Tunnel Ventilation for Tie Stall Dairy Barns

G-78

John T. Tyson, Agricultural Engineer, Mifflin County
Dan F. McFarland, Agricultural Engineer, York County
Robert E. Graves, Professor Emeritus, Agricultural & Biological Engineering

Shade, **A**ir exchange (1000 - 1500 cubic feet per minute (cfm) per cow), **A**ir flow over cows (300 - 500 fpm), and plenty of cool **W**ater (SAAW) are all important ingredients in providing hot weather cow comfort. At air temperatures above 70°F, a producing dairy cow must either decrease heat input (get in the shade or reduce feed intake) or increase heat loss (increase respiration rate, stand in a strong breeze, evaporate extra moisture from skin surface, or find a cooler location). Cows that are too hot, quickly drop in milk production. Reproductive efficiency, fetal development and performance of growing animals are also impacted by heat stress. Changes in animal behavior caused by heat stress can also lead to herd health issues.

Tunnel ventilation is a special summer ventilation system that provides a combination of the high air exchange rates and high speed air flow over cows to help cows remove body heat during hot weather. **Tunnel ventilation systems are not suitable for year round use because they provide inadequate fresh air distribution during low air exchange winter ventilation conditions.** With tunnel ventilation, the calculation for fan capacity to provide the necessary air velocity is independent of the number of cows within the barn. The designs discussed in this fact sheet are best suited for two row tie stall barns with more than 40 cows. In barns with fewer than 40 cows it may be more economical to install a year round slot inlet system with capabilities of providing air exchange rates up to 1500 cfm per cow during hot weather. Tunnel ventilation systems in 2 row barns with more than 110 cows may require extra fan capacity to assure adequate air exchange for all cows.

To equip a barn for tunnel ventilation, place large exhaust fans along one end wall of the barn, and place large openings along the other end. (See figure 1)

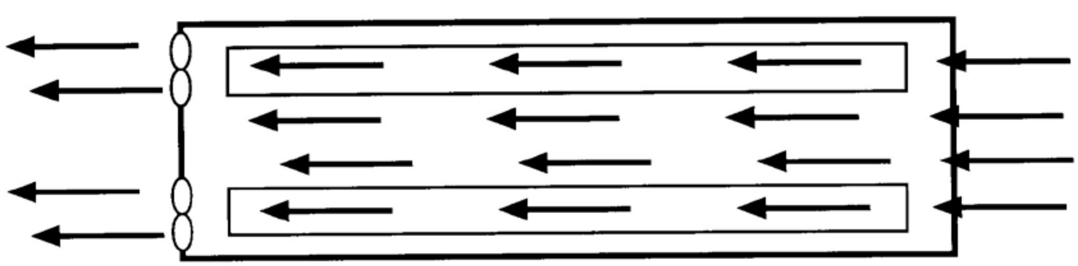

Figure 1. Plan view of two row tie stall barn with air entering at one end and flowing through to exhaust fans.

Close all windows, doors, or other openings along the sidewalls. The fans will pull fresh outside air through the inlet openings across the cows, exhausting hot air out the fans. A properly designed tunnel ventilation system can provide uniform air movement across the entire width of the barn. Research and experience indicates that air moving between 3.5 and 5 miles per hour will increase cow comfort at temperatures over 70°F. Velocities above 5 mph do not seem to provide significant extra comfort or productivity. To increase local air speed between standing cows, rather than increasing the overall design air speed beyond 440 fpm (5 mph) the addition of axial circulation fans over the rows of cows is recommended. Space circulation fans no more than 10 times their diameter apart. Fan size will be dependent on the headroom of the individual barn.

Tunnel ventilation systems are usually designed to provide air velocities inside the barn of between 300 feet per minute (3.5 mph) and 440 feet per minute (5 mph). The required fan capacity is based on the cross sectional area (width times height) of the animal area and is independent of the number of cows in the barn. A wider barn or one with a higher ceiling will require more fan capacity to maintain the same air velocity over the cows.

The critical steps in developing a tunnel ventilation system include:

- Determining fan capacity
- Determining inlet size
- Locating fans and inlet
- Selecting fans
- Installing fans and controls

<u>Calculating Required Fan Capacity and Inlet Size</u>

Tunnel ventilation designs are based on the cross-sectional area of the barn and air velocity. The calculated minimum air velocity inside the barn should be about 300 feet per minute (fpm) to improve comfort, with the inlet sized at 2 – 2.5 square feet (sq. ft.) per 1000 cfm of fan capacity to provide proper inlet velocity. For barns where inlets can be placed at cow level along the end of the barn, 2 sq. ft. per 1000 cfm is usually adequate. For barns requiring more complicated inlet systems, where turns and other obstructions interfere with air flow, calculate inlet area at 2.5 sq. ft. per 1000 cfm of fan capacity.

The required fan capacity is found by multiplying the inside cross-sectional area of the barn by the desired air speed. The inlet size is found by allowing approximately 2 – 2.5 sq. ft. of inlet opening per 1000 cfm of fan capacity. Check for adequate air exchange per animal by dividing the total calculated fan capacity by the number of animals in the barn (1000 cfm is minimum recommended). Another check is to calculate the length of time it takes for the fans to completely change the air in the animal area. It is desirable that this be 45 seconds or less. Remember that as ventilation rate is increased, operating costs for electricity to operate fans also increases.

Example: 70 cow tie stall barn, 38 feet wide, ceiling height 9 feet, barn length 160 feet
A. Cross-section area (width times ceiling height):
    38 ft. x 9 ft. = 342 ft.^{2}
B. Ventilation rate to provide 300 fpm air velocity inside barn:
    342 ft.^{2} x 300 fpm = 102,600 cfm (minimum)
C. Inlet size:
    102,600 cfm x 2.5 ft.^{2}/1,000 cfm = 257ft.^{2}

D. Check ventilation rate per animal
    102,600 cfm÷70 animals = 1,466 cfm/animal,
    This is well over the minimum of 1,000 cfm/animal.
E. Check air exchange (should be less than 45 seconds)
    Animal space volume 38 ft. x 9 ft. x 160 ft. = 54,720 cu ft.
    54,720cu ft. ÷ 102,600 cfm x 60 sec/min = 32 sec

Fan and inlet requirements for tunnel ventilation of typical tie stall barns.

Barn Dimensions			3.5 mph or 300 fpm (minimum)		5 mph or 440 fpm (practical maximum)	
Width (ft.)	Height (ft.)	Area (ft.^{2})	Total Fan Capacity (cfm @1/8 in spwg)	Inlet (2.5 ft.^{2} / 1000 cfm) (ft.^{2})	Total Fan Capacity (cfm @1/8 in spwg)	Inlet (2.5 ft.^{2} / 1000 cfm) (ft.^{2})
36	8	288	86,400	216	126,720	317
	10	360	108,000	270	158,400	396
38	8	304	91,200	228	133,760	334
	10	380	114,000	285	167,200	418
40	8	320	96,000	240	140,800	352
	10	400	120,000	300	176,000	440

Fan Selection

Select good quality high efficiency fans. Fans will be working under load, so purchase those that deliver the desired capacity at a static pressure of 1/10" to 1/8" inch water gauge (spwg). Fan efficiency is expressed in terms of cfm per Watt (W). The more air (cfm) a fan delivers for the same amount of electricity (watts), the cheaper it is to operate. For large fans used in tunnel ventilation, choose fans with no less than 20 cfm/W at 0.05-inches static pressure. Efficient motors have more copper windings and are, hence, more expensive to manufacturer. The payback takes about two to three years in reduced electrical consumption. Higher efficiency motors are readily available and are used on well-designed agricultural fans. Better fans also offer other design advantages in ventilation performance. There has been too much emphasis in the agricultural industry on “cheap” fans. This is a policy that is costing more in operating expense and maintenance than if a better model was selected. The extra cost of high efficiency fans and motors will quickly pay back in electricity savings. Ask your fan supplier for information such as cfm per watt and total cfm versus static pressure for specific fans you are considering. Be sure that the test data is given for fans with shutters, guards, or other needed accessories in place.

Fan Installation and Control

Locate fans where they will cause minimal interference with movement of people, cows, or feeding equipment. Protect all belts, blades, pulleys, or other moving parts to be sure that people or animals do not become entangled. Anchor fans securely in place to minimize vibration.

Each fan should have a separate properly-sized fuse, circuit breaker, or overload device that will turn off electricity to the fan should it become over-loaded. Fan motors that are only protected by larger branch circuit fuses or circuit breakers may overheat and catch fire before they blow the larger fuse in the main supply panel.

Control fans manually as needed with an on/off switch, or install thermostats or temperature sensors in the center of the barn that will begin to turn fans on as temperatures rise above 65°F. All fans should be operating if barn temperature rises above 70°F. Set thermostats so additional fans turn on at 1-2 degree intervals. Thermostats are required on any tunnel system fans that are also used for mild weather ventilation with a slot inlet system.

Tunnel ventilation systems are not suitable for year round use because they provide inadequate fresh air distribution during low air exchange winter ventilation conditions.

Locating Inlets and Fans

Ideally, inlets and fans are placed in opposite end walls at animal level (Figure 2). A continuous inlet is placed at animal level along one end wall of the barn. The fans are evenly spaced across the other end wall at cow level. However, this ideal situation very rarely occurs, especially when installing a tunnel ventilation system in an old or remodeled barn. Other buildings, banks, barn bridges, heavy stone walls, gutter cleaners, milk houses, and silos are often in the way.

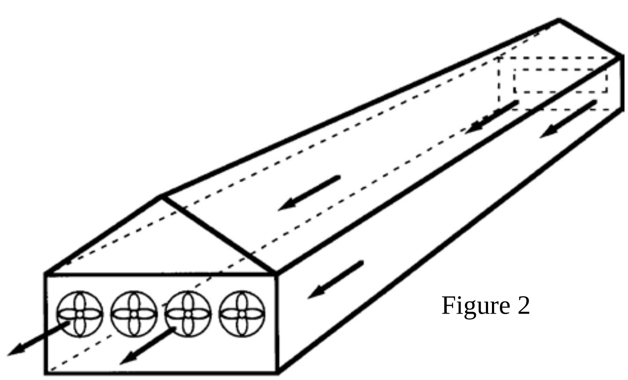

Figure 2. Ideal fan and inlet placement for a tunnel ventilation system.

Tunnel Ventilation System

The following general comments apply to any tunnel ventilation system:

- Have a plan for providing emergency ventilation or taking cows out of the barn if the tunnel ventilation system stops because of power failure. A closed up barn full of cows will warm up very quickly when fans are not operating. An alarm, flashing light or other appropriate warning device may be necessary.
- Consider fan noise and discharge of hot, smelly air when choosing fan location.
- Do not restrict any part of the airflow path through the system less than the calculated inlet area.
- Account for the area taken up by floor joists, studs, support posts, or other construction materials that pass through the opening when determining the effective area of inlets and air ducts.
- Account for loss of open space caused by screening, grates, grills, or louvers. Galvanized 1 x 2 poultry wire provides protection with minimal blockage of air flow. Common window screening will block approximately 50 percent of the area even when clean and will quickly become plugged with dirt. Therefore it is not recommended. Plastic bird meshes with wide bars may block up to 30 percent of the area.
- Inlet and fan openings for the tunnel ventilation system must be tightly closed with insulated panels during winter weather to prevent freeze up of the barn or air leakage that will affect distribution of winter ventilation air.
- **Tunnel ventilation is a hot weather ventilation system and will not provide adequate air distribution at low winter ventilation levels.** (see figure 3) A slot inlet exhaust fan ventilation system with fresh air inlets for both rows of cows is needed for optimum winter ventilation.

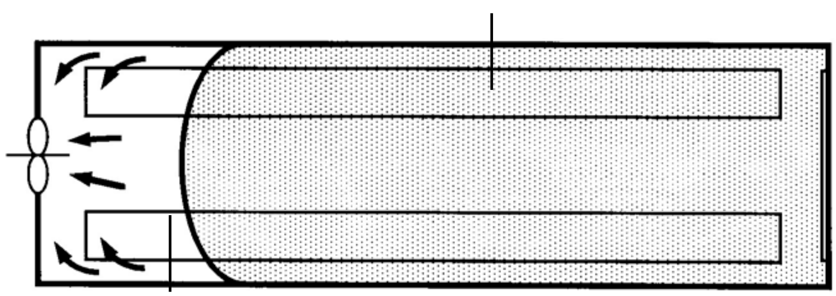

Figure 3

Figure 3. Tunnel ventilation is not a cold weather ventilation system.

If a summer tunnel ventilation system is used for winter ventilation, poor air distribution will be a problem. Enough air can filter through cracks and unplanned inlets to supply the fan(s) operating at low air exchange rates. Minimum winter ventilation rates (50 cfm/cow) may be only 5 percent of the tunnel ventilation rate. At near freezing (100-125 cfm/cow), it still may only be 10 percent of the tunnel ventilation rate. Therefore, an alternative ventilation system using sidewall fans and slot inlets is recommended for winter ventilation. Some of the tunnel ventilation fans may be used for mild weather (i.e. above 50°F outside) ventilation.

Winterizing Tunnel Ventilation Systems

The large inlet openings and fans involved with tunnel ventilation can interfere with operation of the winter slot inlet exhaust fan system. Therefore, as part of preparing the barn for the winter, the inlet openings should be covered and sealed to prevent air leakage. Cover inlets from the mow area with panels and/or a layer of plastic sheeting and a closely stacked layer of hay bales to seal out air and provide insulation to prevent condensation. Fans that are not in use should be manually shut off or disconnected to prevent operation. A tight fitting insulated cover will prevent air leakage and condensation around the fan.

In many cases one or more of the "large" fans installed for the tunnel ventilation system can also be used to increase the air exchange of the slot inlet / sidewall exhaust fan system during mild spring and fall periods.

Alternative Inlet and Fan Locations

Tunnel ventilation can be successful even when alternative fan or inlet locations are necessary. The areas closest to the ends of the barn will be affected most by modifying fan or inlet placement. Advanced planning and careful observation and corrections after installation can minimize performance problems. The most common problems are dead air spaces that do not have sufficient air velocity or fresh air. Additional small inlets can be used to provide fresh air to dead air spaces. Also, plywood baffles or deflectors can be located to divert airflow through dead air spaces. Following are illustrations of common problems and possible solutions. Inlet and fan design and location may be considered separately, because except in very short barns (less than 50 feet), modifying one does not affect the other's performance.

Inlet Alternatives

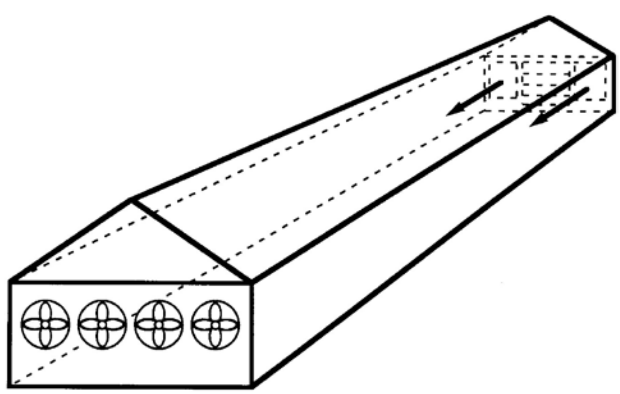

Figure 4.

Figure 4. Inlets are placed on either side of an overhead door that is lined up with the center alley. Ideally, these two inlets represent the entire inlet area and are located directly in line with the two rows of cows. By placing these directly in line with the animals, it assures that all animals will feel the breeze. An adjustable curtain will allow the inlet area to be changed to match the number of fans that are operating.

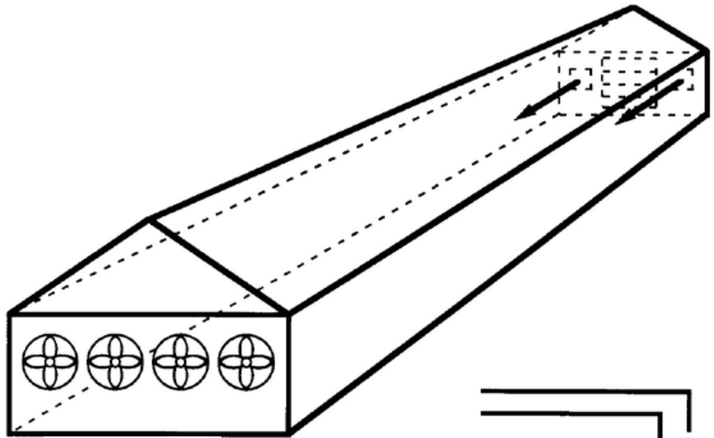

Figure 5

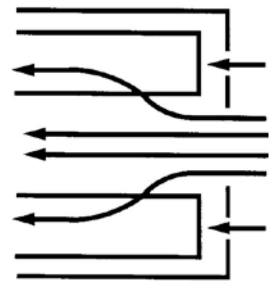

Figure 5a

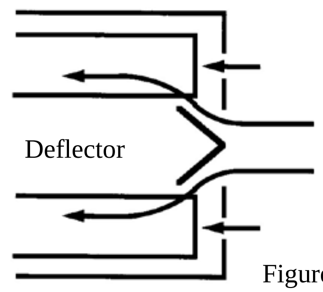

Figure 5b

Figure 5. Openings such as an overhead door and windows may provide the proper area to cfm ratio; however, good air distribution may be lacking. In this case, most of the air will enter through the overhead door and travel part way down the center alley, leaving dead space on either side (Figure 5a). If a center overhead door is used, it may be necessary to direct the incoming air toward the outer two alleys with a V-shaped floor-to-ceiling deflector (Figure 5b).

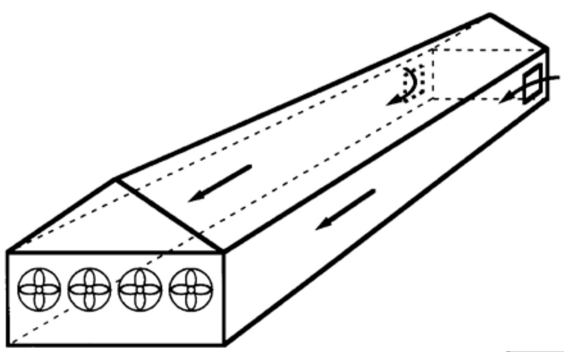

Figure 6

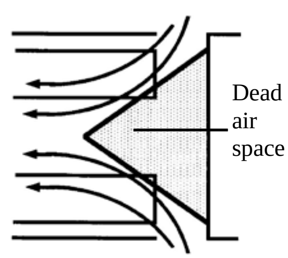

Figure 6a

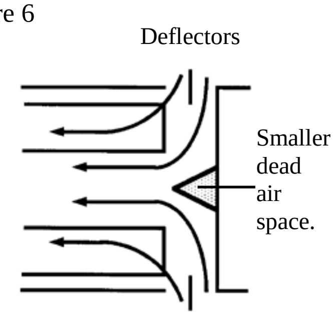

Figure 6b

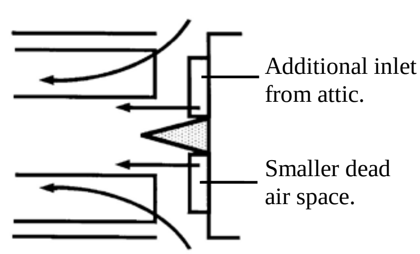

Figure 6c

Figure 6. If end wall inlets are not possible because of a milk house, shed, or other obstruction at the end, large side wall openings can be used. However, a dead air space may be created between the two sidewall openings (Figure 6a). Cows in this dead space will be uncomfortable. To alleviate this problem, one of two things can be done. First, deflectors can be added in the inlet to help push air toward the center of the barn (Figure 6b). Small inlets to draw additional air from the attic space or from the space at the end of the barn are another possibility (Figure 6c).

Figure 7. Another alternative, if end wall inlets are not possible, is to draw air from the attic space over the animals. The flow of air through the attic is so large there is little effect on air temperature. Size the ceiling opening into the attic space at 2.5 ft2 per 1000 cfm. Openings into the attic from outside should be 10 to 15 percent larger than the ceiling opening into the animal area. Adequate air flow into the attic cannot be provided by simply removing the gable end from a single story barn. Inlets, dormers, or large ridge vents must also be added. If the gable end is opened it should the covered with a large opening screen to keep birds and rodents from entering, and the area blocked by the screen wires and studs must be subtracted from the total area of the opening.

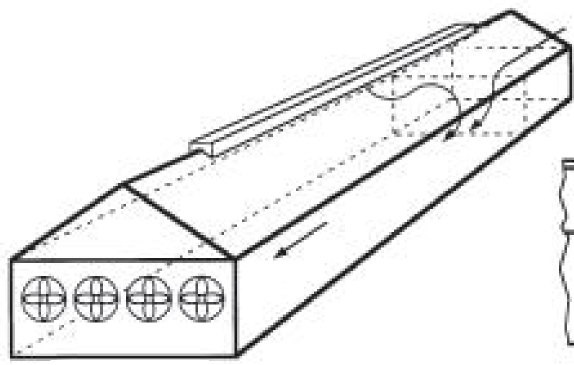

Figure 7

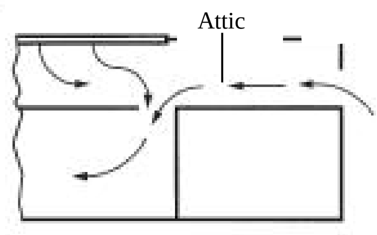

Figure 7a

Figure 8. Two-story barns with heavy stone-end walls or one-story obstructions will require extra construction for inlets. An air plenum in the haymow will allow air to be drawn over the stone wall and into the animal area. If no obstructions exist at the end of the barn, this can be done with a simple plenum (Figure 8a). Typically, the opening from the plenum into the animal area is sized as the controlling opening. However, the area entering the plenum from outside should be at least as large so as not to block air flow. Consider the area occupied by floor joists, building supports, and screening when sizing the inlet area and plenum. Use sliding doors or curtain material to control the opening. If a sloping plenum is used, the shortest distance from the wall to the plenum becomes the controlling dimension (Figure 8b). If hay or other material is to be stored on the plenum, proper structural techniques must be used during design and construction.

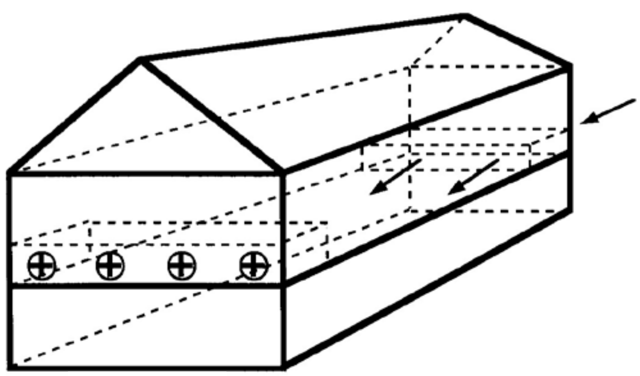

Figure 8

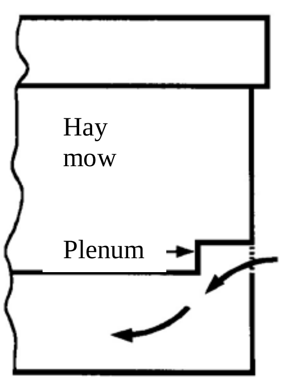

Figure 8a

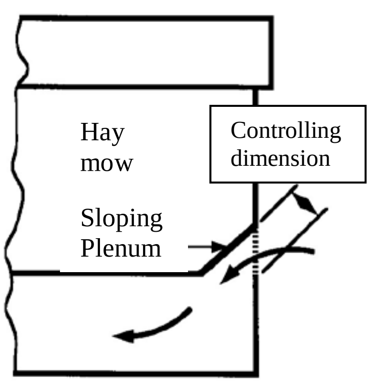

Figure 8b

Figure 9. If the inlet end is blocked due to a milk room or storage room, one alternative is to construct a duct over that room to the end wall (Figure 9a). Any obstructions, such as joists, support posts or screening, must be subtracted from the clear opening area. The cross-section area of the inlet duct should be slightly larger than that of the inlet itself. The opening of the duct into the animal area should be used as the control. If hay or other material is to be stored on the duct, proper structural techniques must be used during design and construction.

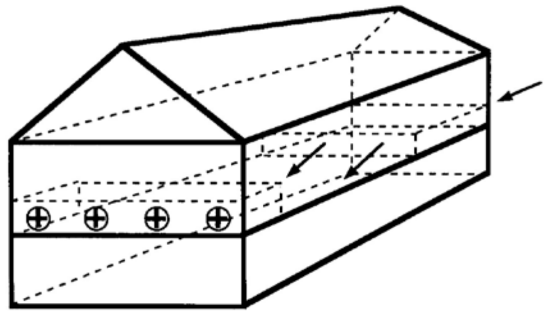
Figure 9

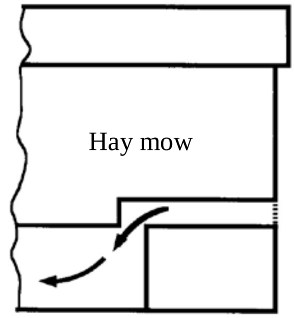

Figure 9a

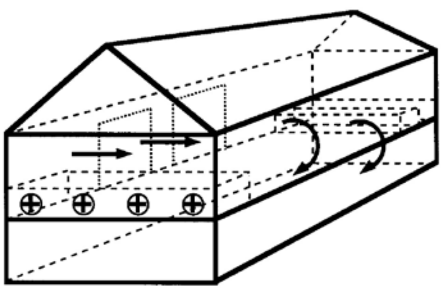
Figure 10

Protective grate

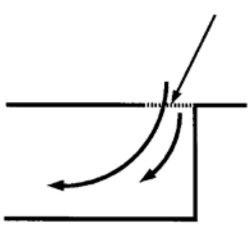
Figure 10a

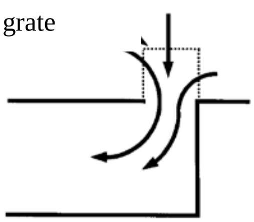
Figure 10b

Figure 10. Another alternative is to draw air directly from the overhead storage space. If this is done, enough space must be left between the openings and the stored items. Safety also becomes a concern. Cover the floor opening with a grating or heavy screen to prevent people and animals from falling through (10a). The area of the grating or mesh must be subtracted from the clear opening. One way to do this is to construct a wooden frame or “box” over the hole and then cover the frame with mesh (Figure 10b). The floor opening into the animal space is the controlling dimension. Also, enough air must be allowed into the second story of the structure to provide the needed volume. It may be necessary to open outside doors or windows into the second story when the system is operating.

Fan Location Alternatives

Obstructions or thick stone end walls may prevent installation of fans in the end wall at cow level as illustrated in Figure 1. Figures 11, 12, 13, 14, 15 and 16 describe possible alternative locations for fans.

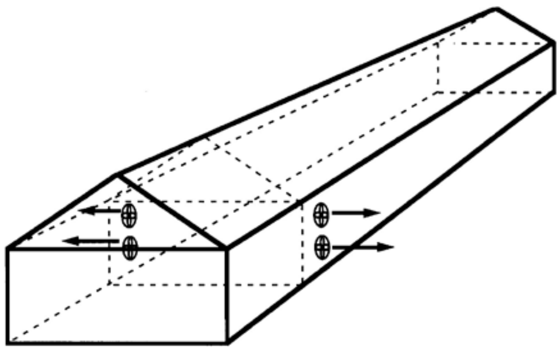

Figure 11

Figure 11. Obstructions at the end of the barn may require fans to be located in the side walls. Place half of the fan capacity in each wall. This configuration may create a dead pocket of air between the fan banks (Figure 11a). If this area is of importance, place about 10 percent of the inlet area in the ceiling, drawing attic air, or in the wall, drawing air from the storage space (Figure 11b).

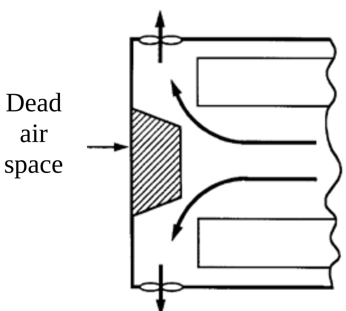

Figure 11a

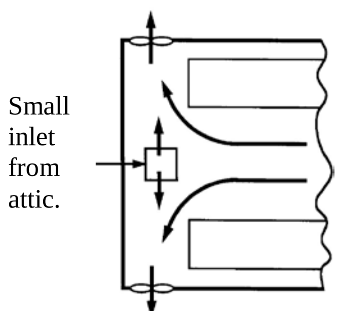

Figure 11b

Figure 12. In single-story barns, fans can be located in "fan dormers." Half of the fan capacity is located on either side above the animal level. The ceiling hole from the animal level into the fan dormer must be at least the same area as the design inlet area or the capacity of the fans will be decreased (Figure 12a).

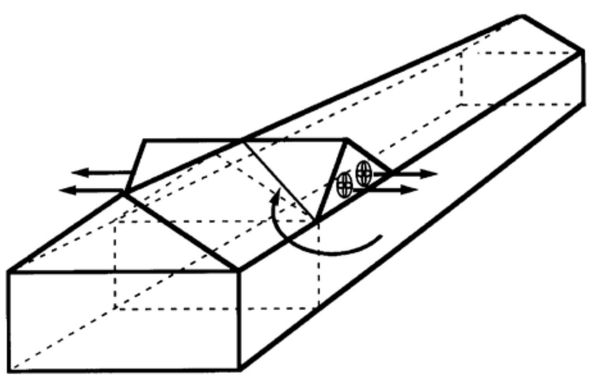

Figure 12

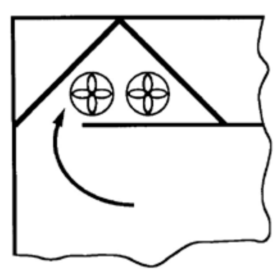

Figure 12a

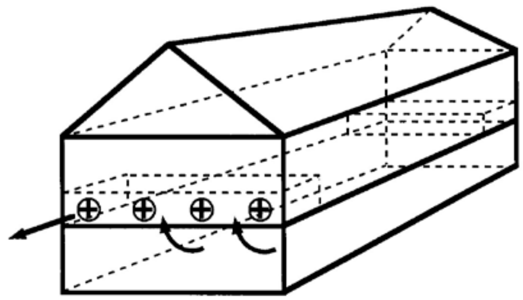

Figure 13

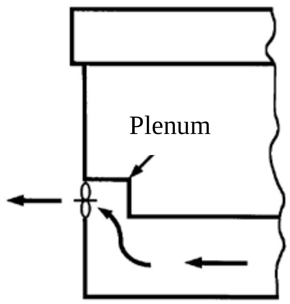

Figure 13a

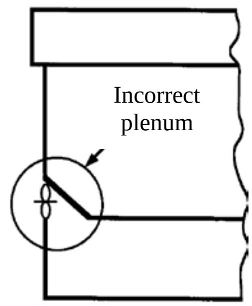

Figure 13b

Figure 13. Fan location in two-story barns may be limited due to thick concrete or stone walls, an earthen embankment, or the fact that doors and windows at the end of the animal area are used for animal movement and cannot be disturbed. Therefore, fans are often located in a plenum or "fan room." Placing fans in the second floor also tends to decrease fan noise in the animal area. The opening from the animal area into the plenum should run the entire width of the animal area and must be at least equal to the inlet area (Figure 13a). Locate the back of the plenum at least one fan diameter behind the fan so as not to effect fan performance. **Do not slope the plenum from the floor directly to the top of the fan, the fan will not perform as rated** (Figure 13b).

If a milk room or shed prevents fans from being placed directly in the end wall, two possible solutions exist. One is to duct air over the room to the end wall (Figure 14), and the other is to exhaust air through sidewall fans (Figures 15 and 16).

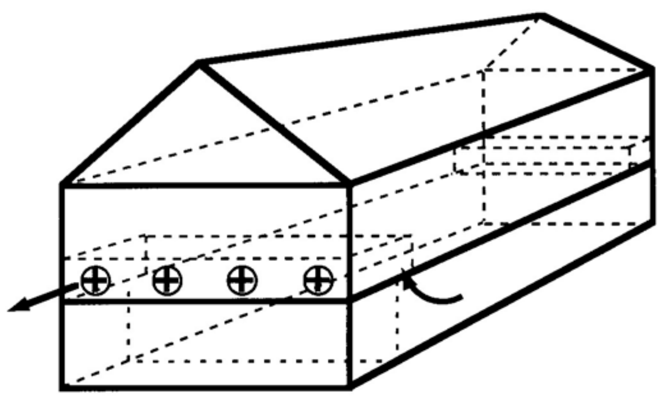

Figure 14

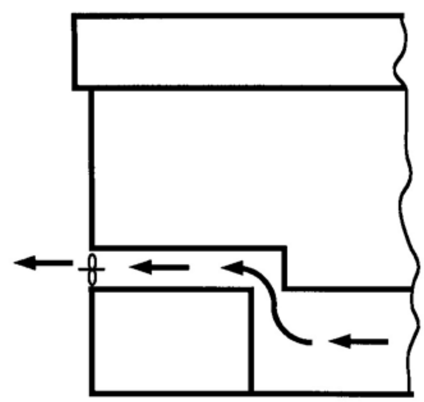

Figure 14a

Figure 14. If a duct is constructed over the room, the opening from the animal area to the duct and the area of the duct itself should be 10 to 15 percent larger than the inlet area. The opening into the fan duct should also be evenly distributed across the barn to provide even air flow. If the top of the duct is to be used for storage, use appropriate construction. The area of joists and supports used in the duct must be subtracted from the area of the duct (Figure 14a).

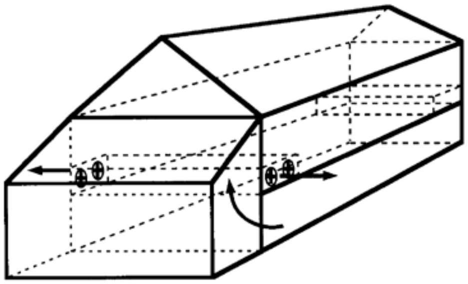

Figure 15

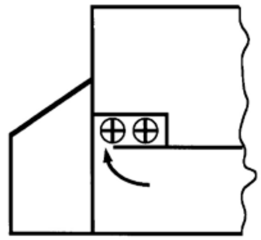

Figure 15a

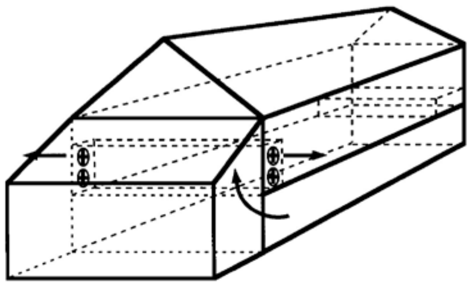

Figure 16

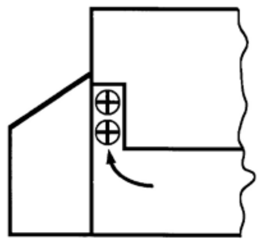

Figure 16a

If sidewall fans are used, a fan room must be constructed the full width of the barn connecting the fans with the animal space. The fans can either be positioned horizontally (Figure 15) or vertically (Figure 16). There is little difference in the performance of the two positions and is a construction decision. The ceiling hole from the animal level into the fan room must be at least the same area as the design inlet area, or the capacity of the fans will be decreased (Figure 15a, 16a).

SPECIAL BARNS

Barns that are L or T shaped are difficult to tunnel ventilate. When possible, use partitions to make rectangular spaces that can be easily ventilated. If the floor plan cannot be altered, then some trial and error will be necessary to provide good ventilation in all portions of the barns.

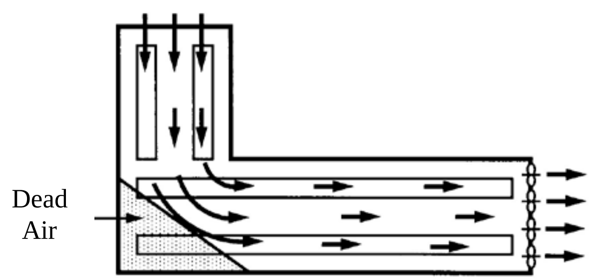

Figure 17

L-shaped barns are a particular problem. If the legs of the L are of different lengths, fans may be placed in the long leg and inlets in the short leg. However, a dead air pocket will be created at the L as air turns the corner (Figure 17). To minimize this problem part of the inlet can be located at the base of the L to provide fresh air to the dead space. A first trial is to place 25 percent of the inlet at the base of the L and 75 percent in the end wall (Figure 17a). However, this may need to be adjusted after the system is started to get the best air distribution. This will also decrease the air velocity in the short leg of the L. It may be necessary to increase air flow rate as well as install additional inlets to provide the desired conditions in all portions of the barn.

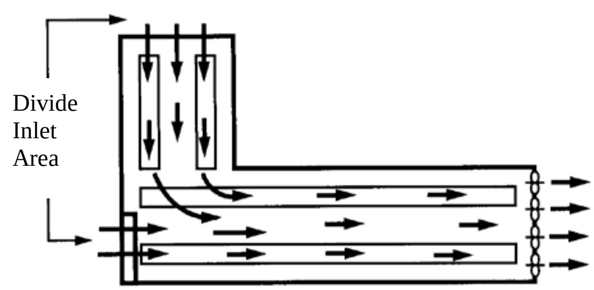

Figure 17a

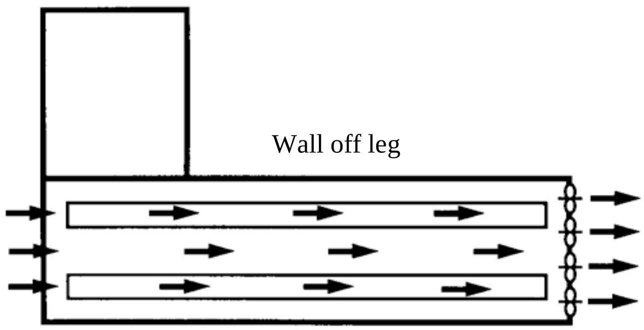

Figure 17b

If the shorter leg is significantly wider than the longer leg (i.e. more than 20% wider), this increases the potential size of the dead air pocket at the corner. The best alternative would be to wall off the wider leg and tunnel ventilate only the longer narrow leg and use an alternative ventilation system for the other (Figure 17b).

If both legs of the L are of equal length, another option is to place fans at the base of the L with inlets in both ends (Figure 17c) or fans in the ends and inlets at the base (Figure 17d). Each leg is designed as a separated system and works somewhat as an independent barn. This system will require twice as many fans to provide the uniform air velocity in all parts of the barn.

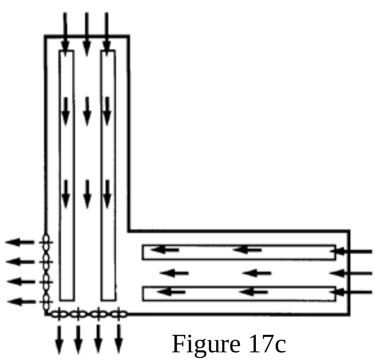
Figure 17c

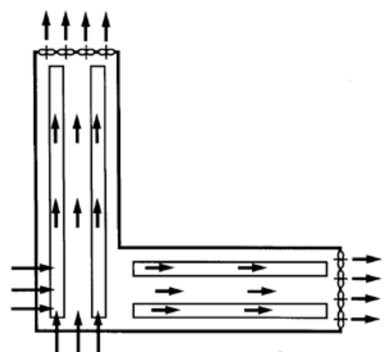
Figure 17d

SUMMARY

Tunnel ventilation is an effective means of providing increased air exchange and high air velocity for improved hot weather cow comfort. A tunnel ventilation system can be easily installed in simple unobstructed rectangular barn layouts. However, with some advanced planning, creative thinking, experimenting, and modification of inlet size and location, this type of ventilation system can also be installed in barns with obstructions or unusual shapes.

Related Information

Selecting Tunnel Ventilation Fans G-103 Agricultural and Biological Engineering
http://pubs.cas.psu.edu/FreePubs/PDFs/G103.pdf

Selecting Rated Ventilation Fans G – 85
http://pubs.cas.psu.edu/freepubs/pdfs/G85.pdf

Agricultural Ventilation Fans
www.bess.uiuc.edu

DPC-44 Guidelines for Mechanical Ventilation of Dairy Tie-Stall Barns
The Dairy Practices Council dairypc@dairypc.org

Worksheet for calculating required fan capacity and inlet size. (See Calculating Required Fan Capacity and Inlet Size at beginning of document)

Worksheet: ______cow tie stall barn, ______feet wide, ceiling height _______feet, barn length ________feet

A. Cross-section area: (width x height)

____ft. x _____ft. = ______ft.^{2}

B. Ventilation rate to provide 300 fpm air velocity inside barn: (cross section area x 300)

______ft.^{2} x 300 fpm = ___________cfm

C. Inlet size: (total ventilation x 2.5)

_________cfm x 2.5 ft.^{2}/1000 cfm = _______ft.^{2}

D. Check ventilation rate per animal: (should be more than 1000 cfm/animal)

_________ cfm ÷ ______animals = _________cfm/animal

E. Check air exchange (should be less than 45 seconds)

Animal space volume __________ ft. x __________ft. x __________ft. =_________cu ft.

__________cu ft. ÷ ___________cfm x 60 sec/min = ___________sec

Revised 06/2014

extension.psu.edu

Penn State College of Agricultural Sciences research and extension programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.