4. Air Circulation & Ventilation

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Purpose and Design – Air Circulation And Ventilation

Air circulation and ventilation systems on California dairies provide fresh air to dairy cows and diminish heat stress. The value and importance of providing a comfortable environment for the high producing dairy cow is demonstrated by the expanding use of air circulation and other cooling methods. The effects of heat stress on dairy cows has been well documented and includes:

- Reduction of feed intake
- Drop in milk production by 20-30%
- Increased susceptibility to mastitis and other diseases
- Reduced conception rates and other reproductive problems

Figure 4-1 on the following page provides a graphic illustration of the impact of temperature and humidity on stress levels for dairy cows. Numbers within the graph are wet bulb temperatures, °F.

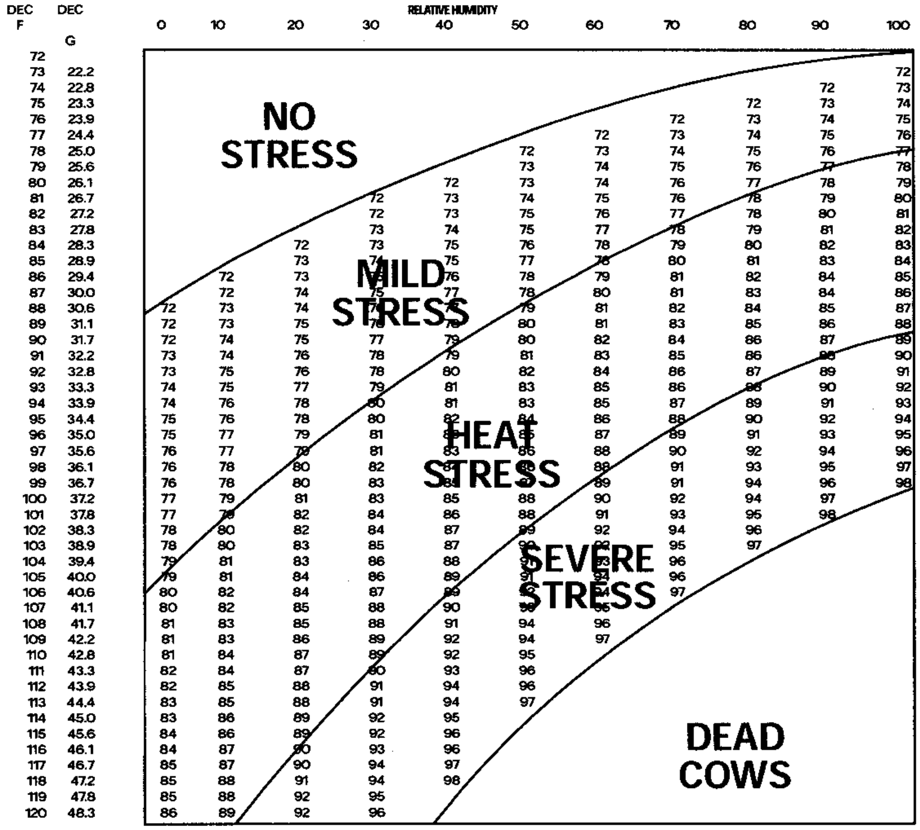

Figure 4-1. Temperature Humidity Indexes (THI)

(Smith, John, J.P. Harner, D. Dunham, J. Stephenson, J. Shirley, G. Stokker, M. Myer. "Coping With Sumnmer Weather – Strategies to Control Heat Stress", Publication MF-2319 Kansas State Universituy Agricultural Experiment Station and Cooperative Extension, March 1998)

To maintain and increase milk production levels, greater numbers of dairy farms are implementing options to mitigate the effects of heat stress. The energy used by these systems to provide air circulation, ventilation and evaporative cooling effects represents an increasing portion of the aggregate electrical energy consumed. However, in California, ventilation continues to be one of the smaller energy consuming functions on dairy farms. The rapid growth of cow comfort systems on dairy farms has occurred because of the magnitude of economic benefit that can be achieved. It is worthwhile to consider the energy management opportunities that exist for these systems.

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Heat Stress Reduction – Air Circulation & Ventilation

Freestall Resting Areas

To reduce the effects of heat stress on dairy cows a variety of measures have been developed that include:

- Natural ventilation
- Shading
- Circulation fans –basket, box, cyclone, high volume low speed fans
- Circulation fans with evaporative cooling - low pressure sprinkler & high pressure mister applications

Shading

Shading is a common method of heat stress reduction on Southern California dairies. Very simple structures with flat roofs or shade cloth covers provide a place for dairy cattle to get out of the direct sun. The shade structure casts a shadow in response to the movement of the sun throughout the day, and the cows are free to move with the shaded zone as the day progresses. Shading systems, like natural ventilation systems, do not require any input energy unless they are supplemented with mechanical air moving systems and/or misting systems to facilitate cooling.

Natural Ventilation

Natural ventilation of dairy housing structures is accomplished by building high-sided, open facilities oriented to take advantage of prevailing winds. If the building has a peaked roof, an open ridge provides a natural outlet to allow warm air to rapidly exit the building. Proper orientation of the building so that prevailing winds blow through the structure from one side to the other helps reduce temperatures for the livestock housed within. The advantage of natural ventilation systems is that there is no energy input. The major disadvantage is that when there is no wind, there is little or no air circulation or cooling effect within the structure.

In large resting barn structures, an open ridge is required to facilitate natural ventilation. The open ridge allows rising warm air in the building to quickly flow out of the structure. There are two types of open ridges. Conventional open ridges are wide open at the peak, with the opening as much as 3 feet wide. California style roof design features a high roof cap that covers a very wide open ridge. The roof cap edge overlaps the primary roof to help keep out rainwater. Warm air escapes out of the opening between the primary roof and the higher roof cap (see Figure 4-2). Studies have shown that the conventional open ridge design exhausts warm air more effectively than the California design.

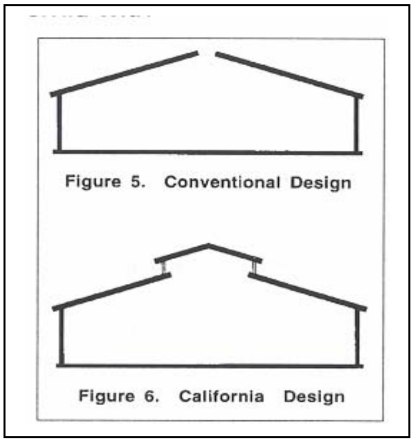

Figure 4-2. Typical Ridge Vent Designs

Circulation Fan Systems

The major users of electrical energy in circulation fan systems are electric motors used to drive various configurations of fans. Experts agree that heat stress in dairy cows begins when ambient temperatures reach 65°F to 70°F and relative humidity is 40% or higher. It is normally recommended that circulation fans should be turned on when temperatures reach 70°F in order to keep cows within their comfort zone.

Circulation fan systems include several different types of fans as shown in Table 4-1. All circulation fans common to dairy housing systems are axial flow propeller fans. They have flat, teardrop or airfoil shaped blades attached directly to a motor or to a motor and belt drive system. Most circulator fans (except the “basket” style) are mounted in a circular ring or an orifice panel to help control air flow through the fan. Overall fan efficiencies vary greatly, and performance is affected by numerous factors including:

- type of blades
- clearance between the blade tip and the fan housing or orifice
- the design of the fan housing and orifice panel
- speed at which the fan operates
- any obstructions to air flow including fan screens, guards, shutters, motor drive, etc.

Table 4-1. Common types of circulator fans and their characteristics

Fan Type	Typical Blade Design	Typical Housing Design	Type of Drive	General Operating Efficiency
Basket fan	Flat Stamped	Metal Basket guard	Direct drive	Low
Panel fan	Flat stamped Or airfoil	Simple circular orifice	Direct or Belt drive	Moderate
Box fan	Airfoil	Metal, wood or plastic box with orifice panel	Direct or Belt drive	Moderate To high
Cyclone/Funnel	Flat stamped or airfoil	Round, tubal Housing	Direct drive	Moderate
Low volume Low speed	Flat stamped or airfoil	None	Direct drive	Moderate
High volume Low speed	Airfoil	None	Direct drive	High

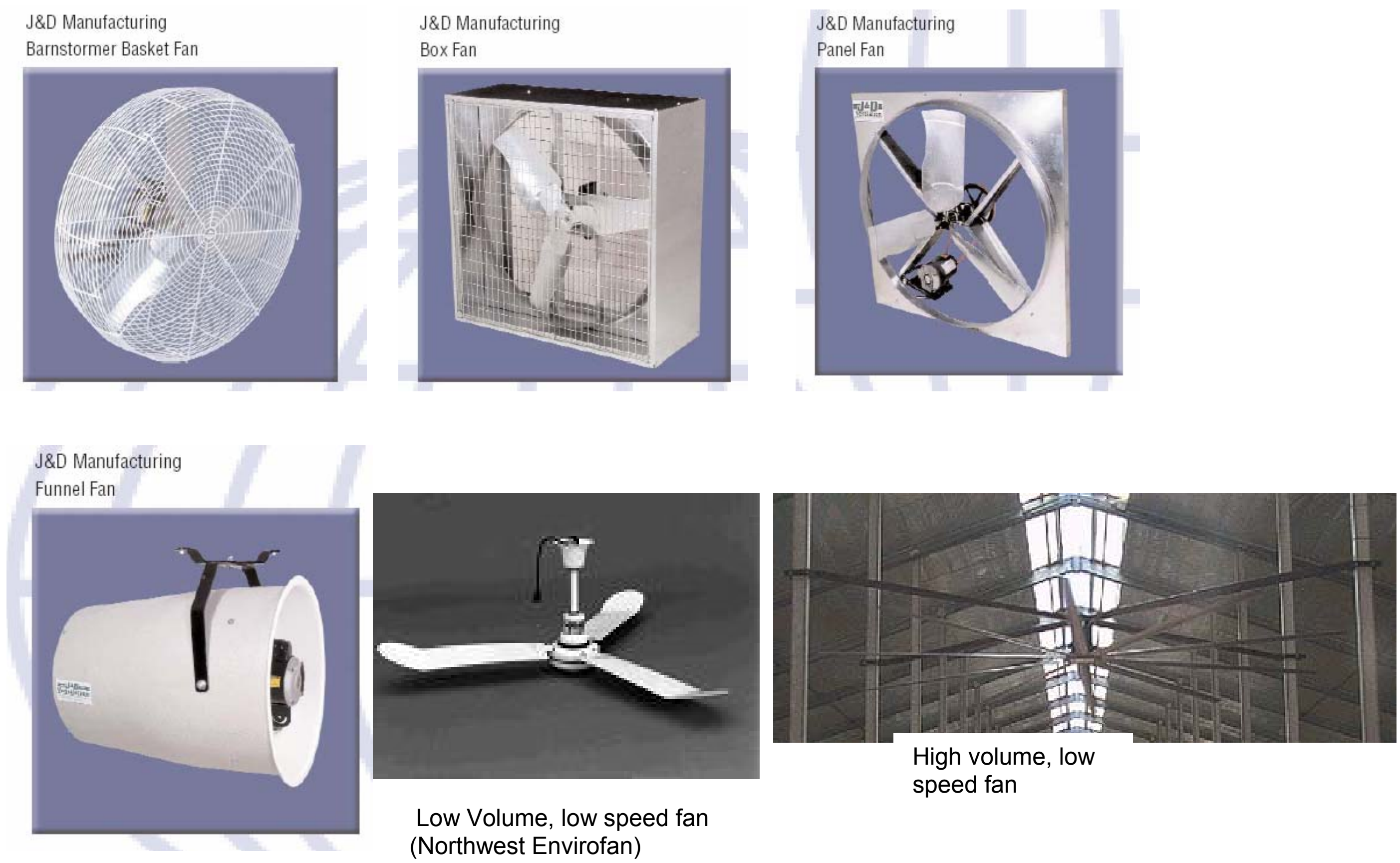

Figure 4-3 Six types of fans

Circulator fans generally operate at 0.0” static pressure or in free air. Thus, these fans will produce their highest airflow rate as determined by testing labs or the manufacturer.

Circulation fan placement in a livestock resting area is dependent on the type and size fan used. Panel and box type circulator fans are usually placed in rows above the feed alley and the freestall area and are spaced at ten times the diameter of the fan. Thus 3-foot diameter fans are spaced 30 feet apart, while 4-foot diameter fans are spaced 40 feet apart. Generally, about ten 4-foot circulator fans are required for each 100 cows in a freestall or resting barn. It is important to have air flow over feed alleys and each row of freestalls in a resting barn. In some instances, circulator fans are mounted under the eaves along exterior walls and aimed into the resting barn in the direction of prevailing winds

Figure 4-4. Example of circulator fans mounted over cows’ backs over the feed alley

Figure 4-5. Circulator fans mounted under the eaves and taking advantage of prevailing winds.

If ceiling mounted fans are considered (low volume, low speed [LVLS] or high volume, low speed fans [HVLS]), fan spacing is based on the size of the air pattern below the fan. Since HVLS fans are generally 10 to 20 feet in diameter, they are often located only down through the center of the building. In some cases this may be over the drive-through feed alley. Although research has shown that LVLS and HVLS circulation fan systems will save energy, it has not been shown that they provide proper air circulation at a high enough velocity to cool cows effectively, especially those cows that are not directly beneath a fan.

The energy used by these systems can be substantial because of the long hours of operation when warm temperatures occur. In southern California, circulation fans will operate 4000 hours or more annually. Energy conservation measures center on the selection of high efficiency fans and motors, carefully planned designs, implementing timely cleaning and maintenance programs and appropriate controls to operate only when conditions warrant.

Circulation Fan Systems with Evaporative Cooling

A dairy cow produces a large amount of heat, but she is not very efficient at dissipating that heat at temperatures above 70° F. If ambient temperatures are 60° F or below, a cow can dissipate excess body heat through convective, conductive and radiant heat transfers from the skin. However, at higher ambient temperatures (above 70°F), cows have to increase heat dissipation by panting. As a cow pants, she increases her breathing rate thus increasing of air flow through her lungs. Evaporative and convective heat transfer moves heat from her body in the exhaled air. However, only about 20% of the excess body heat can be dissipated this way. At high ambient temperatures (above 90° F), common much of the year in southern California, air circulation needs to be supplemented with evaporative cooling to keep cows comfortable.

Evaporative cooling in dairy resting barns uses the cooling effects of rapid air flow from circulator fans along with the cooling effects of evaporating water. There are two common types of systems used to provide cooling water:

- low pressure sprinklers and
- high-pressure misters

Low-pressure sprinkler or “soaker” systems spray water onto the cows’ backs until the hair coat is wet. The spray is then turned off and air moved over the hair coat by the circulator fans, which will cause the water to evaporate, thus cooling the skin of the cow. This cooling effect allows excess body heat to migrate to the cooler skin surface where it is dissipated by convection. The sprinkler systems are generally cycled so that water is sprayed onto cows’ backs for 3 minutes and then allowed to air dry for 12 minutes.

High-pressure misters provide cooling in a different way. Water is forced through special nozzles at high pressure (100 to 900 psi). The nozzle emits the water in the form of very fine droplets. These droplets will quickly evaporate in the air stream of the circulator fans, thus lowering air temperature in the building. The cows will be able to dissipate heat more effectively to the cooler air. Higher-pressure misters are not recommended because the water droplets are so quickly vaporized that their effects on cooling cows are minimized. At the lower end of high pressures (200 psi), the droplets are larger and provide a greater opportunity for cooling the air around the cow.

High-pressure misters are not recommended when the humidity is high, because little evaporation takes place and the air can become damp and foggy.

Spray or soaker systems on a proper on/off cycle are generally most effective in providing evaporative cooling. Care must be taken to locate sprinklers over areas where cows normally stand, and never over areas where cows lie down. The feed alley is a good place to install soakers because it will encourage cows to stand and eat longer, thus improving daily feed intake. Care must be taken to observe cycle times and evaporation rates to ensure that not too much water is sprayed. If excess water collects on the floor, too much water is being sprayed, and the excess moisture can provide a place for mastitis causing organisms to proliferate. Nozzles should be located 8 to 9 feet high and so that the majority of the water falls onto the middle of the cows' backs. Use nozzles that emit large drops of water at a rate of 0.1 to 0.5 gpm. Thus each nozzle will deliver 1.2 to 6 gallons of water during each 12 minute spray cycle.

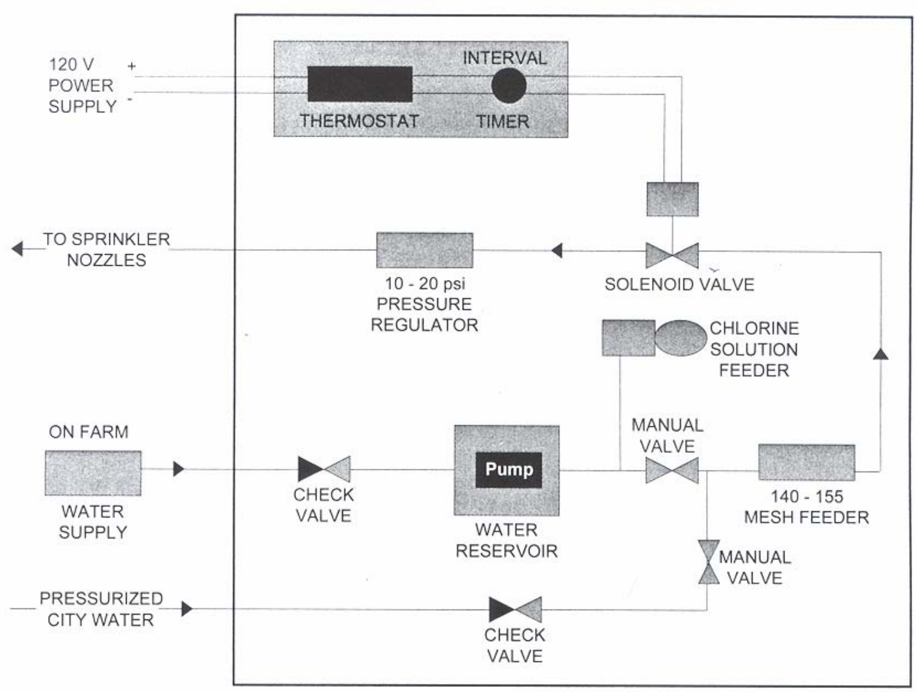

Figure 4-6. Schematic diagram of sprinkler system components

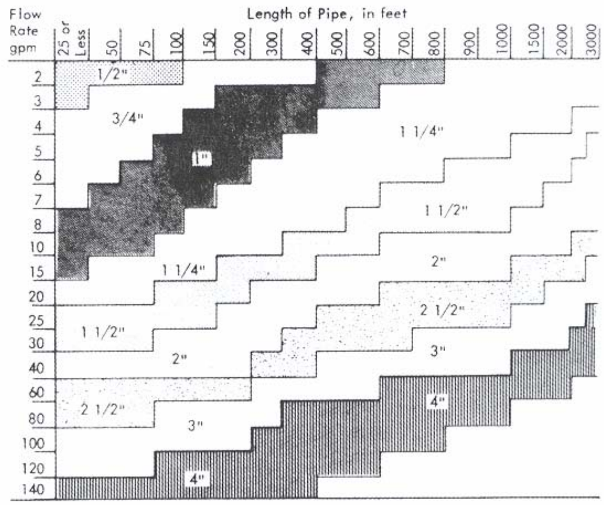

Figure 4-7. Recommended size of pipe based on required flow rate and length
(Source: Private Water Systems Handbook, MidWest Plan Service, Iowa State Univ.)

Circulator fans provide the airflow to enhance air circulation and cooling with the evaporative cooling systems. Fans should be arranged in the same pattern and with the same airflow rates as circulator systems without evaporative cooling.

Milking Center Ventilation

Milking centers require special considerations when designing ventilation systems. The challenge is that human operators, milking cows for 8 hours or more each day, have an entirely different comfort requirement than the cows passing through the holding area and milking parlor for their scheduled milking. Operator comfort is an important factor in maintaining productivity and a high level of job performance. However, ventilation in the milking parlor and holding area has to meet livestock comfort needs first.

Holding Area Ventilation and Cooling

The holding area has a critical cooling need. Large groups of cows stand in crowded conditions for as much as 30 to 60 minutes or more. Without cooling, cows' internal body temperatures can increase to levels of great discomfort quite rapidly. Thus, it is important to move large volumes of cooling air over the cows. Additionally, sprinklers (or misters in very arid climates) mounted over the cows in the holding area, coupled with airflow from fans will greatly improve cooling in very warm weather. Care must be taken not to use more water than will normally evaporate so that excessively wet conditions don't develop in the holding area.

Cooling fans should be mounted over the cows in the holding area and direct airflow away from the milking parlor. The fans should be tilted about 10° to blow air downward and over the cows' backs. As with any circulation system, the fans should not be spaced more than 10 times their diameter. Thus, 36-inch fans should be spaced no more than 30 feet apart.

Fans should be placed in rows 6 to 8 feet apart, starting at the milking parlor entrance and continuing over the entire length of the holding area. (see diagram below). If the ceiling height is limited so that fans cannot be placed above the cows, fans should be placed 6 to 8 feet apart in the holding area sidewalls and positioned to blow air across the holding area in the direction of prevailing winds.

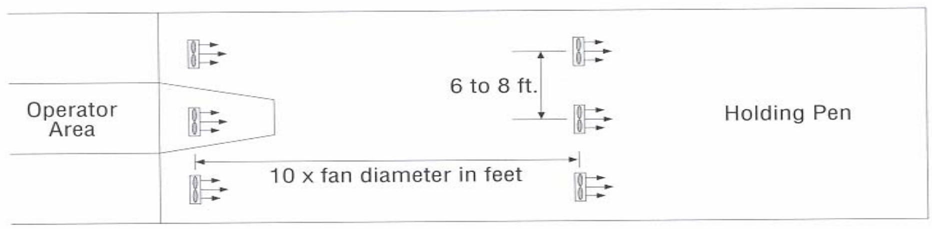

Figure 4-8. Preferred placement of fans for cooling cows within a holding area
(Source: *Building Freestall Barns and Milking Centers: Methods and Materials* (NRAES-148))

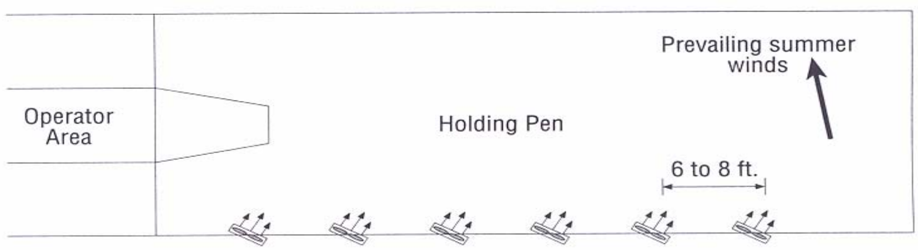

Figure 4-9. Compromised option for locating cooling fans when ceiling heights prohibit preferred arrangement
(Source: *Building Freestall Barns and Milking Centers: Methods and Materials* (NRAES-148))

Figure 4-10. Example of panel fans for cooling holding area

Milking Parlor Cooling

Generally, milking parlors can be cooled in the same manner as the holding area. If ceiling heights allow, fans can be placed in rows 6 to 8 feet apart facing the holding area. If ceiling height is limited, then cooling fans can be placed along the outside parlor wall, blowing across the parlor in the direction of prevailing winds. No sprinklers or misters can be used in the parlor because of sanitary concerns.

Figure 4-11. Example of panel fans for cooling milking parlor

Cooling Employee Break Areas and Offices

Offices and break areas in the milking center are best cooled by window-type air-conditioning units. This allows for a refreshingly cool environment totally separate from the environment in the rest of the milking center.

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Air Circulation & Ventilation Energy Utilization Indices (EUIs)

The majority of electrical energy used for air circulation will occur in the freestall barn where cows spend a majority of their time feeding and resting. Circulating fans are also employed in the holding area and in the milking parlor. The kilowatt-hours used per cow-year for operating circulation fans and evaporative cooling equipment establishes the air circulation EUI.

A practical range for air circulation EUI's on California dairies that have freestall barns and circulating fans would be from 100 to 175 kWh per cow-year. The overall level of the air circulation EUI is linked to the climate where the dairy is located and the extent to which circulating fans are used to counter the consequences of heat stress on dairy cows.

Examination of this EUI can be interpreted from a different perspective. A very low circulation EUI may not indicate a high level of efficiency, but more likely denote a lack adequate air movement to counter the effects of heat stress.

A relatively high EUI level may suggest that the dairy has instituted an aggressive approach to maintain cow comfort and controlling heat stress. Climate and microclimate will also dictate the particular level of air circulation EUI as level and duration of heat stress increases. Factors that will help reduce this EUI, while maintaining adequate air circulation include:

- Careful air circulation system design
- Selection of efficient fan blade design
- Use of high efficiency motors to power fans
- Application of an effective fan control system.
- Implementation of a scheduled cleaning and maintenance program.

Another indicator of general level of effectiveness for an air circulation system can be derived from the baseline recommendation of ten 4-foot circulator fans for each 100 cows in a freestall resting barn. These 10 fans would have a total connected load of 9325 watts (746 watt/hp, 80% motor efficiency) or an installed fan capacity of 93 watts per cow. Based on this guideline, a freestall barn housing 500 cows will require 50 fans with a connected load of 46.6 kW.

Parlor & Holding Area Air Circulation EUI – Electrical energy use for parlor & holding area air circulation typically falls in the range of 10-20 kWh per cow-year. Achieving the most effective air circulation EUI for these areas will also be influenced by the above factors.

Since the milking operation may occur almost around the clock the total hours of use will exceed that in the freestall.

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Air Circulation & Ventilation Energy Conservation Measures (ECMs)

Fan Selection Criteria

The Bioenvironmental and Structural Systems (BESS) Laboratory, Department of Agricultural Engineering, University of Illinois provides extensive fan test data to assist in the selection of efficient fans for dairy ventilation and circulation systems. They have identified important fan selection criteria:

- Quantity of air that must be moved at different static pressures
- Energy efficiency comparisons among fans
- Quality of dealer service and support
- Reliability and life of fans
- Suitability for intended application
- Cost

The quality of dealer service and support is best judged by the farm operator based on his/her experience with local suppliers. Reliability and life expectations of equipment are dependent on many factors such as quality of construction, how the equipment is installed and used, and maintenance. Information provided at the beginning of this section will help identify suitable fans for the intended application.

Fans vary significantly in energy efficiency and air moving performance. BESS Lab tests of commercially available 36 inch diameter fans indicate that air delivery can vary by as much as 100% when comparing low performance fans to high performance fans. When selecting 36 inch diameter fans, look for efficiencies in the 16 to 18 cfm/watt range. When 48 inch diameter fans are compared, the variation from low to high performance fans can be as much as 600%. When selecting 48 inch diameter or larger fans, look for efficiencies in the 21 to 23 cfm/watt range. It is important to compare uniform fan test results from the same test facility (either the BESS Lab or the Air Movement and Control Association International, Inc. (AMCA). If inefficient fans are purchased and installed, the excess operating costs in just 2 to 3 years could exceed the extra cost of a high efficiency fan.

The cost of a fan is not a good selection criteria on its own. The old adage, “you get what you pay for” is very appropriate when choosing fans. After you identify fans of different manufacturers that meet your performance and efficiency criteria, then cost comparison makes sense. Because fans run long hours over a period of years, the excess energy costs of a low efficiency, low cost fan will far exceed any initial purchase cost savings. Consider all fan purchases as an investment that deserves careful selection considerations and performance comparisons.

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Operator Level Checks - Air Circulation & Ventilation

Fan Maintenance

Dairy ventilation/circulation systems require scheduled maintenance. Poor maintenance can reduce fan efficiency by as much as 40%. Cleaning of fan parts, especially the blades, can improve long-term efficiency. Accumulation of as little as 1/8" of dirt on the fan blades can significantly reduce fan performance. Proper lubrication of bearings and other moving parts will keep performance levels high and reduce energy costs.

Bent, damaged or misaligned fan blades should be repaired or replaced. Bent or damaged blades will cause rotational imbalances that reduce fan life and performance. Repairing or replacing the blade is far less costly than purchasing a new fan.

The following fan maintenance procedures should be performed at least monthly to maintain peak fan performance:

- Disconnect power to the fan before performing maintenance.
- Remove all dust accumulated on controls and motors using a small blower, vacuum, or stiff paint brush.
- Remove all dust and dirt build-up from fan blades, fan housing, shutters and guards with a warm detergent solution. Thoroughly dry the fan parts after cleaning.
- Lubricate all pivot points of shutters with a fine grade machine oil. If motor does not have sealed bearings, lubricate the bearings following manufacturer's recommendations.
- Check all wiring from the service panel to each fan to make sure there are no damaged wiring components. Make sure the service entrance ground is adequate. Have a qualified electrician repair or replace any damaged wiring components.
- For belt-drive fans, make sure that pulleys are properly aligned and that the belt has proper tension. Replace any worn belts.
- Reattach all guards before turning power back on.
- If fans are thermostatically controlled, compare the thermostat with a reliable thermometer.

As a measure of long-term fan system performance of circulator systems, use an air velocity meter to determine initial performance of a new installation. A periodic check of air velocity with the same meter is a good way to establish a maintenance schedule and to detect reductions in overall system performance.

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Glossary of Air Circulation and Ventilation Terms

AMCA: (Air Movement and Control Association International, Inc.) A trade association of fan manufacturers. AMCA does testing of fans and associated equipment for its members and publishes the results.

Airflow Rate: Air movement or delivery rate generally expressed as cubic feet per minute (cfm). Also know as air velocity.

BESS Lab: (Bioenvironmental and Structural Systems Laboratory) An independent public university operated laboratory that provides testing of fans and publishes the resulting performance data. The BESS Lab is located at the University of Illinois, Department of Agricultural Engineering.

Btu: (British thermal unit) The quantity if heat energy required to raise 1 pound of water 1°F.

Cfm: Cubic feet per minute. A term used to express airflow rate.

Conductive Heat Transfer: The process by which heat is transferred from one location to another in a body due to a temperature gradient. Heat flows from the warmer area to the cooler area of the body.

Convective Heat Transfer: The process by which heat is transferred from a body to a fluid by passing the fluid over the body.

Degree Of Saturation: The ratio of the weight of water vapor to the saturated weight of water vapor per pound of dry air at the same temperature and barometric pressure. The ratio is also known as relative humidity.

Dewpoint Temperature: The temperature at which moisture begins to condense from air cooled at constant barometric pressure and humidity ratio.

Draft: Combination of air temperature and velocity, which cause thermal stress in livestock. Effects of draft vary with the weight and age of the livestock. Younger animals are more adversely affected by drafts.

Dry-Bulb Temperature: Temperature of air or a body measured with a conventional thermometer.

Evaporate: Process of transforming a liquid to a vapor, such as transforming water to steam.

Evaporative Heat Transfer: Heat energy exchange, which occurs during evaporation. Example is the cooling of warm livestock as water evaporates from the skin.

Fahrenheit (F): Temperature scale with the freezing point of water at 32° and the boiling point at 212°.

<u>Fan</u>: A mechanical device used to move air.

<u>Fan Efficiency</u>: The measure of a fan's output (airflow or cfm) divided by its energy input (electrical energy or watts). Fan efficiency is measured in cfm per watt, which indicates how much air can be moved in one minute by one watt of electric energy input.

<u>Heat</u>: A form of energy, which can be transferred from a body of higher temperature to one of lower temperature.

<u>Heat Transfer</u>: The process of heat energy transport by means of conduction, convection, radiation, evaporative heat transfer or condensation.

<u>Humidity</u>: Moisture contained in the air.

<u>Inlet</u>: Structural opening through which ventilation air enters.

<u>Insulation</u>: Any material that reduces heat transfer from one body to another. Insulation under the rood of a livestock shelter will reduce the transfer of heat from the roof into the cooler area within the shelter.

<u>Mechanical Ventilation</u>: The process of forcing air through a building using mechanical equipment such as fans.

<u>Natural Ventilation</u>: The process of forcing air through a building or shelter using prevailing winds and the thermal buoyancy of air.

<u>Negative Pressure Ventilation</u>: A mechanical ventilation system where fans are used to pull air out of a building, which creates a negative pressure inside the building, thus facilitating the entry of fresh air through an inlet system.

<u>Positive Pressure Ventilating System</u>: A mechanical ventilating system where fans blow air into a structure creating a positive pressure.

<u>Radiant Heat Transfer</u>: The process by which heat is transferred from one body to another by electromagnetic waves such as an animal radiating heat to a cool wall surface.

<u>Relative Humidity</u>: The ratio (expressed as a percent) of actual water vapor pressure in the air to the vapor pressure at saturation at the same temperature and pressure.

<u>Saturated Air</u>: A condition where air can hold no additional water vapor (expressed as 100% relative humidity).

<u>Sensible Heat</u>: Energy absorbed or released by a material that results in a temperature change. For example, an animal losing heat to a cooler surface with which it is in contact.

<u>Sling Psychrometer</u>: A temperature-sensing instrument containing a wet bulb and dry bulb thermometer. By measuring the wet bulb and dry bulb temperatures simultaneously, a psychrometric chart can be used to obtain the humidity ratio, relative humidity, and dewpoint temperature.

Spread: The width of the air pattern at specific distances away from the discharge of the fan.

Static Pressure: The difference in pressure between inside and outside of a building, ventilation fan or air inlet. Static pressure is measured in inches of water.

Temperature: A measure of a body's ability to give up or receive heat.

Thermal Buoyancy: The effect of warm, less dense air being buoyed up by cool, more-dense air. Naturally ventilated buildings depend on thermal buoyancy to remove warm air.

Thermostat: An electro-mechanical device for controlling the operation of heating or cooling equipment to regulate air temperature within an area.

Throw: The velocity of the air at specific distances away from the discharge of a fan.

Ventilating Rate: Airflow rate passing through a building measured in cubic feet per minute (cfm). The airflow rate is usually controlled by fans in a mechanically ventilated building.

Ventilation: The process of exchanging air. In livestock buildings, ventilation is used to control temperature, moisture, odors, pathogenic organisms and dust.

Wet Bulb Temperature: The temperature measured by a thermometer whose bulb is covered by a wet wick and exposed to an air stream with a velocity of 1000 ft./min. The wet bulb temperature is a function of the rate of water evaporation from the wet wick and its resultant cooling which is dependent on the water vapor content in the air.

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