“Let it Flow, Let it Flow”
Moving Air into the Freestall Space

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TAKE HOME MESSAGES

- Baffles allow cool, upper air to mix with warmer air in the lower part of a building.
- Total static pressure drop across a building should be limited to 0.15 inches for optimum fan performance and ventilation.
- The Pitot tube equation may be used to estimate the air velocity beneath a baffle once the static pressure is known.
- A minimum recommended baffle opening is 7 to 8 feet above the freestall curb to minimize equipment and animal damage.
- The baffle opening must be designed based on sidewall inlet area, inlet air speed and static pressure

INTRODUCTION

Research shows that 12 to 14 hours of rest per day are the minimum requirements for dairy cows to maintain optimum performance. In order to achieve this desired rest, a cow’s freestall must be a comfortable size and temperature. Naturally ventilated freestalls use fans to provide air movement in the stalls to ensure they remain comfortable, even during heat stress. Low profile cross ventilated (LPCV) buildings use equivalent fan power to move air across the entire building, rather than blow air directly into individual stalls. The challenge in LPCV buildings is maintaining a proper balance between the cow comfort, fan performance and turbulence created by the moving air.

BAFFLES

Baffles are located over stalls in LPCV facilities to increase air velocity in each freestall area. Air movement beneath a baffle causes air streams from the upper and lower portions of the building to mix and create turbulence. Turbulent flow results when air encounters an obstacle and is diverted in another direction. As a result, cooler air near the roof is forced to move under the baffle and mix with warmer air streams in the cow space, thus avoiding laminar air flow. Laminar flow occurs when the air stream moves straight across the building rather than mixing with adjacent air streams. Because air entering a side wall at 5 miles per hour (mph), will typically exit a 400-foot wide building in less than 2 minutes, there is minimum time for the mixing of air streams unless turbulence is created by a baffle. In addition, an increase in velocity of the air beneath the baffle results in a proportional increase in static pressure which must be overcome by fans.

ENERGY

Fluid mechanics describes fluids, including air, as possessing three different forms of energy that are not based on temperature: pressure, kinetic and potential. Pressure energy is often called pressure head, or static head, and is typically measured by a pressure gauge. For airflow and ventilation applications, a static pressure difference is measured. If a static pressure difference, or difference in pressure head, is observed, the pressure energy differs from one location to the other. Kinetic energy is associated with the movement of a fluid. It is required to accelerate a fluid and is quantified by the velocity of the fluid at a given location. When kinetic energy is added to the air, air velocity increases. The third form of fluid energy is potential energy. Potential energy for fluids is often called gravitational head, or potential head. Potential head is measured by the elevation of the fluid above a defined reference point. A fluid that is located at a high elevation has a greater potential head than a fluid located at a lower elevation.

AIR DEFLECTION BAFFLE TEST

The static pressure and velocity observations of an air deflection baffle are related to the previous fluid mechanics discussion. A static pressure difference was measured from one side of an air deflection baffle to the other, which means that the pressure energy on the inlet side of the baffle was greater than the pressure energy on the exhaust side. Since pressure energy was lost, the lost energy must be found in another type of fluid energy. No difference in elevation existed from one side of the baffle to the other, so no change in potential energy existed. The air stream continued to move through the building, so all the pressure energy differences, as indicated by the measured static pressure differences, was not lost. The baffle caused pressure energy to be converted into kinetic energy because the velocity of the air stream was accelerated from the inlet side of the baffle to the exhaust side. The conversion of the pressure energy to kinetic energy along with some possible losses at the baffle, resulted in the fluid energy being conserved as the air moved from the inlet side of the air deflection baffle to the other side.

BERNOULLI EQUATION

The Bernoulli equation (Henderson and Perry, 1976) from fluid mechanics states that the energy of a fluid at point A must be equal to the energy of the same fluid at point B unless energy loss occurs between the two points, or unless energy is added to the fluid by some other method. Therefore, the Bernoulli equation is the sum of all energies at point A (pressure, kinetic, and potential), plus any energy additions that total the sum of all energies at point B, minus any fluid energy loss from point A to point B. In essence, all the energy in a fluid, or air, moving from point A to point B can be determined and conserved.

The Bernoulli equation can also be used to quantify the static pressure from a fan in a low profile cross ventilated freestall barn. Air moves from outside (point A), through the cool cell pads, under each baffle, and exits the fan to the outside (point B). The fan actually adds pump energy to the energy balance defined by the Bernoulli equation. The increase in air velocity under a baffle is lost because of the air mixing from one baffle to the next. Therefore, the static pressure differences observed at each baffle must add together to estimate the total static pressure, or pressure energy, the exhaust fans must add to the ventilation air stream.

FAN PERFORMANCE

An exhaust ventilation fan delivers different ventilation rates depending upon the static pressure against which the fan is operating. A fan delivers its maximum airflow rate when no static pressure differential is placed against the fan. As the static pressure difference increases, the delivered airflow rate decreases and adds additional stress on the fan, decreasing performance and the length of fan life. The static pressure difference may increase enough to result in the fan being unable to move any air.

The relationship between the operating static pressure and the delivered ventilation rate is called the fan curve, or fan performance curve. The fan curve and maximum operating static pressure are specific to each fan make and model. The static pressure resistance caused by a baffle system and/or air inlet system must be less than this maximum operating static pressure or no air will be ventilated from the facility.

Each baffle in an LPCV facility causes a static pressure difference the fan(s) must overcome to achieve adequate ventilation. Increasing the number of baffles in a facility results in a larger overall static pressure differential. If together the installed fans cannot provide the desired ventilation rate with the resulting static pressure difference created by the baffles, no individual fan is able to deliver adequate ventilation. A balance for the total ventilation system is found when the static pressure differential created by a series of baffles is matched by the fan-operating static pressure differential and the ventilation rate delivered by any given fan. Lower total static pressure generally results in higher delivered ventilation rates for a total ventilation system. On the other hand, higher total static pressure differentials often result in lower delivered ventilation rates.

STATIC PRESSURE

The static pressure against which an exhaust fan must operate is significant when the air velocity is at its highest for summer ventilation rates, as shown in Table 1. The presence of cows in the pen impacts the static pressure. Results of static pressure at the first baffle were as follows: when no cows were in the pen, pressure was 0.025 inches; when cows were locked in headlocks, the pressure measurement was 0.031 inches; when cows were present in the pen, static pressure was 0.029 inches. Static pressure at the second baffle when no cows were present was 0.033 inches, and the measurement increased to 0.037 inches when cows were locked in headlocks. A “buffer adjustment” should be added to the theoretical static pressure estimate for a no-cow, empty-barn scenario.

Table 1: Air Velocity and Static Pressure across an LPCV Barn

		Static Pressure (in H_2O)				
Structural Bay	**Velocity (ft/min)**	**First Baffle[1]**	**Second Baffle**	**Third Baffle**	**Fourth Baffle[2]**	**Comments**
1			0.033	0.026	0.029	West end cross alley
2	547	0.240	0.032	0.028	0.036	
3	525	0.025	0.032	0.027	0.035	
4	560	0.025	0.036	0.026	0.037	
5	580	0.025	0.034	0.027	0.036	Crossover
6	560	0.025	0.028	0.029	0.034	
7	530	0.026	0.032	0.028	0.036	
8	560	0.026	0.033	0.026	0.038	
9	550	0.025	0.038	0.029	0.040	Crossover
10	590	0.026	0.035	0.028	0.035	
11	600	0.023	0.036	0.028	0.036	
12	560	0.026	0.034	0.030	0.034	
13			0.030	0.025	0.041	East end cross alley
14			0.032	0.034	0.032	Palor cross alley
		No cows	No cows	With cows	With cows	Cows in pen when data collected?

[1] = Baffle adjacent to air inlet.

[2] = Baffle adjacent to ventilation fans.

The distribution of cows within the pen also has an impact on the static pressure. The fourth baffle appears to have average static pressure measurements, but the distribution of the static pressure difference is a bit more pronounced. For example, due to a maintenance problem on the farm, cows crowded around the crossover alleys during the third replication at the fourth baffle and created a visible static pressure difference. This variation is directly proportional to the air speed under the baffle because if cows crowd together, less air is able to move through the group.

Overall dairy management must be designed to minimize the opportunities for cows to bunch together, and, therefore, increase static pressure. Stressful situations for cows often result in a herding instinct, even though the resulting cow grouping may actually increase the stress level and reduce ventilation in the facility. The current design practice recommends limiting the total static pressure drop to 0.15 inches.

HELPFUL EQUATIONS

The total static pressure is the sum of the pressure drop across the sidewall inlet and each baffle. The Pitot tube static pressure equation may be used to help design the baffle opening. The equation used to calculate the velocity of Pitot tube (Henderson and Perry, 1976) is:

$$V = 18.3(SP_{\text{pitot tube}} / SW)^{\wedge 0.5} \qquad \text{eq 1}$$

Where:

$SP_{\text{pitot tube}}$ is the static pressure drop (inches of water)
V is the velocity of air in feet per second
SW is the specific weight of the air in pounds per cubic foot.

A simple way to calculate the static pressure drop per baffle is to use the following equation:

$$SP_{\text{baffle}} = (SP_{\text{total}} - Sp_{\text{inlet}}) / \text{ Baffles} \qquad \text{eq 2}$$

Where:

SP_{baffle} is an estimate of the static pressure drop across each baffle
SP_{total} is the total static pressure drop (equal to 0.15)
Sp_{inlet} is the static pressure drop across the sidewall inlet (assume equal to 0.05)
Baffles is the number of baffles.

The air velocity (fps) beneath a baffle is then calculated using equation 1 or equation 3 and may be used to estimate the air velocity (in feet per minute) beneath the baffles.

$$\text{Baffle}_{\text{airflow}} = 4{,}000 \times (SP_{\text{baffle}})^{\wedge 0.5} \qquad \text{eq 3}$$

Where:

$\text{Baffle}_{\text{airflow}}$ is the average air velocity under the baffle in feet per minute.

Finally, the height of the baffle opening in each freestall is found by using

$$\text{Baffle Opening} = \text{Airflow per Foot} / \text{Baffle}_{\text{airflow}}$$

Where:

Baffle Opening is the bottom height of the baffle above the freestall curb (measured in feet)

Airflow per Foot is the total inlet airflow per foot of building.

BAFFLE DATA

Figure 1 shows the influence of air speed on baffle openings for a given number of baffles. Baffle openings less than 72 to 84 inches above the curb are impractical and can result in cow interference and equipment damage. Figure 1 shows a minimum of 4 baffles are recommended when the inlet air speed is 400 feet per minute (fpm) or less. Generally, LPCV facilities are designed with one baffle for every two rows of freestalls to provide adequate ventilation.

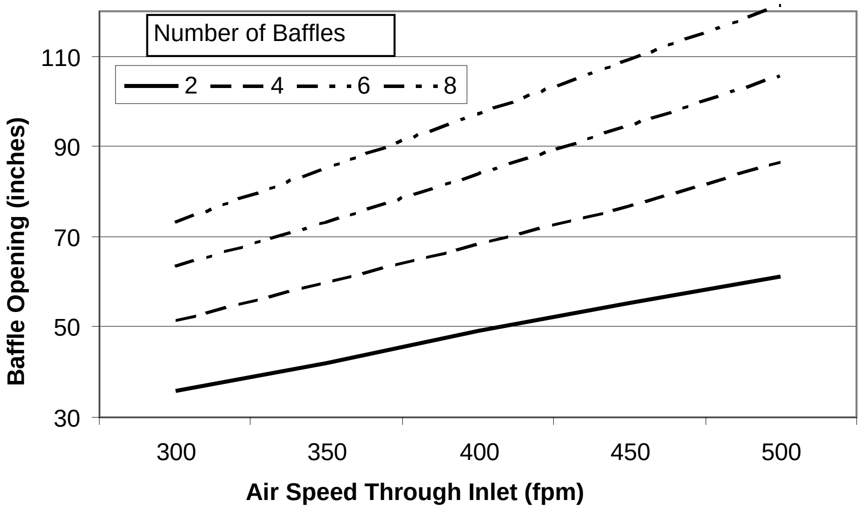

Figure 1: Impact of Air Speed on Baffle Openings and Number of Baffles

Figure 2 illustrates the average air speed beneath a baffle. An air speed of 5 to 6 mph in the freestall area is usually recommended to promote stall usage and improve cow comfort during heat stress periods. Dairy cows begin to exhibit heat stress when ambient temperatures exceed 70 ^{o}F. Air speed in the stall area may be reduced when the environmental temperature decreases.

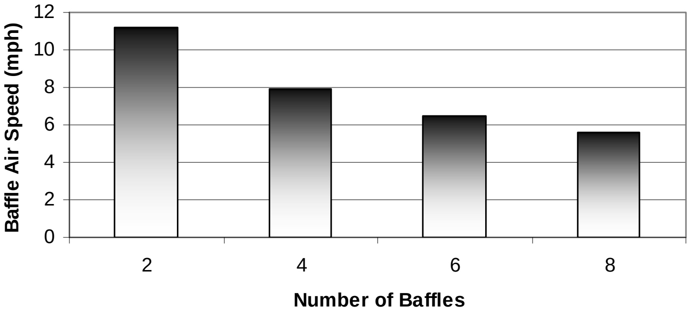

Figure 2: Influence of Number of Baffles on Baffle Air Speed with Limited Static Pressure Drop to 0.1 Inches

SUMMARY

Baffles allow mixing of air streams inside a building and increase the air velocity in the freestall area. An excessive static pressure drop reduces the efficiency of a fan. Proper baffle design limits the total static pressure drops across the inlet and baffles to 0.15 inches of water or less. Baffle openings must also accommodate equipment operating in cross alleys. Animals should not be able to damage the bottom of a baffle if placed 7 to 8 feet above concrete floors.

REFERENCES

Henderson, S.M. and R. L. Perry. 1976. Agricultural process engineering. The AVI Publishing Company, Inc. Westport. Co. pp 9-59.