barns, or newer ones which are lightly insulated, build a duct around the continuously running fan to draw cooler air from near the floor in winter. Make the duct 12 inches deep and as wide as the fan frame. Make a door near the top to give access to the fan. Keep it closed in winter, open in summer.

   A damper may be placed near the bottom of the duct so the air flow can be partially reduced in cold weather. The use of a duct around the continuously operating fan can mean the difference between satisfactory and unsatisfactory performance of the system in barns where the heat balance is critical.
7. In barns that are not filled to capacity, it is usually necessary to add heat if the walls and ceiling of the unoccupied area, even though well-insulated, are to remain dry in severe weather.

Fresh air essential . . .

A well-planned fresh air inlet system **must** be provided if satisfactory ventilation is to be accomplished. This is frequently overlooked or ignored. **Poor fresh-air-intake design is one of the most common causes of unsatisfactory ventilation performance.** Often commercial fresh-air-intake systems may end up being inadequate for one reason or another. Frequently they are made unduly complex and expensive.

The primary function of a fresh air intake is to distribute incoming air uniformly throughout the building in a manner which will not cause undue drafts in winter. This is best accomplished by bringing a small amount of air in at many places. Remember, too, that at the immediate point of air entry, cold will be felt regardless of the inlet system unless heat is added to the incoming air. When cold incoming air is warmed, its moisture holding capacity is greatly increased enabling this air to absorb moisture produced by the animals and carry it out through the exhaust system. Further, the air replacement process allows for the dilution of aerosol contaminants, bacterial and viral, produced by the animals, thereby improving air purity. Some continuous exhaust is thus mandatory from this standpoint alone, a fact which is often unrecognized.

The slot inlet system has proved to be an efficient and economical means of bringing fresh air into dairy barns and other mechanically ventilated livestock housing units. Because of its low cost and simplicity of construction, it is sometimes disregarded in favor of more expensive systems since things that cost more are usually supposed to be better. My observation over more than 25 years is that you cannot buy a system that will perform any better, and in most cases, as well.

A slot inlet can best be built into the barn during construction. It is a continuous narrow opening to the attic or mow at the junction of the ceiling and the walls, except for a distance of 4 feet on either side of 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 some continuous exhaust from the building to prevent back draft of stable air through the slot to the attic.

It is necessary that the slot intake system have two basic capacities–one for winter and one for summer. In winter, there should be an opening 1-inch wide on both sides of the building where the wall and ceiling join, except over the fans. This allows nearly uniform air entry throughout the barn. A minimum velocity of about 100 feet per minute is also maintained to eliminate back draft through the slot. In summer a practical maximum velocity of 800 fpm is recommended when the exhaust system is operating at full capacity. This will allow the static pressure created by the inlet system to remain below the recommended 1/8 inch for best performance of good quality fans. A velocity of 800 fpm is obtained when there is an air flow of 800 cfm through an opening of one square foot.

For example, take the barn 36 x 150, previously discussed, which is to have a minimum of 4 air changes per hour and a maximum of 30 air changes per hour. The minimum fan capacity is 2,880 cfm and the maximum capacity is 21,600 cfm. Consider that this capacity is divided among 7 fans to be placed in the south wall. It is recommended that the slot be closed for a distance of 4 feet on either side of each fan or a total of 8 feet per fan. 7' x 8' = 56' of the south wall which will be without a slot, so 150 – 56 = 94' of slot. The north slot will be unobstructed the full length or 150'. For winter operation there will then be 244 feet of slot, one inch wide. (244 x 12) ÷ 144 = 20 square feet of slot area. 2280 ÷ 20 = 144 feet per minute velocity under minimum conditions. This is above the 100 feet per minute minimum, which is desirable.

During summer it is essential to remove as much of the heat produced by the animals as possible, to prevent the inside barn temperature from rising much above the outside temperature. Then, it is an obvious advantage to draw the coolest air available into the barn. On a hot day, the north side of a building is least affected by the sun. Next coolest is the east. For a barn running east and west, draw in most of the air from the north side, and for one running north and south, draw in most from the east side. To do this, build continuous doors 6 inches wide into the underside of boxed-in eaves. These are then opened in summer to permit outside air from the shaded area beneath the eaves to enter the slot. This is the coolest air available. Because the incoming air can quickly enter the ceiling slots, there is little opportunity for it to be warmed in the attic. Also the eave openings may allow greater natural air movement through the attic as the result of wind action and convection, thereby reducing temperature buildup in the space.

In winter, the ventilation doors are closed and all air entering the barn through the slot inlet then comes from the attic space.

By having a wider slot opening along the north or east wall, as the case may be, best advantage can be taken of natural conditions. Make this slot opening 4 inches wide, and build a hinged damper so that it can be closed to 1 inch in winter. It is easy to do this with a 1 x 3 inch treated wood strip, hinged at intervals of 4 feet. Most of the summer air will come in through this opening since there is less resistance across the greater width. By placing all exhaust fans on the opposite side of the barn, forced cross ventilation results.

In winter, with the damper closed, about the same amount of air will enter on both sides. Because the incoming air is cold, and therefore heavier, convective forces not present in summer when all the air is about the same weight, produce natural air mixing. Some moisture or frost will form at the edges of the slot during prolonged severe weather but this will take place in any system at the point where cold outside air and warm stable air meet. This is a simple engineering fact. Frost formation can be eliminated only if the incoming air is warmed to a temperature above the dew point of that in the stable. It cannot be eliminated by the so-called tempering process, where stable air is blended with outside air in an attempt to raise the temperature of the latter because there has to be an interface between the warm and the cold air.

During the winter, outside air to supply the slot inlet is admitted to the attic through large louvers built high in the gable at each end of the barn. As a general rule, build each louver about twice the size of the combined openings for the fans in the stable below. A minimum size of 4 feet by 4 feet is recommended. Screen louvers with 1/2-inch mesh hardware cloth. Don't use window screen because it can become quickly plugged with air-borne debris which will greatly reduce air flow, thereby causing poor performance of the ventilation system.

Ventilating the older barn . . .

Providing satisfactory ventilation in older dairy barns which are poorly insulated, perhaps having stone or concrete block walls, single windows and loose-fitting doors, is an impossible task. Often one or more fans are installed in an attempt to improve conditions with mediocre results. The degree of improvement will depend upon the construction and state of repair of the building. Providing suitable air inlets is difficult so usually nothing is done. As a consequence, air enters through available openings. These are often at the gutter cleaner exit and, of course, around loose-fitting sliding doors, hay chutes and the like. While the fans may make some improvement it must be recognized that there are severe limitations imposed by the building. There is no magic system for solving such problems. Deficiencies in the building cannot be made up for by circulating air, blending or intermittent operation of the fans.

In two-story barns with mow floors but not a ceiling on the underside of the joists, a satisfactory inlet system can be made by drilling 1-1/2-inch holes as close together as possible to form a slot inlet. If there is both a mow floor and a ceiling, and holes are drilled, cold air will circulate in the space between. Thus, the insulation value of any material in the mow, such as hay or straw, will be lost if tight headers are not placed between the joists at both ends. Unless you put the headers in, don't drill the holes.

In single-story barns having an insulated ceiling, it is often more practical to construct or purchase ceiling intakes rather than to attempt installation of a slot. In some cases a practical alternative may be to build a duct beneath the ceiling which runs the length of the barn, to which air can be supplied from the attic or mow space, or from directly outside. It is important that the duct be insulated with an acceptable rigid insulation material to prevent undue condensation from forming on it in winter. A continuous slot one inch wide on both sides of the duct, or round holes giving an equivalent area, should be made in both sides. The duct size should be such that the maximum air velocity in it does not exceed 800 feet per minute. For example, if the total amount of air to be removed from the barn is 4,000 cfm, $4{,}000 \div 800 = 5$ square feet. The duct then might be 4 feet wide and 15 inches (1-1/4 feet) deep if air is admitted at only one end. By providing air entry at both ends the duct size could be reduced by 1/2, narrowed to 2 feet or reduced in depth to 7-1/2 inches. Another alternative might be to make the duct in the shape of a T with the stem at about the center of the barn to supply the duct running the full length. In this case, the stem would be full size with no openings, and the remainder, running the length of the barn, 1/2 size.

Fan maintenance . . .

Ventilation fans, like other pieces of mechanical equipment, need periodic maintenance. Usually the bearings are permanently lubricated but regular cleaning of the fan blades and shutters is necessary to remove dirt which may greatly reduce air output. As a consequence, unsatisfactory enviornmental conditions develop in the building.

Manure pit fans are constantly exposed to corrosive gases which cause more rapid deterioration of metal than is the case with wall fans. Thus, earlier replacement may be necessary. This is a fact which must be recognized and dealt with as an operating cost, the same as with other items of farm equipment.

It would seem that little can go wrong with a slot inlet system. But the slot openings may become plugged for one reason or another. Fine screen covering the louver and eave openings often becomes plugged with debris, blocking air entry to the slot. Such material should never be used, but sometimes is. The best cure for this problem is to replace the screen rather than attempt to clean it.

In some cases, the slot openings may be partially obstructed by the ceiling vapor barrier, which wasn't trimmed as it should have been at the time of construction.

When a ventilation system is planned within the known rules and properly managed it will give satisfaction. If it isn't, it won't.

Dairy Barn Ventilation Example

Assume

A stall dairy barn 36' x 150' with 8-foot-high ceiling and recommended insulation and vapor barrier. R value in walls, 15; ceiling, 23.

Determine fan capacity

Use 4 air changes per hour minimum, 15 normal winter rate, 30 maximum.

Volume of barn = 36 x 150 x 8 = 43,200 cu. ft.

Minimum rate 4 air changes/hour = 43,200 cu. ft. ÷ 15 = 2,800 cfm.

Normal winter rate 15 air changes/hour = 43,200 ÷ 4 = 10,800 cfm.

Summer rate 30 air changes/hour = 21,600 cfm, or double the winter rate.

1 - 2,800 cfm **continuous.**

10,800 - 2,800 = 8,000 cfm remaining for winter. Divide this among 2 fans of 4,000 cfm each or 3 fans of 2,667 cfm each. A practical solution would be to use 4 fans of 2,800 cfm each. In this case, one would run continuously and the remaining fans would be controlled by thermostats set at perhaps 45, 47 and 50° F so that all fans will not be turned on at the same time. When there is a manure pit beneath the building all of the above capacity should be exhausted from it.

The summer rate of 30 air changes per hour requires doubling the winter rate, for an added 10,800. This capacity could be divided among 3 fans of 3,600 cfm each.

Determine fresh air inlet area

Total exhaust in cfm ÷ velocity in fpm = minimum net inlet area in square feet, then 21,800 ÷ 800 = 27.25 sq. ft.

In this example 7 fans are to be used and the slot is to be closed for a distance of 8 feet over each fan. 7 x 8' = 56'. The barn length is 150 feet so there will be 94' of slot along the south wall where the fans are to be placed and 150' along the north wall for a total of 244 feet.

Using the recommended slot width of 1 inch, then (244 x 12) ÷ 144 = 20 square feet of slot area.

2,880 ÷ 20 = 144 feet per minute slot velocity, which is well above the minimum.

For summer, the slot along the north wall should be opened to 4 inches. Then the open area will become 50 square feet plus 8 square feet along the south wall. 21,600 ÷ 58 = 372 fpm, well below the maximum recommended velocity through the slot system. Because of the wider opening on the side away from the fans, most of the air will come in through it and flow across the barn.

Calf Barn Ventilation Example

Assume

A 30' x 44' calf barn with an 8-foot-high ceiling and recommended insulation. Barn has individual calf pens and 6 group pens. R value in walls, 15; ceiling, 23.

Determine fan capacity

Use 4 air changes per hour minimum, 30 maximum.

Volume of barn = 30' x 44' x 8' = 10,560 cu. ft.

Minimum rate is 4 air changes/hour = 10,560 cu. ft. ÷ 15 = 700 cfm.

Mild weather rate is 15 air changes/hour = 10,560 ÷ 4 = 2,640 cfm.

2,640 - 700 = **1,940** cfm to operate during mild weather when supplemental heat is not needed. Use two fans of about 1,000 cfm each to give a gradual increase in the air exchange rate. Set thermostat controlling one fan 5° F higher than the one controlling the heater. Set thermostat for second fan 10° F higher.

When there is a manure pit beneath the building, all of the above capacity should be exhausted from it. For the summer rate of 30 air changes per hour double the mild weather rate. Add 2,640 cfm, which can be supplied by a single fan.

Supplemental heat needed

To maintain an inside temperature of 50° F with a **continuous** exhaust of 700 cfm, it will be necessary to add heat to the building. A reasonable estimate of the heat required can be made using the following formula:

Heat required in Btu = minimum rate in cfm x temperature difference.

Temperature difference = inside temperature - outside temperature.

Consider 50° F inside and -10° F outside. This is a temperature difference of 60° F.

700 x 60 = 42,000 Btu per hour.

This heat can be provided with a hot air furnace which heats outside air only and distributes it uniformly through a duct, by a hot water system, with electric heaters or other acceptable means.

Determine fresh air inlet area

Total exhaust in cfm ÷ velocity in fpm = minimum net inlet area in square feet = 5,280 ÷ 800 = 6.6 sq. ft.

This can be nearly provided with a 1" wide slot the full length of both long walls except over the fans. Assume that three of the four fans are placed side by side and that the width of each fan is two feet. Then six feet of wall space is occupied. No slot is built over the fans or for four feet on either side, making a total distance of 14 feet. Consider no slot for a distance of eight feet over the remaining fan. This gives a total length of 22 feet without a slot. The total slot length is then 88' - 22' = 66 feet. 66 x 12 ÷ 144 = 5.5 sq. ft. of inlet area.

When all the summer intake air is to come in through the slots, make the slot on the side away from the fans three inches wide and provide an adjustable damper so that it can be restricted to a width of 3/4-inch in winter. Should ceiling intakes be used they must be sufficient in number to permit air entry at acceptable velocities.

In the case of a fresh air intake system where all the incoming air passes over a heat source, which is the most desirable, the duct should be sized to keep the maximum velocity of the mild weather rate below 800 fpm. For the example the main duct size would be 2,640 $\div$ 800 = 3.3 square feet.

For economical construction branch ducts of a smaller size can be used to provide uniform air distribution throughout the building depending upon the location of the heat source. A control system is required which will prevent the thermostatically controlled fans from operating when heat is being supplied to the incoming air.