AIR QUALITY

Evaluating Air Quality in Livestock Housing Environments

AIR QUALITY EDUCATION IN ANIMAL AGRICULTURE

Measuring: Instruments
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This publication focuses on three important aspects of evaluating an animal housing environment.

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Air Quality in Animal Agriculture
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Good air quality leads to healthy animals and productive facilities. When evaluating air quality in livestock housing, these questions should be addressed: What do we want to measure? What makes one indoor animal environment better than another? How do we know when a ventilation system is operating properly?

Instruments allow an objective evaluation and quantification of environmental parameters. Instrument readings can be compared with recommendations to determine the suitability of environment features.

This publication provides an overview of three important aspects of evaluating animal housing environment. Part I features the principles of measurement, Part II describes common instruments along with their appropriate use, and Part III offers a process for evaluating ventilation system performance. This document features portable, hand-held, field-quality instruments commonly used to diagnose animal environments. It does not discuss instruments typical of ventilation system controls or those used to obtain experimental data. *Table 1* includes instrument costs and features.

Part I. Principles of Measuring Air Quality in Animal Environments

An evaluation of indoor air quality must emphasize the animal perspective, which is not necessarily the same environment in which a human would feel comfortable. Air quality characteristics are important in the zone where the animal is confined.

Animal health and comfort are of primary concern in livestock facilities. After all, the animals live in that environment all day while workers visit periodically for chores and inspection. Although the comfort of workers in the facility should not be disregarded, it can be effectively controlled by other means, such as clothing, rather than keeping the whole environment to human standards.

In general, the thermal comfort zones for adult livestock are cooler than the human comfort zone. Temperature seems to be the main environmental difference between comfortable livestock versus human environment.

Dust and air contaminant levels that are acceptable to animals are not always reasonable for humans, so protective breathing masks may be necessary for worker safety and comfort. There may be additional building concerns such as keeping temperatures above freezing, which can usually be accommodated while maintaining adequate animal environment.

Commonly measured air quality characteristics related to animal comfort include temperature, humidity, and air speed. These are easily measured and roughly characterize the animal environment. Contaminant gases and dust are also important factors. Temperature of walls and floors or cold air drafts will affect animal comfort.

Characterizing the ventilation system that is responsible for many major features of indoor air quality is desirable. This is the topic of Part III, Evaluating Mechanical Ventilation Systems. System characteristics, such as air speed through fans, pressure difference the fan is operating against, and air speed at inlet openings, are easily mea-

Table 1: Air quality hand-held instrument costs and examples of suppliers.

Instrument	Measures	Cost ($)	Ben Meadows	Cole Parmer	Davis	Grainger
Thermometer	dry bulb temperature	15-20	x	x		x
Max-Min Thermometer	dry bulb temperature	20-50	x	x	x	x
Sling Psychrometer	dry and wet bulb temperature	60-120	x	x	x	x
Aspirated Psychrometer	dry and wet bulb temperature	150-300		x		
Hygrometer	humidity and dry bulb temperature	40-60 (+/- 5-7% accuracy)	x	x	x	x
		275-350+ (+/- 1-3% accuracy)	x	x	x	x
Hot-Wire Anemometer	air speed	400-1000		x	x	x
Vane Anemometer	air speed	150-400+	x	x	x	x
Velocity Manometer	air speed	60-75		x		x
Airflow Indicator Kit	visualize air speed			x		
Smoke Candles	visualize air speed	50-100	x	x	x	
Infrared Thermometer	radiant surface temperature	300-2600	x	x	x	x
Gas Sampling	noxious gas levels	350-450 + 3.50/tube		x	x	x
Manometer	static pressure	40-100			x	x
Strobe Light	fan rotation (rpm)	500-700		x	x	x
Tachometer	fan rotation (rpm)	200-300		x	x	x

*Price ranges reflect instruments suitable to agricultural applications. Higher priced instruments have improved accuracy and more features than lower priced models. (Spring 2011)

Ben Meadows
PO Box 5277
Janesville, WI 53547-5277
http://www.benmeadows.com
1-800-241-6401

Cole Parmer
7425 North Oak Park Ave.
Niles, IL 60714
http://www.coleparmer.com
1-800-323-4340

Davis Instruments
4701 Mt. Hope Dr.
Baltimore, MD 21215
http://www.inotek.com
1-800-368-2516

Grainger
431 Amity Rd.
Harrisburg, PA 17111-1000
http://www.grainger.com
717-561-8322

sured. Proper techniques in using instruments are required to obtain values that truly represent the system. Air flow visualization is discussed as a tool to evaluate environmental conditions and the ventilation system's air distribution.

Once air quality measurements are taken, the numbers should be compared to desirable conditions.

Principles of Measuring

• Measure the right thing. Measure characteristics of air the animals are breathing and/or the air blowing over their bodies. If cow comfort is the issue, get in with the cows and measure the air quality in their zone. Get down to the level of the pig's nose. Go back into the sleeping areas of penned animals and within (or at least between) the cages of layer hens. Air characteristics such as temperature and humidity, and, particularly, levels of contaminant gases such as ammonia, can vary greatly depending on location within a livestock confinement zone. Compare measurements taken in resting, eating, and dunging areas.

• What is the instrument measuring? The instrument can only read what it is exposed to. Be aware of what part of the instrument is sensing conditions. Exposing an instrument to an environment alters the environment immediately adjacent to the instrument. Positioning an air velocity meter in the jet of air exiting a fan means that the air is disturbed and must go around the meter. The measured velocity represents a disturbed air flow yet this effect cannot be completely avoided.

Add a human positioning and reading the meter while standing in the air jet exiting a fan and now there is a very large human obstruction, in addition to the meter. This obstructed air velocity measurement will not be indicative enough of air flow normally exiting the fan.

Similarly, a temperature probe positioned in direct sunlight will indicate a higher temperature than a similar probe positioned more appropriately under cover. Decide what it is that you want to measure and position the instrument to most appropriately measure that quantity.

• Understand how your instrument works. By understanding basic principles of how the instrument detects air characteristics, you can troubleshoot the instrument when curious readings are obtained or when adjustments and calibrations are needed. A number is only as good as the understanding that went into determining it.

For sensitive instruments, how do you know if fluctuating readings are a natural part of the air you are trying to characterize or part of the instrument measuring mechanism? How long does it take the instrument to determine and display a stabilized reading? Livestock housing may be too dusty, humid, or dirty for some instruments to work properly. Some instruments may work well for a while in livestock buildings, but then go out of calibration or malfunction. You need to be able to diagnose this.

• Question each reading. Does the reading make sense in the environment being considered? Take more than one reading. A set of at least three readings is often necessary to confirm that sporadic measurements are reliable. Air velocity measurements, due to gusty conditions, may never settle down into one distinct reading so a range of readings should be averaged.

• Record your readings and observations. Summarize the results. Is there a pattern? Do measured conditions correspond to an observed or perceived problem? Be sure to include conditions that affect the enclosed animal environment, such as outside weather conditions, livestock density, management practices, behavior, etc.

Now What?

Once measurements are taken, the numbers should be compared to desirable conditions. Improvements to environmental quality can then be pursued with more confidence about current conditions and future achievements.

Desirable air quality characteristics depend on animal species and age. Materials listed in the Additional Resources section provide some guidelines. Within livestock housing, a range of temperature and humidity levels is acceptable. Contaminant gases and dust levels need to be kept below a threshold. For young animals, air speed is kept

Each air quality characteristic, such as temperature, humidity, air speed, and air flow, can be measured in more than one way.

below a certain level to avoid chilling, while for adult livestock, air movement during hot weather is desirable so there will be a minimum air speed for cooling effect.

Part II. Instruments for Measuring Air Quality

Air quality characteristics can be quantified objectively with instruments that provide numbers. With these numbers, you can compare the environment against a standard and then seek improvement in environmental characteristics. You also can evaluate environmental changes over time. For example, a simple thermometer will tell you that air temperature in a dairy barn is 78°F, yet dairy cows are most comfortable at 60 °F or colder (assuming reasonable humidity level). Your goal should be to lower the temperature or compensate for the heat stress in other ways.

Environmental features that can be reasonably measured:
Common:
Air Temperature
Humidity
Air Speed
Air Flow Pattern

Special circumstances:
Surface Temperature
Gases
Dust
Odor
Bioaerosols

Each air quality characteristic, such as temperature, humidity, air speed, and air flow pattern, can be measured in more than one way. The cost of instruments often is weighed against the accuracy of readings. Periodic checks on environmental conditions with instrument readings are a supplement to the everyday observation of building conditions, animal behavior, and production records.

Certain instruments are appropriate only for specific applications. The best readings are obtained when the basic principles of how the instrument detects an environmental characteristic are understood. Proper technique will minimize human impact on the air being measured.

Temperature

Air temperature is measured with a common thermometer. The thermometer indicates the temperature of the exposed sensor tip, or bulb, which has reached equilibrium with the surrounding environment. The sensor tip must not be exposed to radiant energy, such as direct sunlight or a heating system radiator, as this will increase the sensor tip temperature and will not be representative of the surrounding air temperature.

Be sure that your measured temperature is representative of air in the zone of importance, usually the area where animals spend most of their time. Air temperature in a central aisle, where air mixing is relatively unrestricted, is probably not indicative of air temperature at the back of the adjacent animal confinement area.

A simple maximum-minimum thermometer, which can be left in the area of interest, is an inexpensive tool that can help determine whether wide temperature swings occur in the building over a period of time. Digital thermometers are common. They are easier to read and offer remote sensing capabilities in hard-to-reach animal areas. Digital readouts may offer a false sense of accuracy when meters have an accuracy of 3 percent of full scale (or 1 to 2°F), yet the readout displays temperature to a resolution of one-tenth of a degree.

Another option for monitoring over longer time intervals are sensors within dedicated dataloggers that can detect and record temperature with the time of measurement noted. Recording is over a user-specified length of time (for example, 24-hours or a week) at the desired interval (for example, every minute or hour). A digital datalogger does not typically display the temperature being sensed so software is used to retrieve the stored data for analysis on a computer. Accuracy of 1°F is affordably available for these dataloggers that often can include humidity measures for additional cost.

Humidity

Humidity is commonly measured as "relative humidity," which compares the "relative" percentage of moisture in the air to how much moisture the air could potentially hold at that same temperature. Air can hold more moisture as its temperature increases. Other measures of humidity use the dew point temperature or absolute humidity as an indication of the amount of moisture in the air. A psychrometric chart is a rather complicated-looking graph that shows thermal and moisture relationships of air. Its use is covered in the fact sheet *Psychrometric Chart Use* [Wheeler 1996].

The traditional way to measure relative humidity is a two-step process: Both wet bulb and dry bulb temperatures are obtained and then converted to relative humidity using a psychrometric chart. Dry bulb temperature is the commonly measured thermometer temperature.

Wet bulb temperature is determined by moving air past a wetted fabric wick covering the sensor bulb. As water evaporates from the wet wick, temperature falls and the sensor reflects a wet bulb temperature. The drier the air, the lower the wet bulb temperature is.

The best accuracy is provided by a clean bulb wick soaked with distilled water. The wick will have to be wetted periodically. With a wet wick, measured temperatures must be above freezing. Air movement can be provided by an aspirated box (with a fan) or by whirling the sensor through the air. The traditional instrument, called a sling psychrometer, contains two thermometers. One indicates the dry bulb temperature and the other, with a wet wick, indicates the wet bulb temperature. The sling psychrometer is spun around swiftly on a jointed handle for about three minutes to obtain the relative air movement needed to extract the wet bulb temperature.

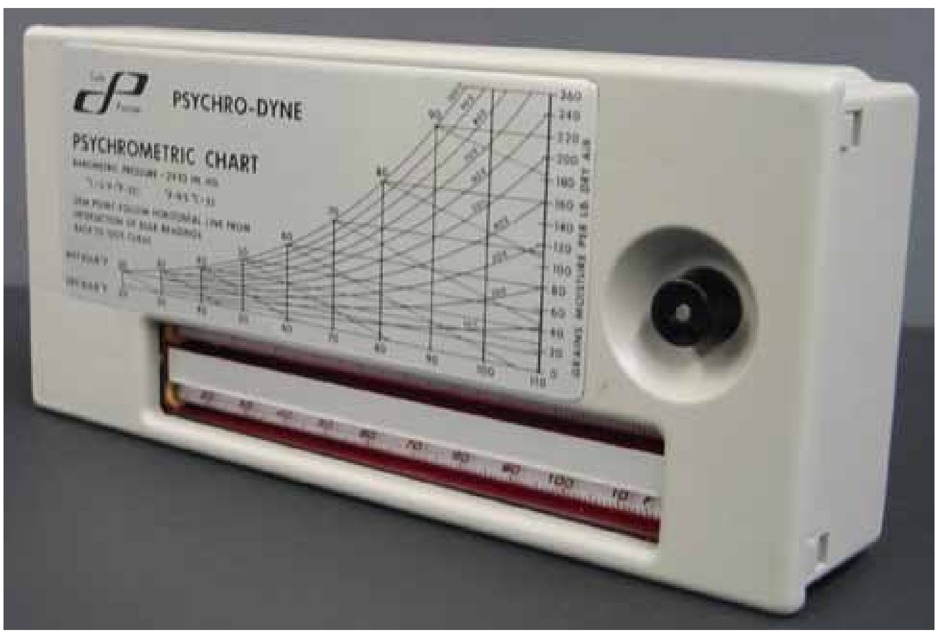

Figure 1. An example of an aspirated psychrometer for humidity measurement

An aspirated psychrometer (*Figure 1*) operates on the same principle as the sling psychrometer, except that a battery-powered fan moves air over the wet wick. Accuracy of the thermometers and careful reading of results are important, yet this method of measuring humidity is considered highly accurate, albeit time consuming and lacking automation.

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Relative humidity also can be measured directly with a hygrometer. Hygrometers measure relative humidity with solid state devices and electronics. The sensor is a matrix material in which electrical properties change as water molecules diffuse into and out of the special material in response to air moisture content.

Other hygrometers use materials that indicate electrical changes as water molecules adhere to their surface. Matrix material changes are interpreted and displayed by the hygrometer.

Careful calibration is essential. In general, the sensor materials do not tolerate conditions near saturation. They are also very susceptible to contamination, so it is essential that the sensing materials are protected from being touched, condensation, and/or dust.

Hygrometers offer the advantage of direct humidity measurements and are available in several cost-accuracy categories (*Figures 2 and 3*). A relatively inexpensive, thick, pen-shaped instrument provides digital dry bulb temperature and relative humidity readings. These pens can take several minutes to display a correct reading and provide humidity measurements with an unimpressive accuracy of about 5 percent. More accurate hygrometers (accuracy +/- 1 percent) are available but cost more. On some models, maximum and minimum temperature and humidity can be captured over a predetermined time period.

Figure 2. An example of temperature, relative humidity, wind speed small meter

Figure 3. An example of a temperature-humidity pen

Air Speed

Air speed is measured with an anemometer. In livestock building applications, two types of anemometers are common, depending on the type of air flow being measured: vane anemometers and hot-wire anemometers. Both instruments are composed of two connected parts: One is the sensing probe and the second displays air speed.

One key technique in using an anemometer is to take measurements while air speed and direction are minimally altered by the instrument's placement. The operator should stand away from the air flow being measured. One option on anemometers is an averaging mode where velocity is displayed as a running average value over time. This aids in scanning a fluctuating air stream.

A hot-wire anemometer (*Figure 4*) has a very fine, short wire, often the thickness of a human hair, positioned horizontally between two upright supports. Another design uses a thicker, vertical wire, which incorporates a temperature-sensing thermistor. The wire is heated by electronic circuitry and air flowing over it causes the wire temperature to decrease. By detecting this temperature decrease, or by evaluating the amount of current supplied to keep the temperature of the wire from decreasing, the anemometer determines the speed of the passing air.

Figure 4. An example of a hot-wire anemometer

Calibration is important for relating hot-wire temperature effects to air speed. The hot-wire portion of the instrument is fragile. Great care must be taken to protect it from physical damage, which can be caused by large dust particles, airborne bedding, feathers, etc.

A hot-wire anemometer is the instrument of choice for low air speed applications. Air moving less than 50 feet per minute (fpm) is considered still air. This condition exists in many animal pens and in many draft evaluations. Due to their small size, hot-wire anemometers can be used in small places, such as an inlet jet of a ventilation system, or in hard to reach spaces, such as ducts.

Figure 5. An example of a vane anemometer

The vane anemometer (*Figure 5*) is a more rugged instrument that is well-suited to several livestock applications. Designs vary, but most have an approximately 3-inch-diameter vane propeller that is turned by moving air. The vane rotates at a speed proportional to air velocity. Since it makes an air speed measurement based on a larger area than the hot-wire anemometer, it is better for determining air flow over the face of a fan, or a large duct or sidewall opening. It is not ruined by dust and small airborne debris since it can be carefully cleaned. It does not measure low air speeds because the mass of the vane requires a fair amount of air movement to rotate. Vane anemometers are not considered accurate below 50 to 70 fpm, even though the meter provides readout at these low air speeds.

Vane anemometers must be used in air streams that are at least as wide as the vane diameter. They will not accurately measure narrow inlet air jets that are smaller than the vane anemometer propeller. Vane anemometers with small, 1-inch-diameter vane heads are available for small jet flow measurement, yet they still cannot detect low air speeds. For low speed air (< 50 fpm) and most small jet measurements, a hot-wire anemometer is required.

Figure 6. An example of a velocity manometer

Velocity manometers (*Figure 6*) may be used in well-defined air streams of fairly high velocity. A Pitot tube is positioned so air flow directly affects the sensing tip and pressure; streamlined air is more desirable than turbulent flow. A velocity pressure is detected, from which air speed is determined. A bouncing ball in the instrument's air tube indicates the velocity reading. Although relatively inexpensive, these flow meters provide accurate, if fluctuating, readings when carefully used.

Air Flow Pattern

It is helpful to see where air is mixing or forming dead zones that influence animal comfort. Unusual air leaks may affect the operation of a ventilation system. Visualizing streamline patterns in livestock buildings has some limitations, but several methods have worked. Devices that generate smoke are the most common and come in gun,

Measure the characteristics of air the animals are breathing and the air blowing over their bodies in resting, eating, and dunging areas.

stick, candle, and bomb formats, with an increasing amount of smoke, respectively.

Smoke candles are rated according to their duration and the volume of smoke they produce. A common beehive smoker provides an inexpensive diagnostic tool for local air flow effects. Smoke bombs have been used, but the abundant smoke quickly obscures air flow patterns and is an irritant to confined animals. Animals should not be present if harmful techniques are used, but since the presence of animals usually affects how air flow patterns develop under normal housing conditions, animal removal may provide unrealistic air flow patterns. It is best to keep the animals in place and use compatible air flow visualization methods. The above smoke devices use combustion to produce smoke, so they also generate heat. This thermal effect tends to produce rising smoke.

Smoke sticks and guns use chemical reactions to produce smoke, so they exhibit few thermal effects. Smoke sticks produce the equivalent of smoke from three cigarettes and look like glass tubes filled with cotton. They produce smoke for 10 minutes once the end is broken off with pliers. An airflow indicator tube kit uses a rubber bulb pump that attaches to a smoke tube. Once the tip of the smoke tube is broken, smoke can be puffed out with a squeeze of the bulb pump.

Very small, neutrally buoyant soap bubbles, constructed with helium and compressed air, can last long enough to show airstreams within an enclosure. Bubbles are surprisingly durable in a free airstream but will not tolerate many impacts with obstructions. The apparatus used to generate bubbles is cumbersome and expensive, compared with other air flow visualization devices. Children's soap bubble toys can be useful in faster-flowing airstreams but are not neutrally buoyant. The bubbles exhibit downward gravitational effects that may not represent true air flow.

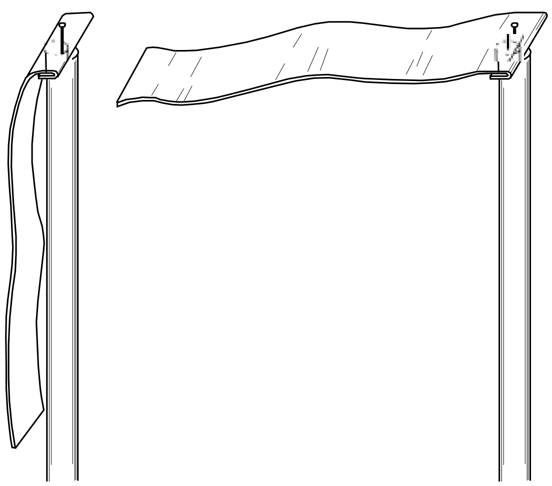

Figure 7. Streamers showing inadequate (left) and adequate (right) air speed.

A set of air speed streamers (*Figure 7*) may be used to detect air speed at various locations in a building. Threads of material or ribbons, such as string or plastic tape, can be "calibrated" to a size that blows horizontally at a particular air flow of interest. These inexpensive tiny posts with attached free-to-spin streamers can be positioned in many locations as indicators of the "calibrated" desired air flow and direction.

As conditions are changed in a livestock building, a quick survey of the streamers will indicate that areas are receiving desirable air flow. For example, a mechanical ventilation system inlet air speed of 700 fpm or faster is desirable. Streamers that have been "calibrated" to blow horizontally at 700 fpm are positioned at various inlet locations to observe whether inlet air speed is at least 700 fpm. See "Make your own ceiling inlet air speed monitors" [Wheeler and Martin 1998] for details of how to construct and position inlet air speed indicators.

Surface Temperature

Where large differences in temperature exist between the animal environment and surrounding surfaces such as walls, ceiling, and floor, determine the radiant (or surface) temperature. Surface temperatures have a strong impact on animal comfort, yet often are ignored in environment analysis. A hot ceiling temperature, from the summer sun, for example, can provide a large radiant load on the enclosed animals. This load would not be detected by a regular, dry bulb air temperature measurement. Surface temperature measurements will indicate ceiling areas with poor insulation.

Similarly, very cold surrounding surfaces can make animals feel chilled even though the air temperature seems adequate. Radiation is a very strong form of heat transfer, yet is purely a surface phenomenon that can be characterized by an object's surface temperature. An object must "see" another surface in order to feel its radiant heat transfer effect.

"Line-of-sight" is a straight, unobstructed pathway where radiant energy wavelengths can travel. Animals in enclosures will be influenced by temperatures of the surrounding walls, ceiling, and floor even though they have limited or no contact with these surfaces.

Even a surface outside the barn can cause heat stress if the enclosed animals can "see" it. For example, black asphalt pavement may heat to 200°F on a sunny day. This surface adjacent to a curtained, naturally-ventilated freestall dairy may affect cow comfort when the curtains are completely opened, since there is a clear radiant heat transfer sight line between the cow and the hot surface.

An infrared thermometer (*Figure 8*) measures surface temperature. This is a line-of-sight instrument and detects the radiant temperature of object(s) it can "see." Readings are calibrated, or zeroed, on a black disc that is at the same temperature as the air temperature in the enclosure being evaluated. An infrared thermometer looks like a hand-held hair dryer with a small, circular sensing element that is aimed at a surface. It does not touch the surface, but it detects the wavelength of thermal energy emitted from that surface, which is displayed as a radiant temperature. The instrument's field of view widens with increasing distance between the object of interest and the instrument. Therefore, be sure that it is not also detecting adjacent surfaces. Small objects will require having the instrument close. A large object, such as a ceiling, can be evaluated while standing several feet away at floor level. Be sure to evaluate surfaces that the animals "see" from their enclosure.

Gas Levels

A portable and relatively inexpensive way to detect gas levels of ammonia, hydrogen sulfide, carbon dioxide, and carbon monoxide is with a handheld sampler pump and colorimetric tubes (*Figure 9*). This manually operated, piston-type pump draws a specific amount of sample air through a detector tube. It is very important to hold the pump so the air pulled in through the detector tube comes from the location of interest. This means holding it near the floor during the sampling period for floor-level measurements. Remote sampling is possible for hard-to-reach areas.

Figure 8. Examples of infrared camera (top) and thermometer (bottom) for surface temperature evaluation

Figure 9. Examples of handheld sampler pumps and colorimetric tubes to measure gas levels

The thin glass detector tube is specific to the type of gas that you are measuring. For example, if ammonia is a concern in veal calf housing, a detector tube filled with an ammonia-sensitive material would be attached to the pump. The contents of the tube react with the air contaminants and change color. The length of the color change in the detector tube indicates the concentration of gas in the sample, similar to reading a glass thermometer. Tubes come in a choice of measurable ranges so that accurate analysis is possible. For example, a manufacturer may offer ammonia detection tubes in 2 to 50 parts per million (ppm) and 20 to 1000 ppm ranges. Each tube is used once to obtain a reading and then discarded. A short fact sheet *Ammonia Monitoring in Animal Environments Using Simple Instruments* [Wheeler 2009] offers more detail on colorimetric gas detection.

Dozens of gas- and vapor-specific detector tubes are available, including ones for ammonia, hydrogen sulfide, carbon dioxide, and carbon monoxide. Several types of sampling pumps are available, such as a design with a rubberized bulb that is squeezed for sampling. The pump and detector tubes must be compatible. As with other instruments, the pumps need to be periodically checked for leakage and calibration.

Dust is more appropriately referred to as particulate matter and can be detrimental to animals, workers, and equipment with moving parts.

Dust

A wide variety of dust-measuring instruments are available. Most of the instruments are relatively expensive, either in labor for analysis or the instrument itself. Dust is more appropriately referred to as particulate matter and can be detrimental to animals, workers, and equipment with moving parts. Particulates often need to be sorted by size to determine the respirable portion. This dust can go directly to the lungs and can contribute to animal and human health problems.

A cascade impactor is one device used to determine dust levels in a range of predetermined sizes. Dust is commonly collected by gravimetric settling from air over a time frame of hours or a full day. Then the collection plate is submitted to a lab for careful conditioning and weighing analysis. Airborne dust can be collected on a filter by using a sampling pump; the filter can be weighed or further analyzed under a microscope. Direct-reading instruments are also available for real-time measurement of dust concentration. In general, direct-reading instruments are expensive and have to be used with great care in livestock housing environments. Optical measures of dust can provide relative changes in dust in agricultural settings. Hand-held optical instruments are only accurate when the particle shape approximates spherical, which is close to the shape of particles used to calibrate the instrument.

Part III. Characterizing a Mechanical Ventilation System's Performance

When people think of air quality in an animal environment, they often think of the ventilation system. Fortunately, mechanical-fan ventilation systems can be measured easily, relative to natural-wind ventilation systems. Air exchange and air distribution are the main concerns, meaning that measurements are focused on fan performance and inlet characteristics. Air speed at the fan and inlets can be measured to get the necessary information to calculate the capacity of the ventilation system.

The static pressure against which the system is operating can be checked. Fan performance can be verified. Evaluate the system under typical animal density and weather conditions.

Although the performance of a ventilation system is important, conditions in the area occupied by the animals are even more important. The ventilation system will influence conditions within the animals' space, so environmental measurements should be made along with observations of animal behavior. For example, in some cases the ventilation system may appear to be working correctly and within its design specifications, yet air quality in parts of the animal facility is unacceptable.

Fan Air Speed

Fast air speed at the discharge or entry into a fan can be measured with a vane anemometer. Many readings should be taken across the face of the fan to get an average air speed (*Figure 10*). Because this is a rather crude field measurement, include as many readings as possible in your average air speed.

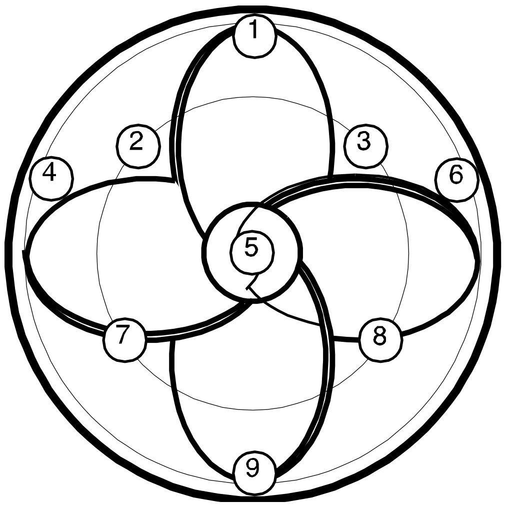

Figure 10. Take air speed measurements at several locations across the fan area

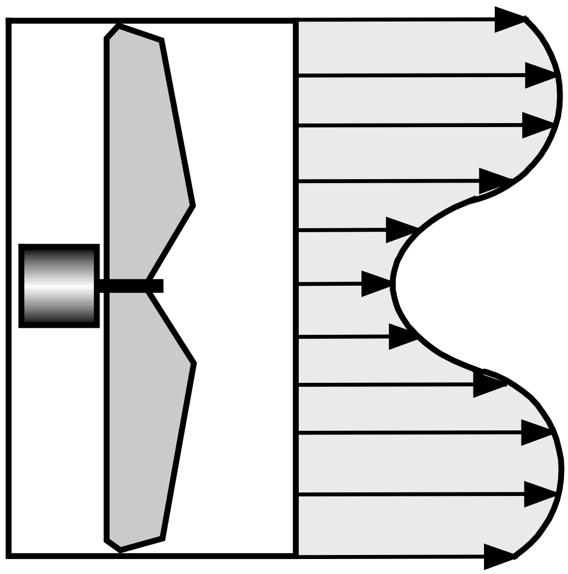

Figure 11. A cross section of a fan showing a large variation in air speed coming off the fan tips versus near the fan hub

Use the nine readings shown in *Figure 10* as a minimum. Each measurement represents only a very small area of air flow over the fan face. Air speed varies greatly across the face of a fan, with highest velocities coming off the blade tips and minimal velocity near the hub as shown in *Figure 11*. Sample velocities near the blade tip, in the middle, and at the center of the fan.

Some fans will have negative air flow at the center, indicating a draft of air short-circuiting backwards through the fan. Therefore, it is important to take a measurement at the fan hub. Obstructions and wind gusts cause uneven air speed distribution over the fan face. A poultry house fan under a light-reducing hood will exhibit lower air flow at the top quadrant of the fan due to the resistance of the external hood, which is open at the bottom. Air speeds are more accurately determined by this technique on the side of the fan that does not have the shutter.

When people think of air quality in an animal environment, they often think of the ventilation system. Fortunately, mechanical-fan ventilation systems can be measured fairly easily compared to natural-wind driven ventilation.

Although the performance of a ventilation system is important, conditions in the area occupied by the animals are even more important.

A more sophisticated approach to measuring fan airflow using hand-held instruments is presented in *Ventilation Fan Airflow Measurements Using the Air Velocity Traverse Method* [Lim 2006].

It is important to minimize the amount of air flow that your body blocks as you position the anemometer. Step back out of the air flow, to the side of the fan when possible. Vanes that attach by cable to the air speed display unit offer an advantage here. Several instruments are appropriate for measuring the fast air speeds exiting a fan, including a velocity manometer, vane anemometer, hot-wire anemometer, or air speed streamer.

Inlet Air Speed

Air speed from inlets should be quite fast, between 700 and 1000 ft/min, in a properly operated mechanical ventilation system. Unfortunately, the inlet gap of a slotted or baffle inlet is often so small, at 1/4 inch to 1 inch wide, that the large 3-inch diameter head of a typical vane anemometer cannot determine a meaningful air speed.

The small probe head of a hot wire anemometer is most appropriate for measuring air speed out of slotted inlets. A vane anemometer can be used to measure air speed out of duct holes (rigid or polytube ducts) or other inlets with large openings. The key is to make sure the vane anemometer head is not larger than the airstream being measured. Small-headed vane anemometers can measure smaller diameter airstreams. The low-cost air velocity manometer may be used with these fast inlet air speeds.

Air speed from slotted inlets is not uniform over the vertical cross section of the inlet. The air speed will be nearly zero at the edges of the inlet and will typically increase to its maximum near the middle of the inlet opening. Take air speed measurements across the vertical opening of the inlet until you get a maximum air speed reading, then correct for the edge effects by using a concept called the "coefficient of discharge." This has been empirically determined to be about 0.6 for sharp-edged openings such as ventilation slots, holes, or windows. The real inlet air speed is the maximum measured air speed multiplied by the coefficient of discharge of 0.6. In other words, the average air speed over the face of the entire inlet opening is 60 percent of the maximum speed you measured.

Capacity of Ventilation System

To calculate the air volume being moved by a ventilation system (e.g., fan), you will need a measured air speed and an estimate of cross-sectional area through which that air is moving. Air speed involves measurements at the fan and/or inlets. To determine cross-sectional area, measure the fan wall opening(s) or the sum of inlet areas.

It is easier and better to determine ventilation capacity by taking measurements at the fan. Inlet air speeds may seem easy to measure, but the effective inlet area and average air speed are not as easy to determine. Particularly with long slotted inlets, construction irregularities will mean that small openings such as 1/4 inch cannot be maintained along the length of the slot. In polytube or other ducted inlets, air velocity in the duct and at the holes will vary with the distance along the duct, so many measurements will be needed. Even tightly constructed buildings have some "unplanned" inlets for air exchange, and these are very hard to account for.

Use this very simplified method to calculate air flow capacity of a fan in cubic feet per minute (cfm): multiply the average air speed you measured in feet/minute (fpm) by the area of the fan face in square feet. Area of circle = $\pi d^2/4$; where d = diameter in feet and π is approximately 3.14. Example: you calculated an 800 ft/min average air speed across the face of a 48-inch (4-foot) diameter fan. Air flow (cfm) = speed (fpm) * area (sq ft) = 800 fpm*3.14 $(4)^2/4$ sq ft =10,048 cfm.

The ventilation system capacity equals the sum of all fan capacities. For each type of fan in a staged ventilation system, one set of representative data may be used. For example, in a poultry house with banks of 36-inch and 52-inch fans, determine an average velocity reading from one (or two or three) of the 36-inch fans and one (or two or three) of the 52-inch fans. Total ventilation capacity at any stage would be estimated as the measured average air flow capacity of a 36-inch fan times the number of 36-inch fans operating, plus the average air flow capacity of a 52-inch fan times the number of 52-inch fans operating.

When there are differences in fan types due to the manufacturer, motor, blades, maintenance, or suspected reliability, air speed measurements will need to be taken for each different type of fan. Fans in locations where obstructions or wind effects are dominant features also will need to be evaluated separately. There is no need to measure air flow at each and every fan unless an unusual air flow imbalance is suspected.

Static Pressure

Static pressure difference is very important to a mechanical ventilation system since it is the driving force for air movement. Air enters or leaves the building because the interior static pressure is different than the outside pressure.

Static pressure is measured with a manometer (*Figure 12*), which determines the pressure difference between the ventilated space and the building exterior (atmospheric pressure). The exterior is anywhere outside the mechanically ventilated livestock confinement that is exposed to outside air conditions.

The manometer has one port open to the building interior. The second port is connected to a flexible hose that has its open end positioned outside the ventilated space. The manometer then measures the static pressure difference that influences air entering the inlets.

Inclined manometers are the most accurate manometers for agricultural ventilation situations. A colored fluid in a thin tube equilibrates to a position representing the pressure difference between the two measuring ports. Units are in fractions of an inch of water. Static pressure differences in agricultural ventilation are so small, on the order of 0.02-inches to 0.20-inches water, that an inclined rather than upright manometer is needed to accurately determine a scale reading.

Care must be taken in positioning the tubes connected to the measuring ports. Be sure they are not exposed to any moving air. The objective is to measure a "static" pressure of air and not the "velocity" pressure of moving air. The exterior measuring port often is placed in the building attic, which represents an outside condition without wind effects. The interior port should be kept away from high air velocity areas such as near the fans or inlets.

Figure 12. An example of a static pressure bubble meter (manometer)

Static pressure difference is very important to a mechanical ventilation system since it is the driving force for air movement.

Using common sense to identify where leaks and trouble spots may be occurring will lead to appropriate positioning of air visualization equipment. Pure curiosity is allowed.

Ventilation system controls often operate by measuring the static pressure difference across the inlets. This measurement can be verified as discussed above. Ventilation fans actually operate against more pressure drop than that associated with just the inlets. They also have a pressure drop in exhausting air through the fan enclosure restrictions, including the fan housing, guard, and any louvers. (This pressure change is almost impossible to measure under field conditions.) Fans are chosen for operating performance at 0.10-inch to 0.125-inch (1/10 inch to 1/8 inch) water pressure to account for fan enclosure and inlet restrictions.

Evaporative cooling pads or other air restricting devices (heat exchangers, biofilters, earth tubes, and ducts) will offer additional resistance to air flow. Additional manometer readings should be taken when each source of air flow resistance is being used. This "total" static pressure is used for comparing actual versus expected fan performance.

For example, a ventilation system may be set to operate at 0.04-inch static pressure for part of the year. This control setting represents the static pressure difference across the inlets. The pressure difference with an evaporative cooling pad in place will be higher. A new measurement may find the static pressure the fan is operating against is 0.08-inch water. Fan capacity, as shown on a fan characteristic curve, would have to be evaluated at or above 0.08-inch water to account for inlets, evaporative pad, and fan restrictions.

Air Flow Pattern

Sometimes it is helpful to see where air mixing or unusual leaks are occurring in a ventilation system. It may be surprising, but not uncommon, to learn that a good portion of air flow in the enclosure is coming through unplanned inlets. These may include leaks around the fan installation, broken window panes, leaks around door and window frames, broken siding materials, and any other loose construction detail. These significant leaks are very detrimental to performance of the ventilation system. Unplanned inlets are often not controllable and probably provide uneven air flow patterns, in turn creating uncontrolled and uneven air quality conditions around the building interior.

An improperly operated ventilation system may have adequate air flow in volume as measured at the fan(s), but not in distribution throughout the enclosure. The inlets and their resultant air flow distribution create the desirable air conditions within the animal area. Fans provide a motive force (the pressure difference in combination with the tight building construction) to keep a volume of air moving through a building at a certain rate, but it is the inlet system that distributes fresh air.

Air flow visualization will provide information about whether fresh air is being distributed evenly to the animal areas where it belongs. Visualizing air flow patterns in livestock buildings has a few limitations, but several methods have worked as described previously.

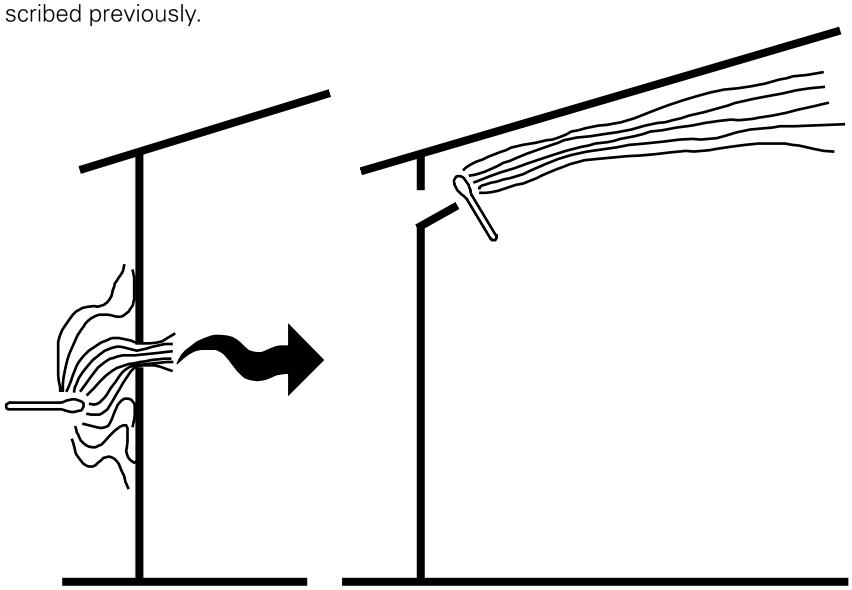

Figure 13. Air flow visualization by positioning smoke devices

A certain amount of creative license is allowed in using air flow visualization. A visualization tool such as a smoke candle can be placed just outside (or just inside) an inlet to see how far the air jet is penetrating into the animal enclosure as shown in *Figure 13*. Similarly, a smoker can be positioned close to the exterior of a building to see where smoke is drawn through building leaks. Smoke sticks can be held down into an animal pen to look for drafts or dead air zones.

Using common sense to identify where leaks and trouble spots may be occurring will lead to appropriate positioning of the air visualization equipment. Pure curiosity is allowed! Move around with the instruments and look for unusual air flow patterns. Sudden, dropping drafts of air may be caused by temperature and/or velocity changes. Look for obstructions and use other instruments to help determine causes for the air flow observations.

Fan Speed (rpm)

Fan operation also can be checked by measuring the fan blade rotational speed in revolutions per minute, or rpm. Because the amount of air a fan moves is directly proportional to its rotational speed, a fan running at 75 percent of its rated speed will move only 75 percent of its rated or intended air flow.

Fan speed measurement can quickly indicate if belts are loose or worn, or if the voltage level is too low. Inadequate wiring can lead to substantial voltage drops along the building length, causing fans to run slowly. Measuring fan speed is as important as other performance indicators, particularly for belt-driven fans, which can slip with worn or poorly-adjusted belts.

Fan rotational speed can be measured using a tachometer or strobe light. Tachometers can be either mechanical or electronic. With mechanical tachometers, the tachometer shaft is rotated by pressing it against the center of the fan shaft so that both the tachometer shaft and fan shaft have the same speed.

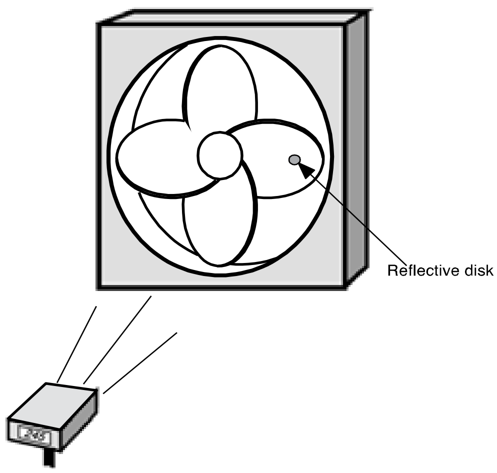

Figure 14. An example of an electronic tachometer

Mechanical tachometers should be used carefully so that no personnel or equipment damage occurs if the tachometer shaft slips off the fan shaft. Electronic tachometers send light to a shiny, rotating object, such as a silver sticker attached to a fan blade or shaft, and the reflected light is measured by the tachometer and converted to an rpm measurement (*Figure 14*).

A strobe light (*Figure 15*) produces flashes of bright light at an adjustable frequency (flashes per minute). As the frequency approaches the fan rpm, the blades appear to slow down, stop, and may even appear to reverse direction. The fan rpm is determined by adjusting the flash rate until a rotating part (blade, shaft, or pulley) appears to be stopped.

Figure 15. An example of a strobe light

It is important to note that simply adjusting the flash rate until the fan blades appear to be stopped does not ensure an accurate reading because the same blade may not be in the same position at each flash. For example, with a four-blade fan, running

With the tools and methods outlined in this publication, you can better understand and characterize the environment to which your animals are exposed.

the strobe at 3/4 or 1 1/4 times the correct flash rate will appear to stop the blades, but a given blade will not be in the same position with each flash. The correct strobe flash rate and rpm can be obtained by stopping a unique rotating part, such as an oil fitting, bolt, or key shaft on the shaft, or a shiny sticker that is half black and half shiny placed on the fan shaft.

Summary

Evaluation of a mechanical ventilation system emphasizes measurements of air exchange capacity (fan air speed) and air distribution (inlet air speed and air flow visualization). Ventilation system capacity is best measured at the fan(s) by determining an average air speed over the face of the fan. Multiply average air speed (ft/min) by the area (square feet) of the fan face to determine airflow capacity (cfm). Appropriate inlet air speed encourages good air mixing and distribution.

When environmental problems are suspected, techniques such as air flow visualization can help identify trouble spots. Static pressure and fan speed (rpm) measurements can help pinpoint causes of poor performance.

The environmental conditions under which animals are housed are very important to their comfort and productivity. With the tools and methods outlined here, one can better understand and characterize the environment to which the animals are exposed. Part I emphasized the principles of how reliable measurements are obtained. Instruments needed to make appropriate measurements in agricultural environments were described in Part II. Proper techniques for using each instrument have been emphasized. Once good measurements are taken, comparisons can be made to desirable environmental characteristics. Part III highlighted methods to use instruments and observations to evaluate air exchange capacity and air distribution of a ventilation system.

Resources

Pork Industry Handbook. Troubleshooting Swine Ventilation Systems, Purdue Extension, Purdue University, West Lafayette, Ind.
Mid-West Plan Service, Ames, Iowa (www.mwps.org)
MWPS-32, Mechanical Ventilating Systems for Livestock Housing
MWPS-33, Natural Ventilating Systems for Livestock Housing
MWPS-34, Heating, Cooling and Tempering Air for Livestock Housing
MWPS-7 Dairy Freestall Housing and Equipment
MWPS-8 Swine Housing and Equipment Handbook
Natural Resources, Agriculture, and Engineering Service, Ithaca, N.Y. (www.nraes.org)
NRAES-17 Special-Fed Veal Production Guide
NRAES-63 Dairy Reference Manual

References

Wheeler, E. F. 2009. Ammonia monitoring in animal environments using simple instruments. Agricultural and Biological Engineering Fact Sheet G-110, The Pennsylvania State University, University Park, Penn. Available at: *http://www.abe.psu.edu/extension/factsheets/g/G110.pdf.*

Wheeler, E. F., and J. Martin. 1998. Make your own ceiling inlet air speed monitors. Agricultural and Biological Engineering Fact Sheet G-94. The Pennsylvania State University, University Park, Penn. Available at: *http://www.abe.psu.edu/extension/factsheets/g/G94.pdf.*

Wheeler, E. F. 1996. Psychrometric chart use. Agricultural and Biological Engineering Fact Sheet G83. The Pennsylvania State University, University Park, Penn. Available at: *http://www.abe.psu.edu/extension/factsheets/g/G93.pdf*.

Lim, Teng Teeh. 2006. Ventilation fan airflow measurements using the air velocity traverse method. Purdue Agricultural Air Quality Laboratory, West Lafayette, Ind. Available at: *http://create.extension.org/sites/default/files/SOP%20A8%20Fan%20Velocity%20Traverse%20for%20NAEMS%20by%20Purdue%20%28Rev%200%200%29%203-6-08.pdf*.

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