DESIGN OF HIGH VOLUME LOW SPEED FAN SUPPLEMENTAL COOLING SYSTEM IN DAIRY FREE STALL BARNS

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Abstract

High volume low speed (HVLS) fans are configured as large diameter paddle fans with 10 foils (blades). The foils range from 4-12' long making the diameter of the fan approximately 8-24' in diameter. The foils are positioned horizontally attached to a hub mounted on a ¾-1 hp motor shaft. The fan operates at a speed of between 117 and 50 rpm (8-24' diameter). The fans have been used in industrial buildings to circulate ventilation air at a low velocity (3 mph). The fans have also been used in poultry and livestock barns to provide supplemental cooling of the animals by increasing air circulation and air velocity in the barn. Horizontal velocity data at the cow level (5' from floor) was collected on several dairy farms where the HVLS fans have been installed to document velocities achieved with different fan arrangements.

KEYWORDS: Fans, Supplemental Cooling, Dairy

INTRODUCTION

High volume low speed (HVLS) fans are configured as large diameter paddle fans with 10 foils (blades). They operate on the same principle as a ceiling paddle fan in a home (Figure 1). The foils range from 4-12' in length, making the fan diameter 8-24'. The foils are positioned horizontally attached to a hub mounted on a ¾-1 hp motor shaft. The fan operates at a speed of between 117 and 50 rpm (8-24' diameter). Product literature states that a ceiling mounted, 20' diameter airfoil fan can influence a floor area up to 20,000 sq.ft., displacing 120,000 cfm at a velocity of 280 fpm (3.2 mph). Haag (2001) states that the fan can move 5 times the volume as a standard 48" ceiling fan.

Although originally developed for livestock barns, HVLS fans were initially marketed for industrial applications (Aynsley, 2002) to keep workers in large areas cool by increasing the velocity of air across them. HVLS fans have also recently been used in poultry houses (Bottcher et al., 1998) and livestock barns (Shultz and Williams, 2002 and Kammel, 2002) to provide supplemental cooling of the animals by increasing air circulation at a low velocity. The fans move the air in the building space by generating a downward vertical velocity. The vertical air stream hits the floor and is then directed in a horizontal direction and radially away from the centerline of

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the fan. Product literature suggests that the floor jet is approximately 9' deep for a 20' diameter fan.

A study conducted in several California free stall barns (Haag, 2001) used HVLS fans placed approximately 60 feet apart, mounted in the middle of the barn over the feed driveway. This arrangement assumed the fans could potentially increase wind velocity over the entire barn width in a 4 or 6-row free stall barn. Research results found no difference in respiration rates and milk production of the barns with the HVLS or high speed fan systems. In a similar study of the use of HVLS fans in poultry houses (Bottcher et al., 1995), mortality rates decreased and feed conversion increased over control house values.

Product literature states that reduced energy use and lower maintenance of their HVLS fan make them competitive to high speed fan systems. The 24' HVLS fan operating at 50 rpm is rated at 740 watts, which is equivalent to the energy used by a conventional ventilation agricultural fan with a 3 foot diameter rotating at 800 rpm (SCE, 2000). Aynsley (2002) concluded that the fans not only are energy efficient but also reduce fan noise. Energy savings is achieved through use of fewer HVLS fans. Aynsley et al. (2002) estimated the energy efficiency of the HVLS fans at 0.010 W/m^2 of floor area compared with 0.35 W/m^2 for more conventional, smaller, high speed ceiling fans.

HVLS fans were introduced in the summer of 2001 into the Wisconsin dairy free stall market as a supplemental cooling system. Approximately 30 systems have been installed, with more expected to be installed pending the results of research documenting their cost effectiveness.

Figure 1. High Volume Low Speed Fan

HVLS System Design

Current design recommendations from the company and installers are to place one row of 20-24' diameter fans over the center drive through lane (Figure 1) in a 4-row or 6-row free stall barn (Figure 2). The fans are mounted at a height of approximately 16'-18'. [Note: The installation height is typically 1' higher than the height of the overhead garage door at the ends of the center drive through feed lane.] In a 3-row barn the fans are placed in a row over the centerline of the freestall platforms (Figure 3). Recommendations at this time are placing the 20-24' diameter fans approximately 60-70 feet apart. An alternate system design that has not been explored for 4-row or 6-row barns would place two rows of fans with one row over each freestall pen on each side of the barn (Figure 4). This would be similar to the 3-row barn layout but would require twice as many fans as currently used in the one row layout of 4-row and 6-row barns.

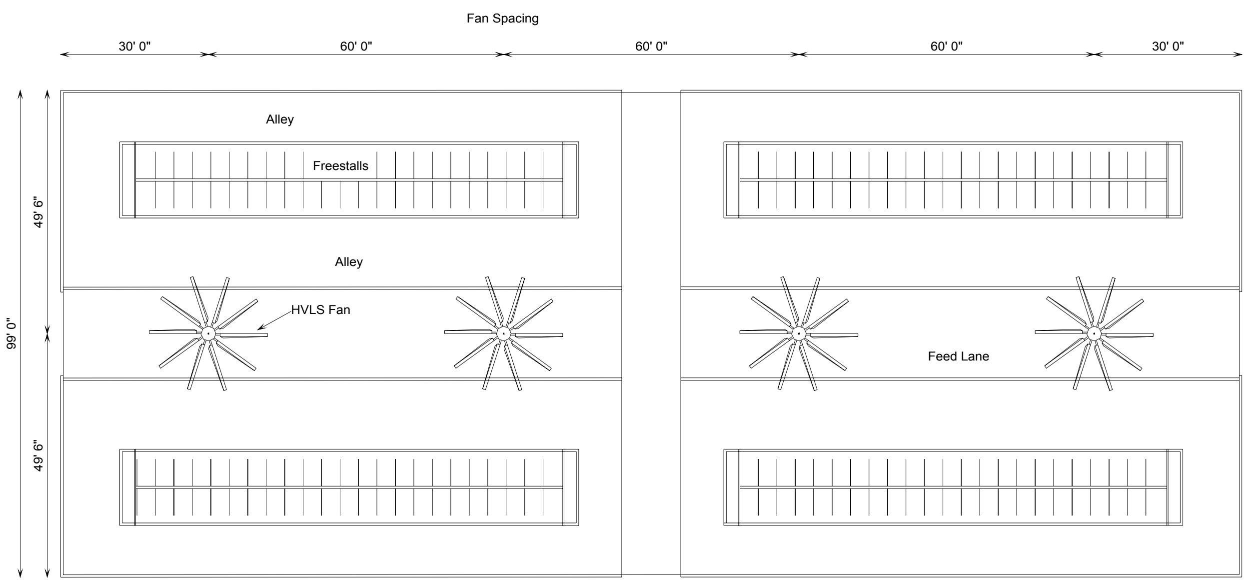

Figure 2. Four (4) Row or Six (6) Row Freestall Barn Fan System Layout

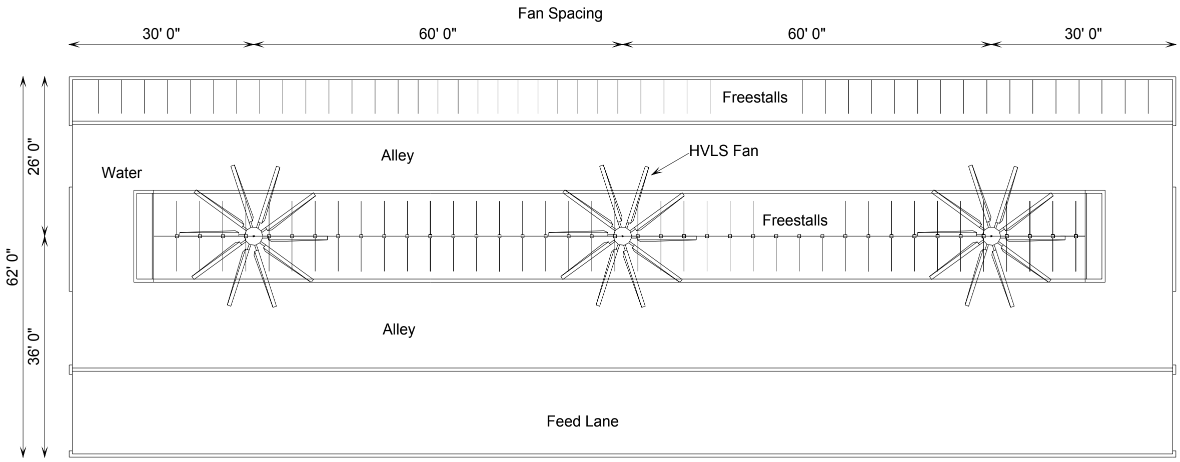

Figure 3. Three (3) Row Freestall Barn Fan System Layout

Installed System Costs

The system costs including installation costs were documented for several farm systems. (Table 1). The cost of HVLS fans was approximately \$3,700-\$4,100 depending on diameter. Controls and installation cost were additional, bringing the approximate cost to \$4,000-\$5,000 per installed fan.

Measuring Velocities in Free Stall Barns

The main objective of this study was to document the system designs currently used in existing freestall barns for several configurations. This included collecting data on barn dimensions, natural ventilation system design such as curtains eave and ridge outlet sizes, layout of fans installed including number and location of rows of fans, fan spacing and mounting heights of fans.

Table 1. Cost for HVLS Fan Systems

Farm	# Fans and Diameter	Equipment Cost	Labor Cost	Total Cost
Farm # 1	10 @ 24 ft.	$41,150	$8,500	$49,650
Farm #2	3 @ 20ft.	N/A	N/A	$12,000
Farm #3	8 @ 20 ft.	$32,000	N/A	$32,000 *
Farm # 4	5 @ 24 ft/	$18,500	$1500	$20,000
Farm #5	5 @ 20 ft.	$18,750	N/A	$18,750 *
Average Cost Per fan		$3,900		$4,200 * does not include labor

A 4 inch diameter rotating vane anemometer (TSI Model 8324 VelociCalc Plus) with digital readout and data collection and storage was used to collect velocity data. The rotating vane anemometer was placed on a rod to measure velocities at a height measured from the floor or stall surface approximately 6" higher than the cows back when either lying or standing. Velocities were measured at 5' height from the floor for a standing cow and at a 4' height from the stall platform for cows lying. The velocity was measured as a moving time average over a 10 second period. The velocity data was analyzed with Arc View 8.2 (http://www.esri.com) GIS mapping software to map out the velocity pattern. The data was used to develop velocity patterns for each barn layout.

Velocity data was collected on several dairy farms with 3 row, 4 row, and 6 row arrangements to document the velocities over the cow's back at various locations in the barn. Velocities were measure at the centerline of the row of fans, at the feed bunk line, and at the freestall platforms at a spacing that matched the post or steel frame spacing of the building (typical 10-12' spacing) The anemometer was placed to measure the velocity at a radial direction from the centerline of the fan and +/-45 degrees to the radial direction. The maximum 10 second average velocity of the three measurements at a position was reported. Wind speed and direction during the data collection period was noted. Temperature in the barn at the time of the data collections was also noted and ranged from 85-90 ^{o}F on most farm visits. All of the barns had full sidewall curtains that remained open during the velocity measurements. There was no attempt to close the curtains during the data collection period on the farm, to reduce the effect of the wind on the barn interior velocities. Wind did have an affect on the air velocity measurements at the windward side and/or end of the barn. The wind effect on measured velocities diminished as the measuring positions moved into the barn interior and toward the leeward side and/or end of the barn.

Velocity Patterns in 3 Row Barn

Three (3) fans were mounted at 14' height and spaced 68' centers (Figure 4). The influence of a easterly wind can be seen by the high velocities (> 500 fpm) measured at several locations along the east feed bunk wall of the barn. Horizontal velocities 200-300 fpm along most of the east feed bunk wall except where the wind velocity effect is seen. Horizontal velocities were highest (up to

500 fpm) at several locations near the fan at the west outside freestall platforms. Horizontal velocities were 200-300 fpm at most places along the head to head freestall platforms and the outside row of freestall platforms.

Velocity Patterns in 4 Row Barn

Seven (7) fans were mounted at 16' height and spaced 60' centers. (Figure 5). The influence of a westerly wind can be seen by the high velocities (> 600 fpm) measured at the overhead door openings on the west end of the barn. Horizontal velocities were highest (up to 400 fpm) at the feed bunk lines. Horizontal velocities measured at the center of the head to head freestall platforms were usually lower than 200 fpm. Horizontal velocities were often less than 99 fpm along the outside alleys.

Velocity Patterns in 6 Row Barn

Five (5) fans were mounted at 16' height and spaced at 60 feet centers. (Figure 6). The influence of a south westerly wind can be seen by the high velocities measured at the overhead door openings on the west end of the barn and along the south east corner of the barn. Horizontal velocities were highest (up 299 fpm) at the feed bunk lines. Horizontal velocities measured at the rear of the head to head freestall platforms were 100-299 fpm. Horizontal velocities were sometimes less than 99 fpm along the leeward (north) stall row especially near the holding area on the north side of the barn.

Individual HVLS Fan Airflow Pattern

The horizontal velocity data from the five (5) interior fans of the 4 row barn (Figure 5) was averaged to develop a composite average air velocity pattern at 5' off the floor for a single fan (Figure 7). The two end fans were not used in the analysis due to the anomalies of wind effect. The 20' diameter fans were mounted at a 16' height and at a 60' spacing. The horizontal velocity data from the same relative position from the center of the fans was averaged for each position where velocity was measured. This analysis attempted to take out some of the wind velocity affect to show what a fan could do without the influence of the wind. The pattern of Figure 7 shows that a velocity of between 200-299 fpm is possible within 20' of the center of the fan which coincides with the feed bunk line. A velocity of between 100-199 fpm is possible within 30' of the center of the fan which coincides with the interior freestall platforms. Horizontal velocities were usually less than 100 fpm at 40' from the fan center which coincides with the outside alley and freestall platforms. In this barn each fan has a potential influence area of approximately 6,000 square feet. The fan created a horizontal velocity of more than 100 fpm over a 40' diameter (5,000 square feet). The fan created a horizontal velocity of between 100-299 fpm over a 30' diameter (2,800 square feet) and a horizontal velocity of between 200-299 fpm over a 20' circular area (1,200 square feet).

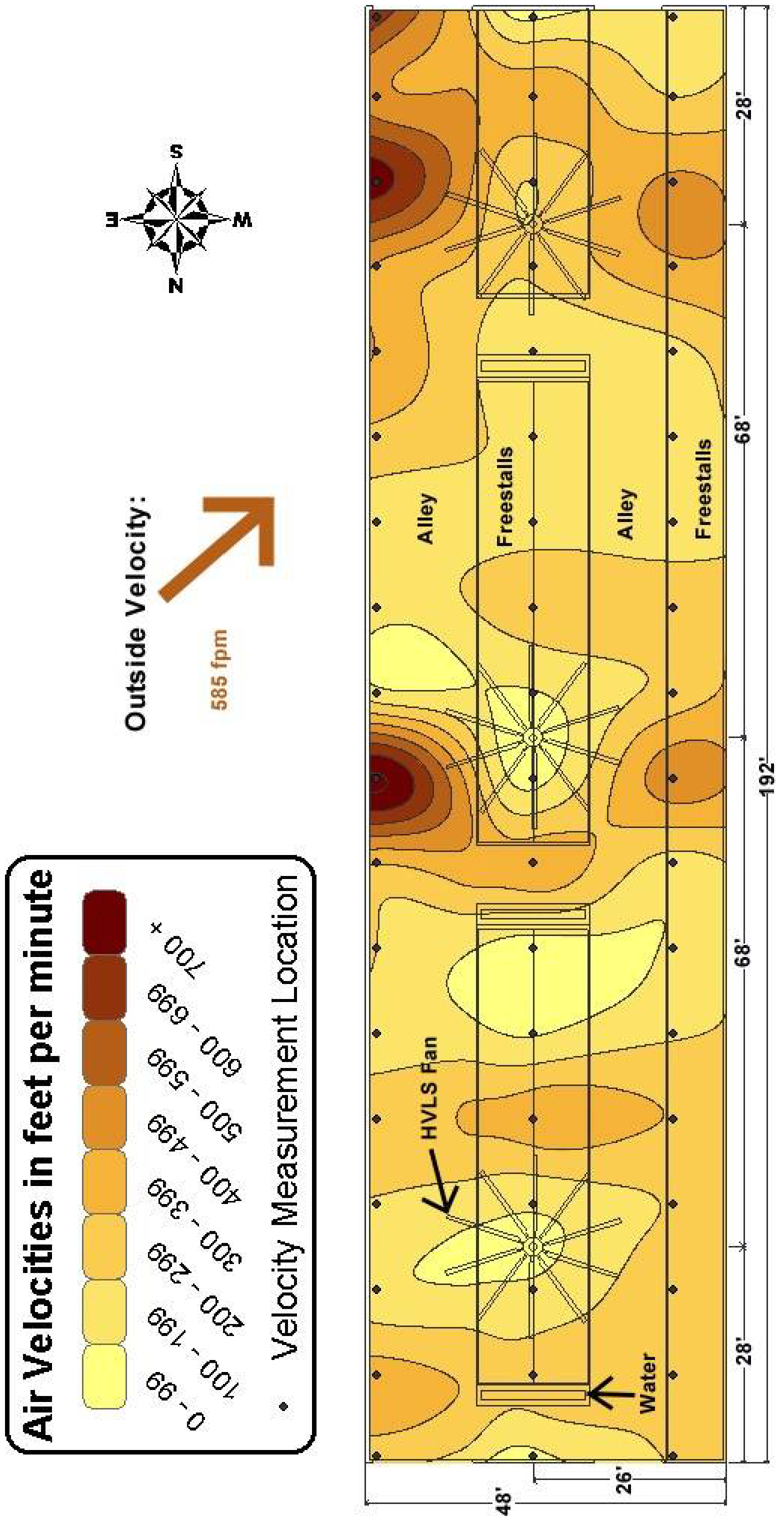

Figure 4. Three (3) Row Freestall Barn Velocity Pattern

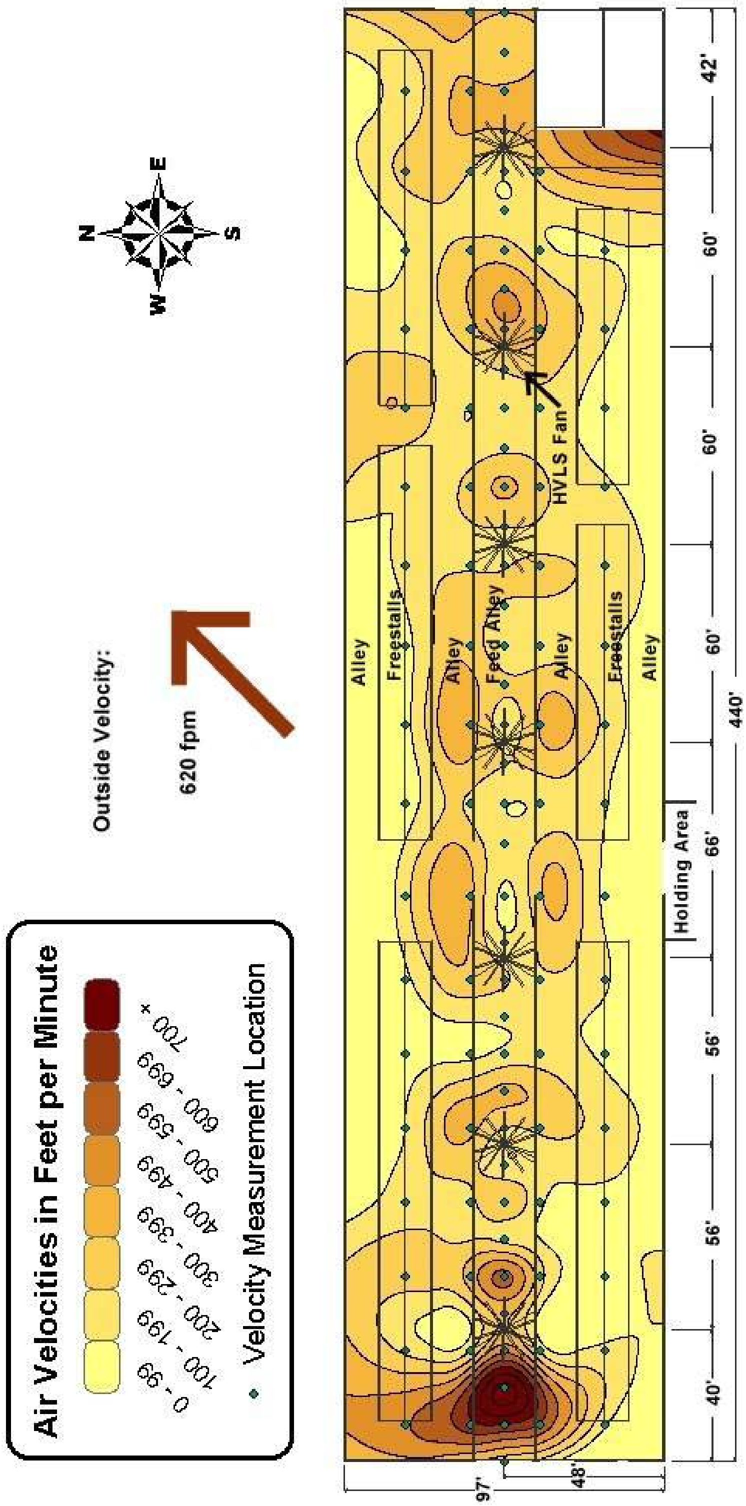

Figure 5. Four (4) Row Freestall Barn Velocity Pattern

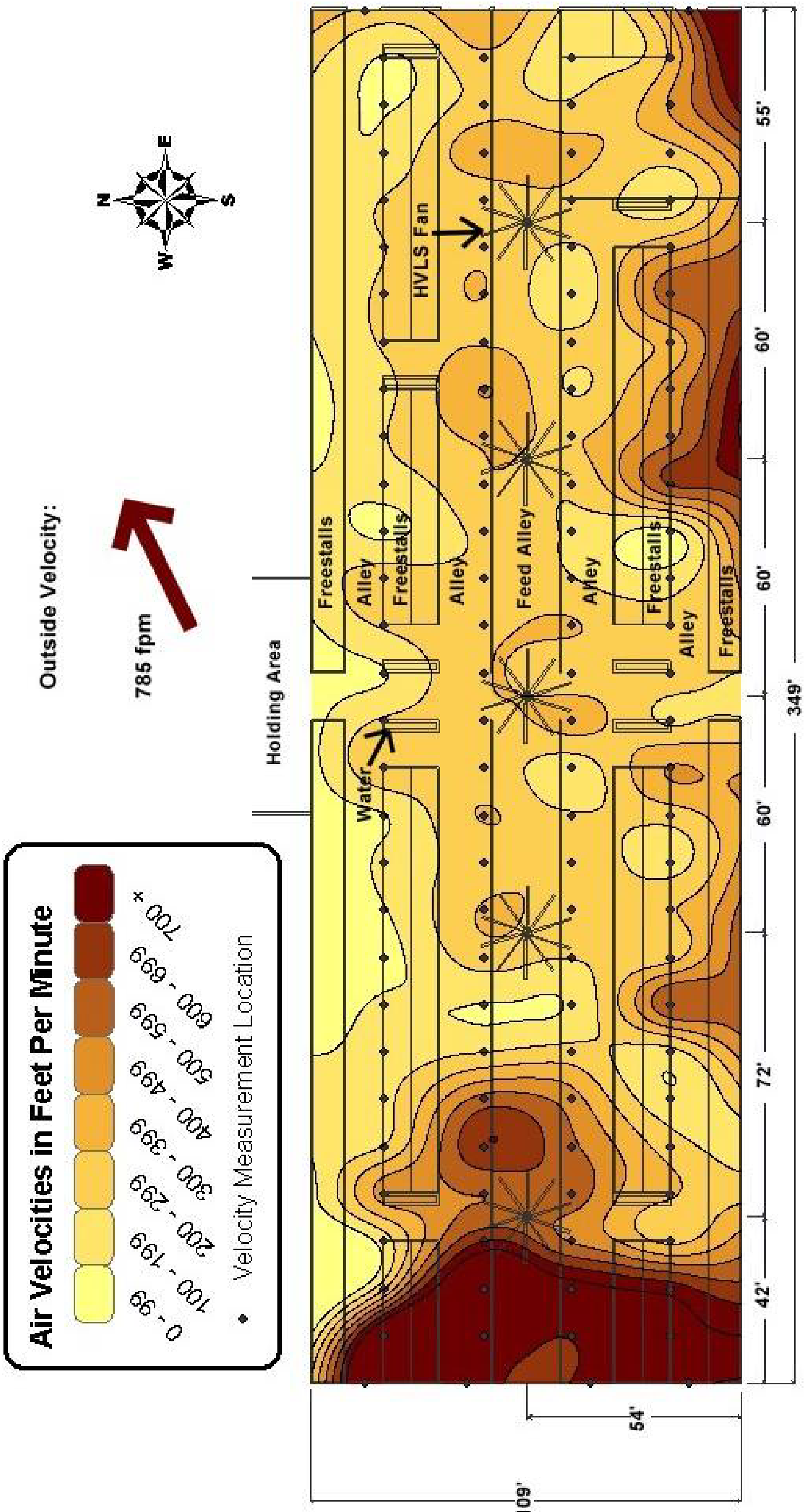

Figure 6. Six (6) Row Freestall Barn Velocity Pattern

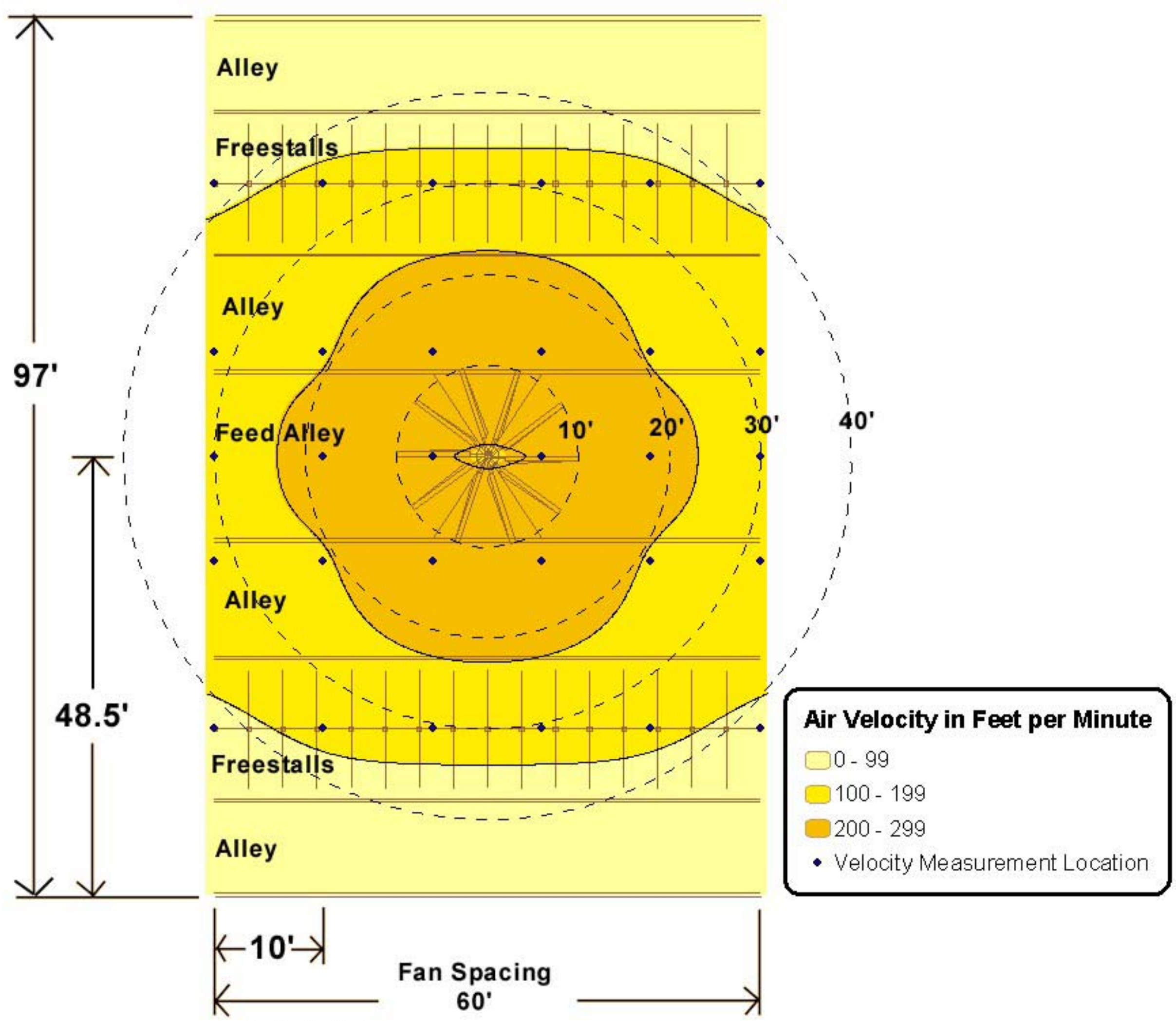

Figure 7. Composite Velocity Pattern of 20' HVLS Fan at 16' mounting high and 60' spacing

Horizontal Floor Jet

As the vertical column of air from the fan hits the floor it is directed horizontally and radially away from the center of the fan. Horizontal velocity data of a single 24' diameter fan mounted at 18' 6" height from the floor in a 4 row barn was measured at 10' radial increments from the fan center. Horizontal velocities were measured in the unrestricted area of the feed lane. Data was collected at two positions in opposite directions from the center of the fan at 1' increments from the floor up to a 12' height. The maximum velocities from two equal radial positions were averaged and plotted in a grid assuming symmetry about the center of the fan. The unrestricted horizontal floor jet velocity pattern is shown in Figure 8. The velocities under the fan are very turbulent. The floor jet begins to develop just past the tips of the blades. The horizontal velocity is in general highest close to the floor and decreases with increasing height off the floor. The horizontal velocity was highest (approximately 500 fpm) at 1' foot off the floor 20' from the center of the fan. The horizontal velocity decreased to around 100 fpm at a 12' height from the floor. The horizontal velocity at 5' height from the floor was greater than 200 fpm at up to 70' from the center of the fan affecting an area of approximately 15,000 square feet.

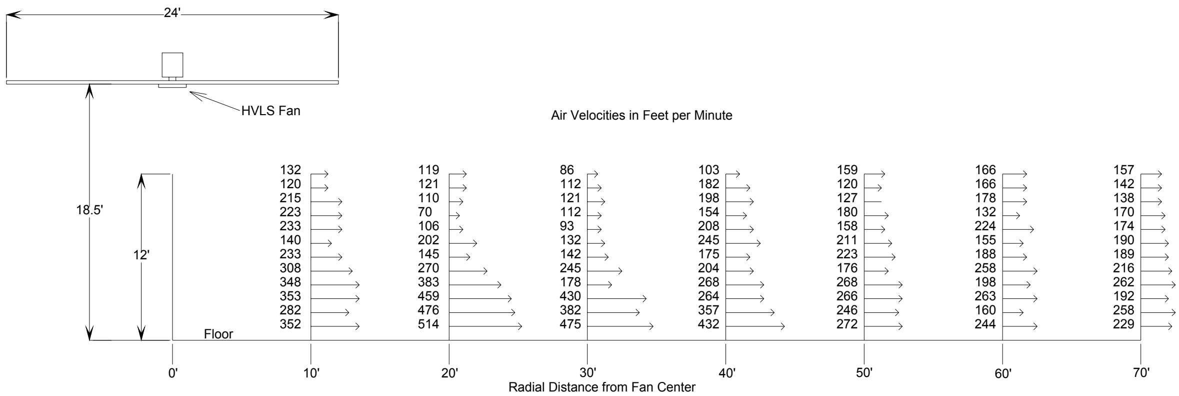

Figure 8. Velocity Contours of single HVLS fan (Longitudinal view of unrestricted flow in center feed lane)

<u>Average Air Velocity and Average Air Flow Volume</u>

An estimate of the air volume moved by 24' diameter fans was calculated two ways (Fabian Wheeler, 2002):

- One method to calculate air flow moved by the fan was to determine the average velocity and multiply by the area of the fan (Q = V* A), where Q is the air volume in cfm, V is the air velocity in fpm, and A is the area of the fan in square feet. Velocity was measured at a vertical distance from the fan at 13 positions in 1 foot increments in 2-4 radial directions from the fan centerline (Figure 9). The velocities were averaged to determine the average velocity at each radial position. The vertical velocities were measured at 4' from the fan. The average of the 13 velocities was 260 fpm. The corresponding air volume moved was calculated to be 117,500 cfm.
- The second method used a summation of velocity x area products over the fan area. The velocity at each radial position is associated with a donut area for that radial position. As the radial position increases so does the corresponding area. The velocity at a radial position was assumed to be the same across the area of each donut (Figure 9). The sum of the products of each area x velocity for each 1' wide donut area equals 150,000 cfm. The air volume moved (150,000 cfm) divided by the area of the 24' diameter fan (453 square feet) gives an average of 330 fpm over the total fan area.

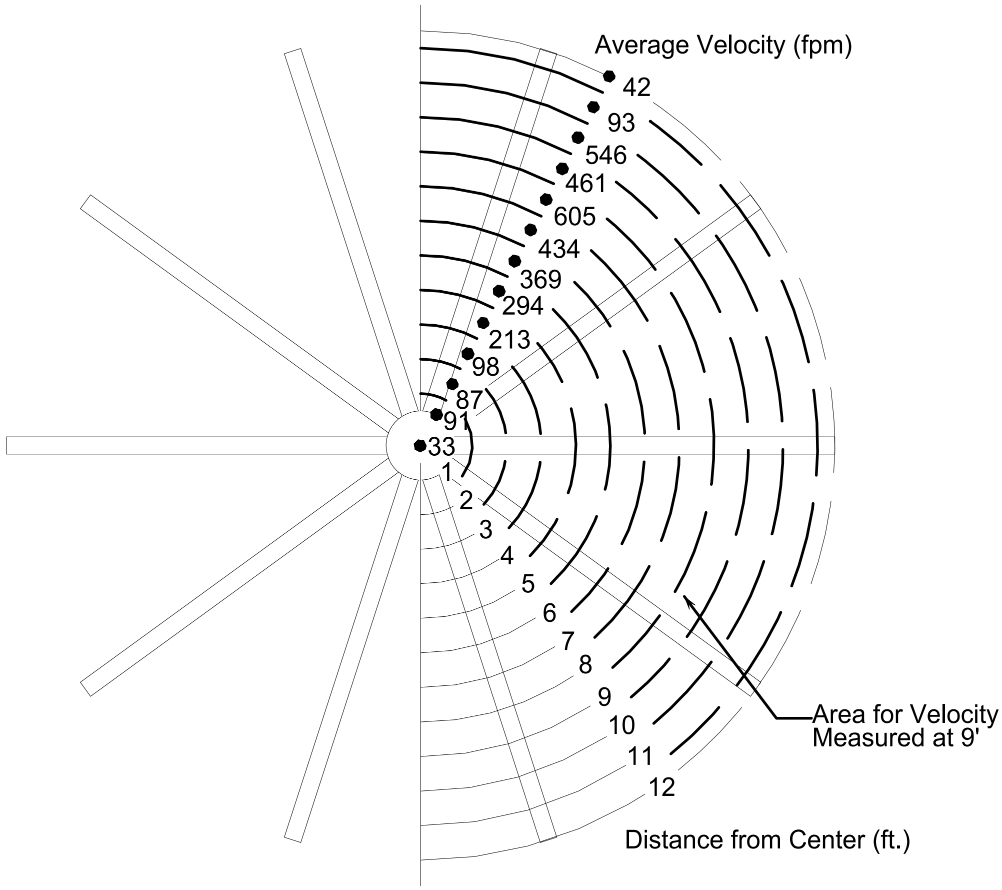

Figure 9. Average Velocities over a 24' Diameter Fan

Airflow Visualization

The airflow visualization of the air stream created by the fans was observed using smoke and soap bubbles. Smoke testing helped to identify general air flow patterns, but eventually the smoke dissipated to where it was difficult to determine the air flow pattern. Although soap bubbles are not neutrally buoyant, for purposes of field observations it was decided that observations would be beneficial to determine how the air flow pattern of the barn was impacted with the HVLS fan. The soap bubbles lasted longer to allow air flow patterns to be observed further from the fan and show the circulation pattern of the fan. Digital images and video could be used to document the air flow direction and influence of the fan.

Energy Use

Electric meters were installed on two farms with HVLS fans to measure electrical use of the HVLS system. Fans operated at the maximum speed continuously. The 1 hp fan was rated to use 740 kW of energy. Operating at 24 hours each fan uses 17.7 kWh per fan per day. The average energy use per fan was measured to be 14.5 kWh per fan per day or 604 kW of energy used per fan. The energy cost per day at $.07/kWh was $1.00 per day per fan. The energy cost per day to operate the fans for the 3 row, 4 row and 6 row barns was $3/day, $7/day, and $5/day respectively. The freestall to fan ratio (FS/fan) was 45 FS/fan, 53 FS/fan, and 88 FS/fan for the 3 row, 4 row, and 6 row barns. The energy cost per stall per day ($/FS-day) was $.02/FS-day, $.02/FS-day, and $.01/FS-day for the 3 row, 4 row, and 6 row barn respectively.

Farmer Testimonials and Observations

Although there was no way to measure effectiveness of the HVLS fan system on milk production, dry matter intake and/or heat stress abatement, anecdotal data from the farmers may still be valuable to address the issue of effectiveness of the system and the perceived benefits of the system installed. Each farmer was interviewed as part of the data collection process. Their experience and comments, and observations by the study team, are summarized as follows:

- All farmers stated that the installation of HVLS fans provide a noticeable improvement in air quality inside the barn, possibly due to increased air circulation. Additional benefits identified were reduced noise and drier alley floors. It was observed that in steel frame barns that the fans did cause rattling and vibration noise if the fan support frames were not isolated from the steel columns by a sound dampening material such as rubber.
- Many of the farmers commented that the HVLS fans reduced the number of birds within the barn. The research team noted that small birds (e.g., sparrows) typically congregate near overhead door openings but were reluctant to fly further inside the barn. The presence of a few dead birds indicates that some venture inside and are struck by the blades of the fans.
- Two farmers commented that after installation of the fans, cows no longer crowded closely together as they had observed in previous summers without fans. Flies may be less likely to be found in certain areas of the barn – e.g., the feed alley – due to the velocity of the air.. The research team noted the presence of flies in some barns and not in others. This may have been due to other fly control measures taken at some farms and not others.
- Some of the farmers stated that the use of the fans reduced the loss of milk production during periods of high heat and humidity compared to no fans. Furthermore, production rebounded more quickly as temperatures and humidity declined. This study did not document milk production loss or change. The farmer comparisons were made based upon a prior condition where no fans were used in the previous summer.

CONCLUSION

High volume low speed (HVLS) have been installed in several barns in Wisconsin. Horizontal velocities were measured in several different barn arrangements to determine if current design guidelines for the use of the fans are adequate. HVLS fan spacing of 60' apart seemed to be a reasonable compromise based on the velocity data collected. HVLS fan mounting height varied between 14'-18'. Installers used a reference for mounting height of 1' higher than the height of the overhead door to prevent fans being hit by equipment. Horizontal velocities in the barn are turbulent similar to a light breeze. In most cases, air movement above 100 fpm was observed over most of the barn area. Calculated air volume moved by a 24' fan ranged from 117,500 cfm-150,000 cfm. Velocity data collected in this study suggest that a velocity of 200-299 fpm can be achieved over the feed bunk in a 4 or 6 row barn layout. A velocity of 100-199 fpm was documented over the interior row of freestall platforms for 4 or 6 row barn layouts. A velocity of less than 100 fpm was measured at the outside row of freestall platforms for a 6 row barn. Each fan used approximately 14.5 kw of energy per day. The energy cost to run a single fan was approximately $1/day. Additional velocity data will be collected for other fan arrangements and conditions in the future.

Acknowledgements

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