Cooling Inlet Air in Low Profile Cross Ventilated Freestall Facilities

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TAKE HOME MESSAGES

- Evaporative cooling is effective in lowering the ambient air temperature of a low profile cross ventilated freestall building.
- In the Upper Midwest where the relative humidity tends to be above 50%, air temperatures inside an LPCV building are consistently 8 to 15 ^{o}F cooler than the ambient temperatures after evaporative cooling. The temperature differential is a function of relative humidity.
- Evaporative pads and high-pressure mist systems are two commons systems for cooling incoming air in a low profile cross ventilated freestall building.

INTRODUCTION

Cooling the air inside a low profile cross ventilated facility requires the consideration of several factors. Outdoor air temperature, relative humidity, and the evaporative cooling system all affect the indoor temperature of the buildings.

Because air temperature decreases and humidity increases as moisture is added to the air, the lowest temperature occurs when the air is at 100% humidity, or saturation. If two air streams are at the same temperature but have different relative humidity levels, the stream with less humidity is able to be cooled to a lower temperature than the stream with high humidity.

The air-water vapor properties of air provide a method to determine the temperature drop of an air stream after passing through an evaporative cooling system. The dry bulb temperature is the measurement of the air temperature with a thermometer or reported by a weather station. This temperature is measured with a dry wick, or bulb, on the thermometer. The wet bulb temperature may be calculated using the air-water vapor equations if the relative humidity is known. The wet bulb temperature is measured by placing a “wet” wick over the bulb of a thermometer. The dry and wet bulb temperatures are equal at 100% relative humidity, so if an evaporative cooling system is 100% efficient, then the dry and wet bulb temperatures are equal and the relative humidity is 100 percent. This state point provides an estimate of the maximum cooling potential of the air.

Figure 1 shows the wet bulb temperature for air at different dry bulb (ambient) temperatures and relative humidities. Cooling potential is the difference between the dry and wet bulb temperatures. If the temperature is equal, the cooling potential decreases as the relative humidity increases. The greatest cooling potential is observed at a higher air temperature and a lower humidity**.**

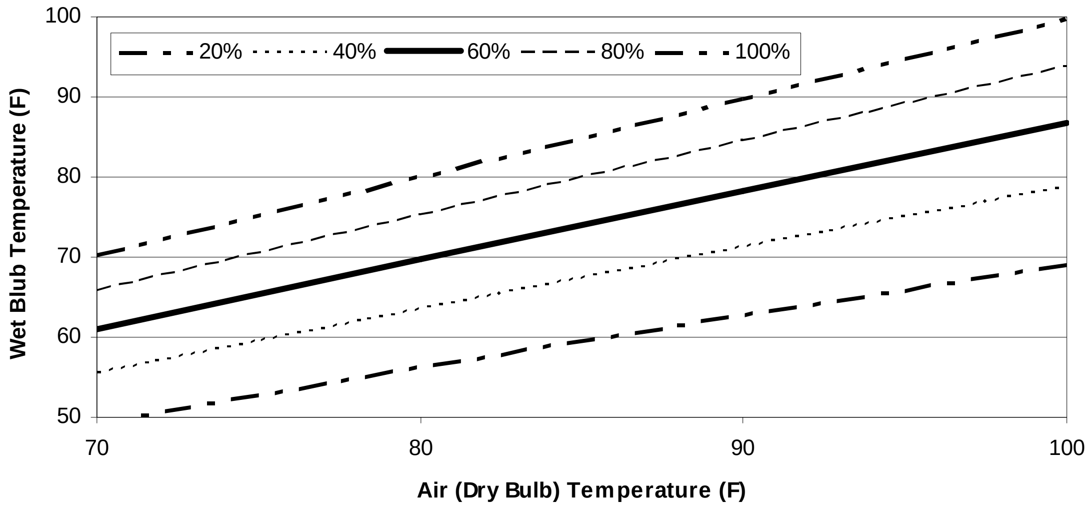

Figure 1: Impact of Air Temperature and Relative Humidity on Wet Bulb Temperature

The temperature humidity index (THI) is used as an indicator of heat stress. Cows begin to experience heat stress at a THI value of 70 and above. Figure 2 shows the THI values for different temperatures and relative humidity. The THI index exceeds 70 anytime air temperatures exceed 80 ^{o}F, irrespective of relative humidity. Relative humidity influences the THI index when temperatures are between 70 and 80 ^{o}F.

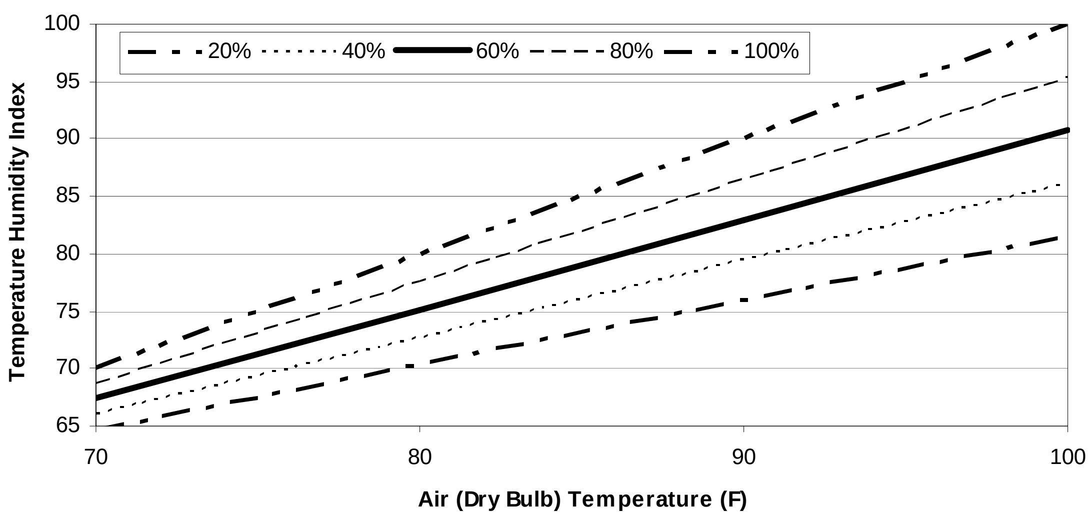

Figure 2: Impact of Air Temperature and Relative Humidity on Temperature Humidity Index

DATA FOR SIOUX FALLS, SOUTH DAKOTA

Figure 3 shows the temperature, relative humidity and temperature humidity index (THI) for Sioux Falls, SD on July 10, 2008. The relative humidity decreases during the afternoon hours as the temperature increases. Data shows that humidity levels are highest around 6:00 a.m. and lowest around 6:00 p.m., which means the temperature is lowest in the morning and highest during the late afternoon. The critical period for heat abatement and cooling cows is when the temperature humidity index is above 70. As Figure 3 shows, when the THI is above 70, the humidity is less than 70 %. As the THI increases, the humidity decreases. Figure 4 charts the weather in Sioux Falls, SD from July 10 to 16, 2008. Similar temperature-relative humidity patterns are observed throughout the week, as compared to data collected on one day in Figure 3.

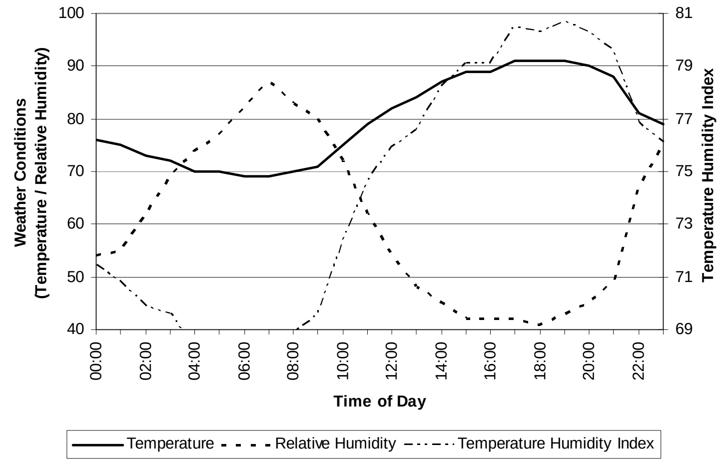

Figure 3: Weather Conditions for Sioux Falls, SD on July 10, 2008

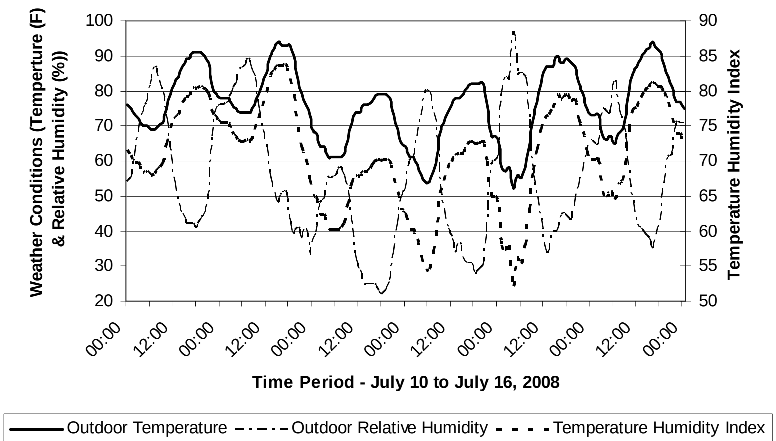

Figure 4: Weather Conditions for Sioux Falls, SD from July 10-16, 2008

Figure 5 plots the relative humidity and wet bulb temperature in comparison to the actual air temperature in Sioux Falls, SD for the week of July 10-16, 2008. The wet bulb temperature is defined as the potential temperature to which the air could be cooled, assuming a cooling system is 100% efficient, or creating 100% relative humidity level in the air. The trend line illustrates a decline in relative humidity as outdoor temperature increases.

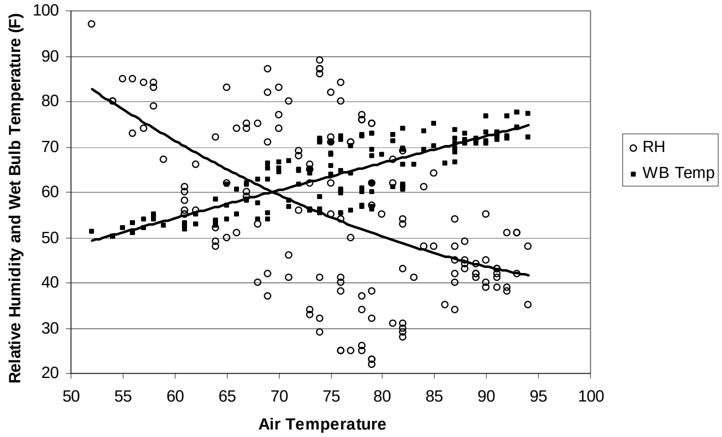

Figure 5: Relative Humidity, Wet Bulb Temperature, and Air Temperature from July 10-16, 2008, in Sioux Falls, SD

Figure 6 shows the potential temperature drops in Sioux Falls, SD that could occur, assuming 100% efficiency of a cooling system. The temperature drop varies at a given temperature because the relative humidity changes.

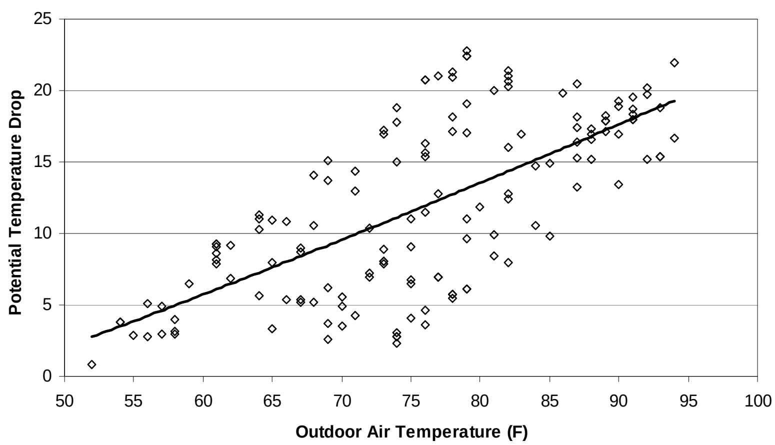

Figure 6: Potential Temperature Drops from July 10 -16, 2008, in Sioux Falls, SD

A comparison of minimum THI and outdoor THI is shown for Sioux Falls, SD in Figure 7. As the data demonstrates, the outdoor temperature humidity index is generally above 70 when the air temperature exceeds 72 ^{o}F. The minimum temperature humidity index occurs if the cooling system is 100% efficient. However, maintaining the environment at a THI of 70 or lower is possible even if the cooling system functions with less efficiency. The THI index should be below 72 anytime the outdoor air temperature is 85 ^{o}F or less.

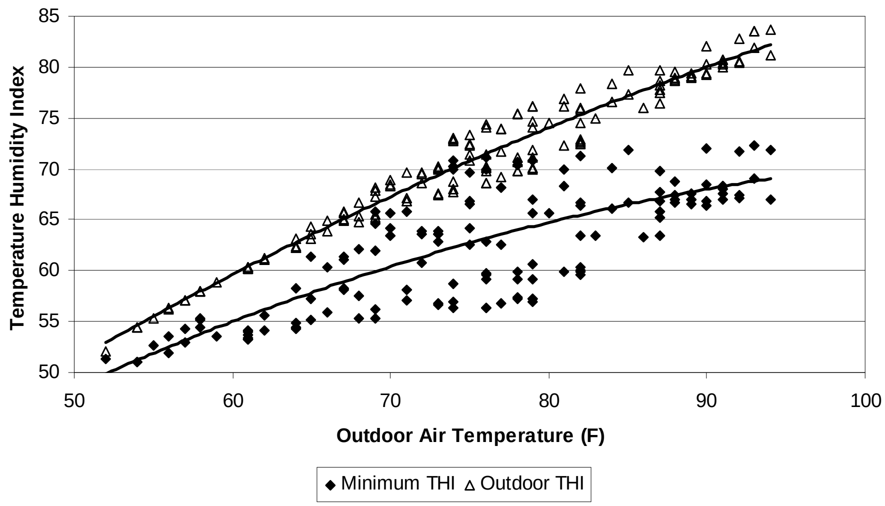

Figure 7: Minimum and Outdoor THI at Different Temperatures from July 10-16, 2008, in Sioux Falls, SD

COOLING SYSTEM FUNCTION

The cooling potential of any system is dependent upon the air's ability to absorb moisture. Lower relative humidity results in a lower air temperature inside the LPCV buildings. There are currently two systems used for cooling facilities: evaporative pad cooling and high-pressure mist systems. Evaporative cooling is currently the most common method for cooling LPCV buildings. Evaporative cooling results from warm air coming into contact with a high-pressure stream of moisture or a wetted surface, and the system is designed so no heat is added or lost from the air.

EVAPORATIVE PAD COOLING SYSTEM

The evaporative pad is a saturated cellulous material with channels that allow air to encounter moisture as it passes through the openings. Water is distributed along the top of the pad and flows down through the cellulous material, causing it to become saturated. Excess water at the bottom of the pipe is collected and recycled back to the top. Construction of evaporative pad cooling systems necessitates equal distribution of air through the pad and uniform temperature drops. Most evaporative cooling system designers assume the ideal air temperature is reached when the air absorbs 75 % of the available moisture. Figure 8 shows a graph of typical pad efficiencies for various face velocities and pad thickness. Manufacturers recommend limiting face velocity to 400 feet per minute (fpm). A 6 inch pad is commonly selected due to economics. The decrease in air temperature across an evaporative cooling system is a function of the relative humidity.

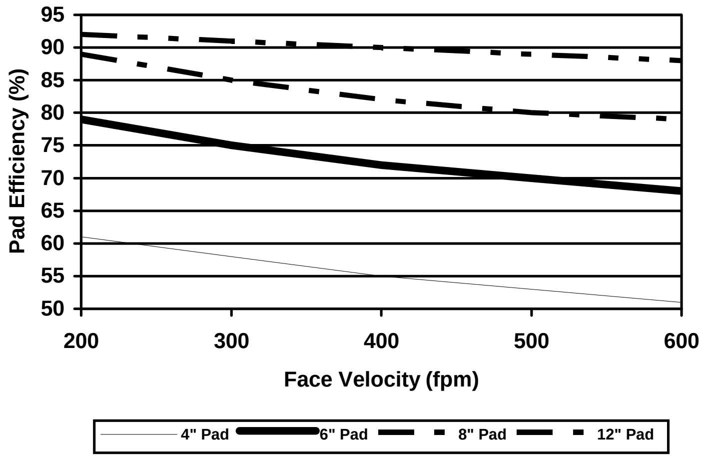

Figure 8: Impact of Face Velocity and Pad Thickness on Evaporative Pad Efficiencies (adapted from Anon, 2008).

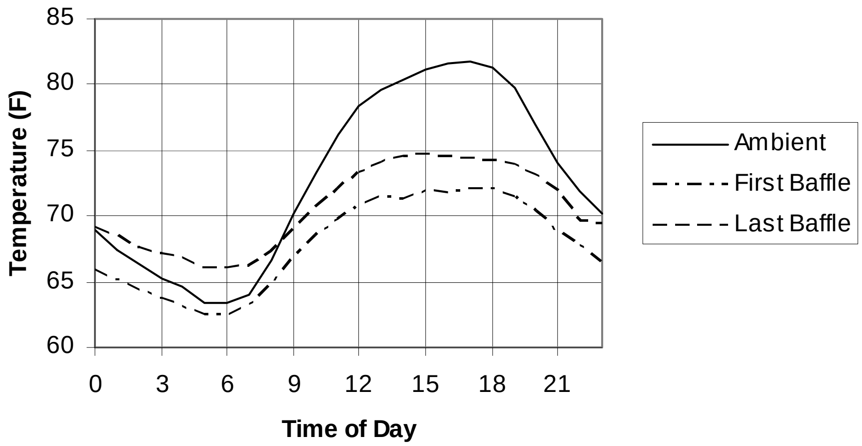

Figure 9: Impact of an Evaporative Cooling System on Air Temperature at the First and Last Baffle Over a 30-day Period

The hourly average temperature differences between the first baffle in an LPCV building and ambient air, as shown in Figure 9, illustrate the cooling potential of an evaporative pad. On average, the evaporative pad cools the air 8 to 13 ^{o}F during the afternoon hours. The cooling potential increases as the relative humidity decreases.

The performance of evaporative pads in LPCV facilities has been studied to determine water usage, changes in temperature, humidity, and THI. Water usage ranges from 0.3 to 0.4 gallons per hour per square foot of an evaporative pad area.

EVAPORATIVE PAD STUDY

Water usage per square foot of an evaporative pad for a dairy in Kansas was compared to a research dairy in North Dakota in the summer of 2006. As Figure 10 shows, similar water usage was observed between the Kansas dairy and the medium airflow rate at the North Dakota dairy.

Measured airflow rates were 320 feet per minute (fpm) through the pads at the Kansas site and 282 fpm in the medium airflow rate study. Water usage by the pad did not increase in proportion to the airflow rate. When comparing the high and medium airflow rates, the difference in air velocity was 47%. However, the increase in water usage of the evaporative pad was only 27% greater.

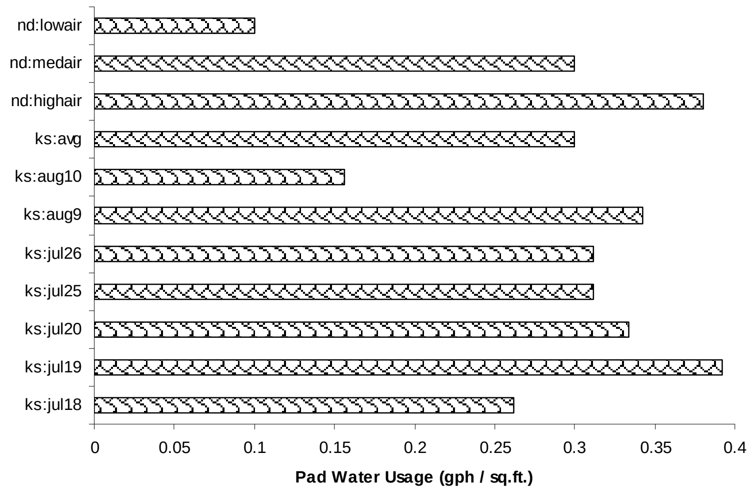

Figure 10: Evaporative Pad Water Usage at a Kansas (ks) and North Dakota (nd) Study Dairy (gph/sq.ft. = gallons per hour per square foot of evaporative pad surface)

At the North Dakota site, measured airflow rates through the pad averaged 106, 185, and 282 fpm for the low, medium, and high airflows, respectively. Per cow, water usage was 0.45, 1.37, and 1.75 gallons per hour while the evaporative pad was operating. Consumptive water use for each 15-minute period equaled 30.1 gallons for low airflow rate, 91.5 gallons for medium airflow rate, and 115.7 gallons for high airflow rate for a pad measuring 10 feet tall and 330 feet long.

HIGH-PRESSURE MIST SYSTEMS

High-pressure mist systems are an alternative to the evaporative pad cooling systems. The high-pressure mist system sprays fine droplets of water into the air stream, so the potential exists for non-uniform air temperature drops from the top to bottom along the sidewalls. This problem is overcome by installing multiple rows of nozzles. As air passes each row of nozzles, the droplets fall further down into the air stream until the air is able to absorb moisture. The multiple rows of nozzles also allow an automated controller to determine the number of nozzles operating and the volume of water sprayed into the air stream based on ambient relative humidity. Water droplets that are not evaporated either drift and exhaust through the fans or fall to the floor. The controller conserves water by limiting the number of nozzles operating to the estimated water that may be absorbed by the air.

A typical nozzle of a high-pressure mist system has a flow rate of 0.03 gallons per minute (gpm) for a high-volume nozzle, or 1.8 gallons per hour (gph). At 75% efficiency, the actual water absorbed by the air equals 1.4 gph. Therefore, one high-pressure mist nozzle is equal to about four square feet of evaporative pad, assuming equal efficiencies. As a result, either a 10-foot evaporative pad or approximately 2 1/2 high pressure nozzles are required per running foot of building length, assuming equal performance.

The high-pressure system provides an open sidewall with a curtain-controlled inlet that operates from September to May. It allows some natural light to penetrate into the building which impacts the orientation requirement of the LPCV structure. One high-pressure mist distributor assumes the air temperature exiting the system equals the wet bulb temperature, minus 3 ^{o}F. At 100% relative humidity, the wet bulb temperature equals the dry bulb (ambient) temperature. These systems are being used in the southeast part of the United States in conventional tunnel ventilated freestalls, along with poultry houses.

The high-pressure mist system also requires an understanding of the aerodynamics of particles. Figure 11 shows the influence of air inlet velocity on exhaust time in an LPCV building. An increase in inlet velocity decreases the time required to move air from the inlet to the outlet, or exhaust fans. The horizontal lines show the time required for a 10, 30 and 100 micron water drop to fall 10 feet based on the terminal velocity of the droplet at a given size. A water droplet of 20 microns requires 254 seconds to fall 10 feet, while a 100 micron droplet requires 10 seconds.

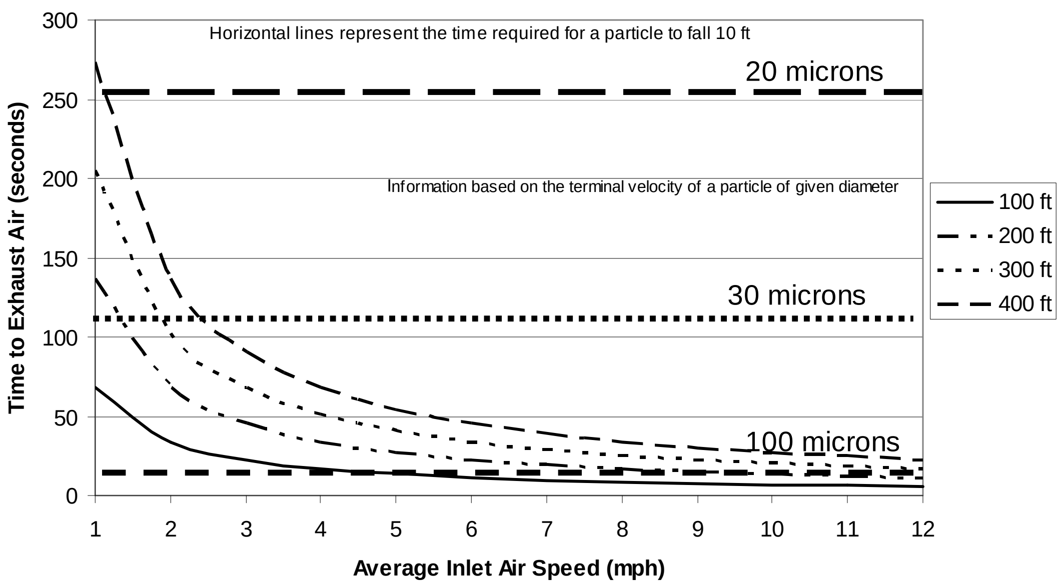

Figure 11: Influence of Inlet Speed, Exhaust Time, and Time Required for Different Size Particles to Fall

High-pressure nozzles create water droplets of 10 to 20 microns. Reducing the water pressure conserves water, but the water droplet size also increases. If the air inlet velocity is 3 miles per hour (mph), a 20 micron particle travels horizontally over 1,000 feet before falling 10 feet. Therefore, 10 to 20 micron particles tend to remain suspended in the air and be exhausted if not absorbed or evaporated.

Figure 12 shows the duration of a water droplet as a function of the droplet size for 0, 50 and 100% relative humidity at 68 ^{o}F (Hinds, 1999). As humidity or particle size increases, the droplet lifetime increases. A 20 micron diameter water droplet evaporates in approximately 1 second at

50% relative humidity. However, at 70% humidity, the same droplet takes 20 seconds to evaporate.

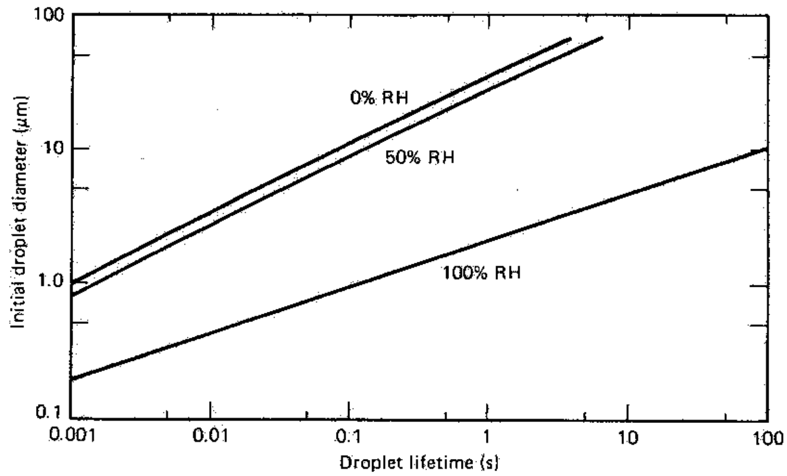

Figure 12: Impact of Relative Humidity and Droplet Size on Droplet Lifetime at 68 ^{o}F (Hinds, 199)

High-pressure mist lines are often installed beneath the roof of a building where the droplets are sprayed from the lines into the atmosphere, and the air stream absorbs the moisture. Lines installed beneath the ceiling depend on a certain percentage of particles to fall into the lower air stream, or cow area, since the air flow across the building is laminar. Laminar flow occurs when air entering at the top of the inlet remains below the roof without mixing with air near the bottom as it moves across the building. The air temperature near the floor remains high if the air is cooled in the upper air stream only and water particles are exhausted from the building before they have time to fall 10 feet. Larger particle sizes may fall to the floor prior to being absorbed into the air stream. Therefore, mixing the air stream beyond the inlet is critical for uniform cooling.

Figure 13 shows the influence of pressure on high-pressure mist nozzle capacity. For this specific nozzle, reducing the pressure from 1,500 pounds per square inch (psi) to 1.000 psi reduces the water requirements from 0.024 gpm to 0.019 gpm. This reduces water consumption by 21%, resulting in less moisture available for evaporative cooling. If adequate water supply is not available, reducing system pressure to lessen water usage has a negative impact on the cow's environment.

COOLING SYSTEM MAINTENANCE

Water quality is important to the performance of both cooling systems. Minerals in the water system result in plugged nozzles if the nozzle orifice is too small or scaling on evaporative pads. Minerals and lack of maintenance lessen the performance of evaporative cooling systems. Therefore, both systems require periodic maintenance to ensure optimum performance. Reverse osmosis, or a similar treatment process, which removes minerals from the water, is the recommended treatment method. Because adequate quantity and quality of water is essential, clear communication between the cooling system and water treatment manufacturers is extremely important. The supplier of the cooling system must also convey to the engineer(s) or designer(s) the water usage and water demands. The water system may then properly be designed

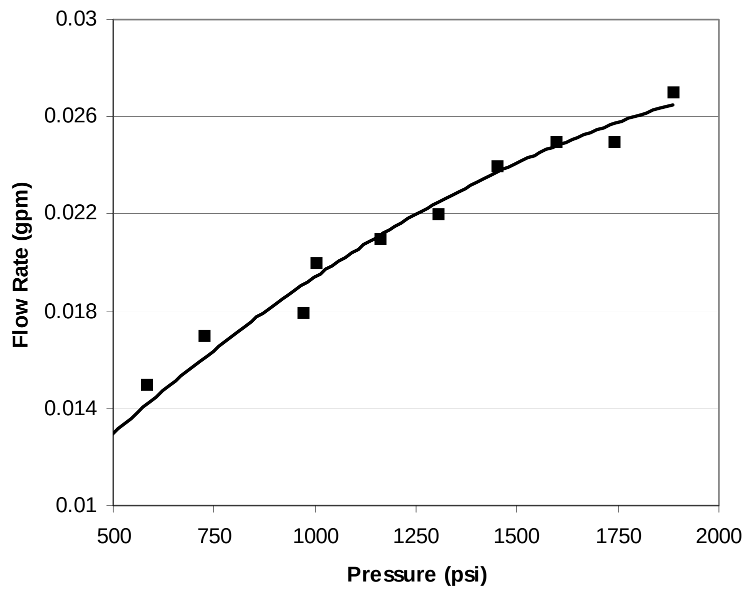

Figure 13: Impact of Pressure on Flow Rate

SUMMARY

Evaporative cooling occurs when air absorbs moisture. Evaporative pads or high pressure mist systems are two methods used to bring air in contact with moisture. In the upper Midwest, the air temperature in the cow space typically is 8 to 15 ^{o}F cooler than ambient temperatures when evaporative pads are used. The temperature differential is a function relative humidity

RESOURCES UTILIZED

Anon. 2008. Kuul Pads. http://www.port-a-cool.com/downloads/KUULPADS2008.pdf

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