Mechanical Ventilating Systems
for Livestock Housing

TABLE OF CONTENTS

1. Providing A Proper Environment
   1. Ventilating Process
   2. Ventilating Systems

2. Air Requirements
   1. Air Quality
     2. Gases and Odors
     3. Gas measuring Instruments
     4. Potentially Lethal Situations
     5. Controlling Odors and Gases
     6. Dust
     7. Animal Heat Loss
     8. Moisture Balance
     9. Heat Balance
     10. How Much Air

3. Mechanical Ventilating Systems
   1. Negative Pressure System
     2. Air Inlets
     3. Inlet design
     4. Inlet size
     5. Wet management
     6. Porous ceilings inlet
     7. Negative Pressure With Recirculation
     8. Positive Pressure Systems
     9. Neutral-Pressure Systems
     10. Manure Pit Ventilation
     11. Rigid pipe ducts
     12. Design of suction ducts

4. Emergency Ventilation

5. Insulation
   1. Where to Insulate
   2. Insulation Levels
   3. Moisture Problems
   4. Fire Resistance
   5. Birds and Rodents

6. Fans
   1. Fan Types
   2. Fan Performance
   3. Fan Selection
   4. Electrical Cost
   5. Multi-Variable Speed Fans
   6. Fan Location
   7. Fan Motors
   8. Codes
   9. Motor Types
   10. Motor Nameplate
   11. Motor Enclosures
   12. Motor Bearings
   13. Motor Drive

7. Controls
   1. Thermostats
   2. Humidifiers
   3. Timers
   4. Solid State Controls
   5. Inlet Baffle and Vent Door Controls
   6. Controlling Variable Cold Water Rates
   7. Alarm Systems
     1. Relay Switch Alarm
     2. Solenoid Valve Controlled Alarm
     3. Combination Alarm System
     4. Automatic Phone Dialer

8. Maintenance

9. Troubleshooting
   1. Troubleshooting Tools
   2. Thermostat
   3. Psychrometer
   4. Smoke Generator
   5. Meters
   6. Air Pressure Meters

10. Applications and Examples

11. Beef

12. Dairy
   1. General
   2. Cows
   3. Calves and replacement heifers
   4. Milking Center Environment
   5. Holding area
   6. Treatment-hospital area
   7. Milking parlor
   8. Milk room
   9. Other areas

13. Dairy Design Examples
   1. Pen area
   2. Stall barn
   3. Delineated required ventilating rates
   4. Stall barn fans
   5. Inlets
   6. Inlet location and construction
   7. Attic ventilation
   8. Other modifications
   9. Young calf housing
   10. Young heifer housing

14. Veal Calves
   1. General
   2. Ventilation
   3. Air tempering
   4. Veal Calf Design Examples
1. PROVIDING A PROPER ENVIRONMENT FOR ANIMALS AND WORKERS

This is one of three handbooks on ventilation for livestock housing being published by the Midwest Plan Service:
  - Mechanical Ventilating Systems for Livestock Housing, MWPS-32.
  - Natural Ventilating Systems for Livestock Housing, MWPS-33.
  - Heating, Cooling and Tempering Air for Livestock Housing, MWPS-34.
Contact your state's Extension Agricultural Engineer for copies.

This handbook has information on the ventilating process in livestock housing. It will help you evaluate existing systems, examine alternatives for new systems, and troubleshoot malfunctioning systems. It is not a design manual for professional consultants. Ventilating system type and desired inside environment depend on animal species and management system. Ventilating systems to satisfy the requirements of different livestock are shown.

Retaining animal body heat in the building is important in cold weather to maintain desired room temperature and evaporate excess moisture. See chapter on selection and use of building insulation to reduce heat loss.

Even the best ventilating system occasionally fails to maintain desired building conditions. Troubleshooting sections help diagnose problems.

Ventilating Systems

Ventilating systems for livestock buildings are mechanical, natural, or a combination of the two. Mechanical systems force air through buildings with fans, while natural systems depend on wind and thermal buoyancy. Ventilating systems require carefully designed air inlets and outlets for proper air mixing and circulation inside the building.

Mechanical ventilating systems are negative pressure, positive pressure, or neutral pressure. Negative pressure systems force air from the structure with fans; the reduced pressure sucks air in through inlets. Positive pressure systems force air into the structure with fans; the increased pressure forces inside air out through outlets. Neutral systems use fans to force air both into and out of a building, so room air pressure is the same as outdoors. Heat exchangers and "push-pull" systems are examples.

Mechanically ventilate where careful control of the environment is needed, as for young and smaller animals. Mature, "finishing," or large animals are often in naturally ventilated buildings. They are discussed in MWPS-33, Natural Ventilating Systems for Livestock Housing.

Heating and cooling are sometimes needed to maintain the desired environment. Young animals often use additional heat and brooding stock may require summer cooling. MWPS-33, Heating, Cooling and Tempering Air for Livestock Housing, discusses combining the ventilating system with supplemental heating (heaters, solar collectors, earth tubes, and heat exchangers) and cooling (mechanical refrigeration, evaporative cooling, earth tubes, spray or drip cooling, and circulating fans) systems.

![Fig 1. A basic ventilating process.](image-url)
2. AIR REQUIREMENTS

Air Quality

Gases and Odors

Atmospheric air is 78% nitrogen, 21% oxygen, 0.9% argon, 0.03% carbon dioxide, and smaller amounts of other gases. Air composition is changed by livestock in buildings. Breathing uses oxygen and releases carbon dioxide. Air oxygen content less than 16% causes discomfort; less than 10% is dangerous. Odors are given off by respiration, animals’ skin, urine, and manure. Anaerobic decomposition of manure in a pit releases additional noxious gases. Without enough fresh air, toxic gases and dust in enclosed livestock buildings can harm animals and operators.

Post warning signs in worker lounges, on livestock buildings, and near manure storage to warn workers of potentially dangerous situations. Post warning signs at building doors to prevent access while agitating manure.

Gas in livestock buildings that may affect animal productivity are ammonia, carbon dioxide, carbon monoxide, hydrogen sulfide, and methane. See Table 1 for human responses to the gases. Decomposing wastes give off odorous gases such as amines, amides, mercaptans, sulfides, and disulfides.

In a properly designed and managed naturally ventilated building, noxious gases usually do not reach lethal or even harmful concentrations, except perhaps during manure pit agitation. However, low levels of these gases could contribute to chronic disease. See the Potentially Lethal Situations section.

Ammonia (NH3) is released from from manure and during anaerobic decay. Ammonia levels tend to be high in buildings with litter, solid floors, or scrapers because manure spread over the floor area increases ammonia release. Heated floors also increase ammonia production. Ammonia release is less with liquid manure systems, because ammonia is absorbed in water. Ammonia is absorbed less with high pH levels. It is explosive at concentrations above 16 (180,000 ppm). Well-managed ventilation should prevent ammonia levels above 10 ppm.

Concentrations up to 200 ppm induce sneezing, salivation, and appetite loss. Above 30 ppm, some respiratory lesions can develop, and above 50 ppm, eye inflammation in chickens. Prolonged exposure may increase respiratory diseases. Ammonia can combine with nitrites or nitrates, which are poisonous if ingested.

Carbon dioxide (CO2) is from animal respiration, manure decomposition, and unwetted heaters. CO2 concentration in a well-ventilated swine confinement unit may be 2,000 ppm (0.2%), about 7 times normal atmospheric level. Without ventilation in a closed building, the level can rise to over 30,000 ppm (3%) in 6 hr.

Carbon dioxide triggers breathing, but at high concentrations contributes to oxygen deficiency. Above about 100,000 ppm, carbon dioxide is narcotic, even with adequate oxygen. At this concentration, dizziness and even unconsciousness may occur.

Carbon monoxide (CO) is exhausted from internal combustion gas engines and from fuel burning heaters. Vent engines to the outside and ventilate rooms with unwetted heaters adequately to prevent toxic concentrations. Well-managed ventilation should prevent CO levels as above 50 ppm.

Carbon monoxide is poisonous, and can cause abortions in gestating swine. Hydrogen sulfide (H2S) is the most toxic gas from liquid manure storage. See Potentially Lethal Situations. It is soluble in water, so it can be reduced somewhat by diluting manure and raising pH level. The gas burns with a bluish flame and can explode violently at concentrations of 4%-46%.

Hydrogen sulfide is produced by anaerobic decomposition of organic wastes. Concentrations are usually negligible in well ventilated buildings except during agitation and pumping of liquid wastes. High ventilating rates can help reduce dangerous conditions during agitation and pumping of stored manure.

At low concentration, hydrogen sulfide smells like rotten eggs. Paper impregnated with lead acetate solution turns black from hydrogen sulfide. Hydrogen sulfide forms a black sulfide on copper, white sulfide on galvanized steel, and black discoloration of lead-pigmented white paint. Hydrogen sulfide concentrations in a well-managed facility should not be measurable.

H2S can rapidly destroy the sense of smell temporarily; lack of an H2S odor is not an adequate warning. See the Potentially Lethal Situations section. As much as 8,000 ppm (0.6%) have been reported in confinement hog houses during manure agitation. Animals continuously exposed to 20 ppm (0.002%) develop fear of light, nervousness, and appetite loss.

Methane (CH4) is highly flammable and explosive and burns with a blue flame. Methane is explosive at concentrations of 5%-15%.

Ruminant animals exhale a little methane, but most comes from manure decomposition. Methane is lighter than air and tends to rise and accumulate near the top of stagnant areas or tight manure storage pits. It dissipates fairly rapidly with some ventilation.

Methane is not usually considered toxic. Accumulations in stagnant areas can be asphyxiating, but explosions are a more serious hazard.

Gas measuring instruments

There are many ways to measure gas levels, from charts that change color to electronic detectors. Typically, more sophisticated methods are more accurate. Some inexpensive units indicate only whether the gas is present and do not tell when it is safe to enter an area. Use simpler systems only to monitor animal and worker environment. See "Selected References" for sources of gas measuring instruments.

Potentially Lethal Situations

Ventilating system failure can cause death by asphyxiation from lack of oxygen and increased carbon dioxide, by heat prostration, by poisoning by other gases, or some combination. These effects can occur in minutes or hours, depending on outside conditions, animal density, etc. Post warning signs in worker lounges, on buildings with manure storage, on manure spreaders, etc. Teach workers of the risks and dangers involved.

Agitation of liquid manure releases large quantities of noxious gases and creates possible lethal conditions. Remove workers, and if possible animals, before agitation. If not possible to remove animals, check them frequently from a window or doorway. If manure under slotted floors must be agitated with animals in a building, choose a mild day and ventilate at maximum capacity. Stop agitation immediately if problems occur and ventilate well before entering a building.

Entering a manure storage pit can cause death from hydrogen sulfide or lack of oxygen. Enter a manure storage or transfer pit only after it has been well ventilated, wear self-contained breathing tanks, and have an attached safety rope with at least two people standing by who are able to pull you out at the first sign of dizziness.

Methane can accumulate in unwetted covered manure storages and cause an explosion with a flame or spark. Ventilate the pit thoroughly.

Controlling Odors and Gases

Odor levels depend on animal type, manure handling system, air temperature, ventilating rate, and building management. Except during the coldest part

---

Table 1. Properties and effects of noxious gases.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Odor</th>
<th>Odor threshold ppm</th>
<th>Maximum allowable concentrations, ppm</th>
<th>Level ppm</th>
<th>Exposure period minutes</th>
<th>Physiological effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>----</td>
<td>------</td>
<td>--------------------</td>
<td>--------------------------------------</td>
<td>-----------</td>
<td>------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Carbon dioxide (CO2)</td>
<td>None</td>
<td>−</td>
<td>5,000</td>
<td>20,000</td>
<td>−</td>
<td>Increased breathing, heart rate, unconsciousness</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>None</td>
<td>−</td>
<td>500</td>
<td>20,000</td>
<td>−</td>
<td>Heavy, asphyxiating, unconsciousness</td>
</tr>
<tr>
<td>Hydrogen sulfide (H2S)</td>
<td>None</td>
<td>−</td>
<td>50</td>
<td>200</td>
<td>−</td>
<td>Asphyxiating, unconsciousness</td>
</tr>
<tr>
<td>Ammonia (NH3)</td>
<td>Smooth, pungent</td>
<td>5</td>
<td>50</td>
<td>400</td>
<td>−</td>
<td>Intoxication</td>
</tr>
<tr>
<td>Methane (CH4)</td>
<td>Rotten egg</td>
<td>0.7</td>
<td>10</td>
<td>100</td>
<td>−</td>
<td>Several</td>
</tr>
<tr>
<td>Hydrogen sul</td>
<td>Rotten egg smell. nauseating</td>
<td>2.0</td>
<td>30</td>
<td>300</td>
<td>−</td>
<td>Asphyxiating, unconsciousness, death</td>
</tr>
<tr>
<td>Methane (CH4)</td>
<td>None</td>
<td>−</td>
<td>1,000</td>
<td>500,000</td>
<td>−</td>
<td>Apnea</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>None</td>
<td>−</td>
<td>50</td>
<td>500</td>
<td>1,000</td>
<td>Diaphragmatic, cardiac</td>
</tr>
</tbody>
</table>

Note: The lowest concentration of which odor is detected.

*Maximum allowable concentration allowed by health agencies for workloads in 8 hr periods.

*Parts of pure gas per million parts of atmospheric air. Divide by 10,000 to get % by volume. Example: 30,000 ppm = 3% by volume.

*The time with immediate reaction to the gas.

*Intoxication.

*Poison.

*Eye and nose irritation.

*Headaches, dizziness.

*Hypoxia, unconsciousness.

*Unconsciousness, death.

*Apnea.

*Headaches, narcosis.

*Diaphragmatic, cardiac.

*Diaphragmatic, cardiac.
of the year, ventilating rates that remove excess animal heat and moisture usually control odor. How-
never, winter ventilating rates that just prevent moist-
ure buildup may not control odor or disease, so indoor manure pits may require higher ventilating
rates.

- To reduce odors:
  - Clean solid floors at least once a day by flushing or scraping. Locate quick-connect water lines in build-
ings for convenient use of high pressure washers.
  - Keep bedding dry. Ventilate to dry wet areas quickly or add new bedding.
  - If manure is stored or collected beneath a slotted floor, exhaust at least some ventilating air from under
  - the slats to reduce gases at the animal level. This is especially important for concrete slats, narrow slat
  - openings, long storage periods, and flush or scrape-under-slat systems.
  - Do not overfill a pit under slotted floors—leave at least 12" between the bottom of slat supports and
  - top of manure.
  - Add enough water to manure storages so manure falls into liquid and so solids are sub-
  - merged.
  - Isolate animals with diarrheas from other animals.
  - Include an air trap in drain lines to reduce back-
  - draft of manure gases.
  - Dust carries odors, so wash pen partitions, walls, ceilings, and floors regularly. Cover and adjust
  - feeders to minimize flying dust.
  - Avoid storing manure in the building for long periods. Shorter periods lower odor levels. Little
  - odor is produced for 2 to 3 days so, however, there is a peak in ammonia production at 3 days and
  - again at 21 days. Frequent manure removal helps minimize this situation.
  - Install heat exchangers, solar collectors, or other air tempering methods to heat and allow higher
  - ventilating rates for odor control while maintaining warm temperatures.
  - Fuel burning heaters must be vented to the out-
  - side with a U.S. listed chimney or flue to remove combustion byproducts. Or, with an unvented heater,
  - remove the moisture of combustion with at least 2.5
cfm continuous ventilating capacity per 1,000 Btu/hr
  - heater capacity in addition to recommendations in
  - Table 2. With exhaust ventilation, install a fan-
  - powered flow, so exhaust fans do not draw combustion products down the flow and into the room. An anti-
  - backdraft device prevents air from being drawn down the flue when the heater is off.

Dust

Dust includes feed, dried feces, animal hair and dandruff, mold spores, bacteria, fungi, and litter. Poultry dust has cylindrical feather particles. Dust particles absorb gases and liquids and may carry viruses and bacteria. Animal movement and feed handling usually increase dust levels. Reduce dust levels with proper sanitation, regular cleaning, and feed additives. Animal fats and oils reduce feed dust.

Relatively small dust particles, like those in swine nurseries, tend to stay suspended longer and can deposit deeper in the lungs. Relatively large dust particles, as in swine finishing units, tend to settle on equipment and partitions.

High dust levels can be health hazards to people who spend a lot of time in confined livestock environ-
ments. Workers’ symptoms include shortness of breath, coughing, chest tightness, wheezing, and

- stuffy noses. Small feed dust particles pass into lungs, while larger particles are filtered out in the
  - upper respiratory tract where they cause irritation and inflammation.

Respiratory filtering masks give some protection to workers in dusty environments. For complete dust
  - protection, masks must be approved for 0.3 micron diameter particles. Inexpensive fabric filters available
  - at local stores do not meet this requirement. Activated charcoal masks filter low-level odors, but do
  - not protect from droplet-levels of manure gases. Do not reuse filter masks.

Animal Heat Loss

A ventilating system is used to control the environment. Ventilating capacity is based primarily on the
amount of air exchanged needed to remove mois-
ure in winter and excess heat in summer. Animals try to maintain a constant body temperature, so they either lose metabolic heat to their surroundings at the rate it is produced, or their body temperature changes. An animal overheats if it cannot lose heat fast enough and chills if it loses heat too fast. Heat loss rate depends considerably on the environment. Factors include, temperature, relative humidity, air velocity, and solar radiation. The temperature is an effective temperature of these factors. A cooling effect is the wind chill factor. How heat is lost is important. Animals lose heat by conduction, thermal radiation, convection, and evaporation. Conduction transposes heat from a warmer to a cooler body through a contacting surface. Thermal radiation moves energy by electromagnetic waves. A moving fluid such as air transfers heat by convection. Evaporation of moisture requires heat. Natural evaporative heat loss is largely from the upper respiratory tract and little is from the skin of most farm animals. Sweating and evaporative heat loss are small with horses and cattle but are even less with swine. Conduction, thermal radiation, and con-

- vection are sensible heat losses; evaporation is latent heat loss.

- As temperature increases, an animal cannot lose as much sensible heat, so it pants and sweats, Fig
  - 2. As the temperature increases, even more mois-

- ture is produced. As relative humidity rises, an animal loses less heat by evaporation. If temperature and relative humidity are both high, the animal be-

- comes heat-stressed. See Table 25 for animal heat and moisture production rates.

Fig 2. Heat and moisture loss vary with air temperature.

Typical sensible heat loss and moisture loss at 0.75 lb/ft².

Moisture Balance

Water and water vapor enter the environment from respiration, spilling water, evaporation from sur-
faces, and manure. Excess water vapor is removed by ventilation. The amount of moisture to be removed depends on animal type and size and on the manure handling system. Generally, larger animals give off more moisture and require more moisture control ventilation.

During cold weather, ventilation brings cold, rela-

- tively dry air into a building. The air is warmed by heat from animals, electrical equipment, and sup-
  - plemental heaters. As air temperature rises, air can hold more moisture and its relative humidity decreases. Moisture holding capacity of air nearly doubles for every 20° F rise in temperature. Ventilat-
  - ing air picks up moisture and removes it from the building. These properties are shown schematically in Figs 3 and 4.

- Ventilation to maintain room air between 40% and 60% relative humidity. Higher humidities increase condensation; lower humidities increase dust levels. Also, 40%-60% relative humidity is detrimental to airborne bacteria found in livestock buildings.

Heat Balance

To maintain constant room temperature, heat produced by animals and hosts has to equal heat lost through building walls, ceiling/roof, and ven-

- tilation. If heat loss exceeds animal heat production, provide supplemental heat. If heat production ex-
  - ceeds heat loss, increase the ventilating rate or use other cooling methods. When ventilating air entering a building is cooler than indoor air, it removes heat from the building. Estimate the rate (Btu/hr) of heat removed by venti-

- lating air with Eq 1.

\[ HVENT = cfm \times 0.8 \times (TIN - TOUT) \]

Where:

\[ cfm \] is the ventilation rate (cfm)
\[ TIN \] is the indoor temperature (°F)
\[ TOUT \] is the outdoor temperature (°F)

Example 1:

- A building is ventilated at 1,000 cfm. The inside temperature is 70° F and outside temperature is 20° F. Determine the heat removal rate.

Solution:

Using Eq 1, find the heat removal rate.

\[ HVENT = 1,000 \times 0.8 \times (70 - 20) = 50,000 \text{ Btu/hr} \]

How Much Air

Airflow requirements vary with animal size and outside environmental conditions. Ideally, ventilat-

- ing air must vary from just enough air to maintain air quality during very cold weather, up to a maxi-

- mum.
mum rate to eliminate heat stress during hot weather. Design the system to provide at least three seasonal ventilating rates—cold, mild, and hot weather.

Cold weather ventilation provides oxygen and removes moisture. Ventilate only at the cold weather rate when supplemental heaters are running. To prevent freezing pipes, provide an alarm and a safety thermostat to shut off cold weather fans if the building temperature drops to near freezing. See Alarm section.

Mild weather ventilation modifies temperature and removes moisture. Fans to provide this additional air are usually turned on by thermostats when building temperature exceeds a desired level. Hot weather ventilation reduces heat buildup and increases air movement. Thermostats turn on maximum rate fans when the indoor temperature exceeds a set level.

Table 2 gives recommended ventilating rates for several types of livestock.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Weight Unit</th>
<th>Cold weather rate</th>
<th>Mild weather rate</th>
<th>Hot weather rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(cfm/kg)</td>
<td>(cfm/100 lb)</td>
<td>(cfm/1000 lb)</td>
</tr>
<tr>
<td>Swine</td>
<td>400</td>
<td>40</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>Sow and litter</td>
<td>20</td>
<td>40</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>Piglet</td>
<td>10</td>
<td>20</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Goat</td>
<td>10</td>
<td>20</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Cow</td>
<td>1000</td>
<td>1000</td>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>Veal calf</td>
<td>1000</td>
<td>1000</td>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>Dairy</td>
<td>1000</td>
<td>1000</td>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>Poultry</td>
<td>1000</td>
<td>1000</td>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>Horse</td>
<td>1000</td>
<td>1000</td>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>Horse, equine environment barn</td>
<td>1000</td>
<td>1000</td>
<td>900</td>
<td>800</td>
</tr>
</tbody>
</table>

**Negative Pressure System**

**Air Distribution**

Building air exchange rate depends on fan capacity, but air distribution uniformity depends on air inlet location, design, and adjustment. Distribute and adjust inlets to develop a high inlet air velocity (800 to 1,000 fpm) independent of air rate (number of fans operating). Adjust air inlets manually or automatically.

For inlets to perform properly, seal doors, windows, and openings to prevent unwanted drafts. The desired negative pressure is maintained by air entering planned inlets and disrupts air distribution. Unwanted openings include:

- Open doors, windows, and hay chutes.
- Too much air entering one area can leave other areas stagnant.
- Cracks in walls, ceilings, and around doors and windows. Even small openings can interfere with good air distribution, especially at low winter ventilating rates.
- Flush or scraper gutter openings to the outside or between rooms. Close these large openings with removable doors or weighted curtains.
- Feed conveyors.

**Air Inlets**

**Types**

Negative pressure air inlets include continuous slot inlets and box or area inlets. Continuous slots with adjustable baffles are common. Fig. 5. Adjust the baffles to restrict the inlet opening for increased air velocity and improved air mixing. Rigid baffles avoid warping, which causes uneven air distribution. Make the ceiling near the inlet smooth so airflow is not interrupted. Keep augers, fluorescent lights, pipes, conduits, etc., at least 6' away. With ribbed ceiling slats, orient the ribs parallel to airflow. If the ribs must be perpendicular to the airflow, line the ceiling with a smooth surface for at least 12" from the opening.

Negative pressure, continuous slot inlets are difficult to control at low airflow rates. Uniformly spaced inserts in wall inlets can improve distribution at low airflows. Low air velocities can create poor distribution and drafts that are harmful to young animals. An air contaminant system can supplement or replace continuous slots for young animals. Continuous slot inlets work well for mature animals because of relatively high winter ventilating rates.

**Instalation**

Consider the following while selecting and locating slot inlets. See Fig. 5.

- **Building width.** For buildings up to 38' wide, place continuous slots at the ceiling along both sidewalls. For wider buildings, add one or more interior ceiling slot or box inlets.
- **Maximum distance.** The maximum distance between a fan and inlet is 75'. Close inlets within 8' of each side of a fan during winter ventilation.
- **Cold weather inlets.** The attic can be a wind-protected air inlet. Inlet air from the attic or from outdoors.
- **Air intakes.** Make sure that intakes can provide enough fresh air to inlets. For example, for slot inlets supplying winter and mild weather ventilating air, make the eave or wall openings supplying the slot at least 1½ times the mild-weather maximum slot opening.

**Hot weather inlets.** Optimize intake: bring fresh air directly from outdoors. Insulate the roof to reduce sun warming, and bring air in through the attic. Draw air through an insulated duct from a screened opening in the gable end or eave.

- **Adjustable box inlets (speeded rather than continuous).** Individual inlets, (e.g., one per rowing stall), ease control over slot length and air distribution as building population changes.
- **Air across ceiling vs. air down sidewall.** Consider baffles to deflect incoming winter air down the sidewall instead of across the ceiling in:
  - Adult animal housing (e.g., stall dairy barns).
  - Large buildings requiring high air volumes that can drop into the animal zone before proper mixing.
  - Buildings with outside walk or manure alleys, such as swine housing with dunging along the outside wall.
  - Buildings that cannot be tight enough to maintain enough negative pressure for inlet velocities of 800 to 1,000 fpm.
Fig 5. Negative pressure ventilation inlet locations.

Box inlets are easier to install than continuous slots during remodeling. Space box inlets uniformly in the room. Space openings 8'-12' from building walls and 16'-24' apart, Fig 5e. If commercial units, check with the manufacturer for recommended locations. Extend the baffle 4' beyond all sides of the inlet opening, Fig 6d.

Airflow patterns can affect animal behavior and comfort. Air movement in the pen affects swine dunging patterns. Pigs tend to sleep where they are comfortable and dung elsewhere. In winter, pigs avoid sleeping in drafts, and in hot weather, may seek air movement to keep cool. Generally, direct air to the dunging area (e.g., slats of partially slotted pens) in winter and to the sleeping area in hot weather. When to redirect inlet air depends on animal size, weather, and pen conditions, so management is required. If air cools and the inlets are not adjusted, dunging patterns can quickly change.

For animals in stalls, direct summer air toward the animal’s head and winter air along ceiling or wall surfaces for mixing with room air before reaching the animals.

Inlet size

Air velocity through a slot inlet depends on slot width and static pressure across the slot. Airflow through a slot at constant static pressure is proportional to slot width. For example, the average airflow rate through a 1'-0" wide slot at 0.04" static pressure is 50 cfm/ft. The airflow rate through a 1'-0" slot at the same pressure is four times as much (200 cfm/ft). Increasing static pressure across the slot also increases airflow. For example, increasing the static pressure across a 1'-0" slot from 0.04" to 0.125", doubles airflow from 50 cfm to 100 cfm. Note: Increasing static pressure across a fan reduces fan delivery. Make the total air inlet area proportional to total fan capacity. Size across-the-ceiling inlets (Fig 6a, b, c, d) for 800 to 1,000 cfm velocity as air leaves the baffle to get good mixing of cold and warm air. If air velocity is less than about 800 cfm, cold air settles too rapidly and can chill animals. Air velocities greater than about 1,000 cfm increase static pressure and decrease fan capacity and efficiency. For down-the-wall inlets, Fig 6c, use 500 cfm in cold weather and 800-1,000 cfm in warm and hot weather. Size inlets for the maximum rate and adjust for the desired pressure difference and air distribution. Fig 7 shows an across-the-ceiling inlet with too large an opening.

Size long narrow slot inlets for 1.5 at (44 in²) of area for each 540 cfm of fan capacity. Use this rule only to estimate inlet size. During normal operation, use a manometer and adjust inlet baffles to maintain static pressure at about 0.04". Air velocity is about 900 cfm at 0.04" static pressure. Inlets less than 15 in² opening are too small to control accurately. Instead, during cold weather close every other inlet section and adjust the remaining slot openings for good air distribution. See Table 3 for recommended slot inlet widths.

Example 1:

Size negative pressure ventilation air inlets for a 32x24', 800-head swine finishing building. Group exhaust fans in the center of the downwind wall to simplify wiring and controls. Assume across-the-ceiling air flow from the slot inlets.

Solution:

1. Use a continuous slot inlet in each long wall because the building is wider than 18'. Determine the total slot inlet length.

(Building length x 2) = (84 x 2) = 168"
In cold weather, close inlets over continuous exhaust fans to prevent short circuiting air. Close about 8' of slot opening on each side of the continuous winter fan for a total of 16'. Winter slot length = 152' (168' - 16').

1. Determine the recommended slot opening for cold, mild, and hot ventilating rates. Determine the airflow per foot of slot length, then read slot width from Table 3.

(Ventilating rate, Table 2 x Number of animals) + (Slot length, ft)

Cold weather: From Table 3, the ventilating rate is 10 cfm/pig. Slot length = 152'.

(10 cfm/pig x 300 pigs) = 152' = 19.7 cfm/ft

From Table 3, a 1/4" slot width is needed for 900 fpm velocity.

Mild weather: From Table 3, the ventilating rate is 30 cfm/pig. Slot length = 168'.

(35 cfm/pig x 300 pigs) = 168' = 62.5 cfm/ft

From Table 3, a 1/4" slot width is needed.

Hot weather: From Table 2, the ventilating rate is 120 cfm/pig. Slot length = 168'.

(120 cfm/pig x 300 pigs) = 168' = 24.3 cfm/ft

From Table 3, a 5" slot width is needed.

3. Size the inlet opening for the maximum slot width calculated in Step 2: 5". Adjust the baffle for manometer readings near 0.04" static pressure.

Table 3. Slot inlet widths.

<table>
<thead>
<tr>
<th>Slot width, in.</th>
<th>Airflow cfm of slot length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>5.6</td>
</tr>
<tr>
<td>1/8</td>
<td>11.2</td>
</tr>
<tr>
<td>1/4</td>
<td>22.3</td>
</tr>
<tr>
<td>1/2</td>
<td>33.6</td>
</tr>
<tr>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>1 1/2</td>
<td>67.5</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
</tr>
<tr>
<td>4</td>
<td>157</td>
</tr>
<tr>
<td>5</td>
<td>182</td>
</tr>
<tr>
<td>6</td>
<td>205</td>
</tr>
<tr>
<td>7</td>
<td>220</td>
</tr>
<tr>
<td>8</td>
<td>247</td>
</tr>
<tr>
<td>9</td>
<td>270</td>
</tr>
<tr>
<td>10</td>
<td>310</td>
</tr>
<tr>
<td>11</td>
<td>350</td>
</tr>
<tr>
<td>12</td>
<td>390</td>
</tr>
</tbody>
</table>

Inlet control

Proper air inlet control is critical to good ventilation. Ideally, inlet size is changed as ventilating rates change (i.e., as fans turn on and off or change speed). Automatically controlled inlets are recommended. Manually controlled inlets require periodic adjustment. Operate manually-adjusted baffles from one location with a winch and cable system for convenience, Fig 8. Install a manometer next to the winch for more accurate baffle adjustments, Fig 9. Anticipate weather changes when making manual baffle adjustments.

Self-adjusting curtain slot inlets are not as precise as rigid baffles, Fig 10. They tend to have low inlet velocity at low airflow rates and deflect cold air downward. Condensation and frost on the curtain and ceiling are often a problem. Plastic curtains tend to become less flexible with age, so check them at least once a year and replace as needed.

Inlet management

In winter, bring fresh air from the attic if possible. Operate the minimum cold weather fan continuously to control moisture buildup and to prevent warm room air from rising through the slot, condensing on the underside of the cold roof, and dripping on attic insulation. In winter, air enters the attic through soffit openings, gable louvers, and/or ridge vents, Fig 5. Design attic intake area (ft²) for at least the mild weather ventilating rate = 200.
In hot weather, bring fresh air directly from outdoors instead of the attic. If air inlets from the attic, insulate the roof or draw air through an insulated duct, Fig. 11. If no insulated roof or duct is not possible, increase attic ventilation up to twice the hot weather rate to maintain attic air temperature. Ventilate the attic to lower the ceiling temperature. Completely open eave intakes on both sides of the building. Screen attic openings with 3/4" hardware cloth to keep birds out. Smaller mesh screens may plug with dust and restrict airflow.

**Negative Pressure With Recirculation**

Several types of recirculation systems are being used. Air blending systems are similar and work on the same principles, but are not discussed here. MWPS-34, Heating, Cooling and Ventilating Air for Livestock Housing, has information on blending systems. This discussion is limited to systems with exhaust fans, recirculation duct with fan, and air inlet shutters, Fig. 13.

Negative pressure ventilation with recirculation has good distribution at low ventilating rates. It works in remodeled buildings where excessive air leaks interfere with other ventilating systems.

In cold and mild weather, ventilating air is distributed through the duct and exhausted through wall fans. Fresh air enters the duct from the outside through a motorized shutter or from the attic through a ceiling inlet, Fig. 14, and exhausts through a continuously operating exhaust fan.

Exhaust fans control airflow through the inlet. Control shutters with a thermostat. When shutters are closed, fresh air enters from the attic or building cracks, Fig. 14. With closed shutters and exhaust fan off, only room air circulates through the distribution duct and no air exchange occurs. Shutter freezeup can be a problem with no supplemental heat, or if the duct fan is too far from shutters to move warm air past them. This is a serious problem because it restricts ventilation. Reduce shutter freezing with a heat lamp.

To reduce condensation in the duct, size the duct fan for four times the cold weather ventilating rate. Enough room air must mix with fresh air to maintain duct air above the dewpoint temperature. Size the duct for 600 cfm duct air velocity, Table 4. However, a duct fan size can cause drafty conditions for small animals. Provide hovers and solid pen partitions. With a recirculation duct system, it may be necessary to increase room temperature 3 to 5 degrees. With a multi-speed or variable speed duct fan, some duct holes may need to be closed to maintain proper air velocity at lower fan speeds.

If the recirculation fan is too far from the inlet, cold air may drop and cause drafts near the floor. To reduce drafts, move the fan closer to the shutters or add an insulated board under the shutters, Fig. 14.

Some systems operate cold weather exhaust fans and inlet shutters intermittently with a timer and thermostat. When the exhaust fan is off, the duct fan recirculates only room air, which can produce fluctuating room temperatures and relative humidities that are unsuitable for young animals. A high humidity exchange control and moisture with a continuously operating exhaust fan. With an intermittently operating exhaust fan, size the duct and fan for at least twice the capacity of the exhaust fan, but not more than required for mild weather ventilation.

Positive Pressure Systems

In a positive pressure system, fans force fresh air into a building and create a positive indoor pressure. Air is distributed through area inlets or a duct the full length of the building. See Fig. 15.
Since the distribution duct cross-section with Table 4 for the maximum ventilating rate. Insulate distribution ducts to prevent condensation. With area inlets, consider an insulated duct in the attic or insulating the roof to reduce solar heating of summer ventilating air.

Size pressurized duct outlets to provide 1.60 in²/1,000 cfm of fan capacity. Allow one 2" square hole/20 cfm or one 3" square hole per 45 cfm of airflow through a duct. Round holes are shown in Table 6. Space outlet holes uniformly along the duct. For area inlets, size slot openings for the desired area. When operating at lower airflow rates, block some of the openings to reduce inlet air temperature. Pressure ventilating is exhausted from the building through all open doors, windows, and other openings. Size the building’s exhaust area for 100 in²/1,000 cfm. Table 4.

Positive pressure systems work well with below floor manure storages. They provide good air distribution, but can force moist air into walls and attic spaces. Install a vapor retarder to reduce moisture migration. Frost may freeze doors and windows shut.

Neutral-Pressure Systems

In neutral-pressure ventilation, one fan pushes fresh air into the room through a duct while an exhaust fan pulls stale air out of the room (Fig 16). The two fans create a near-neutral pressure in the room, which reduces the effect of air leaks around doors, windows, etc.

In winter, an adjustable baffle forces incoming air into a thin airstream with enough velocity for adequate mixing. In summer, move the baffles away from the holes for greater air volumes (Fig 17).

Complete duct and fan systems are commercially available. Consult the manufacturers’ representatives for complete system design information. If you decide to design and build the system, no good design information is available at this time. Size the duct for the maximum rate it will carry (usually the summer fan capacity) using the design factors discussed in the "Positive Pressure System" section of this book. Extend the duct bottom 6 inches beyond the duct sides to direct air horizontally. The insulated duct bottom minimizes condensation in winter. The baffle squeezes incoming air into a thin film. The size and distribution of holes must be determined based on system performance. As a starting point, use the design information for positive pressure ducts to size and locate holes. Using a smoking device, check for uniformity of air distribution and lack of drafts on the floor or the low ventilation rate in cold weather. Change the area of holes to improve the air distribution. Try to maintain a static pressure within the duct of 0.03-0.05 inches of water. Remember that the weight of the baffle can highly influence the performance of the system.

The winter pressure fan is mounted at the end of the duct where it can draw relatively clean preheated air from a hallway, tempered air from an attic, or untempered air from outdoors. Size this fan for the normal winter ventilating rate, Table 2. Provide exhaust fans with at least two capacities—normal winter rate and minimum continuous winter rate. Select fans with the needed capacities at about 0.1" static pressure.

One way of providing the winter and summer air flows is presented in Fig 16. Inlet air is provided by the one pressurized duct sized to deliver summer fan capacity. Usually the winter fans run all year, so size the summer capacity for the exact need for hot weather. A louvre over the summer pressure fan should close when the fan stops. This louvre prevents back flow through the summer fan when the winter fan is operating. Winter exhaust air is drawn from the pit through an exhaust duct. Summer exhaust capacity is provided by fan(s) in the building wall.

Even in summer, air enters the room at relatively high velocities, so air speed at animal height is relatively high. Total summer ventilating rates can be reduced by about 1/2 below those recommended in Table 2 with a neutral pressure system in farrowing and nursery rooms.

Manure Pit Ventilation

Properly designed pit ventilation reduces manure gas and odors in the animal area, and helps warm and dry the floor. Provide pit ventilation in all mechanically ventilated totally and partially slotted floor buildings. Design pit ventilation to supply at least the cold weather rate but no more than the mild weather rate.
Two pit ventilating systems are:

- A fan to draw air from along the pit through a perforated duct.
- An annex and fan outside the pit that draws air directly from the pit.

Allow at least 12" clearance between the bottom of the slab support beams or pit duct and the masonry surface. Large fans and ducts (24" diameter and larger) may require more clearance. Consider installing a pit level indicator.

Masonry pit conditions are very corrosive. Totally enclosed fans constructed from erosion resistant materials are required—stainless steel or plastic. Use high static pressure fans (0.25-0.50" of water) to draw air through pit ducts, especially rigid plastic pipe ducts. Normal ventilation fans operate at less than ¼" static pressure.

**Ducts**

Ducts are expensive but perform better than annexes, especially with wire mesh or other slotted floors that have a high percentage of open area.

**Rigid pipe ducts**

Rigid plastic pipe makes an excellent duct for small buildings. Space ducts so no point of the slotted floor is farther than 12" from a duct.

Drill inlet holes with a hole saw to ensure uniform openings with smooth edges. Drill 1/4" diameter holes in the bottom of the duct at several locations to drain moisture. Cap the end to prevent the fan. Provide for cleaning the duct.

**Design of suction ducts**

Pressure ducts, discussed earlier, have uniformly spaced holes. Suction ducts (the fan pulls air from the duct) work better if hole spacing varies along the duct length. The duct designs here suggest maximum airflow for each size duct (Table 6) based on 800,000 cfm for each square foot of duct cross-sectional area.

The procedure outlined is a compromise that simplifies drilling the holes in the tube. The result is almost uniform ventilation from the pit.

1. Base tube diameter on ventilation rate, Table 5.
2. Select a hole size from Table 6.
3. The total number of holes needed is ventilation rate divided by cfm/holes.
4. The tube has four sections (Fig 18) with section 1 (with holes farthest apart) at the fan end. Each section has 1/4 the total number of holes needed.

**Table 5. Suggested air flow per tube.**

<table>
<thead>
<tr>
<th>Tube diameter, in.</th>
<th>Air flow, cfm</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>190-210</td>
</tr>
<tr>
<td>9</td>
<td>255-290</td>
</tr>
<tr>
<td>12</td>
<td>320-365</td>
</tr>
<tr>
<td>15</td>
<td>380-420</td>
</tr>
<tr>
<td>18</td>
<td>440-480</td>
</tr>
</tbody>
</table>

**Table 6. Air flow per hole.**

<table>
<thead>
<tr>
<th>Hole diameter, in.</th>
<th>Cfm per hole</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>2.7</td>
</tr>
<tr>
<td>1/3</td>
<td>4.2</td>
</tr>
<tr>
<td>1/2</td>
<td>6.1</td>
</tr>
<tr>
<td>5/8</td>
<td>7.0</td>
</tr>
<tr>
<td>3/4</td>
<td>7.8</td>
</tr>
<tr>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
</tr>
</tbody>
</table>

5. Multiply total duct length by the percent of length to find the length of each section.

6. Divide the duct length of each section by the number of holes per section to find hole spacing.

7. Because holes are usually drilled in pairs, spacing of pairs of holes = 2 x hole spacing.

8. Drill holes as shown in Fig 20.

9. Select a fan for total pit ventilation rate and for adequate static pressure.

Caution: The pit fan must overcome the static pressure required to pull air through the tube, plus any additional pressure from operating wall exhaust fans. Typical static pressure in an exhaust fan system is about 0.6". Add this to the static pressure in the tube (0.16" to 0.36" for the capacities shown) to determine the static pressure need of the pit fan.

**Example 4:**

A pipe will ventilate a pit 50' long. Ventilation rate is 800 cfm.

**Solution:**

1. Pipe size is 12", Table 5.
2. Try 1-1/8" holes, supplying 4.2 cfm each, Table 6.
3. Divide 800 cfm by 4.2 cfm per hole = 190 holes.
4. A 2" hole will require 800 + 11 = 72.70 holes. Use 72 holes. Each section requires 72 + 4 = 18 holes per section.
5. Divide the duct into four sections. Put the same number of holes in each of the four lengths.
6. The table below summarizes the duct hole data.

<table>
<thead>
<tr>
<th>Section</th>
<th>% of length</th>
<th>37% of Length</th>
<th>26% of Length</th>
<th>20% of Length</th>
<th>17% of Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

**Fig 18. Pit ventilation tube hole layout.**

**Fig 19. Rigid plastic tube pit duct.**

Use non-corrosive material for fan blades and housing and for ducts.

6. Hole spacing = section length divided by number of holes.

222" = 18 holes = 12" spacing of single holes.

222" = 8 pairs of holes = 144" spacing between pairs.

7. Drill pairs of 2" diameter holes and an occasional 1/4" drain hole.

8. Assuming static pressure is about 0.06" from exhaust fans and 0.16" from the pit fan, select a fan that can deliver 800 cfm against 0.22" static pressure.

**Fig 20. Holes in suction ducts.**

Locate inlet holes on one or both sides at a 30" angle from the centerline. Constrained water or accidental liquid moisture in the duct drains to the pit.

**Annexes:**

Annexes, Fig 21, do not provide as uniform air distribution through the floor as a duct, but are cheaper and simpler to build.

Annexes work best for concrete slats with only 1.5% - 20% open area, because the space below slats creates a draft effect. Air distribution is poor with an
To prevent "short-circuiting" between fans, put each pit fan in its own annex. Shutter are not necessary on fans that run continuously.

4. EMERGENCY VENTILATION

Provide for emergency ventilation in all environmentally controlled buildings. Animals can die from suffocation or heat stress if the power or ventilating system fails.

Carbon dioxide concentration in properly ventilated livestock housing can be 5,000 ppm. High CO₂ concentration (above 30,000 ppm) contributes to oxygen deficiency and asphyxiation. Without ventilation, it takes about 6 hr to reach a 30,000 ppm concentration in a conventional swine nursery. Therefore, the real short-term problem is not CO₂ buildup, but heat and moisture buildup.

Air in nonventilated livestock buildings can become saturated and reach temperatures equal to the animals' body temperature in an hour or less. The animal will have very little sensitive and latent heat loss at these conditions. In one case, after the ventilating system was off for about 1 hr, "the air temperature did not seem hot" but the walls and ceiling were dripping. Recent studies indicate that deep swine nursery buildings reach life threatening conditions within 45 min after ventilation is stopped. Poultry can survive only 20 to 30 min at temperatures above 97°F. Life threatening conditions can be reached even sooner with larger animals housed in tightly constructed buildings.

Emergency ventilating systems can be as simple as several manually opened sidewalk doors or as sophisticated as an electric generator that starts automatically to power fans in case of electrical failure. Consider installing an alarm system to alert you when electrical power is off. Test your emergency ventilation and alarm systems monthly or according to manufacturers' instructions. See Chapter 7 for information on alarms. MWFPS-88, Farm Buildings Wiring Handbook, discusses animal and standby power systems in its "Selected References" section.

Manual solutions include PTO- or engine-driven electricity generators, knock-out panels, or large doors to provide natural ventilation during a mechanical ventilation failure. Size natural ventilating openings to provide the mild weather ventilating rate. Assuming a wind velocity of about 94 mph, each 1 ft² of opening provides about 500 cfm. Provide the same amount of opening on both sides of the building to allow air to pass through the building. For example, a 20 ft row opening room requires 1600 cfm; provides 8 ft² of opening on each sidewalk (doors, windows, or vent doors).

Electromagnet-locked ventilating doors, which open when electrical power is cut off or the room temperature rises sharply, are available commercially. A simple cold weather emergency ventilating method is to remove the top few blades from the cold weather fan(s) shutters and have a fixed (non-closing) inlet near the ceiling. When power fails, air enters through the fan opening and back drafts through the inlet. This helps delay life-threatening conditions, but does not give long term protection.

These solutions are only temporary. They will not solve serious problems for an outage in very hot or cold weather or for an extended period. Restore power to the ventilating system as soon as possible to prevent loss of production and animals.

Table 7. Minimum opening through pit fan annex

<table>
<thead>
<tr>
<th>Pit fan capacity</th>
<th>Opening area</th>
<th>Inside dimensions</th>
<th>Wall, in.</th>
<th>Dia., in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>72</td>
<td>4x18</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>90</td>
<td>4x20</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>108</td>
<td>4x27</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>700</td>
<td>126</td>
<td>4x30</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>800</td>
<td>144</td>
<td>4x36</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>900</td>
<td>162</td>
<td>6x27</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>1,000</td>
<td>180</td>
<td>6x30</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>1,100</td>
<td>198</td>
<td>6x36</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>1,200</td>
<td>216</td>
<td>6x39</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>1,300</td>
<td>234</td>
<td>6x45</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>1,400</td>
<td>252</td>
<td>6x48</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>1,500</td>
<td>270</td>
<td>8x34</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>1,600</td>
<td>288</td>
<td>8x36</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>1,700</td>
<td>304</td>
<td>8x42</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>1,800</td>
<td>320</td>
<td>12x30</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>1,900</td>
<td>338</td>
<td>12x36</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>2,000</td>
<td>356</td>
<td>12x45</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>2,500</td>
<td>420</td>
<td>12x48</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>3,000</td>
<td>490</td>
<td>12x54</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>3,500</td>
<td>560</td>
<td>12x60</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>4,000</td>
<td>630</td>
<td>12x62</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>5,000</td>
<td>720</td>
<td>12x70</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>6,000</td>
<td>810</td>
<td>12x80</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

annex under wire or metal flooring with 60%-60% open area.

Design annex pit ventilation to supply at least the cold weather rate but no more than the mild weather rate. With variable speed fans, size the fan to operate at least 40% of maximum fan capacity. Table 7 shows the minimum pit wall opening for various fan capacities. Larger openings do not significantly affect performance. Locate annexes so no point in the pit is further than 50' from an annex.
5. INSULATION

Insulation is any material that reduces heat transfer from one area to another. The resistance of a material to heat flow is indicated by its R-value. Good insulators have high R-values. See Table 8.

During cold weather, insulation conserves heat, reduces supplemental heat requirement, maintains warmer inside face temperatures, and reduces condensation and radiant heat loss.

During warm summer months, insulation reduces heat gain, improving comfort and reducing cooling costs. The temperature of the walls and roofs of buildings exposed to direct sunlight can be as much as 50°F above air temperature.

In a poorly insulated building, inside ceiling and wall surfaces become cold in winter. If the surface temperature is below the dew point temperature, air next to the surface becomes saturated and moisture condenses, Fig. 22. If the surface temperature is below freezing, frost occurs.

Five common forms of insulation are:
- Batt or blanket. The most common.
- Loose-fill. Good for ceilings of existing buildings and can be blown into the stud spaces of existing walls. If improperly installed, insulation can settle in walls, leaving the top inadequately insulated.
- Rigid insulations. Provide rigidity and strength that other insulation types do not.
- Foam or formed-in-place insulation.

Reflective materials. Like aluminum foil, reflect most of the radiant heat that strikes it on an air space is provided. Radiant heat loss is a small part of the total heat loss. Several air spaces are needed to resist heat flow by conduction and convection. Dust and corrosion greatly reduce reflective insulation values.

Insulating effectiveness of an air space depends on its position and thickness. A 4" x 4" thick non-reflective dead air space has a maximum R-value of about 0.9.

Where to Insulate

Use insulation in all spaces that are heated in winter or cooled in summer. In addition to walls, ceilings, and foundation perimeters, consider insulating:
- Under metal roof surfaces in cold housing where winter or summer weather conditions are severe, to reduce radiant heat gain and moisture condensation.
- Under heated floors.
- Heating or ventilating ducts passing through unheated spaces.
- Raised floors with an unheated space below.
- In winter, windows and summer ventilating fans.

Insulation Levels

The amount of insulation needed in farm buildings depends on factors such as expected outside temperature (degree days), number and size of animals housed, desired inside temperature, and economics.

Cold buildings usually do not require insulation. However, in severe climates, insulation can be installed in the roof of cold buildings to reduce solar heat gain in summer and condensation in winter. Examples are cold free stall barns and open-front livestock buildings. Compare the benefits and cost of providing properly protected insulation.

Modified environmental buildings rely on animal heat and controlled natural ventilation to remove moisture and maintain desired inside temperatures. Insulation is required to conserve heat and control condensation. Examples are warm barns, poultry production buildings, and swine finishing units.

Supplementally heated buildings require extra heat to maintain the desired inside temperature. Examples include farrowing buildings, farm shops, and offices. Cold and modified environment buildings require supplemental heating in a small area, such as brooders in an open-front building, are not classified as supplementally heated.

Recommended minimum insulation levels for degree days ranges are in Table 9. More insulation may be justified with increasing energy costs in supplementally heated buildings.

Moisture Problems

Most building materials are highly permeable and are not good vapor retarders. Prevent moisture problems in building sections by installing a vapor retarder on the warm side of all insulated walls, ceilings, and roofs.

One of the best vapor retarder materials for farm structures is polyethylene film. It is low cost, easily installed, and not corroded by agents in farm buildings. A 4-mil (0.004") thickness is commonly used, but 6-mil (0.006") is easier to handle without tearing. Aluminum foil can also act as a vapor retarder.

Use vapor retarders with sheet metal ceilings and walls. Although metal is a good vapor retarder, joints and screw holes create many openings for moisture to pass through. With rigid board insulation, moist air can pass through the joints and condense. Follow manufacturer's instructions for sealing board joints.
Fire Resistance

Many plastic foam insulations have high flame spread rates, and many common in farm buildings have extremely high flame spread rates and need to be protected from potential fire. If plastic foam insulations are not protected from potential fire, your insurance company may refuse to cover the structure.

To reduce risk, protect plastic foam insulation with fire-resistant coatings. Do not use fire-rated gypsum board (sheet rock) in high moisture environments such as animal housing. Materials that provide satisfactory protection include:
- 1/4” thick cement plaster.
- 1/4” thick sprayed-on magnesium oxychloride (60 lbs/ft²) or 1/8” of the lighter, foam material.
- Fire rated 1/4” exterior plywood.

Birds and Rodents

Protect insulation from bird and rodent damage with an inside liner. An aluminum foil covering is not sufficient protection.

Cover exposed perimeter insulation with a protective liner and maintain a rodent bait program. High density fiberglass reinforced plastic is preferred. Foundation grade plywood, %x, resists physical and moisture damage but is not rodentproof. Seal holes and cracks in walls and ceilings to limit rodent access.

Screws can vary openings with %x hardware cloth to exclude birds. You may need to knock ice off the screen regularly during prolonged cold periods.

6. FANS

Fans create a pressure difference and cause air to flow. With mechanical ventilating systems, the primary goal is to provide sufficient airflow at a low pressure difference. Fans are also used for circulation to eliminate dead air zones or increase air velocity to promote animal cooling.

When selecting ventilating fans, consider:
- Fan type.
- Required air moving capacity, cfm.
- System static pressure.
- Energy efficiency, cfm/watt.
- Durability, corrosion resistance, and maintenance.
- Noise level.
- Drive motor characteristics.
- Cost.

Fan Types

Fans can be axial flow or centrifugal. Axial flow fans move air parallel to the fan axis. Centrifugal fans bring air in through a center inlet and discharge it perpendicular to the fan axis.

Centrifugal fans are quieter and can operate at higher static pressure than axial flow fans. They are common in grain drying and hot-air heating systems. Axial fans are common in livestock buildings. Initial cost is less and performance is influenced less by dirt building than centrifugal fans.

See Table 10 for the characteristics of four types of fans. Propeller fans are common in livestock housing. They have propeller shaped blades mounted in a circular ring or orifice plate. Fig 26a. Blade tip clearance is an important factor in fan performance. A small, uniform clearance is preferred to prevent air from flowing back around the propeller. Those fans move large volumes of air at low static pressure, such as ventilation through walls, air circulation, and to provide make-up air.

Circulation fans help improve air distribution, reduce temperature stratification, increase air velocity past animals, and reduce dead air zones. Fig 59. Paddle fans, a type of circulation fan, circulate large air volumes against zero or low static pressure, Fig 27.

Tube-axial fans have a tubular-shaped housing with propeller shaped blades. Tube-axial fans can operate at higher static pressure because of a larger hub and reduced blade tip clearance. Less air can flow back through fan blades. Typical use is in low and medium pressure duct air distribution systems.

Vane-axial fans are for higher pressure applications. They are similar to tubaxial fans except air straightening vanes reduce the circular motion of the air. Typical uses are grain drying, aeration, and sometimes pressure duct air distribution systems.

Fan Performance

Characteristics that affect performance include:
- Blade design.
- Tip clearance.
- Speed.
- Housing or orifice panel design.
- Obstructions—fan guard, motor, shutters, wind hood.

Fan blades usually have uniform thickness or are airfoil shaped. Uniform thickness blades are usually metal stampings and are attached to a central hub. They have fixed or variable pitch. Airfoil blades are shaped like airplane wings. They are usually cast aluminum or molded plastic. Plastic blades are more corrosion resistant and are self-cleaning.

Blade shape affects fan capacity. Airfoil and teardrop shaped blades are usually more efficient than cleverleaf blades. Blade rigidity helps maintain blade shape at high speed and properly "scoops" air. A blade that loses its shape is inefficient. Airfoil blades are usually more rigid. Blade pitch or twist also affects the ability to properly "scoop" air. More blade twist is needed near the hub, because this part moves slower than the blade tip. Air tends to slide past the fan center if there is not enough twist near the hub.

Fig 25. Axial flow fan housing and blade type.

Fig 27. Paddle fan.
### Table 10. Fan types.

<table>
<thead>
<tr>
<th>Type</th>
<th>Housing</th>
<th>Impeller</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propeller</td>
<td>Simple circular</td>
<td>High pressure, high volume air movement.</td>
<td>Centrifugally through a wide cross-sectional area.</td>
</tr>
<tr>
<td></td>
<td>Tapered or other</td>
<td>Medium volume air movement.</td>
<td>In a space.</td>
</tr>
<tr>
<td></td>
<td>Blades with a flat or triangular tail.</td>
<td>Low pressure, low volume air movement.</td>
<td>Variable pitch fan.</td>
</tr>
<tr>
<td></td>
<td>Round tubing</td>
<td>Uniform thickness blade on a small hub.</td>
<td>Uniform thickness blades.</td>
</tr>
<tr>
<td></td>
<td>Round tubing</td>
<td>Uniform thickness blade on a small hub.</td>
<td>Uniform thickness blades on a small hub.</td>
</tr>
</tbody>
</table>

### Table 11. Fan speed for 11,000 fpm blade tip speed.

<table>
<thead>
<tr>
<th>Blade dia., in.</th>
<th>Fan speed, fpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>875</td>
</tr>
<tr>
<td>24</td>
<td>915</td>
</tr>
<tr>
<td>36</td>
<td>930</td>
</tr>
<tr>
<td>48</td>
<td>915</td>
</tr>
</tbody>
</table>

### Table 12. Typical resistances to air movement.

<table>
<thead>
<tr>
<th>Static pressure in H2O</th>
<th>Fan</th>
<th>Airflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>0.06</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>0.08</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>0.10</td>
<td>0.14</td>
<td>0.16</td>
</tr>
</tbody>
</table>

### Table 13. Sample data—consult manufacturers literature for values specific to fans.

<table>
<thead>
<tr>
<th>Fan</th>
<th>Airflow</th>
<th>Static pressure, in. of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1/30</td>
<td>3.00</td>
</tr>
<tr>
<td>8</td>
<td>2/30</td>
<td>3.35</td>
</tr>
<tr>
<td>9</td>
<td>3/30</td>
<td>3.65</td>
</tr>
<tr>
<td>10</td>
<td>4/30</td>
<td>3.91</td>
</tr>
</tbody>
</table>

### Table 20. Typical resistances to air movement.

<table>
<thead>
<tr>
<th>Static pressure in H2O</th>
<th>Fan</th>
<th>Airflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>0.06</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>0.08</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>0.10</td>
<td>0.14</td>
<td>0.16</td>
</tr>
</tbody>
</table>

### Table 21. Fan manufacturers test fans to rate airflow at different pressures. Many manufacturers use an independent testing laboratory, such as Air Movement and Control Association (AMCA), for unbiased fan performance ratings. Some manufacturers list only the static pressure at maximum fan delivery (zero static pressure). Be sure to compare ratings on the same basis, such as with or without screens or shutters.

### Table 22. Fan manufacturers test fans to rate airflow at different pressures. Many manufacturers use an independent testing laboratory, such as Air Movement and Control Association (AMCA), for unbiased fan performance ratings. Some manufacturers list only the static pressure at maximum fan delivery (zero static pressure). Be sure to compare ratings on the same basis, such as with or without screens or shutters.

### Table 23. The shutter and guard represent 0.16% of static pressure or 6% of the total static pressure. Some manufacturers test their fans with this equipment in place and others do not. To use the table, you must know how the fan was tested when selecting fans for a given application.

### Fan Selection

Most agricultural fan applications operate against a static pressure or resistance. A pressure of 0.15" (H2O) of water is typical for livestock ventilating. Several inches of water pressure may be met with solar collectors, heat exchangers, and geothermal systems. Room air circulation fans run at nearly zero pressure. Select fans based on air moving capacity (cfm) and estimated system resistance (static pressure) from Table 13.
static pressure by 0.16" to 0.21". At this static pressure, fan B delivers less than 4,000 cfm.

Table 14. Multi-rating table—Example 7.

<table>
<thead>
<tr>
<th>Model</th>
<th>Dia.</th>
<th>0.07</th>
<th>0.08</th>
<th>0.10</th>
<th>0.15</th>
<th>0.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static pressure, in. of water</td>
<td>0.07</td>
<td>0.08</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
<td></td>
</tr>
</tbody>
</table>

As a rule, it is much more important to be concerned with reliable airflow from winter fans than it is to calculate precise energy consumption.

Table 16. Cfm/watt fan rating and maximum BHP.

<table>
<thead>
<tr>
<th>Model</th>
<th>Dia.</th>
<th>0.07</th>
<th>0.08</th>
<th>0.10</th>
<th>0.15</th>
<th>0.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan</td>
<td>in.</td>
<td>Hp</td>
<td>0.07</td>
<td>0.08</td>
<td>0.10</td>
<td>0.15</td>
</tr>
<tr>
<td>Static pressure</td>
<td>cfm</td>
<td>0.07</td>
<td>0.08</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>Max</td>
<td>BHP</td>
<td>0.07</td>
<td>0.08</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Fan A 24" 5,500 5,600 4,000 3,700 2,900
Fan B 24" 7,000 7,000 6,000 5,200 4,700

Example 8: Assuming that both fan C and D in Table 16 were tested with shutters, which fan will perform better after shutters have got very dirty?

Solution: From Table 15, both fan C and D can supply at least 5,000 cfm at 0.07" static pressure. To evaluate fan performance with dirty shutters compare fan rating at the extra static pressure caused by the dirty shutter. From Table 15, at 0.20" static pressure fan C delivers 4,700 cfm and fan D supplies 3,800 cfm. Performance of fan C is affected less by dirty shutters than fan D.

Table 15. Multi-rating table—Example 8.

<table>
<thead>
<tr>
<th>Model</th>
<th>Dia.</th>
<th>0.07</th>
<th>0.08</th>
<th>0.10</th>
<th>0.15</th>
<th>0.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static pressure, in. of water</td>
<td>0.07</td>
<td>0.08</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
<td></td>
</tr>
</tbody>
</table>

Electrical Cost

Selecting the most energy efficient fan can be difficult. Manufacturers do not know how their fans will be operated, so there is no standard way to determine how much it will cost to run. See Table 17 for typical electric costs of motors run continuously. When selecting a fan system, consider differences in operating efficiency, performance, and cost.

Table 17. Typical annual electrical cost, continuous use.

<table>
<thead>
<tr>
<th>Cost</th>
<th>Electric power</th>
<th>Motor size, watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW/Hr</td>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>0.04</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>0.06</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>0.10</td>
<td>300</td>
<td>360</td>
</tr>
</tbody>
</table>

Multi-Variable Rating Tables

For cold weather ventilation, low airflow rates are often desirable. Multi-speed fans can run at 50% rated capacity. Determining operating speed for desired airflow from the manufacturer's fan table. Do not estimate airflow as proportional to rpm. At lower speeds, fans operate less effectively under static pressure. Consider the effect shutters, weatherheads, providing winds, changes in fans on the operating static pressure when adjusting multi-speed fans.

When selecting a fan for variable speed control, it is best to buy the fan and control as a unit to work together properly. While delivering variable airflow, variable speed fans may not overcome the static pressure caused by normal operating conditions when operated at their lowest speed.

Use direct drive motors for variable speed applications. Use variable transformers, series resistors, or solid-state power control devices can control voltage to a motor. Motor design is important for proper operation under variable voltage applications. See the Controls section for methods of adjusting multi-variable speed fans. Before selecting a variable speed motor, talk to the equipment manufacturer and your local power supplier.

Consider the following precautions when operating variable speed motors:

- Limit the lowest speed setting to no less than 20% of maximum speed for proper bearing lubrication; no less than 50% if fan is for cold weather ventilation.
- The speed controller must provide sufficient voltage to start the motor under load at low speed settings.
- Set the lowest speed to provide sufficient airflow to prevent the motor from overheating or to prevent freeze-ups in winter due to condensation and frost formation.
- Protect fans from wind gusts. Wind can stop fans running at low speed.

Fan Location

Wind blowing into a fan's discharge reduces capacity and building ventilating rate. When possible, locate low speed fans on the leeward side of the building.

Within a tightly constructed building and negative pressure ventilation, fan location (neglecting wind pressure) has little influence on air quality. Inlets are more important for uniform air distribution. With fully mixed air, the fan exhausts a representative quantity of air independent of location.

Fan motors can be banked together in one location, but limit the distance between a fan and inlet to 70'-80'.

Loose construction lets air leak into the building through non-designated inlets such as cracks around doors and windows. Air can move directly from a non-designated inlet to a nearby fan before thorough mixing with room air, which reduces the fan's effectiveness.

In loosely constructed buildings, space fans along the building length to reduce short circuiting and improve air distribution. Because inlets do not always produce uniform air distribution, locate fans on both sides of buildings wider than 30'.

Locate minimum winter ventilation fans to remove air continuously from a manure storage pit. When pulling air through the pit wall, seal around the fan and housing to prevent short circuiting. Connect pit fans to pit ducts when perforated floor permeability exceeds about 20% open (wire mesh floors).

With wall fans mounted in some houses, the fan motor protrudes into the room. To avoid obstructing animal, worker, and equipment movement, select a housing that allows flush mounting on the inside wall.

Fan Motors

When selecting a fan motor consider total operating cost not just initial purchase price. The lowest cost motor may not be the best if it must be replaced frequently. Consider the annual costs such as repair, replacement, and electricity cost.

Codes

The code referred to for electrical work in the United States is NFPA 70 National Electrical Code (NEC), published by the National Fire Protection Association (NFPA), Quincy, MA 02269. The NEC is a guide to proper and safe materials and motors and their installation. Though many farm buildings do not presently fall under code jurisdiction, it is a good idea to follow the NEC. Also, your insurance company may require installing to NEC standards. Before starting construction, check if a wiring permit or inspection is required, and what state or local codes apply. Consult MNPS-26, Farm Buildings Wiring Handbook, for complete information on farm wiring.

Motor Types

The most common fan motor is a single phase induction motor. Base fan motor type on the application. See Table 18.

Motor Nameplate

Many motors that look alike perform differently. Get motor characteristics off the motor nameplate: horsepower, phase rating, voltage, amperage, service factor, and continuous or intermittent duty rating.
Table 10. Types of single-phase motors.

<table>
<thead>
<tr>
<th>Type</th>
<th>Horsepower ranges</th>
<th>Load-starting ability</th>
<th>Starting current</th>
<th>Characteristics</th>
<th>Electrically reversible</th>
<th>Typical uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split-phase</td>
<td>1/20-1/2</td>
<td>Easy starting load</td>
<td>High - full load</td>
<td>Inexpensive, simple construction, low efficiency, nearly constant speed with varying load.</td>
<td>Yes</td>
<td>Fans, centrifugal pumps, loads that increase with speed.</td>
</tr>
<tr>
<td>1/8-1/2</td>
<td>Hard starting load</td>
<td>Medium - full load</td>
<td></td>
<td></td>
<td>Yes</td>
<td>Compressor, conveyors, pumps, special design for unloading, tank cleaners.</td>
</tr>
<tr>
<td>Capacitor-start</td>
<td>1/20-1/2</td>
<td>Easy starting load</td>
<td>High - full load</td>
<td>Inexpensive, simple construction, long service life, nearly constant speed with varying load.</td>
<td>Yes</td>
<td>Conveyors, fans, stacks, elevators, tank cleaners.</td>
</tr>
<tr>
<td>Two-value capacitor</td>
<td>2-20</td>
<td>Medium - full load</td>
<td></td>
<td>Simple construction, long service life, minimum maintenance, high operating efficiency.</td>
<td>Yes</td>
<td>Variable speed fans and blowers.</td>
</tr>
<tr>
<td>Permanent-split capa-</td>
<td>1/20-1/2</td>
<td>Easy starting load</td>
<td>Low, two to four</td>
<td>Inexpensive, simple construction, no short-circuit protection, can control speed with voltage for fans, etc.</td>
<td>No</td>
<td>Small blowers, fans, and appliances.</td>
</tr>
<tr>
<td>Shaded pole</td>
<td>1/20-1/2</td>
<td>Medium - full load</td>
<td></td>
<td>Inexpensive, moderate efficiency, light duty.</td>
<td>Yes</td>
<td>Fans, centrifugal pumps, loads that increase with speed.</td>
</tr>
</tbody>
</table>

Table 19. Service factors for AC motors.

<table>
<thead>
<tr>
<th>Horsepower, (hp)</th>
<th>Service factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/20, 1/12, 1/8</td>
<td>1.35</td>
</tr>
<tr>
<td>1/4, 1/2, 1/3</td>
<td>1.25</td>
</tr>
<tr>
<td>1 hp and up</td>
<td></td>
</tr>
</tbody>
</table>

Motor drives

On a direct drive motor, the shaft directly connects to the fan blade hub, so the motor and fan run at the same speed. Use direct drive motors with variable speed fans. Typically, fans do not require high starting torque; high torque motors cost more.

Belt drive

Belt drives can offset the very high starting torques required by leads driven with high horsepower motors. Belt drives are also used for fans run at different speeds than the motor. Adjust fan speed by changing the pulleys. Do not use belt drives with variable speed fans.

Controls

Controls adjust and maintain the amount of air delivered. A manual switch simply turns fans off when not needed or during maintenance.

Automatic fan controls are thermostats, variable speed motor controls, and timers. Thermostats turn fans on and off to control building cooling. Motor speed controllers maintain fan delivery above and below preset values to regulate building temperature more gradually than with a thermostat. Timers achieve desired delivery rates by running for only part of each hour.

Place each fan on a separate circuit with overload protection. Always provide a fan failure alarm or backup system. See the Controls chapter. More than one fan circuit must be active at all times with timers and thermostats set to provide ventilation.

Installation

Damp buildings

Animal housing (open or closed), milkhouses and other areas that are washed periodically, manure pits, well pits, silos, silo rooms, and high humidity produce storages (e.g., potatoes and apples) fall under common instructions for "damp buildings".

Damp buildings require special materials and wiring methods, because high moisture levels, dust, and gas can quickly corrode standard electrical equipment. Dust and moisture can also cause fire and safety hazards by creating short circuits or heat build-up in electrical fixtures. All wiring boxes and fixtures must be dust and moisture tight and made of corrosion-resistant materials.

Branch circuits

Branch circuits carry current from an overcurrent protection device (fuse or circuit breaker) to the loads (lights, outlets, motors). They are either nominal 120 volt (V) or 240 V circuits. Actual voltages generally vary from 110 V to 130 V and 230 V to 240 V.

120 V circuits

Circuits at 120 V have one hot wire, one circuit neutral, and one equipment ground. The hot wire is usually black or red, the circuit neutral is white, and the equipment ground is bare or green.

An equipment ground must make a continuous connection from the neutral bar in the service entrance panel to all receptacles, metal fixtures, and motor frames. Connect the equipment ground to the frame of metal fixtures or motors. Do NOT connect the equipment ground to the circuit neutral (NEC 250-61). Even though these two wires are often connected to the same busbar in the service entrance panel, a connection earlier in the branch circuit can load in current to the equipment ground.

240 V circuits

Circuits at 240 V have two hot wires and an equipment ground. Circuit neutrals are not required by 240 V equipment.

Three wires run from the power supplier transformer to the building. One wire is grounded at the transformer and at the building service entrance; it is called the neutral (wire N of Fig 30). Voltages between lines A, B, and N of Fig 30 are as shown.

Circuit types

Two types of branch circuits are:

- General purpose branch circuits for loads such as lights up to 180 W and duplex convenience outlets (DCO). DCOs are for small or occasional loads such as portable power tools.
- Equipment branch circuits for known specific loads (e.g., stationary motors) and special purpose outlets (SPO). An equipment circuit may have only one load, such as a fan motor. Equipment circuits usually require higher capacity circuit breakers and larger wires than general purpose circuits. Size equipment circuit breakers and circuit breakers for the specific loads.

These circuits are often on 240 V service.

Individual circuits and SPOs are recommended for larger motors and heaters. Hard-wire stationary equipment into a SPO. Wire only one, or at most two, fans per circuit, and at least two fan circuits in each room of environmentally-controlled animal buildings. If one circuit fails, fans on the other circuit.
can ventilate the room, if at least two fan circuits are always energized.

Motor Circuits

Every motor circuit must have:
- Branch circuit overcurrent protection to protect circuit conductors against short circuits and ground fault currents.

A power disconnect to completely disconnect the motor from the power supply.
- A controller to start and stop the motor and to interrupt the current if the motor stalls.

An overload protection device to disconnect an overloaded motor.

Overload Protection

When an electric motor is starting or overloaded, it draws more amperes than when delivering its rated horsepower. A motor is not damaged by a larger than normal current for a short time. Provide overload protection that allows high starting current for a short time, but disconnects the motor if high current due to overload flows through the motor for a longer time. Most manually operated controllers contain a heater device to trip the mechanism on overload. These devices do not operate fast enough to protect against short circuits, so protect branch circuits with circuit breakers or fuses.

If a fuse protects for overload, install one in each hot conductor for 120 V or 240 V single phase service. For other devices, install overload protection in one hot conductor for 120 V or 240 V single phase service. If two overload devices are required, use a common trip.

For motors greater than 1 hp or automatic start (e.g., fans on thermostats), either:
- Obtain a motor with a built-in overload protection device.
- Install an overload device separate from the motor.

7. CONTROLS

Controls automatically adjust fans, heaters, inlet baffles, and vent doors to maintain desired environmental conditions. Ventilating equipment is adjusted according to temperature, humidity, static pressure, and time. Recently developed control systems have manual switches to override automatic controls. Be careful to keep environmental conditions within acceptable limits when using manual overrides.

Thermostats measure air temperature and help control heaters, fans, and vent doors. Humidistats measure air moisture level (humidity), but are not common in livestock buildings because they become inaccurate after exposure to dust and gases. Static pressure sensors automatically control inlet baffles and vent doors.

Thoroughly check all controls after installation and again every six months. Dust, dirt, and gases can corrode contacts, slow response times, or change calibration. Cover controls (not sensors) to protect from dust, dust, and moisture. If possible, locate controls outside the animal area. Calibrate control sensors using independent, accurate measuring devices. Thermostats can be checked with a thermometer placed next to them to see what temperatures in the room produce on or off. If the thermostat dial is incorrect, mark the dial with correct readings. Calibrate pressure sensors with a manometer.

Thermostats

Thermostats do more than just turn fans on and off—they control room environment. Several different types of controls have been tried but thermostats have evolved as the most common and reliable control for ventilating equipment. A thermostat senses temperature to operate an electrical switch. Select thermostats that meet NSC requirements for water- and dust-tight construction. Types of sensing elements are:
- Vapor-filled.
- Liquid-filled.
- Bi-metallic.
- Solid state.

Vapor and liquid-filled thermostats have a pressure spring, capillary tube, and sensing bulb, Fig. 32. The sensing bulb is filled with either a vapor-liquid mixture or liquid that expands or contracts with temperature change to activate a switch.

Vapor filled thermostats are used most often in livestock buildings. They respond well to slight temperature changes, and are fairly resistant to mechanical damage and excess temperatures. However, if the pressure spring is at a lower temperature than the sensing bulb it may activate the switch. Locate thermostats and sensing bulbs according to manufacturer’s recommendations.

Bi-metallic thermostats are not common in agricultural applications. They have a two-metal strip that distorts with changes in temperature. Bi-metallic elements are used primarily with mercury switches, floating contact switches, and in locations where precise rapid response is not critical. Deterioration of the bi-metallic element by corrosive gases rapidly destroys thermostat calibration. Also, exposure to excessive temperatures can distort the element, ruining calibration.

Most thermostats for agriculture have an on-off temperature difference called temperature differential. The temperature differential is published for most thermostats. For most applications, this is desirable. With little or no differential, equipment rapidly cycles on and off, which is hard on equipment and deteriorates switch contacts. A 4°F switching difference is common for ventilating equipment.

Operating temperature ranges for thermostats are normally published. They generally perform best in the middle of the range.
Locate thermostats:
- At or near center of building width.
- Close to, but out of reach of animals.
- Away from cold walls and ceilings.
- Out of the path of furnace exhausts, inlet air, and direct sunlight.
- Away from doors.

In systems with a heater and multiple fans, set thermostats at different temperatures to turn fans on and off at different times to approximate a continuously variable ventilating rate. It is critical to make sure the heater and mild weather fan do not run at the same time.

Solution:
1. The 3-speed fan is for cold and mild weather ventilation. Provide a safety thermostat to shut the fan off at 45°F to prevent excess cooling.
2. Set the furnace thermostat at 71°F to turn the heater on when the air temperature drops below 71°F and shuts off at 75°F.
3. Set multi-speed fan thermostat to switch to middle speed at 81°F and back to low speed at 77°F. Switch the multi-speed fan to high speed at 85°F. With a 4°F on-off range the multi-speed fan switches back to the middle speed at 81°F.
4. Provide a thermostat on the single-speed fan set at 87°F to provide hot weather ventilation. The fan comes on at 87°F and shuts off at 83°F.

Example 11:
Determine the control setup for a heated room maintained at 78°F. One variable speed fan is used for cold and mild weather ventilation. One single-speed fan is used for hot weather ventilation.

Solution:
1. Provide a safety thermostat set to shut off the variable speed fan at 45°F.
2. Set heating unit thermostat at 71°F. The heater comes on when the air temperature drops below 71°F and shuts off at 75°F.
3. Use a manual variable speed controller to change fan speed. Gradually increase fan speed at 79°F and continue increasing to maximum speed at 85°F.
4. Provide a thermostat on the single-speed fan set at 87°F to provide hot weather ventilation. The fan comes on at 87°F and shuts off at 83°F.

Humidistats
Humidistats are similar to thermostats except the sensing element senses humidity rather than temperature. Maintaining proper calibration has been a major problem. Dust, dirt, and chemicals collect on the sensing element and insect or mechanical damage causes a drift in calibration. For best performance, use humidistats in clean environments, and not in typical animal buildings.

Timers
Interval or cycle timers are most common. Interval timers are simply on-off electrical switches actuated by a small clock motor. The timing mechanism makes one revolution every interval. Available intervals are 5, 10, 30 min, and 1, 2, and 4 hr. During an interval, one period is the on mode and the rest of the interval is the off mode. The on mode can be adjusted between fall on and fall off. A 10-min-interval timer is most common with ventilating equipment. Most often, interval timers override the thermostat and operate the fan a minimum percentage of time to maintain minimum ventilation. Interval timers are in parallel with the thermostat. With more multi-speed fans, fewer interval timers are used, because continuous ventilation is better than intermittent ventilation.

Using interval timers to maintain minimum winter ventilation can cause high concentrations of air contaminants and warm, moist air to backdraft into the attic when fans are off. If possible, limit the use of timers to control cold and mild weather ventilation. Adjust the length of time fans run based on animal weight. Do not use interval timers to control fans in a room with unventilated heaters which require continuous, not intermittent ventilation.

Solid State Controls
Solid state controllers use electronic components to perform many different functions. Solid state thermostats sense temperature and make changes in the system. Temperature-sensitive solid state speed controllers can automatically vary the fan motor speed based on room temperature. The controllers can provide continuous fan speed adjustment from low to high speed rather than rely on operator adjustment.

Microprocessors allow better environmental control. They have logic capabilities and can rapidly monitor several inputs. Microprocessor ventilating control systems typically have a microprocessor, analog-to-digital converter, control circuitry, sensors, data storage memory, and a port to download data to a printer or magnetic tape. Possible sensor inputs include dry bulb temperature, dew point temperature, outside temperature, solar radiation, and static pressure. Inputs are converted to digital signals and compared with reference values programmed into the microprocessor. The microprocessor sends out signals to the control circuit, which activates the necessary fans, heaters, evaporative coolers, etc., to maintain the environment within the desired ranges.

Microprocessor-based control systems have great potential for improving environmental control in agricultural structures. Cost of a simple microprocessor control for one room can be comparable to a mechanical control. Cost is high to control several spaces and to communicate data to remote sites.

Different fan controls are described in Table 32. See Figs 34 to 38 for example control circuits.
Controlling Variable Cold Weather Rates

It is sometimes necessary to adjust cold weather ventilation, when young animals grow larger or when the animal population varies. Adjust the cold weather rate with:
- Variable speed fans.
- Multi-speed fans.
- Relatively large, single-speed fans with adjustable intake dampers.
- A continuous small fan and another small fan on a timer.

During cold weather, control variable speed fans with manual, not temperature sensing, controls. Adjust controllers to operate fans at the required cold weather ventilating rate. Variable speed fans are greatly affected by wind blowing into the fan discharge. Protect cold weather fans on the windward side of the building with windbreaks, Fig. 38. Variable speed controllers may not be reliable and tend to have high maintenance costs. Choose fans and controllers carefully.

Size the lowest speed of multi-speed (2 to 4 speeds) fans for the minimum cold weather ventilating rate. Manually adjust the fans when conditions change. A multi-speed fan is more flexible than a single speed fan, but ventilating rates are limited to the preset fan speeds. In large rooms, use more than one multi-speed fan for better control.

Large fans with motorized intake shutters, Fig. 38, vary ventilating rates at different shutter settings. Partially close shutters to provide minimum cold weather ventilation. At higher rates, open shutters. It is difficult to determine proper ventilation with this system, because fans are not rated with shutters attached. Partially closed shutters are not energy efficient (cfm/watt).

One continuous fan and one fan on a timer provide less fluctuation and better ventilation control than one large fan on an internal timer, Fig. 37. One large fan can be used a lot or in a system with other air handlers. When power fails, contacts under spring tension close to sound the alarm. Use a magnetic relay rated at fan voltage for continuous operation with a single-pole, single throw contact. Include a test switch unless the fan has a disconnect.

For several fans, a magnetic relay for each fan can be connected to one alarm, Fig. 41.

Alarm Systems

Alarms can warn of high or low temperature, power outages, fire, smoke, and other potentially dangerous situations. Alarm systems cannot prevent ventilation failure, but can warn that action may be needed to prevent livestock losses. Some systems are commercially available. Common alarm systems include:

- Building or Annex Wall Siren
- Continuous Window Fan
- Exterior Plywood Pads

Relay Switch Alarm

A magnetic relay switch in the fan circuit is energized while power to the fan is on, Fig. 40. The relay contacts act as a switch for a battery operated alarm. When power fails, contacts under spring tension close to sound the alarm. Use a magnetic relay rated at fan voltage for continuous operation with a single-pole, single throw contact. Include a test switch unless the fan has a disconnect.

For several fans, a magnetic relay for each fan can be connected to one alarm, Fig. 41.

Solenoil Valve Controlled Alarm

A solenoid valve in the fan circuit can sound an air horn powered by compressed gas, Fig. 42. The solenoid valve remains closed as long as there is power to the fan. When power is interrupted, the valve opens releasing the gas and sounding the horn. Include a test switch in the alarm circuit.
Combination Alarm System

An alarm system that combines a magnetic relay and thermostat provides additional protection. Fig 44. Ventilation failure due to broken or slipping belts or plugged air ducts can be detected by an increase in temperature with the thermostat. Also, a power failure can be detected immediately with a magnetic relay. The system requires a relay for each fan and a thermostat in each pen or room.

Automatic Phone Dialer

Some alarm systems can automatically dial a preselected phone number and deliver a message. These are useful for buildings at remote sites or farmsteads that are unattended most of the day. However, the dialer helps only if somebody is at that number to receive the message. Some units can dial more than one number, improving the chance of reaching someone. The dialing sequence can be repeated at set intervals until the unit is shut off or sensor is reset. Consider asking the sheriff for his permission to be a contact person. Consult your local telephone company about automatic phone dialers.

8. MAINTENANCE

Environmental control systems need conscientious, thorough, and periodic maintenance. Develop a maintenance schedule from the following guidelines.

Every month:
- Clean fan blades and shutters. Dirty fan shutters can decrease fan airflow up to 40%. Shut off power to thermostatically controlled fans before servicing them.
- Check fans with belt drives for proper tension and correct alignment. If too tight, belts may cause excessive bearing wear; if too loose, slippage reduces fan performance and wears the belt.
- During the heating season, remove dust from heater fins and filters, and check gas jets and safety shut-off valves for proper operation.
- Test emergency ventilation and alarm systems including standby generators.
- Clean heat exchanger (some manufacturers suggest cleaning more often).
- Make certain that shutters open and close freely. Apply graphite (not oil or grease) to fan shutter hinges.
- Check fan shutters during cold weather so they do not freeze open or shut.

Every 3 months:
- Check gable and soffit air intakes for blockages.
- Clean motors and controls. Dirty thermostats do not sense temperature changes accurately or rapidly. Dust insulates fan motors and prevents proper cooling. If dust is allowed to build up, the motor can overheat.
- Clean dust accumulation from recirculation air ducts, if necessary.

Every 6 months:
- Consider fan lubrication. Most ventilating fans have sealed bearings and do not require lubrication. Follow fan manufacturer's recommendations for oil type and amount. Never over lubricate.
- Recalibrate thermostat, as needed.
- Clean guards and weatherhoods.

Every year:
- Clean and repaint chipped spots on fan housings and shutters to prevent further corrosion.
- During winter, disconnect the power supply and cover hot weather fans (not cold or mild weather fans) with plastic or an insulated panel on the warm (animal) side of the fan. Uncover in the spring.
- Check air inlets for debris and warping.
- Check plastic battle curtains. They can become brittle with age and require replacement.
- Check attic insulation for signs of moisture and packing or removal by rodents.
9. TROUBLESHOOTING

A properly designed and operating livestock ventilating system provides an environment which is desirable for livestock—not the thermal comfort of workers. Farm workers unfamiliar with a properly operating system often report the building is too cold or the fans are moving too much air. But, in fact, the system may be operating as designed and creating the optimum environment for animal growth. Table 21 presents desirable temperature ranges for animals.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Desirable temperature, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactating cow</td>
<td>65-70</td>
</tr>
<tr>
<td>Litter weaner</td>
<td>60-65</td>
</tr>
<tr>
<td>Litter 3 weeks old</td>
<td>75-85</td>
</tr>
<tr>
<td>Pre-weaner (12-30 lb)</td>
<td>75-85</td>
</tr>
<tr>
<td>Nursery (50-750 lb)</td>
<td>80-85</td>
</tr>
<tr>
<td>Nursery (50-750 lb)</td>
<td>75-85</td>
</tr>
<tr>
<td>Growing sow</td>
<td>75-90</td>
</tr>
<tr>
<td>Growers (75-220 lb)</td>
<td>55-70</td>
</tr>
<tr>
<td>Dairy cows</td>
<td>65-70</td>
</tr>
<tr>
<td>Calves, floor level</td>
<td>60-65</td>
</tr>
<tr>
<td>Calves, raised stalls</td>
<td>60-70</td>
</tr>
<tr>
<td>Boar cotes</td>
<td>40-60</td>
</tr>
<tr>
<td>Hogs</td>
<td>55-70</td>
</tr>
<tr>
<td>Rabbits</td>
<td>40-60</td>
</tr>
<tr>
<td>Layers</td>
<td>55-70</td>
</tr>
<tr>
<td>Broilers and turkeys</td>
<td>See Poultry. Chapter 16</td>
</tr>
<tr>
<td>Brooding (0-6 weeks)</td>
<td>60-70</td>
</tr>
<tr>
<td>Growers</td>
<td>60-70</td>
</tr>
</tbody>
</table>

Troubleshooting Tools

Several simple tools are available for system diagnosis. Most are available at relatively low cost from suppliers of ventilating equipment or local heating contractors.

Thermometer

Ventilating systems rely heavily on temperature sensing devices. A good thermometer is essential for checking actual conditions and calibrating thermostats that control fans and heaters. Put a thermometer near the thermostat. Calibrate thermostats at least twice a year. At the same time, check thermostat "range" (points at which they turn on and off). Maximum/minimum thermometers make it easier to monitor building temperature fluctuations, Fig. 46. Use maximum/minimum thermometers to monitor air temperature changes in buildings when you are not there. A 1°F & F spread in mechanically ventilated buildings is common. See Table 21 for recommended livestock housing temperatures.

Fig. 45. Maximum/minimum thermometer.

Psychrometer

A psychrometer has two thermometers. The sensing bulb on one thermometer is covered with an absorbent soot which is dipped in water, Fig. 46. The two thermometers are then whisked in the area being investigated. The two thermometers produce readings known as "wet bulb" and "dry bulb" temperatures. These are used to read relative humidity from a chart furnished with the psychrometer.

Relative humidity in mechanically ventilated buildings should be 40-60%. Humidities above 80% may increase condensation and disease. Relative humidities below 40% contribute to dustiness.

Smoke Generator

Smokes are useful for locating dead spots or draft locations. Any device which produces dense smoke can show air movement patterns. Each smoke generating method has advantages and disadvantages. Smoke generated by an insect fogger, bee smokers, cigars, cigarettes, burning rubber, or any other heat source may not accurately show airflow patterns, because warm smoke tends to rise instead of following the trajectory of the air stream. Commercially available chemical smoke generators do not have this problem but are more expensive. A bottle of talcum powder when shaken and squeezed, releases a cloud of dust for checking micro-currents and poses no fire hazard.

To use a smoke generator, hold it near the path of incoming air, e.g., the fresh air inlet in an exhaust ventilating system or in front of the fan in a pressure ventilating system. Air velocities in excess away from air inlets are often erratic and low making it difficult to use smoke to detect airflow. However, by releasing smoke at the air inlet, it is possible to move the smoke generator along the path of incoming air and slowly trace the air stream from inlet to outlet.

Manometer

A manometer measures the difference in atmospheric pressure between the inside and outside of a building. The difference, in inches of water, is referred to as static pressure. Properly designed ventilating systems operate at about 0.04" to 0.1" of static pressure. Measured static pressure below 0.04" usually indicates poor incoming air distribution. Static pressure above 0.1" is above typical fan operating conditions and fans cannot deliver their rated air capacity.

Fig. 47. Manometer.

Air Speed Meters

Inexpensive air speed gauges are available from many heating contractors. They can measure relatively high speed (500 to 1,000 fpm) air entering an inlet and discharging from a fan. A possible limitation is that these air speed gauges need a 0.4" wide air stream and many slot inlets may only be 0.4" in winter. Slower moving air within a building requires more sophisticated and expensive equipment.

A producer not experienced in diagnosing ventilating problems may select a manometer and smoker to estimate airflow speeds and patterns.

Troubleshooting Mechanical Ventilation

In this section, symptoms of common ventilating problems are presented, followed by a list of possible causes and solutions. Not all possible causes are listed but the list is as complete as practical. More than one problem can be present in a ventilating system. Be thorough when establishing symptoms and possible causes. If more than one problem exists, several steps may be needed to get the ventilating system to operate properly. For example, closing a window in a building with a negative pressure ventilating system may not produce improved performance if a door is still open.

Symptom: Cold building

Building is colder than desired even though outside temperature is not below design conditions.

Possible causes and solutions:

- Fan and/or furnace thermostats are set too low or are not sensing correctly. This can cause excess cold air to be pulled into the building. Adjust thermostats. Place a thermometer next to the thermostat's sensing unit to check calibration. Check if heater is operating properly.
- Poorly insulated building. Check ceiling and wall insulation levels.
- Low animal density or young animals. Animals may not be producing enough heat to keep building warm. Maintain designed animal stocking densities, house larger animals in the building, and/or install heaters.
- Air inlets are too small for at least part of their length creating drafts and preventing good air mixing. Also, heated air may escape if fans are shut off. Adjust inlets to the proper setting.
- Insulation is wet. Check for a vapor retarder. No vapor retarder or a vapor retarder on the wrong side of the insulation can cause wet insulation. Always locate the vapor retarder on the warm side (animal side) of insulation. Check ceiling insulation first, it is easily accessible from the attic space. Also look for excessive condensation on interior surfaces as an indication of poor or wet insulation. Inadequate attic ventilation can be a problem because water condenses on the underside of the roof and drips onto insulation.
below. Install gable louveres and/or roof vents, remove wet insulation, and install new insulation with a good vapor retarder.

- No supplemental heat, hester is too small, or heater thermostat improperly set. Evaluate other possible causes and your supplemental heat needs before adding a heater.

- Cold weather fan is not operating, cooling the building too much. Recalibrate the required cold weather ventilating rate and compare to the fan rating. If fan capacity is too large, replace with a properly sized fan.

- Excess air infiltration—wind blows cold air in through cracks and inlets. Seal cracks, especially those on the side of winter prevailing winds, and protect winter inlets from wind effects.

- Animals leave the building for part of the day (i.e., feeding, milking, or exercising). If the animals are the only heat source, the building cools down when they leave. Keep animals in the building in cold weather, install a heater, or turn fans off when animals are out. Protect the water- ing system from freezing.

**Symptom:** Warm building

**Building is too warm.**

**Possible causes and solutions:**

- Fan or furnace control settings are too high or thermostat need recalibration. Adjust thermo- stat settings. Place it next to the thermostat’s sensor to see if the fan and heater turn on at the desired temperature.

- Insufficient fan capacity within the required hot weather ventilating rate and compare to the capacity ratings of existing fans. Install larger or additional fans if needed, select fan based on amount of air needed to be moved.

- Fans are not delivering rated capacity because of dirt on fan blades, shrouds, and shutters; warped orifice; or air-polluted air. Change fan blades, shrouds, and shutters at least once a month.

- Turn off electricity to fans before cleaning.

- Ventilating air is coming from a warm area like the attic. Install fresh air inlets from the outside.

- Inadequate or clogged inlets. Install more inlet area. Adjust inlets to provide proper openings.

- Condensation on ceiling or walls when proper insulation and vapor retarder are installed. Check if ceiling inlets are open, clear of debris, and properly adjusted so the static pressure is in the inlet area.

- Check if designed air inlets are open, clear of debris, and properly adjusted so the static pressure is in the inlet area.

- Check if designed air inlets are open, clear of debris, and properly adjusted so the static pressure is in the inlet area.

**Possible causes and solutions:**

- Extremely low outside temperature (less than -10°F). Ventilating systems operate at minimum levels for extended periods. This problem may correct itself when temperatures increase.

- Single-glazed windows. The best solution is to replace windows with insulated panels. Adding storm windows, covering windows with plastic, or opening the top of the window about 1/4" often improve conditions. Caution: too much additional opening can reduce static pressure and disrupt air circulation.

- Building is poorly insulated or insulation is wet. Replace wet insulation and insulate to proper levels.

- Operations caused by nails, fasteners, and light shadows act as air inlets causing condensation. Check if designed air inlets are open, clear of debris, and properly adjusted so the static pressure is in the inlet area.

- Condensation on ceiling or walls when proper insulation and vapor retarder are installed. Check if ceiling inlets are open, clear of debris, and properly adjusted so the static pressure is in the inlet area.

- Also, see the causes under "High Relative Humidity".

**Symptom:** High relative humidity

Excessive moisture in building; air feels damp and heavy (relative humidity above 80%).

**Possible causes and solutions:**

- Not enough ventilation. Look for unusually warm temperature and high relative humidity because misting can occur. Air is due to over-crowding. Increase ventilation by running existing fans more or increase cold air circulating fans.

- Low animal density. Not enough heat is produced to dry floor and other surfaces. Supplemental heaters may be required.

- Waterer or plumbing system leaks. Adjust waterers and repair leaks.

- Disease outbreaks. Diseases which produce diarrhea-like symptoms add moisture to the building that must be removed by the ventilating system. Treat the disease or change diet to produce less liquid in the manure.

- Excessive moisture evaporation. Reduce moisture on floor by improving dunging habits or by cleaning more often.

**Symptom:** Condensation

Excessive condensation on interior building surfaces.

**Possible causes:**

- Poorly designed and insulated with supplemental heat. Required heat equals amount of heat used to cause frost build-up on the window. Areas with cold surfaces are especially sensitive to condensation buildup.

- Insufficient fan capacity. See causes under "Warm Building".

- Drafts are required. Install havers and/or add air barriers to prevent drafts on small animals.

- Air recirculation system can cause drafts, especially with small animals. Make sure it is properly designed and operated. Check if air in is going to the recirculation duct fan or falling directly to the floor causing a draft.

- Obstructions to air flow can cause air inlet to be directed on animals, causing drafts. Remove obstructions within 6' of the inlet.

**Symptom:** Fan stops

Fans are not working or keep shutting off.

**Possible causes and solutions:**

- Controls. See causes under "Control Problem".

- Fan motor thermal protection is tripped. This may be due to dirt and dust accumulation on the motor. Clean motor, fan blade, and shutters. Reset thermal protection switch on fan and observe fan motor for overheating symptoms.

- Thermostat is defective or the wrong type. Repair or replace the thermostat.

- Fan motor is improperly wired. Check motor for proper wiring and repair if necessary. Replace or repair motor if defective.

**Symptom:** Control problem

Controls not working properly.

**Possible causes and solutions:**

- Controls are defective.

- Heating thermostat improperly used for ventilating fan or cooling thermostat used for heater.

- Controls are not properly calibrated. See the Controls chapter for information about calibrating thermostats.

- Sensing units for controls are not properly located. Locate sensors to measure and respond to conditions experienced by animals. A good location is the center of the building at a height just out of animal reach. Shield sensors from incoming air, heater outlets, and sunshine.

- Controls are improperly wired. Rewire as needed.

**Symptom:** High fuel usage

Fuel costs are higher than expected in a properly designed and insulated building with supplemental heat.

**Possible causes and solutions:**

- Heater controls are set too high. See Table 21 for recommended temperature settings.

- Fan controls are improperly adjusted. Use one cold weather fans when supplemental heat is on. Adjust other fans to turn off at a temperature at least 2°F above or 5°F below the temperature for the heating system. Place fan and heater thermostats close together. See the Controls chapter.

- Temperature differential on thermostat for proper range.

- Building animal population is below design stocking density. The heater must supply some of the heat normally provided by animals.

- Cold weather ventilating rates higher than needed. This is a problem with variable speed fans which do not always fit the desired range. Calculate minimum ventilating rates and install an appropriate sized fan.

- Excessive moisture evaporation. See solutions under "High Humidity".

**Symptom:** Excessive odor

**Possible causes and solutions:**

- Inadequate pit ventilation. Check if pit fans work. Check airflow patterns into the pit for short circuiting. Install ducts on pit fans to reduce short circuiting.

- Ventilating air picks up gases from pit and distributes them into the room. Check airflow patterns near the pit. Install ducts on pit fans for more efficient ventilation. Check for lack of ventilation of manure gases through manure sewer lines and pit annexes.

- Livestock is not covered with manure. Check for proper dunging habits. For swine, direct cold incoming air into the desired dunging area.
may not permit this system if the same heat exchanger preheats washerwater. With a central forced air system, use a down draft furnace with easily changeable filters. Use an induced draft or powered vent furnace to force exhaust gases out powered dampers. Dust hot air into the milker's pit about 8' above the floor, direct air toward the floor. Locate cold air return high on the wall.

Install at least 50,000 Btu/hr (15 kW) for a double 4 herringbone and 70,000 Btu/hr (20 kW) for a double 6 or 8 herringbone milking parlor. In northern states these heat capacities need to be doubled for existing lightly insulated milking parlors.

**Milk room**

This room requires good environmental control and cleanliness for milk storage, equipment cleaning, and equipment storage. Supplemental heat may be needed to prevent freezing.

Draw clean air into a positive pressure ventilating system; put filters on fan inlets. A 600 to 800 cfm fan is usually sufficient, except consider a larger fan if compressors are in the milk room.

Heat the milk room with a unit heater or central heating system to prevent freezing. Do not use forced air system that mixes return air from the parlor, treatment area, etc. with air blown into the milk room because it can be contaminated. Central hot water heating systems do not have this problem. Set thermostats high enough to prevent freezing, except when higher temperatures are needed for chores.

**Other areas**

Use an individual heater separate from the milking parlor to heat the office and toilet. Heater size depends on building size and insulation levels and winter design temperatures. Install a small exhaust fan in the toilet room and extra summer ventilation or air conditioning in the office.

Maintain a storage room between 40 F-60 F. Freezing can damage medical supplies, while high temperatures can accelerate rubber component deterioration. Maintain safe storage temperatures with a supplemental heater or duct from a central heating system. Do not use heat from the utility room.

In an interior space with all surrounding walls insulated, additional heat may not be needed. Heat from refrigerators used to store rubber products and pharmaceuticals helps keep the space warm. Provide fresh air and a thermostatically controlled exhaust fan to control temperature rise. Do not bring air from dusty driveways or animal housing into the storage.

Locate the compressor, vacuum pump, water heater, and furniture in a utility room kept above freezing with equipment heat.

Ventilate for efficient equipment operation. Provide a thermostatically controlled exhaust fan to control temperature rise. Size the fan for one air exchange per minute. Provide 1 ft3/air inlet/600 cfm fan capacity. Cover air inlets with gravity or motorized louver that open when the fan turns on. In winter, move excess heat to other rooms with a fan and duct. During summer, exhaust excess heat outside, Fig. 49.

**Deity Design Examples**

**Example 1:**

A farmer in north eastern Ohio wants to improve the environment in a two story barn with a one story addition, Fig. 53. The barn barn walls are 18" limestone and the addition walls are 8" masonry block. There is one 2"x1" metal ventilator on the ridge of the addition. The barn has one 18" direct drive fan with a small motor and one 24" bell drive fan with no motor. The barn houses 40 cows with an average
weight of 1,296 lb, 6 to 12 calves with an average weight of 260 lb, and 5 heifers with an average weight of 750 lb. There are usually 37 to 40 cows milking at any one time.

The barn is cold and has a high odor level. The farmer has tried to close up the barn to prevent water freezing problems in the pen area and east end of the addition. The veterinarian reports that the herd has a higher than normal level of pneumonia.

Solution:
This barn needs more modification than additional fans. Ventilation requirements and animal density in the pen area make it difficult to ventilate with the rest of the barn. Warm, moist air and pathogens from the cow stalls are probably contributing to health problems in the pens. Therefore, isolate the pen area with a solid partition and ventilate separately.

Pen area
Remove calves less than 3 months old from the barn and put in outside calf hutches. Design the ventilating system for maximum capacity. Assume 18 calves, aged 3 to 12 months old.

To provide ample fresh air, control moisture, and minimize air entering from the main barn, use a positive pressure ventilation system. If the room is heated, insulate the duct. Locate the pressure distribution duct along the ceiling of the west wall and put outlet holes on one side. Provide air with a fan in the north wall or, bring air down from the hay mow.

Required ventilation:
- Cold weather: 20 cfm/calf x 15 calves = 300 cfm
- Mild weather: 80 cfm/calf x 15 calves = 1,200 cfm
- Hot weather: 180 cfm/calf x 15 calves = 2,700 cfm

Use the pressure distribution duct for cold and mild weather ventilation. Install a 5-speed fan in the duct to supply about 360 cfm at low speed and about 1,080 cfm at high speed. Operate fan continuously at low speed for minimum winter ventilation. Use a thermostat to switch the fan to high speed (mild weather) at about 50°F.

Select a duct based on mild weather ventilation. From Table 4, an 18" x 18" duct handles 1,080 cfm. One 3" diameter outlet hole can supply about 45 cfm: 24.37 diameter holes spaced evenly along the duct (1,080 cfm / 45 cfm/hole).

Check the outlet air velocity when operating at the cold weather rate so cold air does not drop on calves creating drafts. If drafts are a problem, cover some of the outlet holes.

If calves are in the barn during the summer, an additional fan is needed. Size the fan to provide 1,200 cfm, the difference between the mild and hot weather ventilation rates. Locate the fan in a separate duct along the north wall. From Table 4, an 18" x 18" duct is needed. See the section on "Positive Pressure Ventilation".

Usually, cracks around doors, windows, and haymow openings are sufficient for minimum ventilation exhaust. If not, open windows slightly on the east side of the barn (farthest from inlet duct). For summer ventilation, completely open windows in the east wall.

Tightly cover the hot weather fan during winter to reduce leakage.

Stall barn
The milking barn is a two row tie stall barn, Fig. 53.

Animal units: One animal unit (a.u.) equals 1,000 lb animal weight.
40 stalls x 1,225 lb/cow = 49,000 lb = 49 a.u.

Determine required ventilating rates
- Cold weather ventilating rate: 80 cfm/cow x 49 a.u. = 3,920 cfm
- Mild weather ventilating rate: 180 cfm/cow x 49 a.u. = 8,760 cfm
- Hot weather ventilating rate: 49 a.u. x 335 cfm/a.u. = 16,415 cfm

Stall barn fans
- Cold weather fan: 1,764 cfm at 0.125" static pressure. This fan runs continuously. Install a safety thermostat to stop the fan at about 35°F to prevent freezing. If less than 1,764 cfm is provided, add the difference to the mild weather ventilation fan.
- Mild weather fan: 4,116 cfm (5,880 cfm - 1,764 cfm). Consider a two speed fan for more ventilating rate changes. Control a single speed fan with a thermostat set at 45°F. With a two speed fan set low speed at 45°F and high speed at 48°F.
- Hot weather fan: 10,035 cfm, the difference between the hot and mild weather rates (15,415 cfm - 5,880 cfm).

Control the fan with a thermostat set at 60°F. If winter, place a tight insulated cover over the fan to reduce leakage. Do not seal the mild weather fan.

Put thermostats opposite the fans, near the center alley, and about 5' above the floor. Mount a thermometer with each thermostat.

Cluster the fans near the center of the south wall, Fig. 54. The longest inlet-to-fan air path is less than 75'.

Inlets
Along the two long dimensions of the cow area. Maximum inlet length is 178' (69' x 2). For cold weather, close the inlet for 8' on each side of the cold weather fan. Deduct 16' of inlet for cold weather ventilation. Winter inlet is 160' (178' - 16').

Cold weather inlet opening:
- Airflow = 1,690 cfm / 10.6 cfm/ft = 10.6 cfm/ft of slot length.
- From Table 3, 4" x 4" slot is required.

Mild weather inlet opening:
- Airflow = (4,920 + 1,690) cfm / 178' = 34.0 cfm/ft.
- 4" x 4" slot is required.

Hot weather inlet opening:
- Airflow = (10,035 + 4,920 + 3,760) cfm / 176' = 63.5 cfm/ft.
- Slightly over 2" slot is required. Windows can provide additional summer inlets.

Make the building slot opening 24" x 3" wide and adjust it for mild and cold weather ventilation. The calculated slots assume there are no other leaks into the room.

Adjust inlets when ventilating rates change. Adjust manual inlets, for the ventilating rate that runs most of the day. During cold and mild weather, adjust the inlets for about 0.04" static pressure. For hot weather, completely open inlets.

Inlet location and construction
- With stone and masonry walls, supply air through ceiling inlets. Direct air down the wall to reduce condensation on cool masonry.
- For inlets along the partition to the pen area, construct an inlet duct unless the hay mow floor allows a continuous slot across it. Protect inlets from the haymow from shaft or other materials. Assume an inlet duct is needed: supply air to the inlet duct from both ends so the duct can be smaller.

Duct length = 28'
Hot weather airflow = 53.5 cfm/ft
Required duct airflow from each end:

95.3 cfm x 28' = 2,633.4 cfm
From Table 4, duct is 18" x 20", or 15" x 30" if head room is limited. Insulate the duct to prevent condensation.

Construct save intakes (Fig. 56) at least 50% larger than the largest slot inlet opening. Minimum save intake is 3.75" (2.5" x 1.5). Construct save intakes on the south side of the 2-story barn to supply inlet air. Install doors on the north save inlets to close in winter.

Attic ventilation
When north save inlets are closed, inlet air comes from the attic; check for adequate attic openings in the 2-story barn. Size attic openings for 500 fpm inlet air velocity at the mild weather ventilating rate. Determine required and available attic openings.
Fig 54. Ventilation design for building in Fig 53.

Mild weather airflow = 34.0 cfm/ft² x (2 x 60') = 4,080 cfm.

Minimum attic opening = 4,080 cfm + 200 fpm = 20.4 ft².

South eave attic opening = 60' x (3.75' + 12 in/ft²) = 18.5 ft². 
1' x 1' roof ridge ventilator attic opening = 1' x 1' = 1 ft²

Total available opening = 18.5 ft² + 1 ft² = 19.5 ft².

Increase attic opening by 1 ft² with more ridge ventilators, gable louvers, or wider eave openings.

Other modifications

Increase ceiling insulation to at least R33, partly because the walls are poorly insulated. Install a 4 to 6 mil polyethylene vapor retarder if no retarder exists. At least one layer of tightly placed hay or straw bales can insulate over the milking area in the two story portion.

Make sure that windows and doors fit tightly. Tightly cover the gutter cleaner discharge chute.

Example 13:
Design warm housing ventilation for 16 calves (0-3 mo) and 60 heifers (8-3 mo) in Madison, Wisconsin. See Fig 55. Two housing sections are needed.

Calves are in 2' x 4' elevated crates; young heifers are on bedded pack.

Solution:

Young calf housing

Cold weather rate: 15 cfm/ft² x 16 ft² = 240 cfm. Mild weather rate: 50 cfm/ft² x 16 ft² = 800 cfm. Hot weather rate: 100 cfm/ft² x 16 ft² = 1,600 cfm.

Fans: 240 cfm continuous cold weather fan; 560 cfm mild weather fan; 800 cfm hot weather fan.

Thermostats: One is not needed for the continuous fan. Control the other two fans with thermostats. Set the mild weather fan thermostat at about 65°F and the hot weather one at about 70°F.

Slot inlet: Total slot length for mild and hot weather is 2 x 16' = 32'. During winter, close inlet slats on each side of fans. For cold weather, use one 16' slot inlet opposite the fans and direct airflow down the wall. Across-the-ceiling airflow could be drafty on calves in elevated pens.

Cold weather inlet: 240 cfm = 16' slot length = 15 cfm/ft².

Nearly 1/3 slot is required for tight buildings.

Fig 55. Building of Example 13.

Mild weather inlet: 600 cfm + 32' slot length = 25 cfm/ft².

A little more than 1/3 slot is needed.

Hot weather inlet: 1,000 cfm + 32' slot length = 50 cfm/ft².

1/4" slot is required.

Make the building slot opening about 1/4" and cover with a baffle to adjust for different ventilating rates. Install a manometer in the room and adjust the baffles to maintain a static pressure of about 0.04".

Supplemental heat: Provide supplemental heat to keep the room at 60°F-70°F. Estimating the supplemental heater size from Table 26. For 16 calves at 1,000 Btu/hr/ft², estimated heater is 16,000 Btu/hr. Calculate heater size more precisely as in Chapter 11.

That procedure includes conduction heat loss through building parts, ventilation heat loss, floor evaporation heat loss, as well as heat produced by calves.

If the heater thermostat has an on-off range of 4°F and the desired room temperature is 60°F, set the thermostat at 56°F.

Install walls to R-20 and the ceiling to R-33. Provide a 4 to 6 mil vapor retarder.

Young heifer housing

Cold weather rate: 20 cfm/ft² x 50 ft² = 1,000 cfm.

Mild weather rate: 60 cfm/ft² x 50 ft² = 3,000 cfm.

Hot weather rate: 130 cfm/ft² x 60 ft² = 5,600 cfm.

Fans: 1,000 cfm continuous cold weather fan; 2,000 cfm (5,000 cfm - 1,000 cfm) mild weather fan, and 3,500 cfm (6,500 cfm - 3,000 cfm) hot weather fan.

Controls: Desired room temperature is 40°F-60°F. A thermostat is not needed for the minimum ventilating fan; it runs continuously. For 40°F room temperature, set the mild weather fan thermostat at 43°F and the hot weather one at 48°F. If the heater thermostat has an on-off range of 4°F and room temperature is 40°F, set the thermostat at 38°F. With a heater thermostat set at 38°F, set the mild and hot weather ventilating fan thermostats above 42°F to avoid cooling fan and heater operating simultaneously.

Slot size: Total slot length for mild and hot weather is 34' x 2' (x 43'). Close 16' of inlet over the continuous cold weather fan in winter. Cold weather inlet length is 65' (34' - 16').

Cold weather inlet: 1,000 cfm + 65' slot length = 14.7 cfm/ft².

From Table 3, 48" slot is required in a tight building.

Mild weather inlet: 3,000 cfm + 84' slot length = 37.3 cfm/ft².

48" slot is required.

Hot weather inlet: 6,500 cfm + 84' slot length = 77.4 cfm/ft².

48" slot is required.

Make the building slot opening about 3" and install an adjustable baffle. Maintain 0.04" static pressure at different ventilating rates. To keep the room above freezing, calculate supplemental heater size as in Chapter 11.

Veal Calves

General

Veal calves are usually in 2x3' elevated wooden pens within the first week of age (100 lb). Start calves at 70°F and decrease the temperature 1 °F every 2 days until the temperature reaches 50°F.

Maintain room air relative humidity at 50%-60% for large calves and 40%-50% for smaller calves. Insulate as recommended in Chapter 5.

Ventilation

Use a two-speed fan for cold weather. The low speed provides minimum ventilation when calves weigh 100 lb. Size the high speed for winter ventilation for 400 lb calves. Increase airflow as calves grow. Operate the fan continuously.

With single-speed fans, provide one continuous fan delivering 10 cfm per head and another for 30 cfm per head. Additional fans supply mild and hot weather ventilation.

Draft control is important for veal calves. In cold weather, temper ventilating air before it enters the calf room. Locate and design inlets to minimize high air velocities around calves.

Air tempering

Temper ventilating air with furnaces in a heated corridor, air-to-air heat exchangers, earth tube heat exchangers, solar collectors, or a combination system.

MWPS-34, Heating, Cooling and Tempering Air for Livestock Housing, has more about air tempering methods.

Size tempering heaters to warm ventilating air to 40°F. Do not heat the air to 50°F, the desired room temperature, because cold air helps warm the room. A gas valve modulating type furnace maintains constant temperature in air tempering corridors or use...
multiple furnaces with thermostats set to control furnaces based on heating needs.

Supplemental heat is needed to maintain desired room temperature. Size heaters as in Chapter 11 and Example 14.

In hot weather, sprinkle walkways for cooling. Room heat evaporates water from the floor and cools room air.

**Veal Calf Design Example**

**Example 14:**

Design the ventilating system for a four-room veal barn with 100 calves per room in southern Wisconsin. The building is 50'x264' with a side air tempering corridor; Fig 66. Ceiling height is 9'.

**Solution:**

Ventilate each room by drawing air from the corridor through a slot inlet.

**Solution:**

**Ventilating rates for each room:**

- Cold weather, 100 lb calves: 10 cfm/100 lb x 100 calves = 1000 cfm = 1000 cfm
- Cold weather, 400 lb calves: 100 cfm/100 lb x 100 calves = 4000 cfm = 4000 cfm
- Mild weather: 20 cfm/100 lb x 100 calves = 2000 cfm = 2000 cfm
- Hot weather: 50 cfm/100 lb x 100 calves = 5000 cfm = 5000 cfm

**Cold weather fans:** 1000 cfm continuous fan. Install a second fan for minimum ventilation for larger calves: 3000 cfm (4000 cfm - 1000 cfm). Install a timer on this fan to adjust as calves grow.

**Mild weather fans:** 4000 cfm (3000 cfm - 4000 cfm) can be used to provide a thermostat set at 55°F.

**Hot weather fans:** 12000 cfm (20000 cfm - 8000 cfm) on a thermostat set at 60°F.

Locate exhaust fans in the outside wall opposite the corridor. Cover and insulate the hot weather fan during winter to reduce drafts.

**Inlets:** Continuous slots along the ceiling of each long wall. During cold and mild weather, close the slot to the outside and pull air only from the air tempering corridor. In hot weather, open slot inlets on both sides. Cold and mild weather: slot length in each room is 80'. Total heat weather: slot length in each room is 120' (2 x 60'). Required inlet opening:

- Cold weather inlet (100 lb calves): 1000 cfm - 60' slot length = 16.2 cfm/ft.
- From Table 3, 4½' slot required.
- Cold weather inlet (400 lb calves): 4000 cfm - 60' slot length = 66.7 cfm/ft.
- 1½' slot required.

**Mild weather inlet:** 8000 cfm - 60' slot length = 133.3 cfm/ft.
- 2½' slot required.

**Hot weather inlet:** 20000 cfm - 130' slot length = 153.8 cfm/ft.
- 3½' slot required.

Make the slot opening on both sides about 6' and close with a baffle to maintain static pressure at about 0.04" at the different ventilating rates.

**Insulation:** Exterior walls, R=20 with 6" of fiberglass insulation; ceiling, R=33 with 12" loose fill fiberglass. Install a vapor retarder on the warm side of the ceiling and wall insulation. Interior walls need no insulation.

**Corridor inlets:** Box inlets in the corridor ceiling bring air from the attic. Size openings for mild weather ventilation at 1 ft² of inlet area per 540 cfm: 5000 cfm/room x 4 rooms x 1 ft²/room = 59 ft². Provide 16-2x2' area inlets evenly spaced along the corridor. A slot at least 6' wide is needed for enough outlet area. Open windows or doors in the outside wall of the corridor for more summer ventilating inlet areas.

**Furnace:** Fans can deliver air about 50' space four furnaces uniformly in the corridor. Run furnace fans continuously in the winter. The furnaces must heat air from -10°F to 40°F. Size furnaces for the maximum cold weather ventilating rate of 4000 cfm/room.

- Heating capacity: 4000 cfm/room x 4 rooms x 1 BTU/min·F·ft² x (40°F - (-10°F)) = 880,000 Btu/hr.
- Use four, 200,000 Btu/hr heaters, (800,000 Btu/hr + 4). Set heater thermostats at 35°F. Vent furnaces or increase ventilating rate by 3,200 cfm (2½ cfm/1000 Btu/hr).

**Calf room heaters:** Size room heaters to maintain desired room temperature when calves are first put in the room. Determine the heat losses due to evaporation, ventilation, and through building surfaces and heat produced by animals to determine furnace size. Use the minimum cold weather ventilating rate of 1 cfm/room.

Determine building surface heat loss with Eq. 2, Appendix.

- Ceiling heat loss + wall heat loss = building heat loss.
  2,640 ft² x (70° - (-10°F)) = 330,240 BTU/hr - 0°F = 10,216 Btu/hr.

- Heat loss from winter evaporation is about 83,000 Btu/hr for this problem. Check with your state extension agricultural engineer for help figuring for your situation.

Determine heat loss through ventilating air with Eq. 3, Appendix. Minimum cold weather ventilation rate is 1,000 cfm.

- 1,000 cfm x 1.1 Btu/min·F·ft² x 18°F = 18,500 Btu/hr.

Determine heat produced by the animals. From Table 35, a 100 lb Ayshire calf produces 310 Btu/hr with 79°F room temperature.

- 100 lb x 310 Btu/hr = 31,000 Btu/hr.

Balance heat losses and production to find furnace size.


Furnace heat = 10,216 Btu/hr + 83,000 Btu/hr + 31,000 Btu/hr = 5,216 Btu/hr.

Note that about 60% of the total heat loss is to evaporate moisture in the room. With vented heaters additional ventilation capacity is not used. Use two 50,000 Btu/hr furnaces in each room. Operate heater fans continuously to improve air circulation.

If heater thermostats have a 4°F on-off range, set at 68°F for a 70°F room temperature. Set cooling fan thermostats to turn on fans at 5°F (i.e., 77°F) above the furnace cut-off temperature.

**Management:** Clean and disinfect each room between groups. Allow a one week drying and rest period between groups. Wash the floor under the pens and remove manure from the barn often to minimize ammonia production rate.

**Horses**

**General**

In mild or moderate climates, horses can be in uninsulated, naturally ventilated buildings. Horses conditioned to cold weather with long hair coats can withstand temperatures below 0°F with adequate shelter and nutrition. Horses can maintain a short hair coat down to -20°F if kept in dry indoor facilities and given blankets, hoods, and leg wraps.

In northern regions, insulated buildings heated to 50°F are common. These buildings are mechanically ventilated during the winter and often naturally ventilated during the summer. In warm buildings, relative humidities between 40% and 70% are satisfactory.

- In cold housing, solid wood sheathing insulation in a R-value of 3 or more reduces condensation in winter and solar heat gain in summer. For warm housing, insulation to recommended levels. See Fig 67 for typical placement. Perimeter insulation is recommended in cold climates.

Mechanical ventilation is required for warm horse housing. Provide one continuous fan for minimum cold weather ventilation and additional fans on thermostats for mild and hot weather.

Horse stall sides are often solid 4' high and open above. If partitions are solid above 4', provide an inlet and outlet in each stall for adequate air movement, especially during warm weather.

Some ventilating systems automatically combine natural and mechanical ventilation. During warm weather, controls sense building temperature and automatic cabinet winches adjust inlets. As weather cools, automatic controls close ventilating doors and turn on fans to ventilate during cold periods. Fan powered systems ensure proper air exchange on calm, cold days.

**Supplemental Heat**

Horses usually produce 2,000 to 3,000 Btu/hr of heat (650 to 1,000 lb of animal weight). With 12'x12' box stalls and a 12' center aisle, the animals provide only 9 to 14 Btu/hr per 1,000 lb, which is much lower than other typical animal housing. Because of low animal density, more supplemental heat is needed—about 8,000 Btu/hr per stall, Table 26. For a more accurate estimate, calculate building and ventilation heat losses using Chapter 11.
Poultry

General

Required temperature depends on bird age:
- Broiler chicks and starter pullets: Maintain the following air temperatures: First 3 to 7 days: 85°F, second week: 80°F, and third week: 75°F. Maintain temperature in the entire house or provide zone heat under brooding hovers. With brooders, room temperature can be about 10°F cooler than brooder house temperature.
- Turkey poult: Provide the following temperatures: first 8 to 10 days: 90°F, second week: 85°F, and third week: 80°F. Brooder hovers can provide zone heat.

Mature birds, layers, and turkeys: Minimum temperature is 55°F. For poultry, maintain air relative humidity at 50%-70% to control litter moisture levels at 20%-30% (wet basis). At higher relative humidities, coccidiosis and other disease outbreaks can occur. Lower humidities can cause dusty litter. Short periods of up to 90% humidity can be tolerated.

In warmer climates, consider rigid insulation (up to R=10) in the roof and walls and fibrous insulation above a flat ceiling. If an attic is insulated with fiberglass, see Table 8 for your climate. Install a vapor retarder to control moisture migration.

Ventilation

Poultry buildings are often mechanically ventilated. Provide one continuous fan for minimum winter ventilation and additional fans on thermostats for mild and hot weather.

Supplemental Heat

Open flame, non-vented natural gas or propane heaters with metal burners (brooders) are common for supplemental heat. The oven promotes radiant heat transfer to chicks. A whole house or air makeup heater can blow warm air into the brooding area. These units add fresh air to the brooding room, so adjust ventilating rates.

Buildings with only makeup heaters have higher building heat loss than those with brooders because the whole room is maintained at the brooding temperature. With a brooder, the room temperature can be cooler to conserve energy.

For caged layer or turkey growout, consider heaters in walkways to maintain minimum room temperatures during extremely cold weather.

Cooling

Cooling is often required in poultry buildings, especially in the Southeast U.S. Maintain adequate air velocities in and around the birds to promote cooling.

Evaporative pad cooling and fogging are two common mechanical cooling methods. Both systems convert sensible heat in the air to latent heat.

Use evaporative pad cooling only with mechanically ventilated houses. Pull all incoming air through the wetted pads. Operate at or above hot water ventilating rates to achieve the greatest production benefits. Pad systems operating at 90% evaporative efficiency can give up to 20°F sensible cooling in humid climates. Pad systems usually cool breeding and egg laying birds but also cool commercial broilers subject to extreme heat stress.

High pressure foggers create a very fine smoke-like fog with excellent distribution. Lice water pressure up to 600 psi. Cooling capacity is about half of pad systems at half the cost. No mechanical ventilation is required, so it applies to naturally ventilated broiler houses. Low pressure fogging is not recommended because of limited effectiveness and problems with wet litter. More information on cooling systems is in MWPS-34, Heating, Cooling, and Tempering Air for Livestock Housing.

Deep Manure Pit Ventilation

Deep pit systems allow manure from hens and started pullets to be handled as a solid. Waterers must not leak. Dry manure collects in 8'-10' deep pits under cages before cleanings. See Fig 59.

Fig 57. Typical insulation placement.

Fig 58. Cupola ridge vent.

Fig 59. Deep pit ventilation.

Ventilate the pit to dry manure enough to handle as a solid. With adequate air velocity, Fig 60, ridges form under the cages. Exhaust building ventilating air through the pit and install circulation fans.

Bird density

Bird density affects deep manure pit ventilation performance. Increasing bird density results in more odor and difficult-to-handle manure. With bird densities of 2 to 5 birds/ft² in high rise houses, manure dries to 82% moisture or less causing less odor and handling problems. With 5 or more birds/ft² in triple-deck systems, manure does not dry below 80% moisture unless pit air velocities are increased.

Fig 60. Conditions for manure ridge formation, in high-rise poultry houses.

Example 15:
Design the ventilating system and building to house 20,000 broilers to be marketed at 6 lb. Building is located in central Missouri. Bird density is 0.8 ft²/bird.

Solution:
A mechanically ventilated building with brooders is needed.

Building dimensions: Determine house dimensions to maintain a bird density of 0.8 ft²/bird. Required area is 15,000 ft² (20,000 birds x 0.8 ft²/bird).

Use a 40° wide house because wider houses are difficult to ventilate. Required house dimensions are 69' x 400' (16,000 ft² x 40'). Provide 10' ceiling clearance for broiler loading near the house center.

Insulation: Insulate with 8' fiberglass with a reinforced plastic covering above the ceiling to get an R ≥ 19. Install 1/4" fiberglass batts in outside walls. Insulate doors. Install a 6 mil plastic vapor retarder on the warm side of the wall insulation.

Ventilation: Orient the house east-west to minimize summer heat gain. Install 3 wide continuous sidewall curtains on each side of the building for natural summer ventilation. Install solid walls 8' on each side of any exhaust fans. Control curtains automatically with a single power winch on each sidewall.

Base the ventilating on maximum size bird, i.e. 4 lb.

Cold weather rate (Table 2):
20,000 birds x 0.1 cfm/bird x 4 lb = 8,000 cfm

Mild weather rate:
20,000 birds x 0.5 cfm/bird x 4 lb = 40,000 cfm

Hot weather rate:
20,000 birds x 1.0 cfm/bird x 4 lb = 80,000 cfm

Cold weather fans: Place an 8,000 cfm fan on the brooder end of the building for cold weather ventilation. This fan runs continuously so a thermostat is not needed. Install a timer control to reduce the cold weather rate when smaller birds are in the building.

Consider using circulation fans to reduce temp gradients and moisture stratification.

Mild weather fans: Select one 33,000 cfm or two 16,000 cfm mild weather fans (40,000 cfm - 8,000 cfm). Set thermostats at 70°F.
Brooder inlets are continuous slots along both sides of the 28" center section. Bring air in through ducts from lower eaves or through ceiling inlets from the attic. Total slot inlet length is 334'.

Cold weather rate inlet:

- 2,000 cfm = 334' = 8.0 cfm/ft

From Table 3, slot opening is 14/". An option to the narrow slot, consider closing half the inlet(s) opening the other half to 1/4" in winter.

Mild weather rate inlet:

- 7,000 cfm = 334' = 21.0 cfm/ft

Slot opening is 1/4".

Hot weather rate inlet:

- 20,000 cfm = 334' = 60.0 cfm/ft

Slot opening is used on upper 1/4". Size slot openings at about 2" and close down with an adjustable baffle to maintain static pressures of about 0.06" at different ventilating rates. Consider installing automatic controls on the inlets to maintain desired air velocities.

Circulation fans: Circulation fans in poorly insulated, leaky brooder barns help prevent temperature and moisture stratification. In a tight, well-insulated building with good inlets, circulation fans are less important.

Supplemental heat: Install 24 brooders with propane type heaters in three rows. For each brooder, set up a solid brooder ring, about 16" in diameter to prevent drafts and to maintain groups of about 420 pounds per brooder, maintaining brooder temperatures at 90°F, 65°F for the first, and second, and third weeks respectively, and maintain room temperature above 10°F cooler. After three weeks maintain room temperature at 70°F. Install 600,000 Btu/hr of supplemental heat.

Management: Completely clean out old litter between brooders and place new poultry on fresh bedding. During brooding, replace wet litter around waterers. If waterers become too high or litter begins to feel damp, increase ventilation until the litter dries. Wet litter and fecal material sticking to poult feet can cause serious problems. Completely wash and disinfect building and equipment surfaces between brooders.

Grower ventilation: Provide for natural ventilation in hot weather, as described in MPFS-33, Natural Ventilating Systems for Livestock Housing. Required ventilating rates depend on bird weight and outside temperature. Table 2. Table 9 shows required ventilating rates for this example. Provide cold and mild weather ventilation with mechanical ventilation and hot weather ventilation by natural ventilation. Orient the building with the long dimension east-west for better summer airflow.

For cold and mild weather ventilation, install two 2,500 cfm fans and five 10,000 cfm fans evenly spaced in the north wall. Operate one 2,500 cfm fan continuously in cold and mild weather and control all other fans with thermostats. If more ventilation is needed adjust thermostats down. In cold and mild weather, air enters through slightly opened inlets or vent doors on the south wall and exits through fans in the north wall. Shut fans off in hot weather and open natural ventilation openings.

Install 800,000 Btu/hr of heating capacity to preheat the grower barn before new poult s are put in and to help dry litter if necessary.

Circulation fans: Use four 36" fans hung vertically in the building or several paddle fans to provide mixing. Run the fans continuously.

Management: Move pouls to the grower barn at 6 to 8 weeks of age. Pre-warm the barn to 70°F before placing the birds. Reduce temperatures to 65°F by 9 weeks of age. Some growers lower temperatures to 80°F at 15 weeks of age.

Add fresh bedding periodically and remove or mix litter with dry litter. Wet litter causes leg and foot problems and increases ammonia levels. Dry litter can cause dust and reduce ventilation rates and heaters to maintain desired litter moisture conditions.

Curing or mixing litter releases large amounts of ammonia. Increase ventilating rates during and after tilling to control ammonia levels. Wear a face mask with respirators to remove ammonia when mixing litters. Dust filters over the respirators reduce plugging.

Example 17: Design ventilation for a 56,320 bird, 40' x 252' building in New York city for layers averaging 3.8 lb/day. The building is high rise construction with an 8' high manure storage underneath. Bird density is 4 birds/ft².

Solution: Insulate the ceiling to at least R-58 and the walls to at least R-90. Table 9. Ceiling insulation forms attic space. Use fiberglass with a reinforced plastic covering. Install fiberglass batts in outside walls. Insulate doors. Install a 6 mil plastic vapor retarder to protect wall insulation. Cover inside walls with plywood or metal siding and protect the bottom 4' from mechanical damage.

Ventilation: Determine required ventilating rates.

Cold weather ventilation, Table 2:

**Table 2. Ventilating rates for grower building.**

<table>
<thead>
<tr>
<th>Bird weight, lb</th>
<th>Bird age, wk</th>
<th>Cold weather</th>
<th>Mild weather</th>
<th>Hot weather</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>8</td>
<td>2,000</td>
<td>2,500</td>
<td>2,500</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
<td>3,200</td>
<td>3,200</td>
<td>3,200</td>
</tr>
<tr>
<td>24</td>
<td>25</td>
<td>4,375</td>
<td>4,375</td>
<td>4,375</td>
</tr>
<tr>
<td>32</td>
<td>33</td>
<td>5,500</td>
<td>5,500</td>
<td>5,500</td>
</tr>
</tbody>
</table>

Cold weather, fans use two 20,000 cfm fans for hot weather (80,000 cfm = 40,000 cfm). Set thermostats at 75°F. Wire controls so fans shut off when curtains are open. Install thermostats near the middle of the room line with the fan they control. Install motorized shutters. Place fans on the leeward wall based on prevailing winter winds.

Inlets: Install a permanent inlet 24" above floor level on the wall opposite the fans. An inlet 24" above the floor maximizes air velocity on the birds and allows using evaporative cooling. Total inlet length is 400'.

Cold weather inlet:

- 8,000 cfm = 400' of slot length = 20 cfm/ft

From Table 3, slot opening is just under 1/4".

Mild weather inlet:

- 40,000 cfm = 400' = 100 cfm/ft

Slot opening is about 1/4".

Hot weather inlet:

- 80,000 cfm = 400' = 200 cfm/ft

Slot opening is 1/4".

Adjust the continuous curtain to provide needed inlet size or install adjustable baffle on a permanent 6' inlet 24" above the floor. Adjust inlets to maintain static pressure at about 0.04" at different ventilating rates.

Management: Cleaning between brooders is not necessary. Completely clean out at least once a year. Between brooders, remove caked litter around feeders, drinkers, and brooders. Top dress with clean shavings. Warm bird rooms three days to drive off ammonia. Ferrous sulfate compounds mixed in the litter help control ammonia release. Poll in halves or less of the building floor space—preferably the building half that is least affected by wind.

Supplemental heat: Install about 24 brooders, preferably with electronic ignition, in the brooding end of the building. Maintain chick hovers at 85°F, 80°F for the first, second, and third weeks. An additional 4 to 6 brooders in the non-brooding end are for cold weather after brooding.

Adjust the fan thermostat in the brooding end as bird size and/or weather changes.

Cooling: After brooding, open sidewall curtains and shut off fans. Maintain temperatures around 70°F with thermostatically controlled curtains. When inside temperature rises above 80°F, close the curtains and mechanically ventilate until temperatures are below 80°F.

Install high pressure misting along the continuous inlet. Run the misting system only while mechanically ventilating. Use a cycle timer to mist for no more than 50% of the time, e.g. 5 min on, 5 min off, with a 10-min cycle timer. Higher rates can cause wet litter.

Example 16:

Design housing for 10,000 turkey toms to be grown to 32 lb (heavy tom production) near Willmar, Minnesota.

Solution:

- **Housing:** Turkeys are typically raised in two phases, brooding and growout. Brooding building: ponds from one day to 6 weeks at 1.5°F/ton; 10,000 tons x 1.5°F/ton = 15,000°F. Growout building: 3.5°F/ton; 10,000 tons x 3.5°F/ton = 35,000°F.

- Make the brooder building 60' x 67' (60' x 67' = 10,000 SF). Use two growout buildings, each 60' x 200' (60' x 200' = 12,000°F). See Fig. 61.

- **Insulation:** Insulate the ceiling and roof to R-33 and the walls, and endwalls, and doors to R-20. Table 9. Grower buildings are cooler and growers produce more litter heat, so insulate the ceiling and roof to R-35 and walls, and endwalls, and doors to R-25.

- **Brooder ventilation:** Turkeys grow rapidly; adjust ventilation rates weekly. Also adjust ventilation to maintain desired litter conditions.

- Cold weather rate (Table 2):

  - 10,000 birds = 0.5 cfm/ft = 2,000 cfm
  - Mild weather rate:

    - 10,000 birds = 0.7 cfm/ft = 7,000 cfm
  - Hot weather rate:

    - 10,000 birds x 4.0 cfm/ft = 40,000 cfm

- Install two 5,000 cfm fans, two 8,000 cfm fans, and two 10,000 cfm fans. Space fans evenly in both sidewalks. One 2,500 cfm fan is continuous minimum cold weather ventilation. Set thermostats on all other fans to turn fans on as temperature increases. During the first week, careful management can provide all fresh air requirements through natural infiltration.

- Provide emergency ventilation with 4x8' insulated sidewall doors 60' apart and at least 2' outside grade.
Hot weather ventilation: 56,320 bcf = 0.3214 cf/ft³ = 241,000 cf/h
Install two 11,000 cf/h fans for cold weather. These fans run continuously with large birds so thermostats are not needed. Install a timer on one fan to reduce cold weather ventilation when the birds are smaller.

Mild weather ventilation fans provide 85,000 cf/h (107,000 cf – 22,000 cf). Four 22,000 cf/h fans are needed in addition to cold weather fans. Hot weather ventilation fans must provide 104,000 cf/h (214,000 cf – 110,000 cf). An additional four 20,000 cf/h fans and one 25,000 cf/h fan are needed for hot weather ventilation.

Set two mild weather fan thermostats at 60 F and the other two at 64 F. Set the hot weather fan thermostats to come on at 2 A.M. in increments of 4 F (68 F, 72 F, 76 F). At 76 F operate all fans. Install thermostats near the middle of the room in line with the fan they control. Install motorized shutters on fans.

Inlets. Air can be brought into the building through recirculation tubes or baffled slots along each sidewall. See manufacturer for design of tube system.

Mild and hot weather ventilation slot length is 704 (350 + 350 + 14) in winter. Close up 16 of baffle at each cold weather fan. Cold weather slot length is 672 (704 – 2 + 16).

Cold weather inlet: 22,000 cf + 672 of slot length = 32,7 cf/ft³. From Table 3, slot opening is 1/4.

Mild weather inlet: 110,000 cf + 704 of slot length = 156.3 cf/ft³. Slot opening is 3/4.

Hot weather inlet: 215,000 cf + 704 of slot length = 305.4 cf/ft³. Slot opening is just under 7.

Make the ceiling opening 10’ wide and close down with a baffle to maintain a static pressure of about 0.4’.

Supplemental heat: Install 600,000 Btu/hr heating capacity to maintain room temperature. Use the procedure in Chapter 11 to more accurately determine supplemental heat requirements.

Pit circulation fans: Circulation fans move air a distance about 25 times the fan diameter. Place 24’ diameter fans about 50’ o.c. or 36’ fans about 75’ o.c. Orient fans to create a “race track”, Fig 98. From Fig 60, an air velocity over 125 fpm is required for a bird density of 4 birds/ft². When fans are in place, check air velocities. If less than 125 fpm, add more fans or reposition fans to maintain desired air velocity. Locate fans to protect them from manure buildup.

Management: Layer building temperature is often maintained below 70 F in cold climates. Smoke make-up heaters may be needed. Typical lighting schedule is a 10 hr day length, but some operations use intermittent lighting, e.g. 8 hr light, 10 hr dark, 2 hr light, 4 hr dark. With intermittent lighting schedules, effective light trapping of fans and inlet is required.

Rabbits

General

Cold, naturally ventilated housing is adequate for mature rabbits, provided there are few drafts. Supplemental heat can minimize frozen water lines and appliances in winter.

Temperature for optimum feed conversion for rabbits is about 65 F. Most systems maintain minimum winter temperature at 40 F – 45 F.

Summer heat stress is a severe problem with rabbits. Exposure to continuous temperatures of 85 F or more for 4 to 5 days can cause sterility for up to 60 days in mature bucks. Temperature heat relief for breeding bucks can be wet cloths in their cages and crushed ice in their drinking cups. Remove cloths and clean daily to prevent build up of manure and urine. All rabbits are subject to heat prostration when cage temperatures exceed 92 F.

Relative humidities below 35% dry the respiratory tract which can lead to serious respiratory problems.

Insulate to moderate summer temperatures and reduce winter supplemental costs.

Body heat production for rabbits is about 8 Btu/hr-lb of live weight.

Ventilation

Young rabbit housing is typically mechanically ventilated, Table 2. Relatively low animal density (usually 1 lb/ft² or less) makes it difficult to control cold weather ventilation without drafts. Many producers use negative pressure with recirculation for a more uniform environment. An air tempering system may have merit in rabbit housing.

Periodically remove rabbit hair from cages, because it restricts airflow.

Consider evaporative cooling in climates that regularly have damaging high temperatures.

Example 18: Design a ventilation system for a 1000 lb dairy producing fryers. A 30’x120’ building has R-14 sidewalls and R-20 ceiling insulation.

Solution:

See Table 24. Table 23. Rabbit cages and animal weight.

Temperature (Table 3): 2,738 lb x 0.1 cf/lb = 273 cf
Mild weather ventilation: 3,700 lb x 0.9 cf/lb = 3,330 cf/h

Cold weather ventilation (Table 3): 3,330 cf/h + 0.1 cf/lb = 373 cf
Mild weather ventilation: 3,700 lb x 0.9 cf/lb = 3,330 cf/h

Provide year-round ventilation with a negative pressure recirculation system. Use one recirculation tube at ceiling level along the center of the building.

The cold weather ventilation rate is so low (less than 1% of building volume) that no special fresh air inlets are required unless the building is exceptionally tight.

Two power operated shutters near the tube inlet provide air for mild and hot weather rates. Size each shutter for 1,800 cf of airflow—two 24”x24” shutters. Open one power shutter in mild weather and both in hot weather.

One single speed 400 cf exhaust fan is for cold weather. Locate the fan in the end wall at the opposite end from the tube inlet. Run this fan continuously; a low temperature thermostat shuts the fan off if room temperature drops below 35 F.

A two speed exhaust fan with a low capacity of 1,500 cf and high capacity of 3,500 cf (or one 1,500 cf and one 1,900 cf fan) is for mild and hot weather. Set thermostats to provide low volume rate at 65 F and high volume rate at 70 F. Locate mild and hot weather fans on the same endwall as the cold weather fan.

Supplemental heat is 7 Btu/hr-lb to maintain 45-50 Finside when outside temperature is -10 F. Put a 25,000 Btu/hr heater near the inlet end of the recirculation tube.

Install with temperature and power failure alarms.

Example 19: Design a mechanical/natural ventilating system for a 600 dairy fryer production unit housed in a 20’x120’ building with curved sidewalls. This building is in southern Iowa.

Solution:

See Table 24.

Cold weather ventilation (Table 3): 2,238 lb x 0.1 cf/lb = 223 cf
Mild weather ventilation: 2,238 lb x 0.5 cf/lb = 1,119 cf

Hot weather ventilation: Open sidewall curtains for natural ventilation.

Install a single 15” diameter recirculating tube along the ceiling, down the center of the building for cold and mild weather ventilation. See the section on “Negative Pressure with Recirculation”.

Install a 225 cf exhaust fan (cold weather rate) in the wall opposite the tube inlet. Run this fan continuously; a low temperature thermostat shuts the fan off if room temperature drops below 35 F. Cracks around curtain provide enough inlet area.

Install a 1,000 cf exhaust fan near the cold weather fan for mild weather. Set the thermostat to turn it on when room is above 45 F.

For hot weather, lower sidewall curtains and turn off fans. A 2”x6” roof overhang shades rabbits and protects from blowing rain.

Install a 30” Blower heater near the tube inlet to turn on when room temperature drops below 40 F. See Chapter 11 to size heater.

Sheep

General

Ewes and feeder lambs are usually in cold housing. Warm buildings are used for lambing in cold climates. Design and operate ventilation to maintain room air at 40%-70% relative humidity.

Insulate cold buildings as recommended in Chapter 8 and warm buildings as in Table 2.

Ventilation and Heat

Naturally ventilated buildings are discussed in MWPS-23, Natural Ventilating Systems for Livestock Housing, Warm buildings often have mechanical winter ventilation. See Table 2. Circulation fans increase airflow with over animals and reduce summer ventilation rates up to 40%. Consider evaporative cooling.

Supplemental heat (400 Btu/hr-lb) may be needed in addition to heat lamps for mothering pens. In lambing pens, make pen partitions solid or provide hovers to control drafts and install 250 watt heat lamps.

Example 20: Design a lambing and feeding barn for 200 ewes near DeKalb, Illinois. Floor space is 40’x100’ (200 ewes x 20’/ewe). Select 60’ width. Place 40’x100’ (4,000 ft²) building with solid floors and 10’-12’ high sidewalls for good summer natural ventilation.

Insulate supplemental hosted building in northern Illinois to R-33 in the ceiling and R-20 in the outside walls. Table 23. Rabbit cages and animal weight.

Provide a 6 mil polyethylene plastic vapor retarder on the warm side of the ceiling and walls.
Ventilation: If possible, orient the building east to west to minimize summer heat gain and take advantage of summer breezes. Install continuous sidewall doors or panels at least 30” high along both sidewalls for summer.

Cold weather rate (Table 2):
26 cfm = 1000 lb x 225 lb/cew x 200 eves = 1,125 cfm
Mild weather rate:
100 cfm = 1,000 lb x 225 lb/cew x 200 eves = 4,500 cfm

Select a 1,200 cfm fan for continuous cold weather ventilation and two 1,200 cfm fans for mild weather. Thermostats turn on mild weather fans as temperatures rise.

Inlets: Install continuous slot inlets along the ceiling of both side walls. Total slot inlet length is 200’ (100’ x 2). Close off 16’ of slot inlet over the continuous cold weather fan. Cold slot length is 184’ (200’ - 16’)

Cold weather inlet:
1,200 cfm - 14’8” of slot length = 6.5 cfm/ft.
From Table 3, slot opening is just over 1/4”, which is too small to control accurately. Close off half the inlet sections and open the other half to 1/4”

Mild weather inlet:
4,500 cfm = 200’ of slot length = 22.5 cfm/ft.
Opening is 1/2”

Supplemental heat: Provide 400 Btu/hr-cew of supplemental heat and 250 watt heat lamps for the lambing pens. 400 Btu/hr-cew x 200 eves = 80,000 Btu/hr.

In summer, the building can be for ewe and lamb feeding. Open sidewall doors along both sidewalls and turn off fans. For mechanical ventilation, add more fan capacity.

Breeding-gestation: Temperatures above 85°F with high humidity reduce fertility of boars, sows, and gilts. Maintain the room below 85°F for sows during the first 2 or 3 weeks of gestation for maximum litter size and during the last 2 or 3 weeks to reduce stillborn and abortions. Keep the room at 60°F or above for sows or gilts in crates or tethered or on total skid ladle. If the floor is partly slotted and if sows are in groups that can handle together, temperature can be down to 50°F. Coldest temperatures can be tolerated with bedding, but freezing temperatures with wind can be a problem.

Keep relative humidity at about 45%-60%.

Insulation, Table 9

Install minimum insulation in open front buildings and single row narrow basins: have indoor temperatures only slightly higher than outside conditions.

Modified environment buildings rely on animal heat and controlled, natural ventilation to remove moisture and maintain inside temperatures. Examples are gestation and growing-finishing units.

Environment-controlled buildings require supplemental heat to maintain desired temperatures. Examples are farrowing, nursery, and some breeding-gestation buildings.

Perimeter insulation is highly recommended for modified environment and heated buildings.

Ventilation
Select ventilating rates from Table 2. Select fan sizes from product literature. Use several fans or multi-speed fans. Fans are normally staged to come on in about 4 increments.

For natural ventilation, see MWPS-33, Natural Ventilating Systems for Livestock Housing from Midwest Plan Service.

Draft Control
Solid pen partitions around animal sleeping areas reduce drafts.

Hovers reduce vertical drafts better than boards placed over slotted floors. Hovers can be tempered hardboard, sheet metal, or exterior plywood at no more than twice the animal height. Heavy clear plastic on a frame lets you observe the animals.

Provide hovers for all animals in a pen at one time—about half of a farrowing creep area or a third of a nursery pen area.

Example 21:
Design a ventilating system for a 20-sow farrowing building, 54’x66’, in Northern Iowa.

Solution:
Insulation: From Fig 24, Northern Iowa has over 6,000 degree days. From Table 9, insulate to R=20 in the walls, to R=33 in the ceiling, and the foundation."
Table 25. Moisture and sensible heat from livestock.  
For animals not listed in this table, multiply the animal weight times the values in the per lb animal weight column.  Unknown values shown as "-".  

<table>
<thead>
<tr>
<th>Animal</th>
<th>Building temperature F</th>
<th>lb water/100 lb</th>
<th>Sensible heat loss lb/hour</th>
<th>Animal</th>
<th>Building temperature F</th>
<th>lb water/100 lb</th>
<th>Sensible heat loss lb/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man</td>
<td>70</td>
<td>0.28</td>
<td>8.0</td>
<td>70</td>
<td>0.28</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Calf</td>
<td>80</td>
<td>0.22</td>
<td>5.9</td>
<td>80</td>
<td>0.22</td>
<td>5.9</td>
<td>5.9</td>
</tr>
<tr>
<td>Calf</td>
<td>85</td>
<td>0.16</td>
<td>3.7</td>
<td>85</td>
<td>0.16</td>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Hog</td>
<td>90</td>
<td>0.10</td>
<td>2.3</td>
<td>90</td>
<td>0.10</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Hog</td>
<td>95</td>
<td>0.06</td>
<td>1.0</td>
<td>95</td>
<td>0.06</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Sheep</td>
<td>100</td>
<td>0.04</td>
<td>0.7</td>
<td>100</td>
<td>0.04</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Cow</td>
<td>105</td>
<td>0.02</td>
<td>0.3</td>
<td>105</td>
<td>0.02</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 26. Listing supplemental heaters.  
Use these peak loads only for short intervals and only when water heater tanks are greater than 5,000.  These are based on the minimum outdoor design temperature and twice the cold weather district rate in a moderately insulated building with electrically heated water tanks.  For additional zone heating, separate supplemental heating units are recommended for each zone.  

<table>
<thead>
<tr>
<th>Animal unit</th>
<th>Supplemental heat for animal unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lb/hour</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 27. Calculating heat loss through building surfaces.  
The heat loss rate through each building surface is proportional to its area and the difference between inside and outside temperatures.  The rate of heat flow is also determined by the total heat resistance (R) of the building surface; the higher the R-value, the lower the heat flow rate.  Heat loss from each building, Bhr, is given by:  

\[ Bhr = (A/R) \times (t_i - t_o) \]

Where:  
Bhr = Heat loss rate through a surface, Btu/hr  
A = Surface area, ft² (i.e. wall area)  
R = Total resistance of the surface to heat flow, F-hr.ft²/Btu  
t_i = Inside temperature, F  
t_o = Outside temperature, F  

For total heat loss from a building, add the losses through each building surface.
Worksheet – Heat loss through building surfaces

Step I

Building dimensions (ft)
Length (L) ____________
Width (W) ____________
Frame wall height (H) ____________
Concrete wall height (F) ____________
Perimeter ____________
R¹ values ____________
Ceiling ____________
Window ____________
Door ____________
Frame wall ____________
Concrete wall ____________

Surface area (ft²)
Area ____________
Ceiling area ____________
Window area ____________
Door area ____________
Frame wall area ____________
Less window & door area ____________

Design temperatures, F

\[ t_0 \] (outside temp.) = ____________, \[ t_i \] (inside temp.) = ____________
\[ \Delta T = \text{__________} \]

Step II

Building heat loss, \( q_b \)

<table>
<thead>
<tr>
<th>Component</th>
<th>Heat Loss Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>( q_c = \Delta T \times \text{ceiling area} \times R_T )</td>
</tr>
<tr>
<td>Windows</td>
<td>( q_w = \Delta T \times \text{window area} \times R_T )</td>
</tr>
<tr>
<td>Doors</td>
<td>( q_d = \Delta T \times \text{door area} \times R_T )</td>
</tr>
<tr>
<td>Frame walls</td>
<td>( q_{fw} = \Delta T \times \text{frame wall area} \times R_T )</td>
</tr>
<tr>
<td>Concrete walls</td>
<td>( q_{cw} = \Delta T \times \text{concrete wall area} \times R_T )</td>
</tr>
<tr>
<td>Perimeter</td>
<td>( q_p = \Delta T \times \text{perimeter} \times R_T )</td>
</tr>
</tbody>
</table>

Calculating heat loss: \( q_b = \sum q_i \)

Annual Heating Costs

Total building heat loss is heat loss through building surfaces plus ventilating air. Eqs 2 and 3 can be combined to get Eq 4 for calculating total heat loss rate.

\[ \text{TBL} = HVI + VHL \]
\[ \text{TBL} = (A/R + 1.1 \times cfm_0)(t_i - t_o) \]

\[ \text{TBL} = \text{Total rate of heat loss from building, Btu/hr} \]
\[ \text{HLF} = (A/R + 1.1 \times cfm_0) \]

\[ \text{HLF} = \text{Heat loss factor, Btu/hr-F} \]

To adjust heating degree days from residential buildings to livestock buildings, calculate the balanced point temperature, \( t_b \), Eq 6. It is the minimum outdoor temperature required to maintain the building at the design temperature with no supplemental heat. Using the balanced point temperature, \( t_b \), calculate the heating degree days correction factor, \( C_b \), with Eq 7.

\[ t_b = t_i - (\text{SHL} + \text{HLF}) \]

\[ t_b = \text{Balance point temperature, F} \]

\[ \text{SHL} = \text{Total livestock sensible heat loss, Btu/hr.} \]

\[ \text{Multiply value from Table 28 by number of animals or total weight.} \]

\[ \text{HLF} = \text{From Eq 5} \]
\[ C_b = A + (B \times (t_b - 32)) \]

\[ C_b = \text{Heating degree days correction factor} \]

\[ A, B = \text{Coefficients from Table 27} \]

The animal energy required, \( E \), to heat a building is determined by Eq 8. Supplemental heating requirements are reduced by heat produced by livestock or increased by high room temperatures.

\[ E = C_d \times 24 \times HLF \times HDD \]

\[ E = \text{Annual energy consumption, Btu/year} \]
\[ C_d = \text{Heating degree days correction factor for livestock buildings} \]

\[ HDD = \text{Heating degree days, F-day, from Fig 24} \]

Determine annual fuel cost, AFC:

\[ \text{AFC} = (E \times X) + (E \times V) \]

\[ AFC = \text{Annual fuel cost, $} \]
\[ FC = \text{Fuel cost, ¢/unit} \]

\[ E = \text{Annual heating load, Btu/year (Eq 8)} \]

\[ \text{EFP} = \text{Efficiency of heating system, 90/100} \]

\[ V = \text{Fuel heat content, Table 28} \]
Table 27. Coefficients for Eq. 7:

<table>
<thead>
<tr>
<th>State</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois</td>
<td>-0.3425</td>
</tr>
<tr>
<td>Indiana</td>
<td>-0.3773</td>
</tr>
<tr>
<td>Iowa</td>
<td>-0.3154</td>
</tr>
<tr>
<td>Kansas</td>
<td>-0.3413</td>
</tr>
<tr>
<td>Michigan</td>
<td>-0.3519</td>
</tr>
<tr>
<td>Minnesota</td>
<td>-0.4045</td>
</tr>
<tr>
<td>Missouri</td>
<td>-0.4295</td>
</tr>
<tr>
<td>Nebraska</td>
<td>-0.4245</td>
</tr>
<tr>
<td>North Dakota</td>
<td>-0.2655</td>
</tr>
<tr>
<td>Ohio</td>
<td>-0.3735</td>
</tr>
<tr>
<td>South Dakota</td>
<td>-0.1100</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>-0.1271</td>
</tr>
</tbody>
</table>

Table 28. Approximate fuel heat content, V.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Heat content</th>
<th>Heating system efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>1,000 Btu/lb</td>
<td>70-80%</td>
</tr>
<tr>
<td>LP gas</td>
<td>80,000 Btu/lb</td>
<td>70-80%</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>138,000 Btu/lb</td>
<td>50-60%</td>
</tr>
<tr>
<td>Electricity</td>
<td>3,413 Btu/kWh</td>
<td>100</td>
</tr>
</tbody>
</table>

Example 23:
The 24x84x66 building in Example 22 houses 300 pigs weighing 50 lb each. The building has a cold weather ventilating rate of 800 cfm. Find the heat loss through ventilating air at the outside design temperature. Find annual heating cost with LP gas at $0.70 per gallon and a 15% efficient heater. Find furnace size. Location is Grand Island, Neb.

Solution:

Step 1: Ventilation heat loss rate, VHL, Eq. 3.

VHL = (1.1 x cmhc x (t_0 - t_b))
     = (1.1 x Btu/min/ft^2 x 600 cm^2 x (75°F - 0°F))
     = 49,500 Btu/hr

Step 2: Find the overall heat loss factor, HLF, using Eq. 5.

From Example 22, VHL = 49,500 Btu/hr-F.

HLF = A/R x 1.1 x cmhc
     = 49,500 Btu/hr-F / 1.1 x Btu-min/ft^2 x 600 Btu/hr = 861.5 Btu/hr-F

Step 3: Determine the total sensible heat loss (SHEL) by animals. Find the sensible heat loss rate from Table 25. Since 50 lb is close to 45 lb, use the per-lb value for 45 lb and multiply by 50 lb. However, you will need to interpolate for temperature. From Table 25, a 45 lb pig loses 3.6 Btu/hr/in. at 68°F and 2.5 Btu/hr/in at 77°F. Interpolate to get the heat loss at 70°F.

12. Glossary

Air conditioning: A method of filtering air and regulating its humidity and temperature. Usually employing refrigeration equipment.

Airflow rate: Air delivery rate usually expressed as cubic feet per minute (cfm).

Balance point temperature: Outside temperature at which energy losses from a building equal energy gains without supplemental heat.

Btu: British Thermal Unit. Quantity of heat energy required to raise 1 lb of water by 1°F.

Cellulose insulation: Insulation made of organic fibers, paperly, or wood. Often used as loose-fill.

Celcius (°C): Temperature scale with the freezing point of water at zero and the boiling point at 100. Abbreviated C.

Cfm: Abbreviation for cubic feet per minute.

Condensation: Process by which a change of phase occurs from a vapor to a liquid. Examples include moisture accumulating on building surfaces in winter, operating dehumidifier, and moisture on a cold glass of water in summer.

Conductance: Thermal conductance is a measure of a material's ability to conduct heat energy. Units are Btu/hr°F. Conductances is the inverse of resistance and is abbreviated C.

Conductive heat transfer: Process by which heat is transferred from one location to another in a body due to a temperature gradient in the body. The energy always moves from the high-temperature region to the low-temperature region. Two bodies in contact can also conduct heat. Examples include the hot handle on a heated pan, metal heated by welding.

Convective heat transfer: Process by which heat is transferred from a body to a fluid by passing the fluid over the body. The fluid may or may not be forced to flow resulting in forced or natural convection. Examples include cooling a hot object by blowing air over it, cooling an animal by blowing air on it.

Degree day method: Procedure for estimating energy needs based on the difference between the daily average outside air temperature and the balance point temperature.

Degree of saturation: Ratio of the weight of water vapor to the saturated weight of water vapor per pound of dry air at the same temperature and pressure. Often used interchangeably with relative humidity.

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

Draft: Combination of air temperature and velocity which causes thermal stress in livestock. Specific values of temperature and velocity are different for each age and weight of animal and are not well defined. Generally younger animals are more susceptible to drafts.

Dry-bulb temperature: Temperature of air or a body measured with a conventional thermometer. (See also Sling psychrometer.)

Duct: Structure (rectangular or circular) used to conduct air from one place to another. Often used to distribute air within a building or remove air from a structure.

Eave opening: Opening at the eave of a building through which ventilating air enters. Used in both mechanical and natural ventilating systems.

Energy: Capacity for doing work.

Enthalpy: Heat energy content of an air-water vapor mixture. Incorporates sensible and latent heat of vaporization. Units are Btu/lb dry air.

Evaporate: Process of transforming a liquid to a vapor, for example water to steam.

Evaporative heat transfer: Heat energy exchange which occurs during evaporation. Examples include skin cooling during perspiration, respiratory tract evaporation, and evaporative cooling pads.

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

Fan: Mechanical device to move air—usually electric.

Heat: Form of energy. Heat energy can be transferred from a body of higher temperature to one of lower temperature. Heat energy cannot be seen or measured, but the effects of heat gain or loss can be observed (i.e. evaporation, condensation, temperature rise or decline.)
Heat transfer: Process of heat energy transport. (See Conductive, Convective, Radiant, and Evaporative heat transfer, and Condensation).

Humidity: Refers to moisture contained in the air. (See Relative humidity, Humidity ratio).

Humidity ratio: Ratio of the weight of water vapor to dry air. Units are expressed as lb water/ft³ dry air or grains water/ft³ dry air (7,000 grains water/ft³ water).

Inlet: Structural opening through which ventilation air enters.

Insulation: Any material that reduces heat transfer from one area or body to another. (See R-Value).

Latent heat: Energy absorbed or released by a material when it changes phase with no temperature change in the material.

Mechanical ventilation: Process of forcing air through a building using mechanical equipment (fans, fan controls, inlets, etc.).

Natural ventilation: Process of forcing air through a building using thermal buoyancy of air and wind.

Open ridge: Opening in the ridge which allows warm moist air to leave a livestock building.

Perm: Measure of vaporability. One perm equals one grain of water/hr-ft²-in of mercury pressure difference.

Permeability: Ability of a material to permit water vapor to pass through it.

Polystyrene: Plastic foam insulation. R-value is 4.5-6 (R²-hr·F/ft²·Btu per inch of thickness). Polyurethane: Plastic foam insulation. R-value is 6 (R²-hr·F/ft²·Btu per inch of thickness) (aged).

Positive pressure ventilating system: Mechanical ventilating system where fans blow air into the structure creating a positive pressure.

Radiant heat transfer: Process by which heat is transferred from one body to another body by electromagnetic waves when separated in space, even in a vacuum. Examples include sun radiating to earth, fireplace radiating to a person, animal radiating to a cold wall surface.

Relative humidity: Ratio of actual water vapor pressure in the air to the vapor pressure at saturation, at the same temperature and pressure, expressed as a percent.

R-value: Resistance value of an insulation material to heat flow. The higher the R-value the longer the resistance to heat flow through the material. R-values are additive. Units are (hr·F·F)/Btu.

Saturated air: Condition where air can hold no additional water vapor; 100% relative humidity.

Sensible heat: Energy absorbed or released by a material that results in a temperature change. Examples include heating water, heating or cooling air, animal losing heat to a cold surface with which it is in contact.

Sling psychrometer: Temperature sensing instrument containing a wet bulb and dry bulb thermometer. Knowing these two temperature readings a psychrometric chart is used to obtain relative humidity, humidity ratio, dewpoint temperature, enthalpy, and specific volume.

Specific volume: Space occupied by a given mass of a gas or gas mixture. In ventilation, units are expressed as ft³/ft lb dry air.

Static pressure: Difference in pressure between inside and outside of a building, ventilating fan, or inlet. Units measured in inches of water.

Supplemental heat: Sensible or radiant heat required to keep a room at a desired temperature when internal heat production rate is less than the heat losses through conduction and ventilation. Supplemental heat is often provided by furnaces, unit heaters, solar collectors, radiant heaters, and heat exchangers.

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

Thermal buoyancy: Warm air is less dense than cold air so warmed air is buoyed up by cold air. Thermal buoyancy is the term that describes this process. Examples include hot air balloons, naturally ventilated buildings, chimneys.

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

Vapor pressure: Pressure exerted by a gas in a given space. It is a function of the amount of gas present and its temperature. In ventilation, water vapor pressure is the pressure exerted by the water vapor in a given space of air and water vapor. Units are expressed as in of mercury.
10. Vineland Labs; P.O. Box 70, Vineland NJ 08360

Publications: Available from the Extension Agricultural Engineer at any of the institutions listed on the inside front cover or from Midwest Plan Service.

Air requirements 2, 6
Dust 4
Gas leaks and odors 2-3
Lethal situations 3
Quality 2
Quantity 5.6
Alarms 34-36
Annexes, see Manure pit
Appendix 60
Calculating heat loss 61-63
Heat and moisture production 65
Applications and examples 43
Beef 43
Dairy
Calves, heifers 48
Cows 43
Design examples 45
Holding area 43
Treatmenst hospital area 44
Young calf housing 48
Young heifer housing 43
Horses 51
Poultry 52
Rabbits 56
Sheep 57
Swine 58
Veal calves 49

11. Controls 31
Alarms 34-36
Fan 29
Humidistats 32
Inlet baffle, vent doors 34
Inlets 30
Motors 59
Solid state 33
Thermostats 51
Timers 32
Variables cold weather rates 34

12. Ducts 16
Rigid pipe ducts 16
Suction ducts 16

14. INDEX

Glossary 95
Heat loss 4, 61
Balance 5
Production 60
Irrigation 7
Control 17
Location 7
Management 11
Porous ceilings 12
Size 4-5
Types 7
Insulation 20
Birds and rodents 22
Fire resistance 22
Heat loss, (appendix) 60
Moisture problems 21
Maintenance 37
Manure pit 15
Annexes 17
Ducts 16
Gases and odors 2-3
Ventilation 15
Moisture
Balance 5
Problems 21
Production 60
Negative pressure system 7
Air distribution 7
With recirculation 12
Neutral pressure system 14
Positive pressure systems 13
References 57
Troubleshooting 39-42

15. Ventilation
Emergency 19
Manure pit 15-19
Negative pressure 7
With recirculation 12
Neutral pressure 14
Positive pressure 13
Process 1
Rates
Systems 1
### Table 1. Properties, limits, and effects of nitrous oxide.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Odor intensity</th>
<th>Level of exposure</th>
<th>Threshold limit (oral)</th>
<th>Physiological effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ppm</td>
<td></td>
<td>ppm</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>None</td>
<td>0.00</td>
<td>30,000</td>
<td></td>
</tr>
<tr>
<td>Ammonia (NH₃)</td>
<td>5</td>
<td>15</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Hydrogen sulfide (H₂S)</td>
<td>30</td>
<td>100</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>Chlorine (Cl₂)</td>
<td>None</td>
<td>50</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Hydrogen cyanide (HCN)</td>
<td>None</td>
<td>50</td>
<td>500</td>
<td></td>
</tr>
</tbody>
</table>

Note: The values listed are based on the threshold limit values established by the American Conference of Governmental Industrial Hygienists.