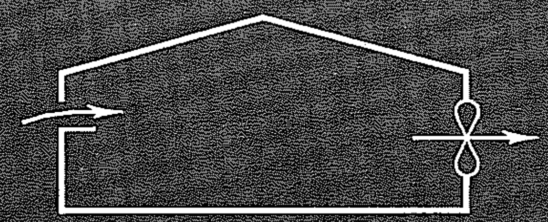
MWPS-32

Mechanical Ventilating Systems for Livestock Housing

First Edition, 1990



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R.E. Graves	Dairy design example.
A.J. Heber	Air quality; gases, odors, and dust.
B.J. Holmes	Troubleshooting tools; troubleshooting natural ventilation; dairy design example; glossary; significant contribution as committee chairman in development of book content.
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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 Process

Ventilation in livestock shelters is a process for controlling several environmental factors by diluting inside air with outside air. Ventilating systems affect:

- Air temperature.
- Moisture level.
- Moisture condensation on surfaces.
- Air temperature uniformity.
- Air speed across animals.
- Odor and gas concentrations.
- Airborne dust and disease organism level.
- Combustion fumes from unvented heaters.

As the ventilating system exchanges air, it brings in oxygen to sustain life. It removes and dilutes harmful dust and gases, undesirable odors, and airborne disease organisms and moisture.

Experience has shown that if a system moderates summer temperature extremes and controls winter moisture buildup, the ventilating rate is sufficient to provide for most needs. High odor levels from underfloor manure storage may require higher air exchange rates.

A basic ventilating process is shown in Fig 1. A properly operating ventilating system:

1. Brings fresh air into the building through planned openings.
2. Thoroughly mixes outside and inside air, picks up heat, moisture, and air contaminants, and lowers temperature, humidity, and contamination levels.
3. Exhausts moist, contaminated air from the building.

Failure to provide for any step of this process results in inadequate ventilation.

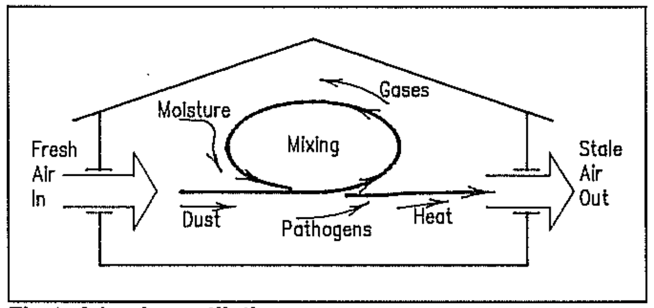


Fig 1. A basic ventilating process.

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 need additional heat and breeding stock may require summer cooling. MWPS-34, *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.

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 from 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 storages to warn workers of potentially dangerous situations. Post warning signs at building doors to prevent access while agitating manure.

Gases 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 (NH_3) is released from fresh manure and during anaerobic decomposition. 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% (160,000 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 condense and oxidize to nitrites or nitrates, which are poisonous if ingested.

Carbon dioxide (CO_2) is from animal respiration, manure decomposition, and unvented heaters. CO_2 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 unconciousness 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 unvented heaters adequately to prevent toxic concentrations. Well managed ventilation should prevent CO levels above 50 ppm.

Carbon monoxide is poisonous, and can cause abortions in gestating swine.

Hydrogen sulfide (H_2S) 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.

H_2S can rapidly destroy the sense of smell temporarily; lack of an H_2S odor is not an adequate warning. See the Potentially Lethal Situations section. As much as 8,000 ppm (0.8%) 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 (CH_4) 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 corners 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.

Table 1. Properties and effects of noxious gases.
This table is based on adult humans. The effects of two or more gases tend to be additive.

Gas	Odor	Odor threshold ppm	Maximum allowable concentrations, ppm	Concentration effects: Level ppm	Exposure period minutes	Physiological effects
		(a)	(b)	(c)	(d)	—
Carbon dioxide (CO_2)	None	—	5,000			Asphyxiant
				20,000	—	Safe
				30,000	—	Increased breathing
				40,000	—	Drowsiness, headaches
				60,000	30	Heavy, asphyxiating breathing
				300,000	30	Could be fatal
Ammonia (NH_3)	Sharp, pungent	5	50			Irritant
				400	—	Throat irritant
				700	—	Eye irritant
				1,700	—	Coughing and frothing
				3,000	30	Asphyxiating
				5,000	40	Could be fatal
Hydrogen sulfide (H_2S)	Rotten egg smell, nauseating	0.7	10			Poison
				100	Several hrs	Eye and nose irritant
				200	60	Headaches, dizziness
				500	30	Nausea, excitement insomnia
				1,000	—	Unconsciousness, death
Methane (CH_4)	None	—	1,000			Asphyxiant
				500,000	—	Headache, nontoxic
Carbon monoxide (CO)	None	—	50			Poison
				500	60	No effect
				1,000	60	Unpleasant, but not dangerous
				2,000	60	Dangerous
				4,000	60+	Fatal

[a] About the lowest concentration at which odor is detected.
[b] Maximum allowable concentration allowed by health agencies for workers in 8 hr periods.
[c] Parts of pure gas per million parts of atmospheric air. Divide by 10,000 for % by volume. Example: 20,000 ppm ÷ 10,000 = 2% by volume.
[d] The time until immediate reaction to the gas.

Potentially Lethal Situations

Ventilating system failure can cause death by asphyxiation from lack of oxygen and increased carbon dioxide, by heat prostration, by poisoning from 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 storages, on manure spreaders, etc. Teach workers of the risks and dangers involved. For automatically controlled systems, provide alarms to alert the manager in case of system malfunction.

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 unvented 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 of the year, ventilating rates that remove excess animal heat and moisture usually control odor. However, winter ventilating rates that just prevent moisture 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 buildings 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 submerged.
- Isolate animals with diarrhea from other animals.
- Include an air trap in drain lines to reduce backdraft of manure gases.
- Dust carries odors, so wash pen partitions, walls, ceilings, and floors regularly. Cover and adjust feeders to minimize feed spillage.
- Avoid storing manure in the building for long periods. Shorter periods lower odor levels. Little odor is produced in the first 3 days or so, but there is a peak in ammonia production at 3 days and again at 21 days. Frequent manure removal helps maintain low odor levels.
- Install heat exchangers, solar collectors, or other air tempering methods to save heat and allow higher ventilating rates for odor control while maintaining warm temperatures.

Fuel burning heaters must be vented to the outside with a U.L. 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 flue, so exhaust fans do not draw combustion products down the flue 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 environments. Workers' symptoms include shortness of breath, coughing, chest tightness, wheezing, and stuffy noses. Small fecal 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 dangerous 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 exchange needed to remove moisture in winter and excess heat in summer.

Farm 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. Air and surface temperatures, relative humidity, air velocity, and solar radiation are important factors of animal heat loss. These factors combine into an effective temperature. For example, increasing air velocity past a pig from 0 to 90 ft/min can decrease the effective temperature about 13 F. This effect is the wind chill factor.

How heat is lost is important. Animals lose heat by conduction, thermal radiation, convection, and evaporation. Conduction transfers 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 convection are **sensible** heat losses; evaporation is **latent** heat loss.

As air temperature increases, an animal cannot lose as much sensible heat, so it pants and sweats, Fig 2. As the temperature increases, even more moisture is produced. As relative humidity rises, an animal loses less heat by evaporation. If temperature and relative humidity are both high, the animal becomes heat stressed. See Table 25 for animal heat and moisture production rates.

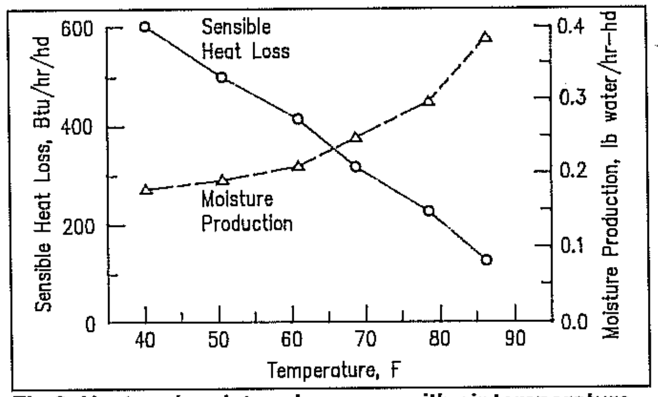


Fig 2. Heat and moisture loss vary with air temperature.
Typical sensible heat loss and moisture loss of a 175 lb pig.

Moisture Balance

Water and water vapor enter the environment from respiration, spilled water, evaporation from surfaces, 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, relatively dry air into a building. The air is warmed by heat from animals, electrical equipment, and supplemental 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. Ventilating air picks up moisture and removes it from the building. These properties are shown schematically in Figs 3 and 4.

Ventilate 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 heaters has to equal heat **lost** through building walls, ceiling/roofs, and ventilation. If heat loss exceeds animal heat production, provide supplemental heat. If heat production exceeds heat loss, increase the ventilating rate or use other cooling methods.

When ventilating air entering a building is cooler than inside air, it removes heat from the building. Estimate the rate (Btu/hr) of heat removed by ventilating air with Eq 1.

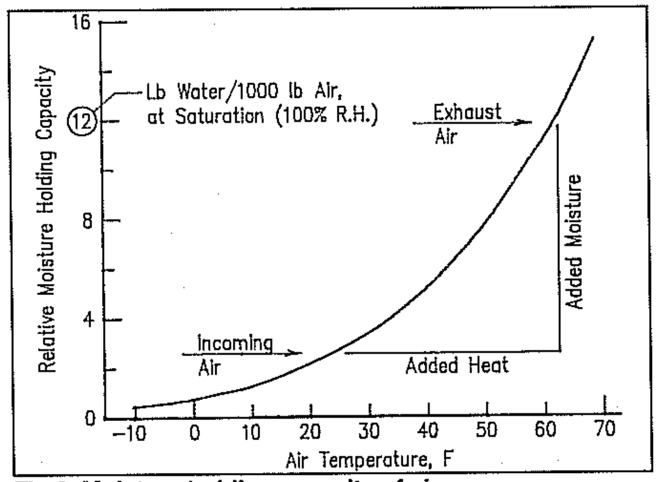


Fig 3. Moisture holding capacity of air.

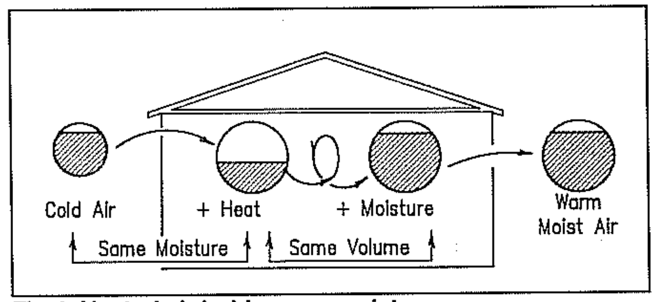


Fig 4. Heated air holds more moisture.
Air expands as it is heated and can absorb more moisture.

$$HVENT = cfm \times 1.1 \times (TIN - TOUT) \quad \textbf{Eq 1.}$$

HVENT = Heat removed by ventilation, Btu/hr
cfm = Ventilating rate, cfm (ft^3/min)
1.1 = Conversion factor, a constant, Btu-min/hr-ft^3-F
TIN = Indoor temperature, F
TOUT = 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.

cfm = 1,000 cfm
TIN = 70 F
TOUT = 20 F

$$HVENT = 1{,}000 \times 1.1 \times (70 - 20) = 55{,}000 \text{ Btu/hr}$$

How Much Air

Airflow requirements vary with animal size and outside environmental conditions. Ideally, ventilating air must vary from just enough air to maintain air quality during very cold weather, up to a maximum 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.

Example 2:

Determine the required cold, mild, and hot weather ventilating rates for a 1,200 lb dairy cow.

Solution:

From Table 2, the recommended ventilating rates for a 1,000 lb cow are:
- Cold weather = 36 cfm.
- Mild weather = 120 cfm.
- Hot weather = 335 cfm.

Required ventilating rates for a 1,200 lb cow are:
- Cold weather = (36 cfm/1,000 lb) x 1,200 lb = 43 cfm.
- Mild weather = (120 cfm/1,000 lb) x 1,200 lb = 144 cfm.
- Hot weather = (335 cfm/1,000 lb) x 1,200 lb = 402 cfm.

Provide a cold weather fan rated at 43 cfm/cow, a mild weather fan to add about 100 cfm/cow, and hot weather fans to provide another 258 cfm/cow.

Ventilating rates that are based on building air changes/hour neglect variation in animal heat and moisture production for different housing densities. Base ventilating rates on animal numbers or weight to eliminate animal density as a factor in ventilating system performance. For example, 10,000 hens in cages need a different ventilating rate than turkeys on floor litter in the same building.

Table 2. Recommended mechanical ventilating rates.
The rate for each season is the **total capacity needed.** For sow and litter: 20 cfm/unit (cold weather) + 60 cfm/unit = 80 cfm/unit (mild); add 420 cfm/unit for 500 cfm/unit total hot weather rate.

Animal	Weight	Unit	Cold weather rate[a]	Mild weather rate	Hot weather rate[b]
	- lb -		------- cfm/unit -------		
Swine					
Sow and litter	400	hd	20	80	500
Prenursery pig	12-30	hd	2	10	25
Nursery pig	30-75	hd	3	15	35
Growing pig	75-150	hd	7	24	75
Finishing pig	150-220	hd	10	35	120
Gestating sow	325	hd	12	40	150
Boar/Breeding sow	400	hd	14	50	300
Beef					
0-2 mo		hd	15	50	100
2-12 mo		hd	20	60	130
12-24 mo		hd	30	80	180
Mature cow		1,000 lb	36	120	335
Veal calf		100 lb	10	20	50
Dairy					
0-2		hd	15	50	100
2-12 mo		hd	20	60	130
12-24 mo		hd	30	80	180
Mature cow		1,000 lb	36	120	335[c]
Horse, controlled-environment barn		1,000 lb	25	100	335
Poultry					
Broiler					
0-7 day		hd	0.04	0.2	0.4
over 7 day		lb	0.1	0.5	1.0
Layers		lb	0.1	0.5	1-1.5
Turkeys					
Poults		hd	0.2	0.7	1-4
Growers		lb	0.08	0.35	0.8
Breeders	20-30	lb	0.05	0.15	0.5
Rabbits		lb	0.1	0.5	1.0
Sheep, controlled-environment barn		1,000 lb	25	100	335

[a]Where unvented heaters are used, provide at least an additional 2½ cfm continuous ventilating capacity per 1,000 Btu/hr of heater capacity.
[b]If mechanical, earth tempered, or wet-skin cooling is provided for mature animals, the hot weather rate may be reduced. See MWPS-34, *Heating, Cooling, and Tempering Air for Livestock Housing,* for design information about heating and cooling systems.
[c]400 cfm/1,000 lb cow is recommended in the mid-Atlantic and southeast states.

The hot weather rates in Table 2 maintain room air temperature within a few degrees of the outdoors and provide high air velocities past the animals. Room air temperature can be lower than outdoor temperature due to evaporative cooling and thermal lag of building materials.

3. MECHANICAL VENTILATING SYSTEMS

There are many types of mechanical ventilating systems. Regardless of the type, recommended ventilating rates are the same, Table 2. This handbook discusses three common systems.
- Negative pressure systems have exhaust fans that blow air out of the building creating a slight negative pressure (vacuum) to draw air into the building through designed inlets.
- Positive pressure systems have fans that blow air into the building creating a slight positive pressure. Air exits the building through exhaust openings. Air distribution ducts or fan baffles are used to reduce drafts and provide fresh air uniformly throughout the building.
- Neutral pressure systems have features of both negative and positive pressure systems. Fans blow air both into and out of the building.

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 ft/min) independent of airflow rate (number of fans operating). Adjust air inlets manually or automatically.

For inlets to perform properly, seal doors, windows, and unplanned openings so fans develop the desired negative pressure. Fresh air entering unwanted openings reduces the amount of 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 baffle 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 sheets, 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 18" from the opening.

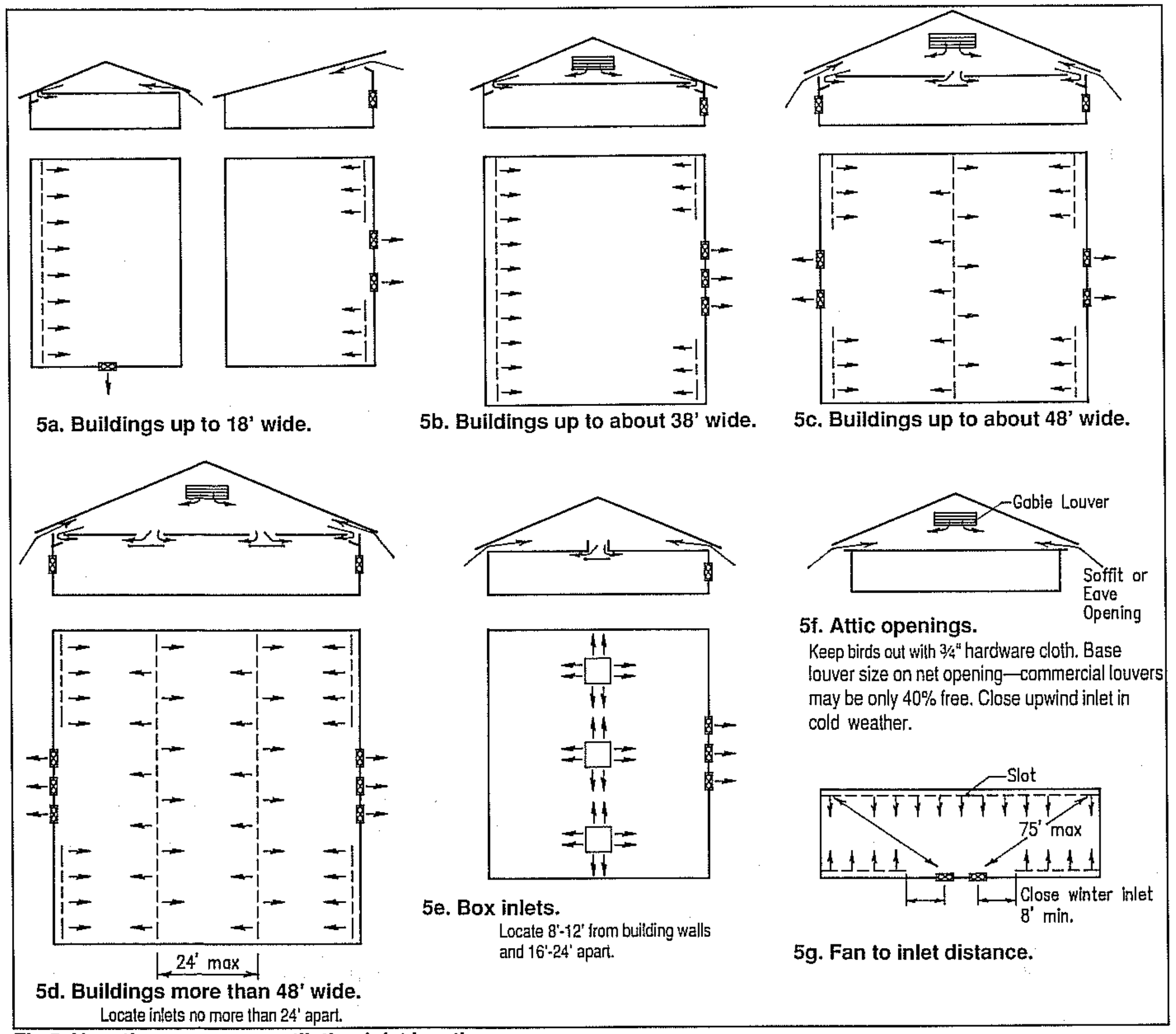
Negative pressure, continuous slot inlets are difficult to control at low airflow rates. Uniformly spaced intermittent inlets can improve distribution at low airflows. Low air velocities can create poor distribution and drafts that are harmful to young animals. An air tempering system can supplement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

Inlet location

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.** Options include: 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 (spaced rather than continuous).** Individual inlets, (e.g. one per farrowing 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 barn).
- 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 cfm.

Fig 5 illustrates different slot inlet locations and air distribution.



5a. Buildings up to 18' wide.

5b. Buildings up to about 38' wide.

5c. Buildings up to about 48' wide.

5d. Buildings more than 48' wide.
Locate inlets no more than 24' apart.

5e. Box inlets.
Locate 8'-12' from building walls and 16'-24' apart.

5f. Attic openings.
Keep birds out with ¾" hardware cloth. Base louver size on net opening—commercial louvers may be only 40% free. Close upwind inlet in cold weather.

5g. Fan to inlet distance.

Fig 5. Negative pressure ventilation inlet locations.
Drawing winter ventilating air through the attic allows some tempering of incoming air.

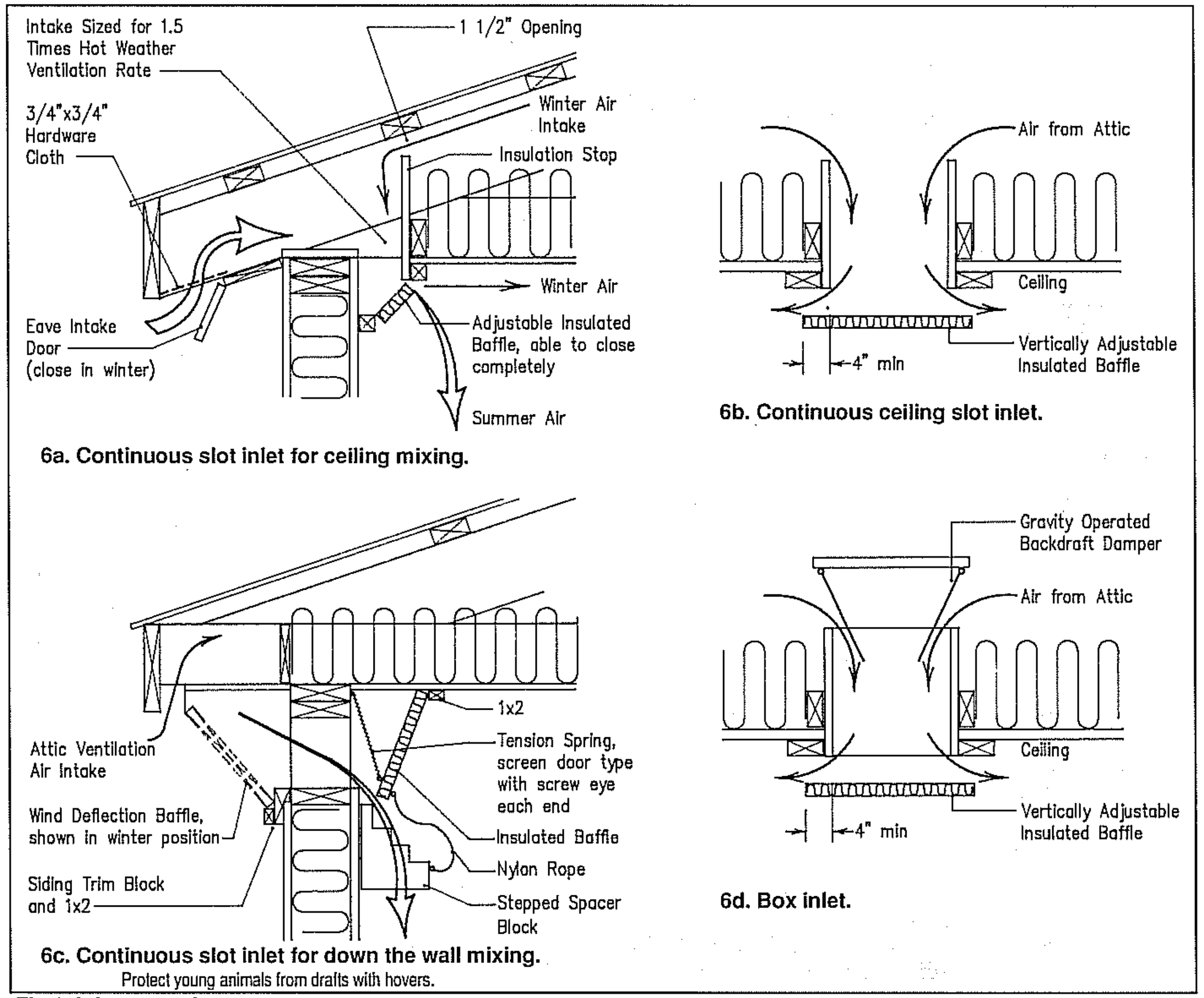
Box inlets are easier to install than continuous slots during remodeling. Space box inlets uniformly in the room. Space openings 8'-12' from building walls and 16'-24' apart, Fig 5e. If commercial units, check with the manufacturer for recommended locations. Extend the baffle 4" beyond all sides of the 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 inlet 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" wide slot at 0.04" static pressure is 50 cfm/ft. The airflow rate through a 4" 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" 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.



6a. Continuous slot inlet for ceiling mixing.

6b. Continuous ceiling slot inlet.

6c. Continuous slot inlet for down the wall mixing.
Protect young animals from drafts with hovers.

6d. Box inlet.

Fig 6. Inlet examples.

Make the total air inlet area proportional to total fan capacity. Size across-the-ceiling inlets (Fig 6a, b, or d) for 800 to 1,000 fpm velocity as air leaves the baffle to get good mixing of cold and warm air. If air velocity is less than about 800 fpm, cold air settles too rapidly and can chill animals. Air velocities greater than about 1,000 fpm increase static pressure and decrease fan capacity and efficiency. For down-the-wall inlets, Fig 6c, use 500 fpm in cold weather and 800-1,000 fpm 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 ft^2 (144 in^2) of area for each 540 cfm 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 fpm at 0.04" static pressure. Inlets less than ⅛" 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 3:

Size negative pressure ventilation air inlets for a 32'x84', 300-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 × 2) = (84' × 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').

2. 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 × Number of animals) ÷ (Slot length, ft)

Cold weather: From Table 2, the ventilating rate is 10 cfm/pig. Slot length = 152'.

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

From Table 3, a ½" slot width is needed for 900 fpm velocity.

Mild weather: From Table 2, the ventilating rate is 35 cfm/pig. Slot length = 168'.

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

From Table 3, a 1½" slot width is needed.

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

(120 cfm/pig × 300 pigs) ÷ 168' = 214.3 cfm/ft

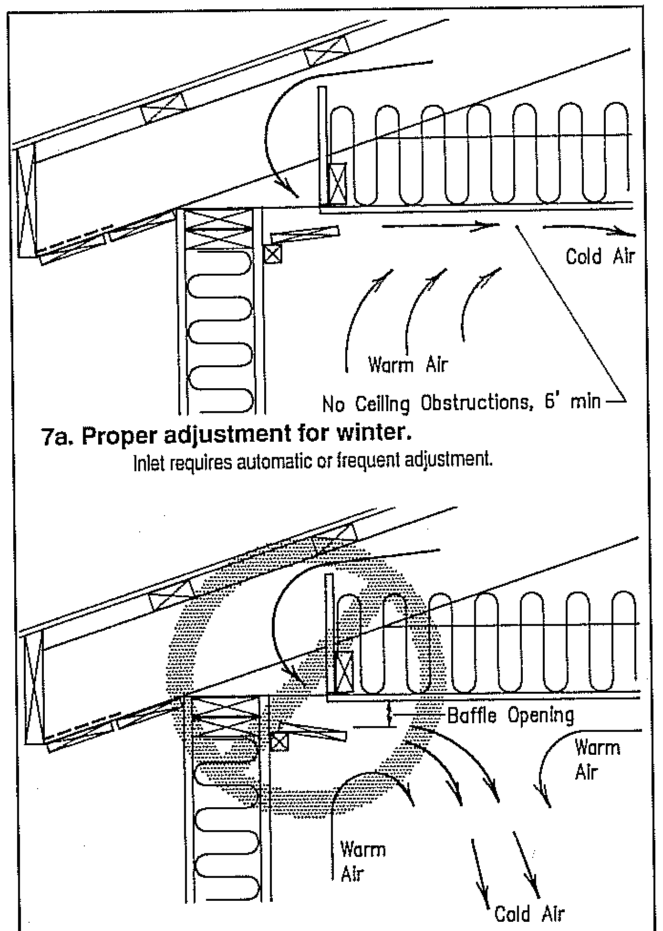
From Table 3, a 5" slot width is needed.

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.

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.



7a. Proper adjustment for winter.
Inlet requires automatic or frequent adjustment.

7b. Improper—baffle is open too far.

Fig 7. Adjusting winter inlets.
For across-the-ceiling inlets.

Table 3. Slot inlet widths.
Slot width for 540 fpm average air velocity from slot inlets. Slot widths less than ⅛" are too small to control accurately and are not recommended. Instead, close every other inlet section and adjust remaining slot openings.

Slot width, in.	Airflow cfm/ft of slot length
⅛	5.6
¼	11.2
½	22.5
¾	33.8
1	45
1½	67.5
2	90
2½	112
3	135
3½	157
4	180
4½	202
5	225
5½	247
6	270
7	315
8	360
9	405
10	450
11	495
12	540

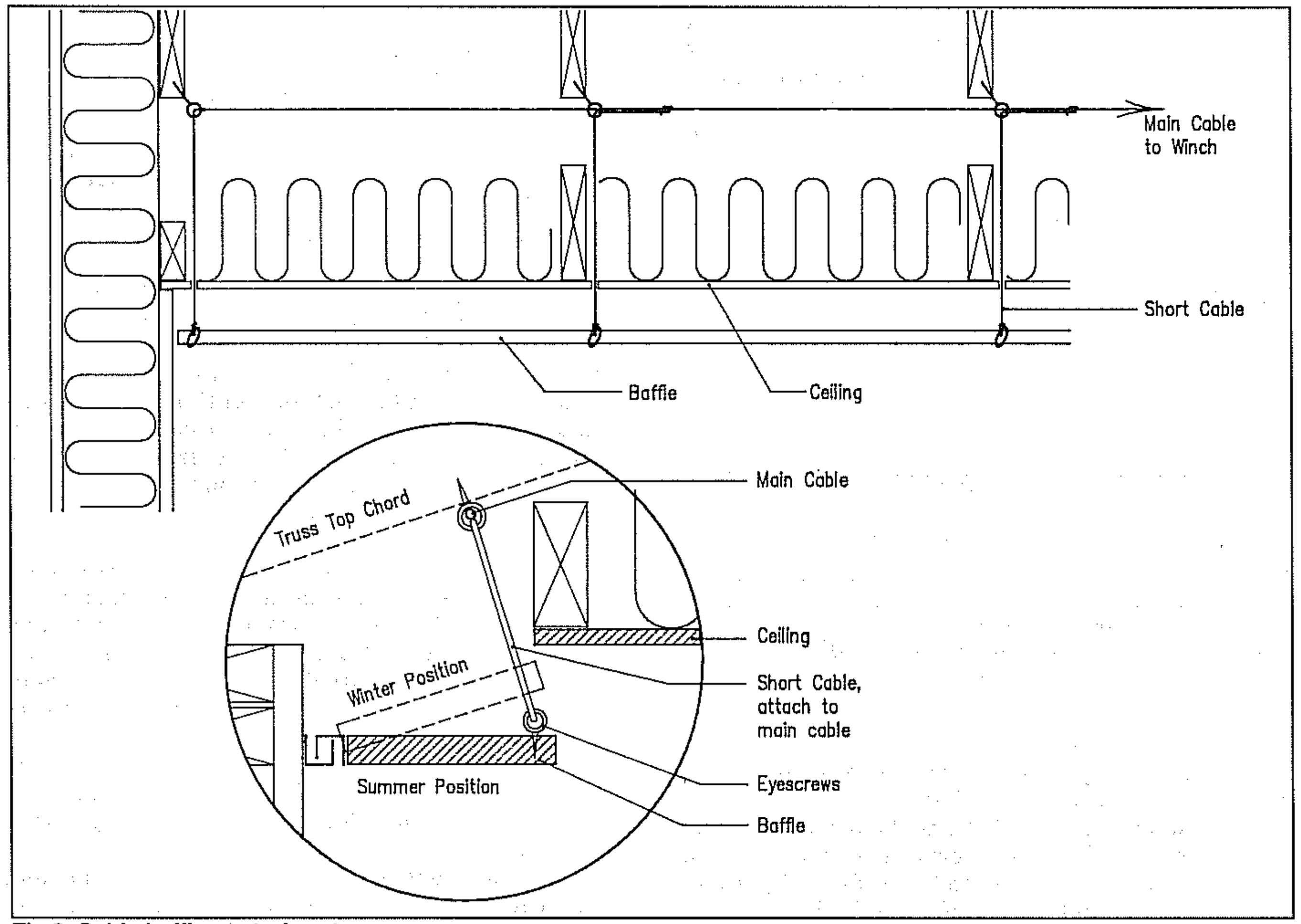


Fig 8. Cable baffle control system.
Select size and location of eyescrews to maintain minimum winter slot opening.

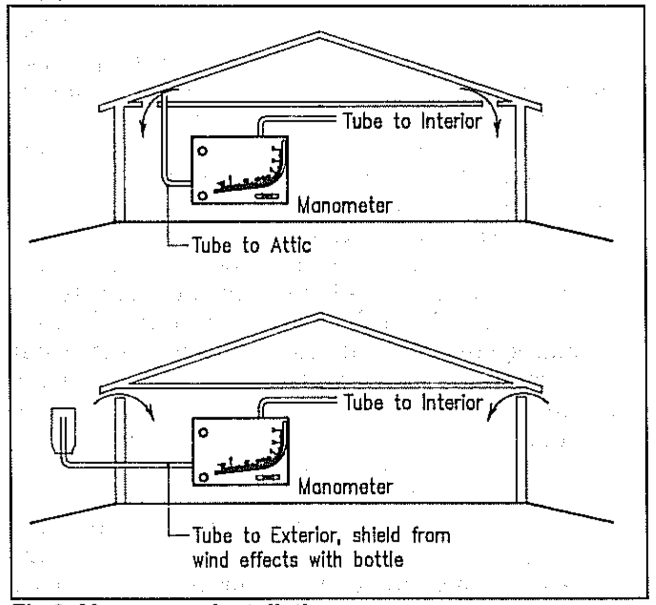


Fig 9. Manometer installation.
Manometers measure static pressure difference across an inlet. A slot width sized for 900fpm average air velocity creates a static pressure across the inlet of about 0.04". Inlet adjustment is most critical in cold weather, so install the manometer to measure static pressure for winter airflow paths.

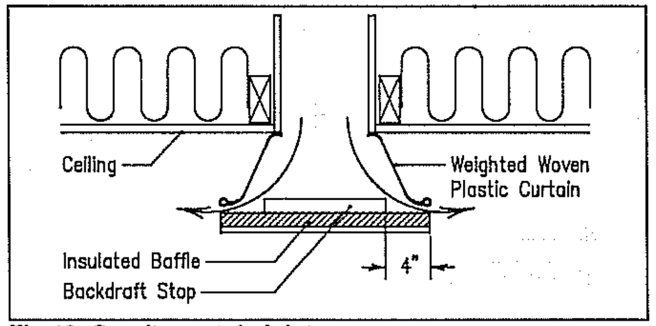


Fig 10. Gravity curtain inlet.
Use only for larger animals. Do not use in buildings with low cold weather airflow rates (e.g. swine farrowing and nursery buildings)

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 (ft^2) 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 an 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 intake doors on both sides of the building. Screen attic openings with ¾" hardware cloth to keep birds out. Smaller mesh screen may plug with dust and restrict airflow.

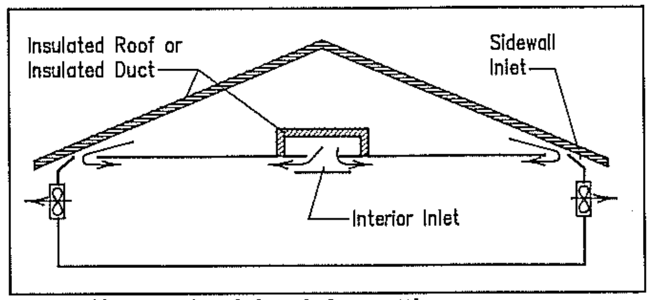


Fig 11. Hot weather inlet air from attic.
If summer air enters through the attic, reduce solar preheating in the attic—insulate the roof or bring air in through an insulated duct.

Porous ceilings inlet

Porous ceiling materials can replace slot or area inlets. One type has 2 or 3 layers of fiberglass or mineral wool insulation batts without a vapor retarder and tightly fitted in alternating directions. The ceiling material is supported by perforated plywood or wire netting and woven nylon cloth, Fig 12.

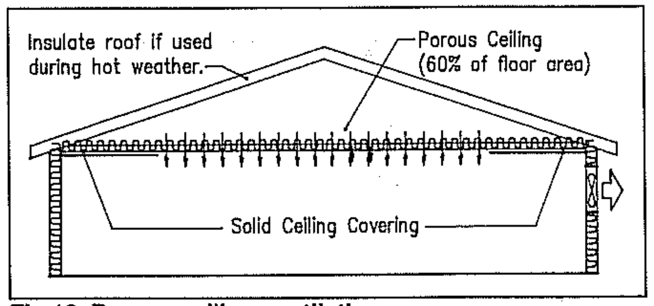


Fig 12. Porous ceiling ventilation.

A porous ceiling also filters dust and bacteria from incoming air and absorbs sound better than conventional construction. One disadvantage is building surfaces cannot be completely cleaned between groups for all-in/all-out operations.

Provide at least one continuous exhaust fan. Size it for minimum winter ventilation for moisture removal. Inlet air velocity is about 20 ft/min with a static pressure less than 0.01". Make the porous ceiling area at least 60% of the floor area. Make ceilings solid within 8' of an exhaust fan. Although commercial systems are available and have shown good performance, criteria for design and operation of ventilating systems with porous ceilings are still not well known.

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 Tempering 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.

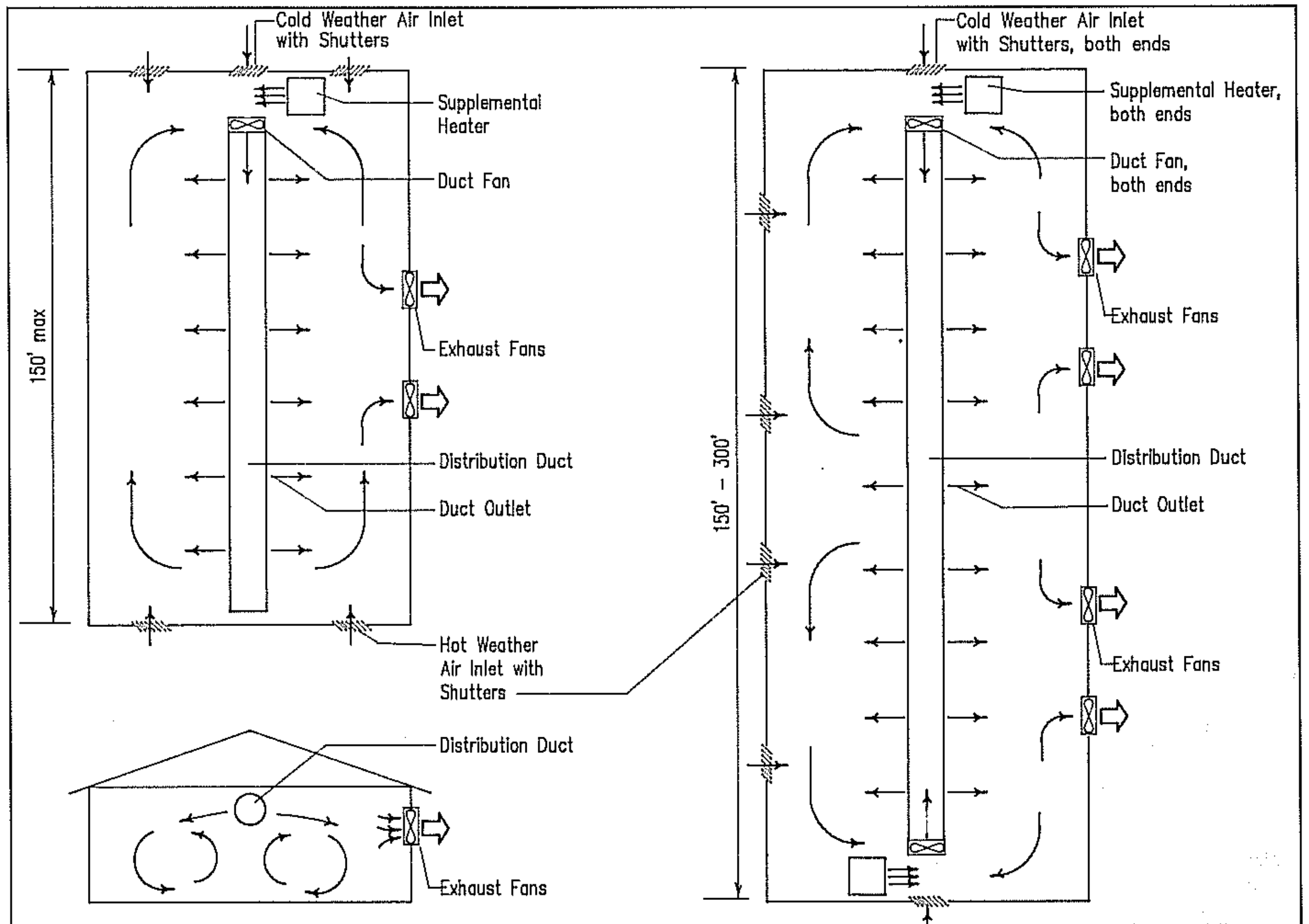
Exhaust fans control airflow through the inlet. Control shutters with a thermostat. When shutters are closed, fresh air enters from the attic or building cracks, Fig 14. With closed shutters and with exhaust fan off, only room air circulates through the distribution duct and no air exchange occurs. Shutter freeze-up 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 then mixes with fresh air to maintain duct air above the dewpoint temperature. Size the duct for 600 fpm duct air velocity, Table 4. However, a duct fan this 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 below 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. Improve air exchange and control moisture with a continuously operating exhaust fan. With an intermittent exhaust fan, size the duct and duct fan for at least twice the capacity of the exhaust fan, but not more than required for mild weather ventilation.

Install additional inlets and exhaust fans for hot weather ventilation. Provide separate summer exhaust ventilation. Put hot weather inlets (usually



13a. For buildings under 150' long.

13b. For buildings 150'-300' long.
Install cold weather inlets at both ends of the duct.

Fig 13. Negative pressure with recirculation.

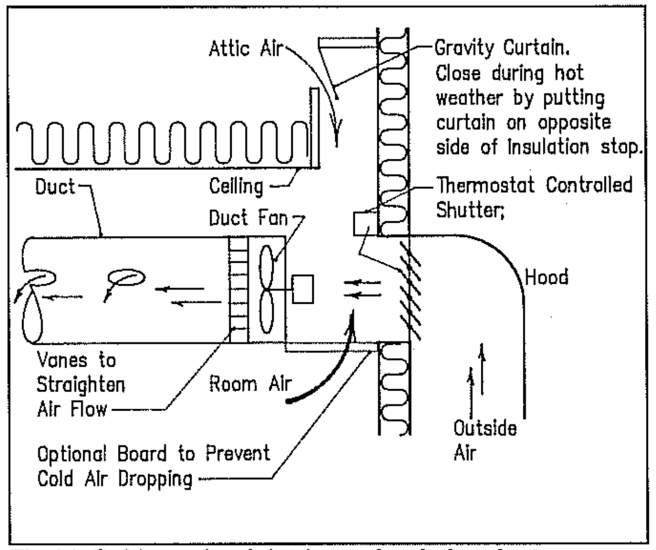


Fig 14. Cold weather inlet for recirculation duct.
With a continuous cold weather fan, provide a curtain inlet from the attic so when the shutter closes, air is drawn from the attic. With no attic inlet, remove the top one or two shutter leaves for some fresh air exchange. With an intermittent cold weather fan, an attic inlet is usually not provided; when the shutter is closed, no fresh air enters.

motorized shutters) opposite the exhaust fans. Locate young animals out of drafts from cold incoming air.

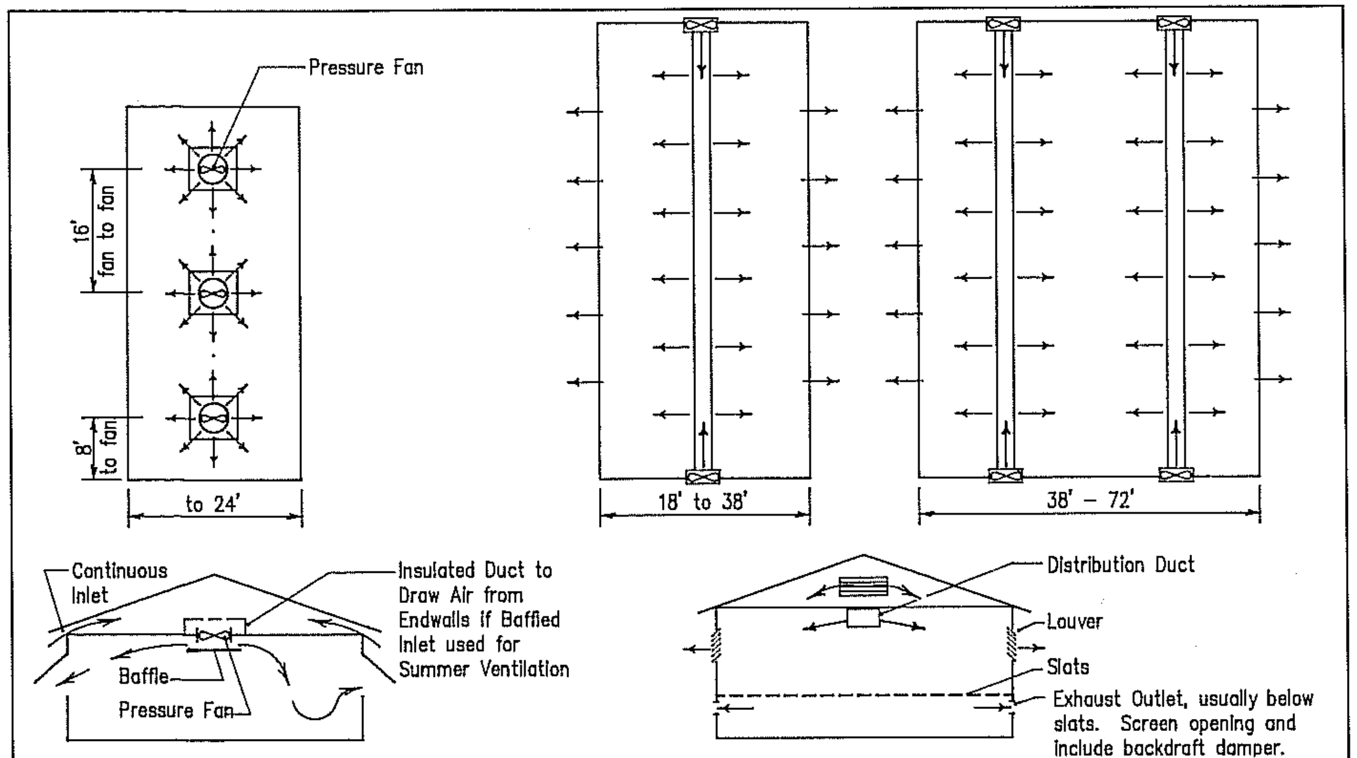
Supplemental heat is needed with smaller animals or low animal densities. Locate unit heaters at the duct inlet. Duct other heat sources (heat exchangers, earth tubes, solar, furnaces, etc.) so they exhaust at the duct fan intake, Fig 13.

Some problems can result from this system:

- Dust collects in the duct and can harbor disease organisms and molds. Clean or replace ducts between animal groups to reduce disease transfer. Consider cleaning ease when building homemade ducts.
- Intake shutters can freeze.
- Increased air movement can create drafts.

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.



15a. Area inlets with fan.

15b. Distribution duct and fan.
Space ducts up to 24' apart for larger buildings.

Fig 15. Positive pressure systems.

Table 4. Ventilating duct and exhaust outlet sizes.
Based on an air velocity of 600 fpm. If louvers or screens are used, increase opening size proportionally.

Airflow rate, cfm	Area in²	Minimum duct size, Inside dimensions: WxH, in.	Minimum duct size, Inside dimensions: WxH, in.	Minimum duct size: Dia., in.
200	48	6x8	4x12	8
250	60	8x8	6x10	9
300	72	8x9	6x12	10
350	84	9x10	6x14	11
400	96	10x10	6x16	12
500	120	10x12	6x20	13
600	144	12x12	6x24	14
700	168	12x14	8x22	15
800	192	14x14	8x24	16
900	216	14x16	8x28	17
1,000	240	16x16	8x30	18
1,250	300	18x18	10x30	20
1,500	360	18x20	12x30	22
2,000	480	20x24	14x36	25
2,500	600	24x26	16x38	28
3,000	720	24x30	18x40	31
3,500	840	28x32	18x48	33
4,000	960	30x32	20x48	35
5,000	1,200	34x36	24x50	39
6,000	1,440	36x40	24x60	43
7,000	1,680	40x42	28x60	47
8,000	1,920	44x44	32x60	50
9,000	2,160	46x48	36x60	53
10,000	2,400	48x50	40x60	56
12,000	2,880	54x54	48x60	61
15,000	3,600	60x60	50x72	68

Size 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 160 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 opening to reduce inlet area proportional to airflow rate.

Ventilating air is exhausted from the building through all open doors, windows, and other openings. Size the building's exhaust area for 160 in²/1,000 cfm (1 ft²/600 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.

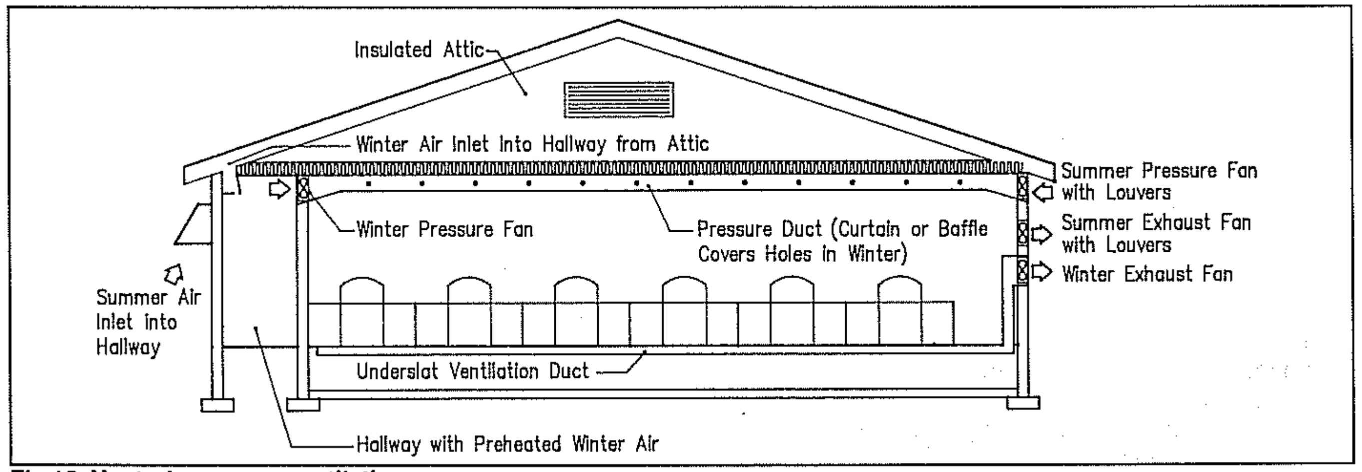


Fig 16. Neutral pressure ventilation.

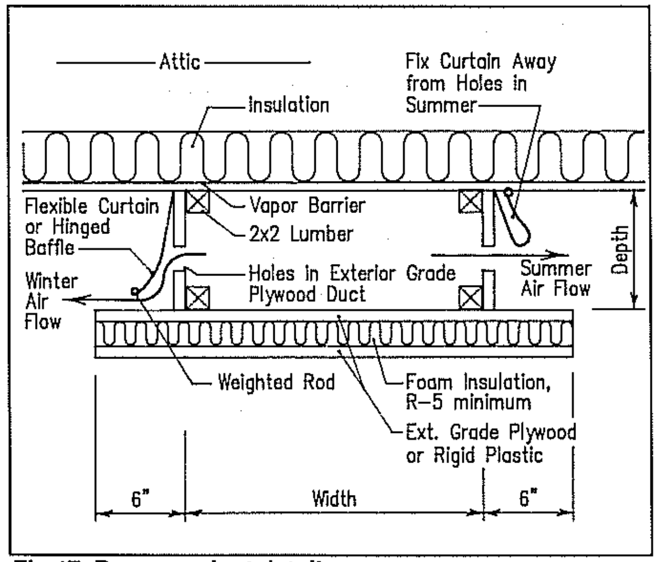


Fig 17. Pressure duct detail.

In winter, an adjustable baffle forces incoming air into a thin airstream with enough velocity for adequate mixing. In summer, move the baffle 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 at 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 fans for the extra capacity needed for hot weather. A louver over the summer pressure fan should close when the fan stops. This louver 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 ⅓ 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 slat support beams or pit duct and the manure surface. Large fans and ducts (24" diameter and larger) may require more clearance. Consider installing a pit level indicator.

Manure pit conditions are very corrosive. Totally enclosed fans constructed from corrosion resistant materials are required—stainless steel or plastic. Use high static pressure fans (0.2"-0.6") to draw air through pit ducts, especially rigid plastic pipe ducts. Normal ventilation fans operate at less than ⅛" 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 ½" diameter holes in the bottom of the duct at several locations to drain moisture. Cap the end opposite 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 5) based on 800-1,000 cfm for each square foot of duct cross-section 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/hole.
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.

Section	1	2	3	4
% of length	37	26	20	17

Table 5. Suggested air flow per tube.

Tube diameter, in.	Air flow, cfm
6	190-210
8	350-400
10	550-600
12	750-850
15	1,000-1,300
18	1,300-1,800
24	2,500-3,200

Table 6. Air flow per hole.

Hole diameter, in.	Cfm per hole
1	2.7
1¼	4.2
1½	6.1
2	11
2½	17
3	24

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 × 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 .06". Add this to the static pressure in the tube (0.10" to 0.16" 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 1¼" holes, supplying 4.2 cfm each, Table 6.
3. Divide 800 cfm by 4.2 cfm per hole = 190 holes. That is a lot of drilling, so select a larger hole size. A 2" hole will require 800 ÷ 11 = 72.73 holes. Use 72 holes. Each section requires 72 ÷ 4 = 18 holes per section.
4. Divide the duct into four sections. Put the same number of holes in each of the four lengths.
5. The table below summarizes the duct hole data.

50' duct = 600" length.
37% × 600 = 222" length in section 1.

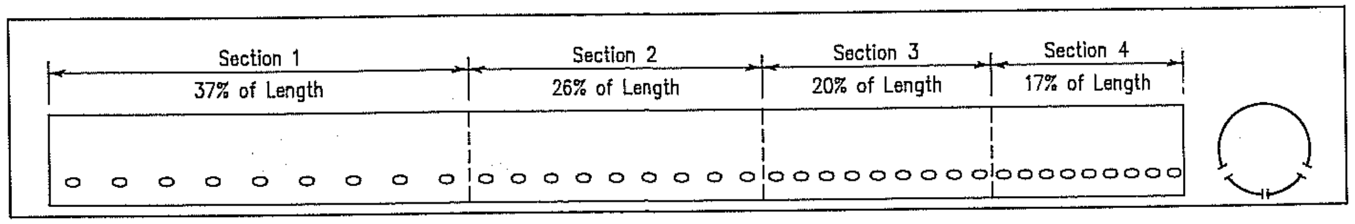


Fig 18. Pit ventilation tube hole layout.

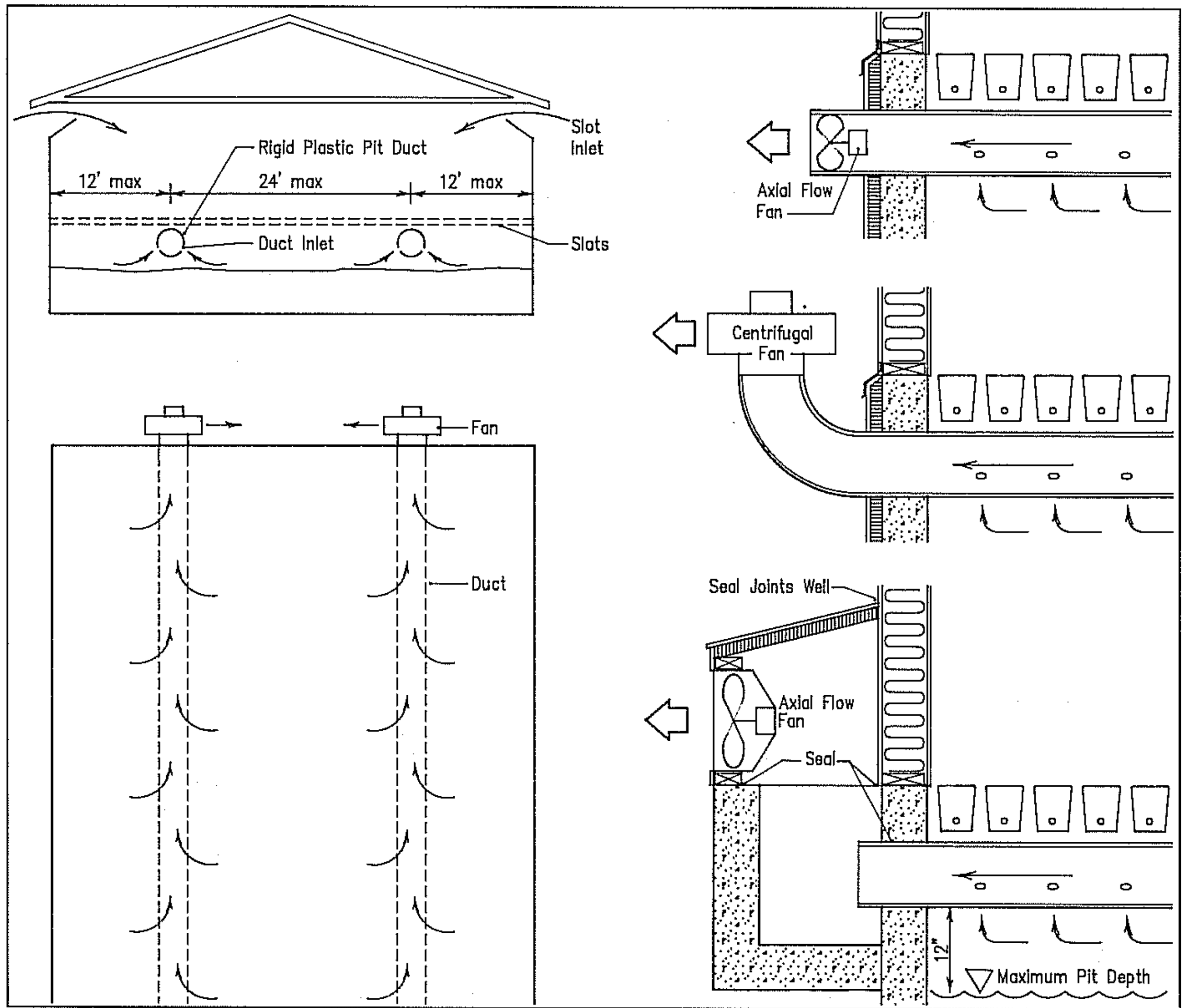


Fig 19. Rigid plastic tube pit duct.
Use non-corrosive material for fan blades and housing and for ducts.

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

   222" ÷ 18 holes = 12⅓" spacing of single holes.
   222" ÷ 9 pairs of holes = 24⅔" spacing between pairs.

7. Drill pairs of 2" diameter holes and an occasional ½" 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.

Section	1	2	3	4
% length	37	26	20	17
600 × %	222"	156"	120"	102"
18 holes at	12⅓"	8⅔"	6⅔"	5⅔"
9 pairs at	24⅔"	17⅓"	13⅓"	11⅓"

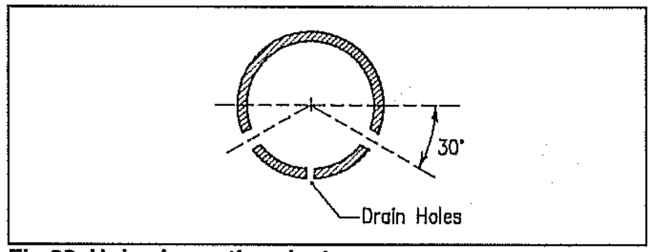


Fig 20. Holes in suction-ducts.
Locate inlet holes on one or both sides at a 30° angle from the centerline. Condensed water or accidental liquid manure in the duct drains to the pit.

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 15%-20% open area, because the space below slats creates a duct effect. Air distribution is poor with an

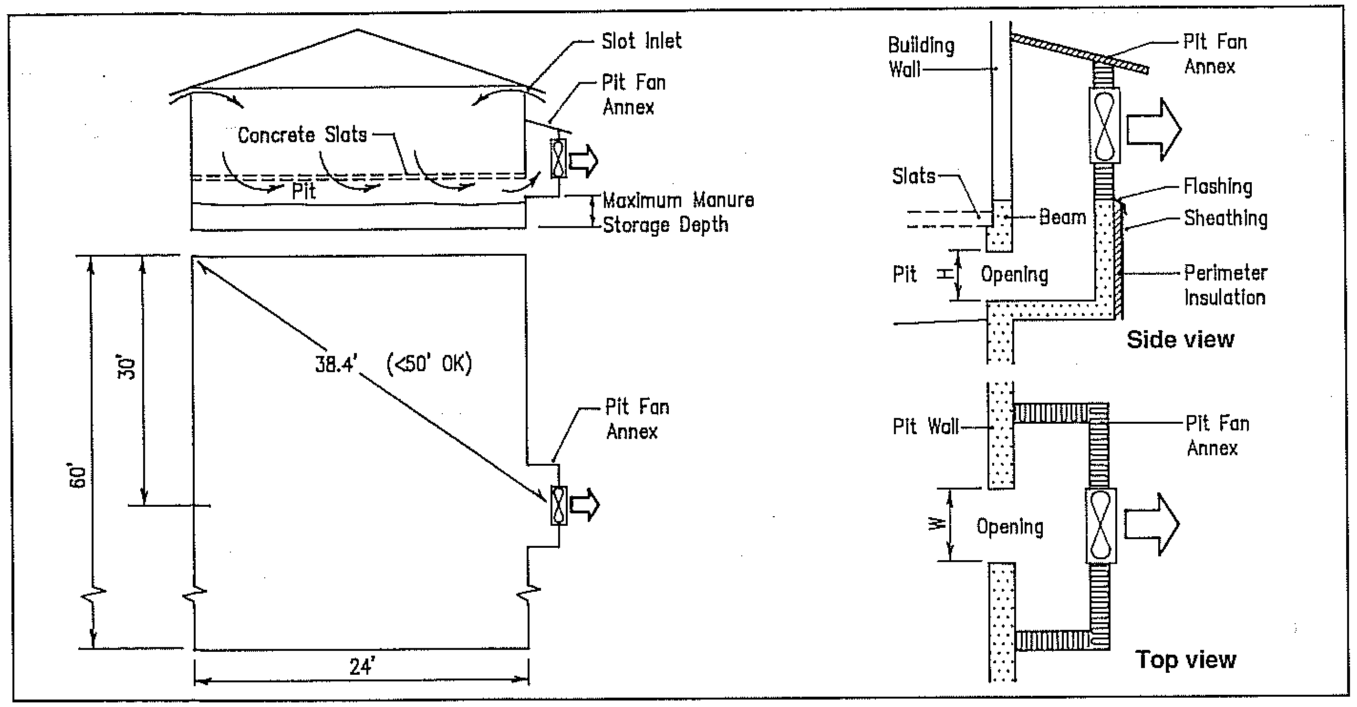


Fig 21. Exhaust pit fan annex.
See Table 7 for spanning dimensions into the annex. Tightly seal the annex to prevent air leaks.

Table 7. Minimum opening through pit fan annex.
Based on 800 fpm air velocity through the opening.

Pit fan capacity cfm	Opening area in^2	Inside dimensions WxH, in.	Inside dimensions Dia., in.
400	72	4x18	10
500	90	4x23	11
600	108	4x27	12
700	126	4x32	13
800	144	4x36	14
900	162	6x27	15
1,000	180	6x30	16
1,100	198	6x33	16
1,200	216	6x36	17
1,300	234	6x39	18
1,400	252	6x42	18
1,500	270	8x34	19
1,600	288	8x36	20
1,800	324	8x42	21
2,000	360	12x30	22
2,500	450	12x38	24
3,000	540	12x45	27
3,500	630	18x36	29
4,000	720	18x40	31
5,000	900	24x38	34

annex under wire or metal flooring with 50%-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 farther than 50' from an annex.

To prevent "short-circuiting" between fans, put each pit fan in its own annex. Shutters are not necessary on fans that run continuously.

Build pit divider walls under room partitions to prevent air short circuiting from one room to another. Pit dividers must be strong enough to support the full depth of manure from each side. Provide for agitating and pumping each pit section.

Example 5:

Design annex pit ventilation for a 24'x60', 400 head, totally slotted floor pig-nursery, Fig 21.

Solution:

1. From Table 2, the cold weather rate for nursery pigs is 3 cfm/pig. Required pit ventilation is:

   3 cfm/pig × 400 nursery pigs = 1,200 cfm.

2. With one annex in the center of the sidewall, the maximum air-pull distance in the pit is:

   $\sqrt{(60' \div 2)^2 + (24')^2} = 38.4'$

   which is less than the 50' limit.
3. From Table 7, a 216 in^2 pit opening into the annex is required. Minimum size opening is 6"x36" rectangular or 17" circular.
4. Select a pit fan for 1,200 cfm at ⅛" static pressure.
5. Provide mild and hot weather ventilation with additional wall fans and inlets.

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 3,000 ppm. High CO_2 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 CO_2 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 sensible 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 decked 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 sidewall 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. MWPS-28, *Farm Buildings Wiring Handbook*, discusses alarms 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 2½ mph, each 1 ft^2 of opening provides about 200 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 sow farrowing room requires 1600 cfm; provide 8 ft^2 of opening on each sidewall (doors, windows, or vent doors).

Electromagnet-locked ventilating doors, which drop open when electrical power is cut off or the room temperature rises sharply, are available commercially. A simple cold weather emergency ventilation 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.

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 surface 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.

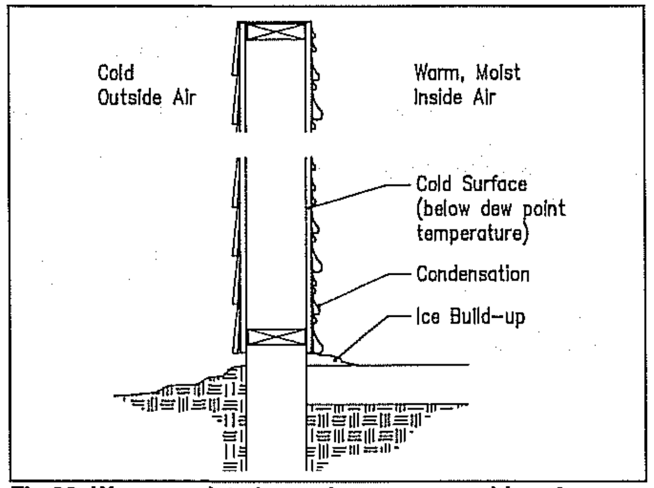


Fig 22. Warm, moist air condenses on a cold surface.

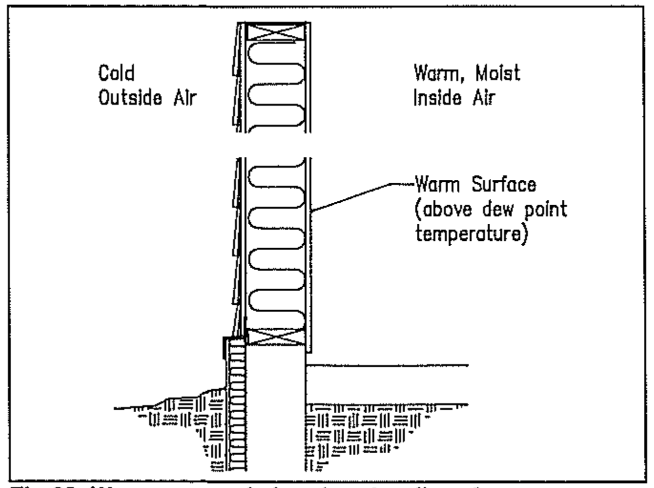


Fig 23. Warm, properly insulated wall surfaces.
The warmer the surface, the less likely it will have condensation.

Five common forms of insulation are:

- **Batt and 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 foamed-in-place insulation.**
- **Reflective materials.** Like aluminum foil, reflect most of the radiant heat that strikes it if 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 ¾"-4" thick non-reflective dead air space has a maximum R-value of about R=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 fan openings.

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 environment 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 free stall 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 requiring supplemental heat in a small area, such as brooders in an open-front building, are **not** classified as supplementally heated.

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

Table 8. Insulation values.
Adapted from *1989 ASHRAE Handbook of Fundamentals*. Values do not include surface conditions unless noted otherwise. All values are approximate.

Material	R-value Per inch (approximate) 1/k	R-value For thickness listed 1/C
Batt and blanket insulation		
Glass or mineral wool, fiberglass	2.75-3.67[a]	
Fill-type insulation		
Cellulose	3.13-3.70	
Glass or mineral wool	2.20-3.00	
Vermiculite	2.13-2.27	
Shavings or sawdust	2.22	
Hay or straw, 20"	1.50	30+
Rigid insulation		
Expanded polystyrene		
Extruded, plain	5.00	
Molded beads, 1 pcf	3.85	
Molded beads, 2 pcf	4.35	
Expanded rubber	4.55	
Expanded polyurethane, aged, unfaced	5.56-6.25	
Glass fiber	4.00	
Wood or cane fiberboard	2.50	
Polyisocyanurate	7.20[b]	
Foamed-in-place insulation		
Polyurethane	5.26-6.25	
Building materials		
Concrete, solid	0.08	
Concrete block, 3 hole, 8"		1.11
Lightweight aggregate, 8"		2.00
Lightweight, cores insulated		5.03
Brick, common		
80 pcf	0.31-0.45	
130 pcf	0.11-0.19	
Metal siding	0.00	
Hollow-backed		0.61
Insulated-backed, ⅜"		1.82
Softwoods		
Southern pine	0.89-1.00	
Douglas fir-larch	0.99-1.06	
Hem-fir, spruce-pine, fir	1.11-1.35	
Hardwoods		
Oak	0.8-0.89	
Birch	0.82-0.87	
Maple	0.84-0.94	
Ash	0.88-0.94	
Plywood, ⅜"	1.25	0.47
Plywood, ½"	1.25	0.62
Particleboard, medium density	1.06	
Hardboard, tempered, ¼"	1.00	0.25
Insulating sheathing, 25/32"		2.06
Gypsum or plasterboard, ½"		0.45
Wood siding, lapped, ½"x8"		0.81
Asphalt shingles		0.44
Wood shingles		0.94
Windows (includes surface conditions)		
Single glazed		0.91
With storm windows		2.00
Insulating glass, ¼" air space		
Double pane		1.69
Triple pane		2.56
Doors (exterior, includes surface conditions)		
Wood, solid core, 1¾"		3.03
Metal, urethane core, 1¾", thermal break		5.88
Metal, urethane core, 1¾", no thermal break		2.50
Air space (¾"-4")		
Non-reflective, Horizontal		0.90
Non-reflective, Vertical		1.25
Reflective, Horizontal		2.2
Reflective, Vertical		3.4
Air films		
Inside surface (air velocity 0 mph)		0.68
Outside surface (air velocity 15 mph)		0.17
Floor perimeter (per ft of exterior wall length)		
Concrete, no perimeter insulation		1.23
Concrete, with 2"x24" perimeter insulation		2.22

[a]Fiberglass R-value varies with batt thickness and manufacturer—check the label.
[b]Time aged value for board stock with gas-retarder quality aluminum foil facers on two major surfaces. A ¾" air space on each side is required.

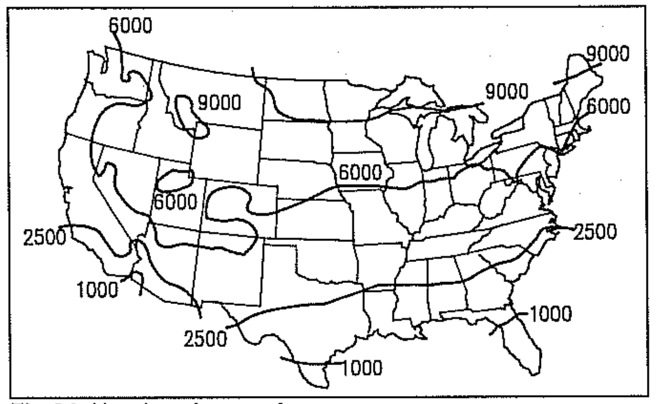


Fig 24. Heating degree days.
These values can vary considerably in mountainous areas. Check local records.

Table 9. Minimum insulation levels for animal buildings.
R-values are for building sections. In cold barns with mature animals, no insulation is needed in the walls or roof. In severe climates, insulation (R=5) in the roof helps control condensation and frosting and reduces summer heat load.

Winter degree days	Recommended minimum R-values: Modified environment Walls	Modified environment Roof	Supplementally heated Walls	Supplementally heated Ceiling
2,500 or less	6	14	14	22
2,501-6,000	12	14	14	25
6,001 or more	12	25	20	33

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 passes through board joints and condenses. Follow manufacturer's instructions for sealing board joints.

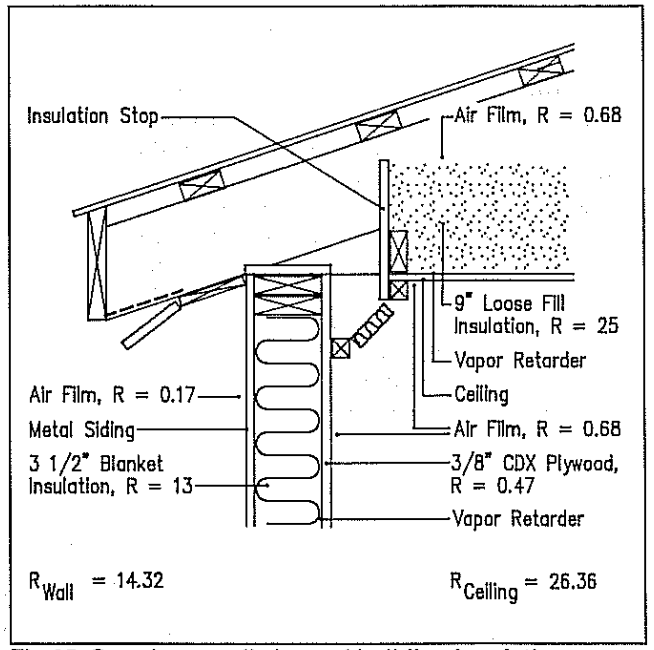


Fig 25. Supplementally heated building insulation.
For areas where winter degree days are less than 6,000. R-values of batt insulation can vary—check the label.

Vapor retarders are interrupted by joints, holes for electric boxes, windows, augers, nail holes, etc. Minimize interruptions by taping joints and sealing other interruptions to reduce moisture movement.

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:

- ½" thick cement plaster.
- ¼" thick sprayed-on magnesium oxychloride (60 lb/ft^3) or ½" of the lighter, foam material.
- Fire rated ½" 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, ⅜", resists physical and moisture damage but is not rodentproof. Seal holes and cracks in walls and ceilings to limit rodent access.

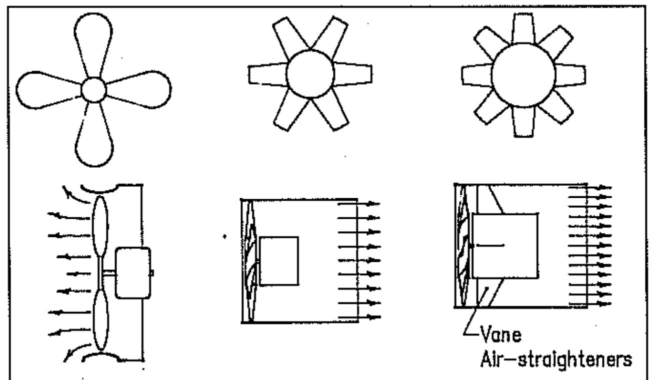
Screen eave vent openings with ¾" hardware cloth to exclude birds. You may need to knock ice off the screen regularly during prolonged cold periods.

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.



26a. Propeller. 26b. Tubeaxial. 26c. Vaneaxial.

Fig 26. Axial flow fan housing and blade type.

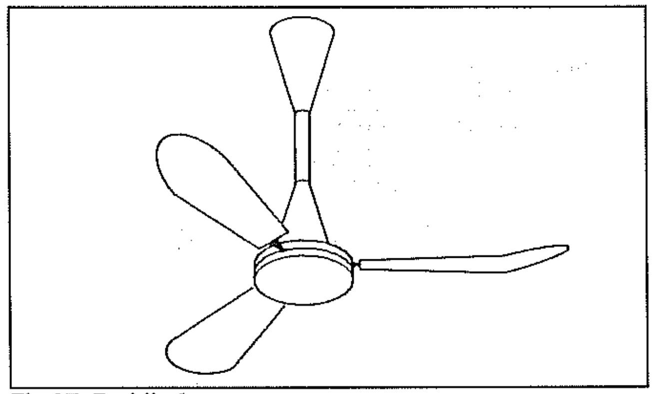


Fig 27. Paddle fan.

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 buildup 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. These 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 tube-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 tubeaxial fans except air straightening vanes reduce the circular motion of the air. Typical uses are grain drying, aeration, and sometimes pressure duct air distribution.

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 cloverleaf blades. Blade rigidity helps maintain blade shape at high speed and properly "scoop" 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.

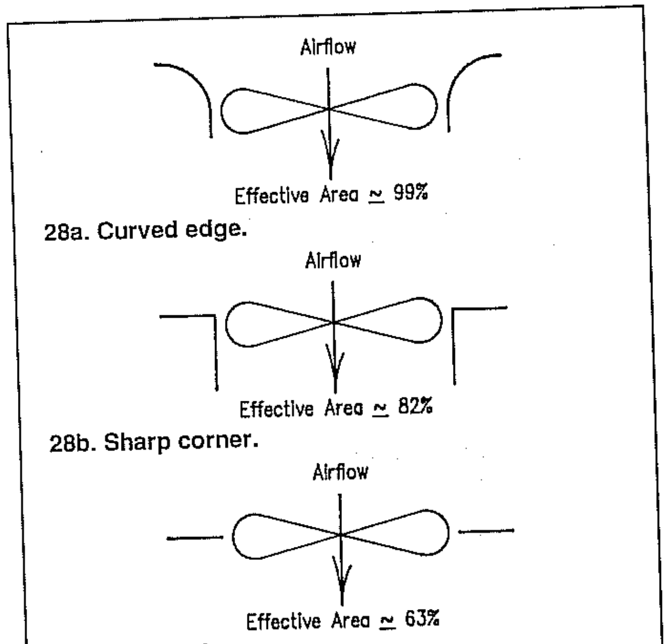
Table 10. Fan types.

Type	Housing	Impeller	Application
Propeller	Simple circular ring, orifice, or venturi.	Two or more uniform thickness blades on a small hub.	Low pressure, high volume air moving. Air circulation in a space. Ventilation through a wall without attached ductwork. Make-up air.
	None	Uniform thickness blades on a small hub.	Circulate large volumes in a space at zero or low pressure. Low speed. Special purpose propeller fan commonly called paddle.
Tube-Axial	Cylindrical tube; blade tips close to housing.	Four to 8 blades. Hub less than 50% of tube diameter. Uniform thickness or airfoil blades.	Can run at higher static pressures. Low or medium pressure ducted heating, ventilating, and air conditioning where downstream air distribution is not important.
Vane-Axial	Cylindrical tube; blade tips close to housing; vanes correct rotary air motion.	Four to 8 blades. Hub usually more than 50% of tube diameter. Fixed or adjustable pitch airfoil blades.	Are efficient at high static pressures. Good for straight through flow or compact design. Many industrial uses.
Centrifugal	Scroll spiral type	Wheel or rotor blades; curved forward, straight, or curved backward.	Usually run at low speeds and high static pressure. Furnaces, air conditioning units. Generally compact in size. Efficient. For relatively clean air.

Clearance between blade tip and orifice or housing determines fan efficiency and static pressure capabilities. Large clearance allows air to slide off the blade and not be propelled through the fan—lower static pressure capability and efficiency result. Single thickness blades have more clearance than airfoil ones.

Fan speed varies with blade type. Airfoil blades usually run faster than uniform thickness blades. At the same speed, single thickness blades deliver more air but airfoil blades are more energy efficient. Fan speed also determines noise level. Noise can be a problem with tip speeds (fan speed, rpm × fan diameter, ft × 3.14) over 11,000 fpm. Fan noise results from air turbulence, which decreases efficiency. Some blade supports can cause unacceptable noise levels at slower speeds. See Table 11 for recommended fan speeds.

Housing or orifice panel design influences fan capacity. A long, smooth contoured orifice panel increases efficiency and airflow through the fan. An abrupt edge can disturb the airflow and reduce capacity. Fig 28 illustrates housing effects on capacity. As the effective area decreases, airflow decreases proportionally.



28a. Curved edge.
28b. Sharp corner.
28c. Sharp edge.

Fig 28. Effect of fan housing on fan capacity.
As the effective area decreases, airflow decreases proportionally.

Table 11. Fan speed for 11,000 fpm blade tip speed.
Greater tip speeds tend to be noisy and less efficient.

Blade dia., in.	Fan speed, rpm
12	3,500
24	1,750
36	1,170
48	875

The above factors affect stalling, another important characteristic of axial flow fans. Stalling is a relatively sharp drop in airflow with a small increase in static pressure and little, if any, change in fan rpm. Stalling severity depends on blade and housing design and the effect of guards, shutters, and other obstructions to airflow. Small fans at full speed may stall at static pressures as low as 0.05 in. H_2O. If stalling does not occur below about 0.25 in. H_2O static pressure, sharp airflow drops due to wind, dirty shutters, etc., are prevented. Other factors that influence fan performance and operating cost include:

- Electrical costs.
- Motor design (standard vs. high efficiency).
- Matching of fan and motor size and characteristics.
- Added devices such as guards and shutters.
- Maintenance.
- Bearing design and lubrication.

Fan Selection

Most agricultural fan applications operate against a static pressure or resistance. A pressure of 0.125" (1/8") of water is typical for livestock ventilation. 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 12.

Table 12. Typical resistances to air movement.
The static pressure the fan must overcome is the sum of the individual resistances.

		Static pressure in. H_2O
Properly sized and managed inlet		0.04
Shutter	clean	0.02-0.10
	dirty	0.05-0.20
Exhausting against wind (no wind shielding)	5 mph	0.02
	10 mph	0.05
	15 mph	0.10
	20 mph	0.20
Fan guards, clean	wire mesh	0.05-0.15
	round ring	0.01-0.02
Ducts	geothermal tubes	0.5-1.5
	solar collector	0.2-1.0

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.

The most common reference for fan selection is a "multi-rating" table. The table includes performance data from fan manufacturers for specific fans, such as fan diameter and air delivery rates (cfm) at different static pressures (in. of water). Table 13 has sample data—do not use them for your fan. Get performance values for your specific fan from the fan manufacturer.

Each entry in the "multi-rating table" is the amount of air that can be moved by the fan against a designated static pressure. As the resistance to air movement or static pressure increases, airflow decreases.

First estimate the system static pressure, Table 12, then locate the column in the table for this static pressure. Read down the column of cfm's until you find the airflow that is required. Usually more than one fan diameter or motor size will be available that delivers the air required at the rated static pressure. The multi-rating table may not have the exact cfm or static pressure you need. Select the next higher static pressure and/or the next higher cfm listed, unless your design values are just a little higher than those listed.

Fan shutters, dust accumulations, and guards or wind hoods all increase static pressure and reduce airflow. As a rule, larger diameter fans at lower rpms produce less noise than smaller fans running faster and needing higher horsepower motors.

Table 13. Example fan multi-rating table.
Sample data—consult manufacturers literature for values for specific fans.

Fan dia., in.	hp	rpm	0.00	0.05	0.10	0.125	0.15	0.20	0.25
			Static pressure, in. of water (cfm)						
7	1/30	3,400	365	328	266	224	197	159	129
		2,800	300	254	146	130	118	100	80
		1,600	169	62	36	22	—	—	—
8	1/15	3,400	588	569	546	533	518	481	313
		2,800	484	458	428	408	377	227	195
		1,600	277	211	98	78	63	30	—
10	1/6	3,400	1,156	1,136	1,113	1,102	1,089	1,064	1,037
		2,700	918	895	864	847	830	789	737
		1,800	612	568	506	453	309	256	208
14	1/8	1700	2,172	2,112	2,028	1,988	1,932	1,840	1,480
		1,400	1,775	1,622	1,473	1,385	1,298	1,005	585
		900	1,110	816	273	—	—	—	—
18	1/3	1,700	3,879	3,777	3,679	3,630	3,567	3,444	3,308
		1,500	3,525	3,379	3,232	3,168	3,053	2,886	2,675
		1,200	2,977	2,727	2,426	2,293	2,176	1,942	1,674
24	1/3	1,200	6,132	5,860	5,600	5,468	5,312	4,956	4,535
		925	5,219	4,775	4,370	4,130	3,785	3,255	2,265
		775	4,383	3,775	3,140	2,864	2,476	—	—
36	1/2	900	11,810	11,150	10,510	101,70	9,770	8,840	7,900

Example 6:

Determine the static pressure loss that a fan must overcome in a 30' wide room when fan shutters are clean, wind is blowing against the fan at 5 mph, and a wire mesh guard is used.

Solution:

From Table 12, select the static pressures corresponding to the appropriate condition and sum them.

Condition	Static pressure in H_2O
Inlet loss	0.04
Clean shutter	0.06
5 mph wind	0.02
Wire mesh guard	0.10
Total static pressure	0.22

The shutter and guard represent 0.16 in. of static pressure or 67% of the total static pressure. Some manufacturers test their fans with this equipment in place and others do not. You must know how the fan was tested when selecting fans for a given application.

Example 7:

Select a fan from Table 14 to deliver 4,500 cfm at 0.10".

Solution:

It is important to consider the effect of shutters, guards, and dust accumulation on fan performance. Fan A was tested with shutters and guards installed. At 0.05" static pressure, it delivers 5,000 cfm.

Fan B was tested without shutters and weatherhoods. If added later, these devices could increase static pressure by 0.16"-0.21". At this static pressure, fan B delivers less than 4,700 cfm.

Table 14. Multi-rating table—Example 7.

Model	Dia.	0.00	0.05	0.10	0.15	0.20
		Static pressure, in. of water				
		cfm				
Fan A	24"	5,500	5,000	4,400	3,700	2,900
	Fan with shutters and guards.					
Fan B	24"	6,100	5,900	5,600	5,200	4,700
	Fan w/o shutters or guards.					

Example 8:

Assuming that both fan C and D in Table 15 were tested with shutters, which fan will perform better after shutters have gotten very dirty?

Solution:

From Table 15, both fan C and D can supply at least 5,000 cfm at 0.04" 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 effected less by dirty shutters than fan D.

Table 15. Multi-rating table—Example 8.

Model	Dia.	0.00	0.05	0.10	0.15	0.20
		Static pressure, in. of water				
Fan C	24"	5,500	5,300	5,100	4,900	4,700
Fan D	24"	5,500	5,200	4,800	4,300	3,800

Multi-rating tables sometimes include MAX BHP (maximum brake horsepower), which is the horsepower the fan requires to deliver air at a specific static pressure, Table 16. BHP indicates the power required to turn the fan blade. BHP does not indicate motor efficiency and is accurate only under certain conditions.

One measure of fan efficiency is the cubic feet of air moved per minute (cfm) for each watt (W) of electrical power input. Some manufacturers include cfm/W ratings in multi-rating tables. This factor can be used to compare efficiencies of different fans. Table 16 shows an example of cfm/W values for fans.

If fan efficiency ratings are not available, the following guidelines can help select energy efficient fans.

- For a given airflow rate and static pressure, a large diameter fan is more energy efficient and less expensive than a smaller one.
- For a given ventilating rate and static pressure, one large fan is more energy efficient and less expensive than several smaller ones.
- When two fans have the same blade diameter, the fan with the lower motor current input rating is usually more efficient.
- If two fans have the same static pressure capabilities, the one with the slower speed motor is usually quieter and more efficient.

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.

Fan dia., in.	Hp	Rpm	0.00	0.05	0.10	0.125	0.15	0.20	0.25	Max BHP
			Static pressure							
			cfm/watt							
7	1/30	3,400	4.7	4.1	3.3	2.7	2.3	1.8	1.4	0.051
8	1/15	3,400	4.2	4.0	3.9	3.8	3.6	3.4	2.2	0.072
10	1/6	3,400	3.7	3.6	3.5	3.4	3.4	3.3	3.2	0.223

Electrical Cost

Selecting the most energy efficient fan can be difficult. Manufacturers do not know how their fan 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.

Cost $/kWhr	500	600	700	800
	Electricity Motor size, watts			
	$/yr			
0.04	105.10	126.10	147.10	168.10
0.06	157.60	189.10	220.60	252.10
0.08	210.20	252.20	294.20	336.20
0.10	262.70	315.20	367.70	420.20

Multi- or Variable Speed Fans

For cold weather ventilation, low airflow rates are often required. Multi-speed or variable speed fans can run at 50% rated capacity. Determine 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, weatherhoods, prevailing winds, etc. have 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 ensure that they work properly together. While delivering variable airflows, 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. 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 chapter for methods of adjusting multi- or variable speed fans. Before selecting a variable speed motor, consult 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-up 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. Fans can be banked together in one location, but limit the distance between a fan and inlet to 75', Fig 5g.

Loose construction lets air leak into the building through non-designed inlets such as cracks around doors and windows. Air can move directly from a non-designed 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 36'.

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 porosity exceeds about 20% open (wire mesh floors).

With wall fans mounted in some housings, 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 annual costs such as repairs, 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. Even 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 MWPS-28, *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.

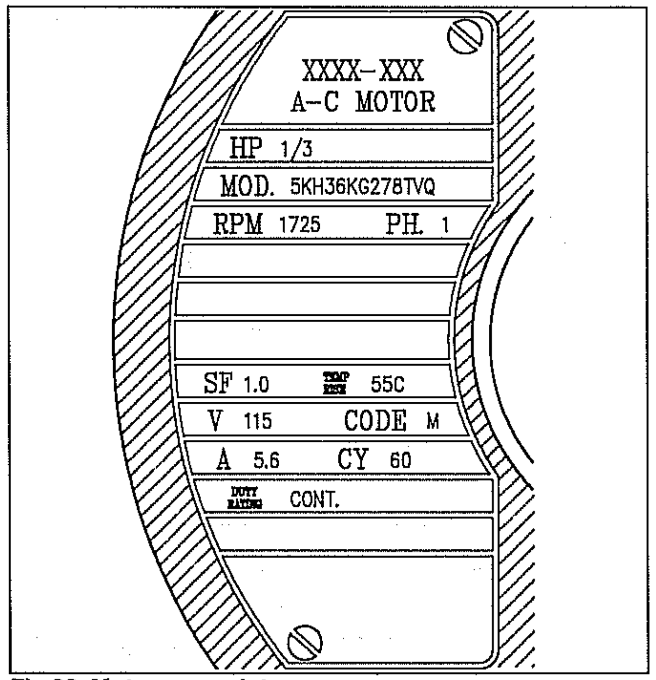


Fig 29. Motor nameplate.

Motor horsepower is the most common rating characteristic. However, without fan airflow rate and static pressure, horsepower gives only a general idea of fan capacity. Horsepower required by a fan is determined by airflow, static pressure, and fan efficiency. The fan motor must be able to operate at maximum horsepower continuously.

A properly cooled motor can run above its horsepower rating. Service factor indicates at what overload the motor can operate. For example, a motor with a service factor of 1.1 can operate successfully at 10% above its nameplate rating for short periods. Check the motor nameplate for the rated service

Table 18. Types of single-phase motors.

Type	Horsepower ranges	Load-starting ability	Starting current	Characteristics	Electrically reversible	Typical uses
Split-phase	1/20-1/2	Easy starting loads. Develops 150% of full-load torque.	High — 5-7 times full-load current.	Inexpensive, simple construction. Low efficiency. Nearly constant speed with varying load.	Yes	Fans, centrifugal pumps; loads that increase with speed.
Capacitor-start	1/8-10	Hard starting loads. Develops 350%-400% of full-load torque.	Medium— 3-6 times full-load current.	Simple construction, long service. Nearly constant speed with varying load.	Yes	Compressors, conveyors, pumps. Special designs for silo unloaders, barn cleaners.
Two-value capacitor	2-20	Hard starting loads. Develops 350%-450% of full-load torque.	Medium — 3-5 times full-load current.	Simple construction, long service with minimum maintenance. High operating efficiency. Large capacitor takes more space. Low line current. Nearly constant speed with varying load.	Yes	Conveyors, barn cleaners, elevators, silo unloaders.
Permanent-split capacitor	1/20-1	Easy starting loads. Develops 150% of full-load torque.	Low, two to four times full-load current.	Inexpensive, simple construction. No start winding switch. Can control speed with voltage for fans, etc.	Yes	Variable speed fans and blowers.
Shaded pole	1/250-1/2	Easy starting loads.	Medium	Inexpensive, moderate efficiency, light duty.	No	Small blowers, fans, and appliances.

Table 19. Service factors for AC motors.
General Purpose motors operated at rated voltage and frequency. Reference: NEMA MG 1-1967, Par. 1.39, 14.33a, 12.44.

Horsepower, (hp)	Service factor
1/20, 1/12, 1/8	1.4
1/6, 1/4, 1/3	1.35
1/2, 3/4	1.25
1 hp and up	1.15

factor. When a motor operates at an allowable overload, it may have a larger temperature rise and different amperage, power factor, and speed (rpm). If a fan motor must operate at a horsepower above the motor's capability, the life of the motor will be reduced.

Nameplate amperage is the motor's full load current rating. Lower operating amperages are fine. While the motor is operating, an electrician can measure the current to detect an overload condition.

If the motor is operating above the nameplate amperage, replace it with a larger motor.

Motor Enclosures

For fractional horsepowers, motor enclosures are typically either drip-proof or totally enclosed.

Open drip-proof motors are not permitted in livestock buildings by NEC.

Totally enclosed motors are recommended in livestock facilities to keep out dust. The enclosure is usually not water- or airtight, but air cannot pass through the motor for cooling. Because less heat can be dissipated, frames are usually larger and motors more costly than open motors of equal rating.

If an air stream must be directed over a motor to meet temperature specifications, it is indicated on the nameplate. These motors are often called "air-over". Totally enclosed air-over motors are common on fans and other air moving equipment because the additional cooling permits smaller motors at lower cost.

Bearings

Motor shafts are commonly supported on sleeves or ball bearings. Sleeve bearings are quieter, usually cheaper, require regular lubrication, may have to be mounted with the shaft essentially horizontal, and may be able to support only limited end thrust. Typical sleeve-bearing motors drive fans with V-belts. Special bearings are designed for the end thrust from shaft-mounted fan blades. Ball bearings may be sealed for life, or may require intermittent lubrication. They can be mounted in any position, can withstand end thrust, but are noisier and more costly.

Motor Drive

Direct drive

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 loads 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 designed 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 code 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 buildup 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 120 V and 220 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 lead to current in 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 periodic 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 conductors 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. Install 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.

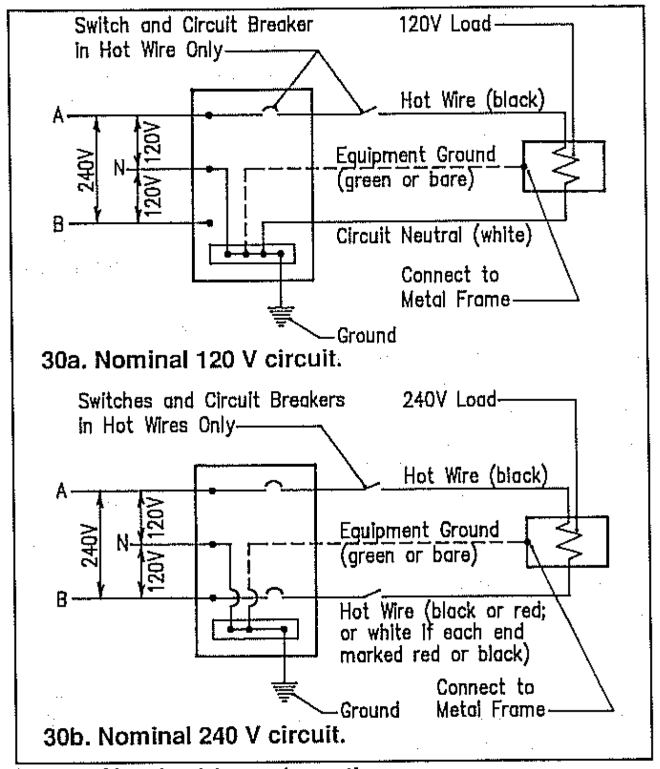


Fig 30. Circuit wiring schematics.

- 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.

Or:

- Install an overload device separate from the motor.

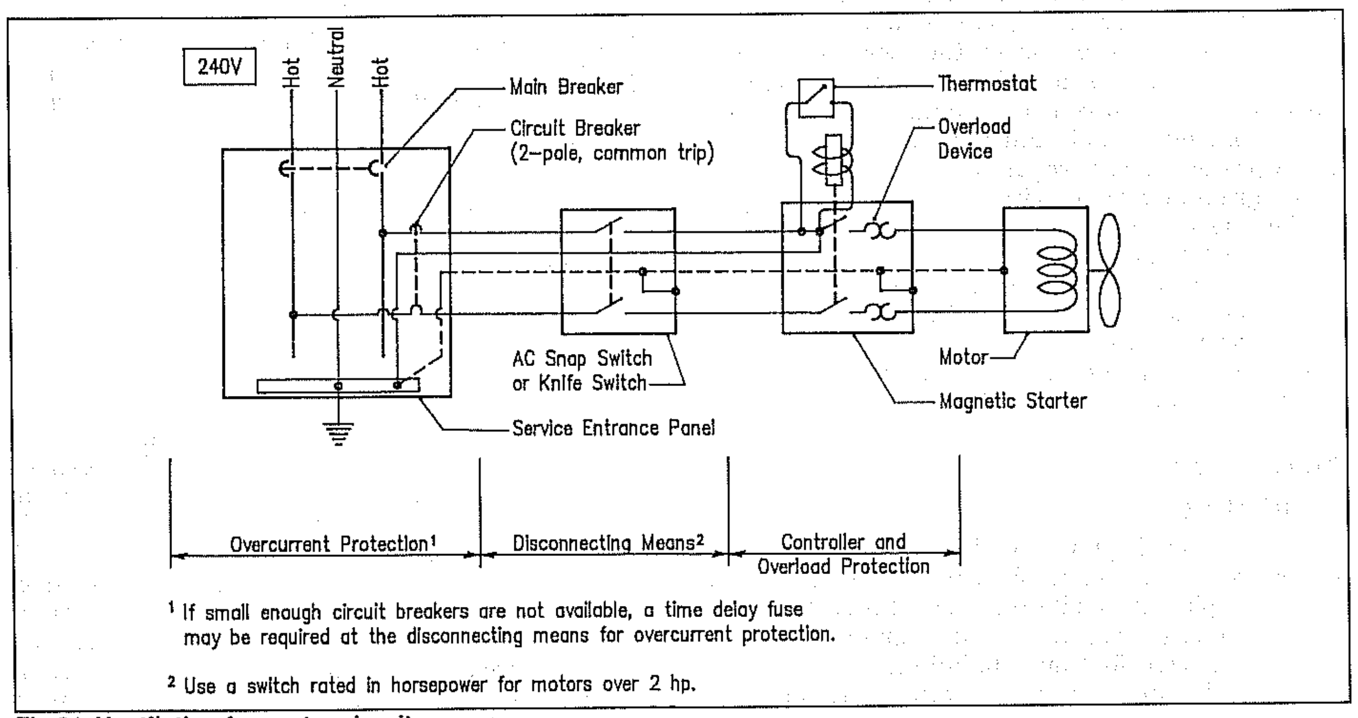


Fig 31. Ventilating fan motor circuit.

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 ammonia concentration has also been monitored.

Some 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 gases, dust, and moisture. If possible, locate controls outside the animal area. Calibrate control sensors using other independent, accurate measuring devices. Thermostats can be checked with a thermometer placed next to them to see at what temperatures equipment turns 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 NEC 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 actuate the switch. Locate thermostats and sensing bulbs according to manufacturer's recommendations.

Liquid filled thermostats have a large volume of liquid relative to the capillary tube, so the bulb is the primary sensor, which makes it suitable for remote sensing. Response to temperature change is slower with liquid filled sensors than vapor filled. Protect liquid filled thermostats from mechanical damage and excess temperatures. Mechanical damage to the sensing bulb or capillary affects calibration or causes failure. Excess temperatures can permanently distort the pressure spring, affecting accuracy.

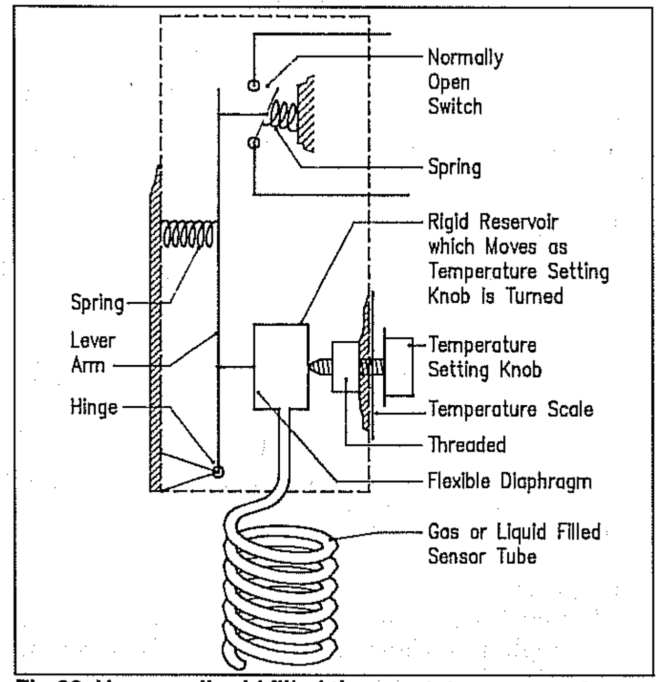


Fig 32. Vapor or liquid filled thermostat components.

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.

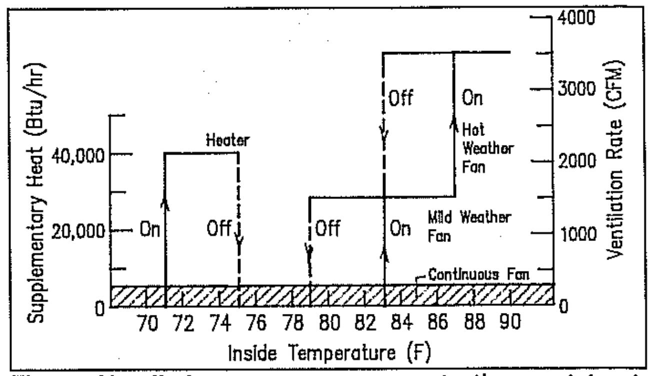


Fig 33. Ventilating system response to thermostat settings.
The heater comes on at the thermostat setting (71 F) and stays on until room temperature is at setting + differential (71 + 4 = 75 F). Fans use cooling thermostats and turn off at the set temperature. In this example, fan settings are 79 F and 83 F and the minimum ventilating rate fan runs continuously. Set thermostats so heater and non-continuous fans do not run at the same time.

Example 9:

Determine control settings for a heated room with three single speed fans for cold, mild, and hot weather ventilating. Desired room temperature is 75 F. Assume a 4 F on-off range for each thermostat.

Solution, Fig 33:

1. Provide a thermostat for each fan and the heater. The cold weather fan runs continuously; provide only a safety thermostat set at 45 F to shut off the fan to prevent excess cooling.
2. Set the heater thermostat at 71 F. The heater comes on when the temperature drops below 71 F and turns off when it has raised the room temperature to 75 F.
3. Set the mild weather fan thermostat so the heater and mild weather fan do not run at the same time. Set the mild weather fan at 79 F. With a 4 F on-off range, the fan turns on at 83 F and off at 79 F.
4. Set the hot weather fan at 83 F so it comes on at 87 F and shuts off at 83 F.

Example 10:

Determine the control settings for a heated room maintained at 75 F. One 3-speed fan and one single speed fan provide ventilation. Assume the thermostat on-off range is 4 F.

Solution:

1. The 3-speed fan is for cold and mild weather ventilation. Provide a safety thermostat to shut off the low speed 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 75 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 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 full on and full 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 winter 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 timers to control fans in a room with unvented 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 adjustments.

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 environmental conditions in 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 20. See Figs 34 to 38 for example control circuits.

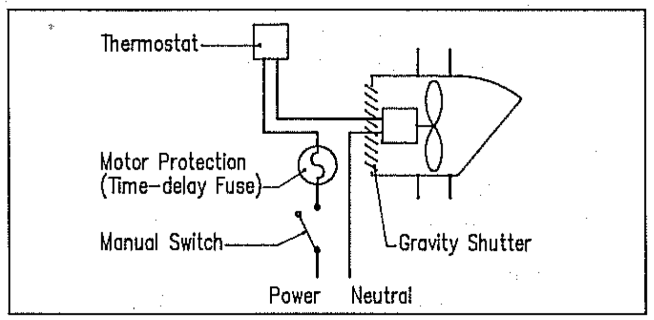
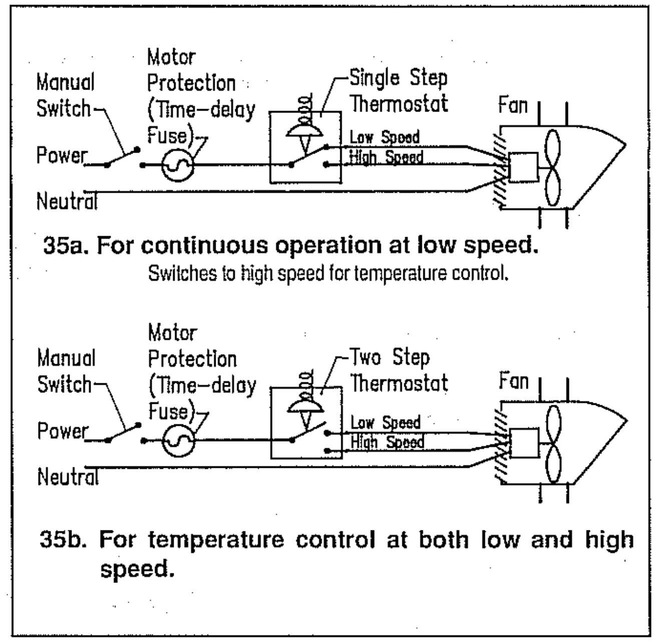


Fig 34. Single-speed fan and thermostat.

Table 20. Ventilating fan controls.

Control	Use
Safety thermostat (Fig 34)	Shut off minimum winter ventilation fans to prevent freezing if weather is unusually cold or heating systems fails. Also alert operator.
Interval timer	To provide variable cold or mild weather ventilating rates in areas with no unvented heaters. Can be adjusted as animal size increases. Usually found in brooding situations.
Thermostat (Fig 32)	Temperature activated on-off fan switch. In multiple fan systems, thermostats set at different temperatures can approximate a continuously variable ventilation rate.
Interval timer and thermostat (Fig 35)	Combination control that provides a time- and temperature-activated fan for warm weather.
Humidistat	Control fans based on humidity. Calibration is difficult to maintain.
Throttling	Provides high and low ventilating rates by varying fan intake. Usually accomplished with manually adjusted and thermostat controlled louvers.
Multi-stage thermostat (Fig 33)	Use with multi-speed fan motor for high and low ventilating rates. Thermostat switches fan speeds based on temperature.
Solid state	Most variable speed controls are based on a solid state electronic phase control. Automatic controls are common. Automatic controls usually have an adjustable minimum temperature setting for cold weather and a setting to increase fan speed for mild weather ventilation. Typically, fan speeds increase over a temperature range of 5 F-10 F.



35a. For continuous operation at low speed.
Switches to high speed for temperature control.

35b. For temperature control at both low and high speed.

Fig 35. Two-speed fan thermostats.

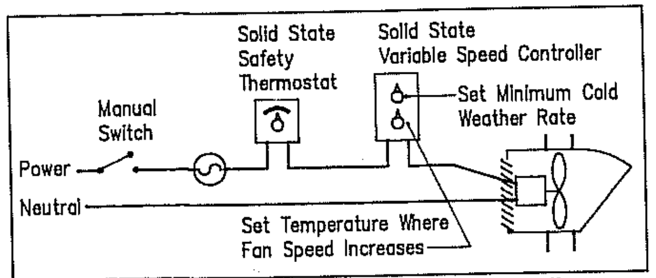


Fig 36. Temperature sensitive solid state controller.

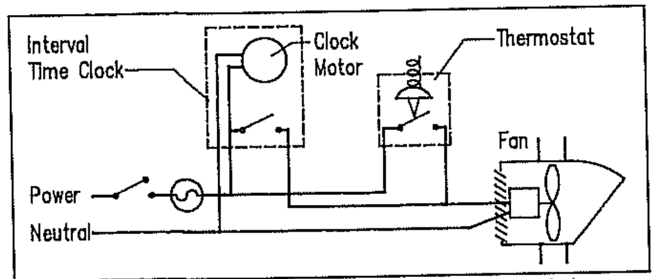


Fig 37. Single-speed fan with interval timer and thermostat.
To supplement a cold weather fan, an interval timer controls a mild weather fan. It runs intermittently, gradually increasing airflow as animals grow. A thermostat overrides the timer so the fan is on continuously at higher indoor temperatures. A separate fan runs continuously for cold weather ventilation.

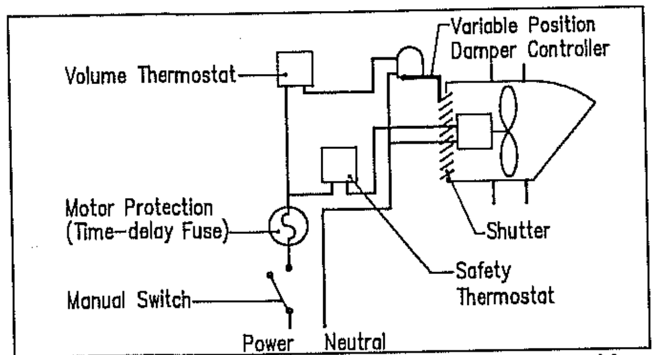


Fig 38. Variable air exhaust system with single speed fan.
A single-speed fan is controlled with a thermostat on the shutter-damper and with a low temperature on-off safety thermostat.

Inlet Baffle and Vent Door Controls

Properly adjusted baffles are important to mechanical ventilating system operation. Baffle doors can be adjusted manually or automatically, either individually or in groups.

To hold doors partly open, manual adjustments are:

- Friction in the joints.
- Chains and hooks.
- Ropes, cables, and pulleys.
- Rods and pins.
- Steps, wedges, and springs.

Locate controls for easy access and adjustment. Avoid systems that require getting into animal pens or using a step ladder. A winch and pulley system can adjust several doors at once.

Pressure sensing units or manometers can help control baffles for mechanical ventilation. Locate pressure sensors to minimize wind effects. Protect the outside sensor. Set the controller to maintain a pressure difference of about 0.04" of water, Fig 9.

Temperature sensing controllers can set vent doors to help maintain desired indoor temperature. Design the system to always provide at least the minimum winter ventilating rate.

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 39. 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 fan 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. Partly 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 interval timer, Fig 37. One large fan can produce large fluctuations in temperature and air contaminant concentrations.

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 you that action may be needed to prevent livestock losses. Some systems are commercially available. Common alarm systems include:

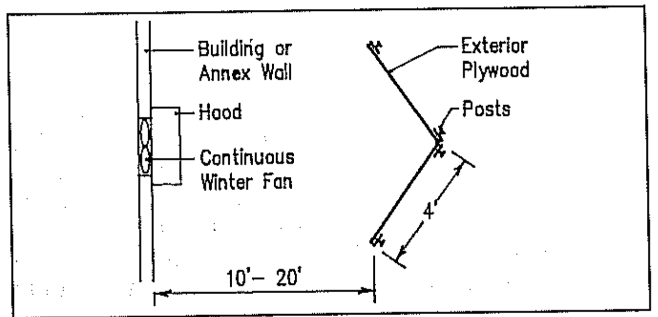


Fig 39. Cold weather fan windbreaks.
Plan view. Extend windbreak at least 1' above fan.

- Relay switch controlled, battery powered alarm.
- Solenoid valve controlled compressed gas horn alarm.
- Thermostat controlled, battery powered alarm.
- Automatic phone dialer.

Most alarms respond to power failure, but the thermostat controlled alarm does not sound until conditions in the building are critical. Some systems have a battery powered alarm. Check dry-cell batteries periodically and replace if they are faulty. Charge wet-cell batteries with a trickle-charger; check the water level frequently.

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.

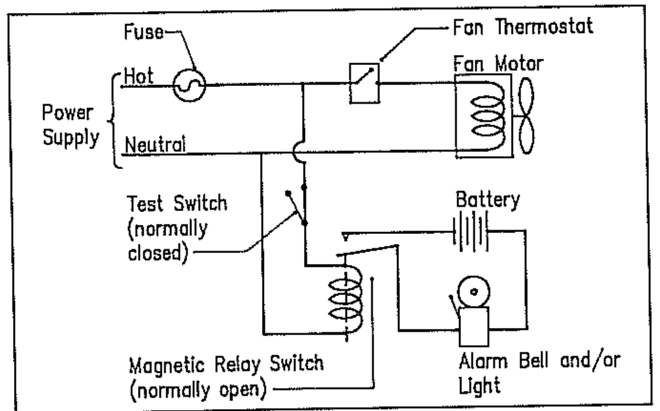


Fig 40. Battery operated, relay controlled alarm.

Solenoid 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.

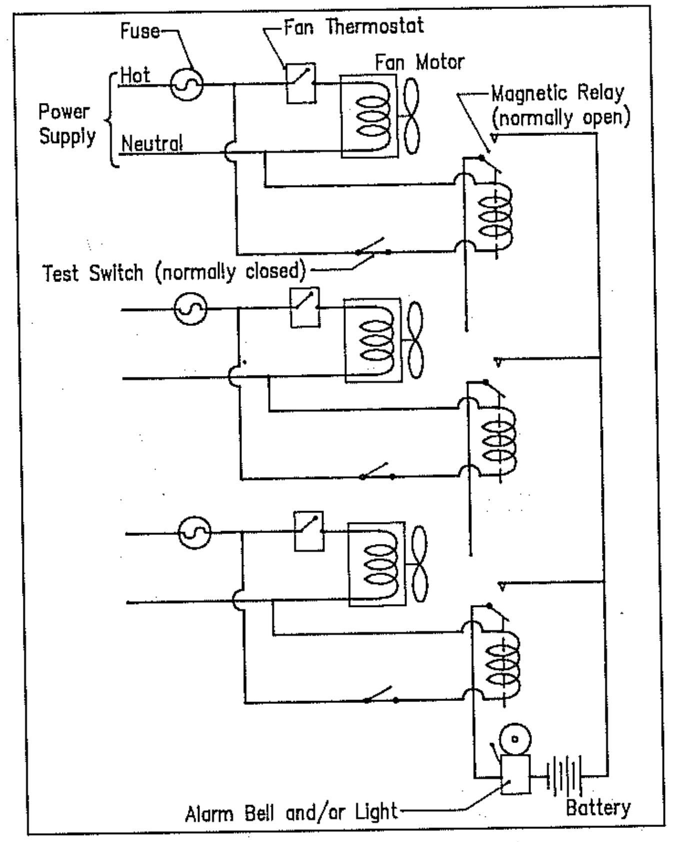


Fig 41. Multiple-fan alarm system.

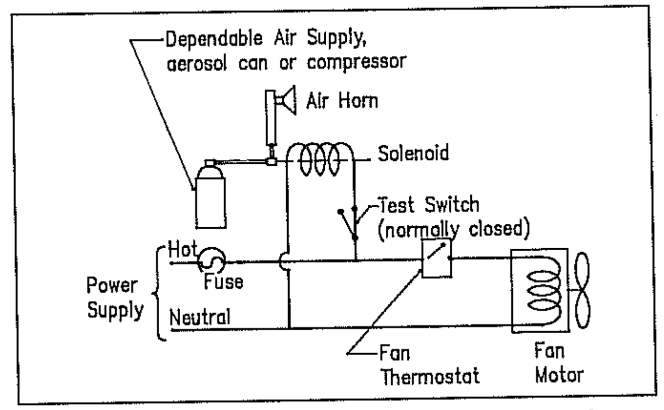


Fig 42. Solenoid valve controlled compressed gas horn.

Thermostat Controlled Alarm

A thermostat controlled, battery operated alarm uses a cooling thermostat to sense a temperature rise or heating thermostat to sense a temperature drop, Fig 43. When air temperature is above normal the contacts close, sounding the alarm. In cold weather with small or young animals, a fan failure may not be sensed by a temperature rise. Humidity and contaminant buildup can cause a health risk. Adjust thermostat settings for season, animal size, density, etc. Test the alarm circuit by changing the thermostat setting. This system can also turn on a sprinkler.

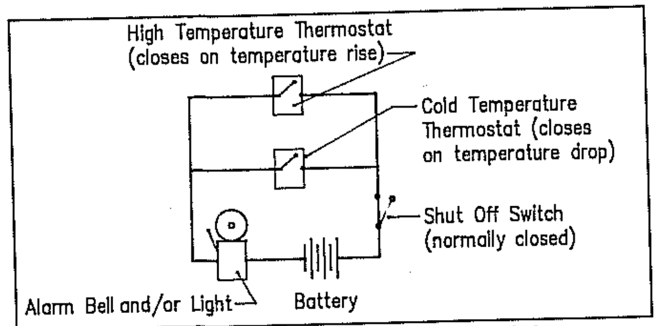


Fig 43. Battery operated alarm with thermostat.

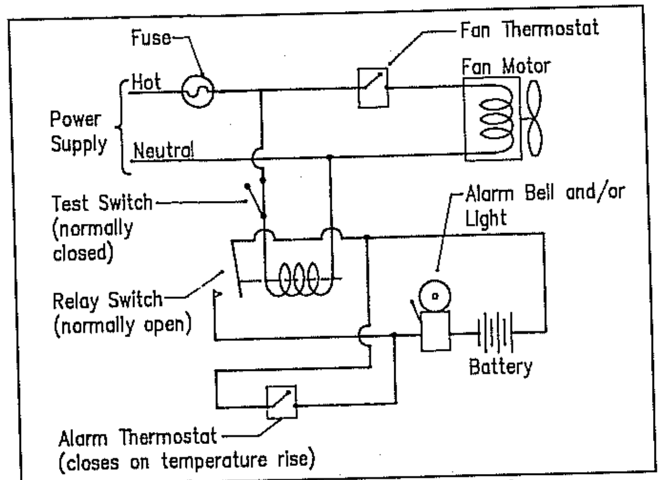


Fig 44. Temperature- and power-sensitive alarm.

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 recommendation for oil type and amount. Never overlubricate.
- 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 baffle 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 21. Temperatures for livestock housing.
Optimum temperature depends on air velocity, humidity, floor type, bedding or not, insulation level, and outdoor temperature. The Temperatures listed assume reasonablehumidity control.

Animal	Desirable temperature, F
Lactating sow	50-70
Litter-newborn	90-95
Litter 3 weeks old	75-85
Pre-nursery (12-30 lb)	75-85
Nursery (30-50 lb)	70-80
Nursery (50-75 lb)	60-70
Growing-finishing (75-220 lb)	50-70
Gestating sows	50-70
Boars	50-70
Dairy cows	40-60
Calves, floor level, bedded	40-60
Calves, raised stalls	60-70
Beef cows	40-60
Horses	50-70
Rabbits	40-60
Layers	55-70
Broilers and turkeys	
Brooding (to 4-5 weeks)	See Poultry, Chapter 10
Growers	

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 45.

Use maximum/minimum thermometers to monitor air temperature changes in buildings when you are not there. A 5 F-8 F spread in mechanically ventilated buildings is common. See Table 21 for recommended livestock housing temperatures.

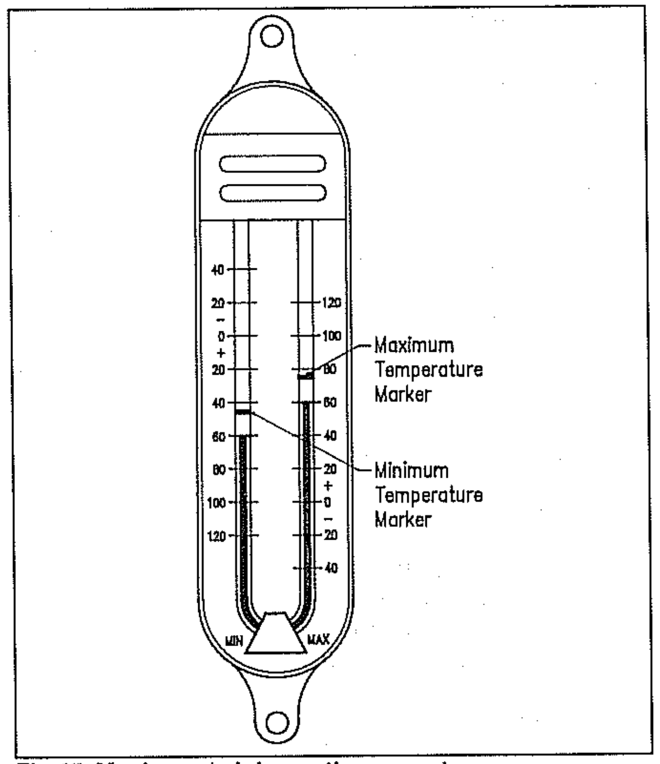


Fig 45. Maximum/minimum thermometer.

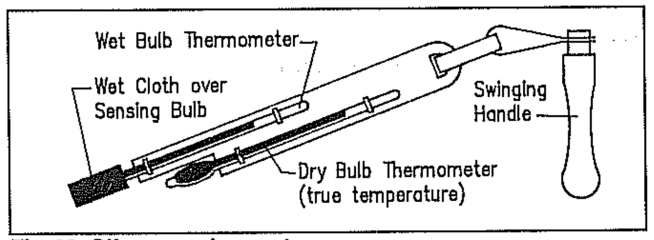


Fig 46. Sling psychrometer.

Psychrometer

A psychrometer has two thermometers. The sensing bulb on one thermometer is covered with an absorbent sock which is dipped in water, Fig 46. The two thermometers are then whirled 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

Smokers are useful for locating **dead spots** or **draft** locations. Any devices which produce 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 areas 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.

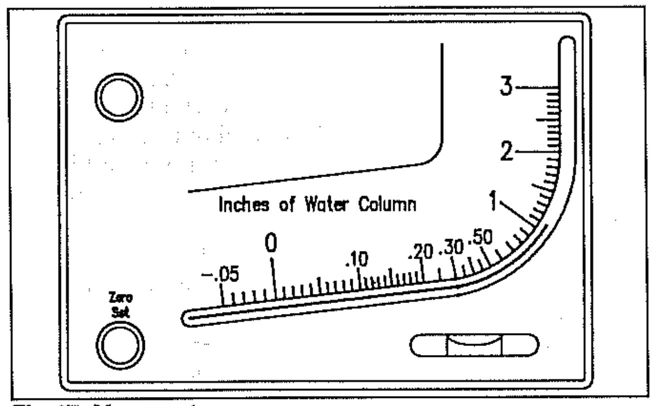


Fig 47. Manometer.

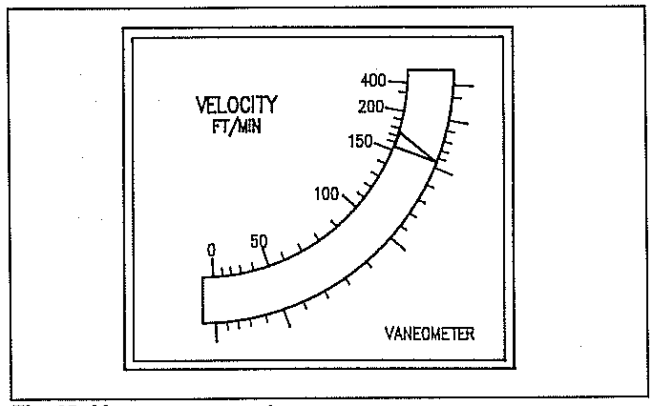


Fig 48. Vane anemometer.

Air Speed Meters

Inexpensive air speed gauges are available from many heating contractors. They can measure relatively high speed (600 to 1,000 fpm) air entering an inlet and discharging from a fan. A possible limitation is these air speed gauges need a 1/4" wide air stream and many slot inlets may only be 1/8" in winter. Slower moving air within a building requires more sophisticated and expensive equipment.

A producer not experienced in diagnosing ventilation problems should use 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 open too wide 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 louvers and/or roof vents, remove wet insulation, and install new insulation with a good vapor retarder.

- No supplemental heat, heater is too small, or heater thermostat is improperly set. Evaluate other possible causes and your supplemental heat needs before adding a heater.
- Cold weather fan is oversized, cooling the building too much. Calculate 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 watering system from freezing.

Symptom: Warm building

Building is too warm.

Possible causes and solutions:

- Fan or furnace control settings are too high or thermostats need recalibration. Adjust thermostat settings. Place a thermometer next to the thermostat's sensor to see if the fan and heater turn on at the desired temperature.
- Insufficient fan capacity. Calculate the required hot weather ventilating rate and compare to the capacity ratings of existing fans. Install larger or additional fans if necessary.
- Fans are not delivering rated capacity because of dirt on fan blades, shrouds, and shutters; warped orifice; or slipping drive belts. Check fan belt adjustment monthly. Clean 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 existing inlets to provide proper openings. Clean screens over intakes at least every 6 months. Also, check if eave doors are closed or other blockage exists. Be suspicious of inlet restrictions if the fans tend to suck the door closed, or if static pressure exceeds 0.1".
- Obstructions within 6'-8' of the intake or exhaust side of the fan. Ventilating fans are not positive displacement air pumps so any obstruction placed in the path of the airflow can greatly reduce fan capacity. Remove any fan obstructions, but do not remove shields or guards.
- Check if ventilating air is short circuited through unplanned openings. Close all openings within 8' on both sides of exhaust fans.

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 temperatures and/or damp and possibly foggy air. Can be due to over-crowding. Increase ventilation by running existing fans more or increase cold weather fan capacity.
- 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 outbreak. 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:

- Extremely low outside temperature (less than -10 F). Ventilating systems operate at minimum levels for extended periods of time. 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 window with plastic, or opening the top of the window about ⅛" often improve conditions. **Caution:** too much additional opening can reduce static pressure and disrupt air distribution.
- Building is poorly insulated or insulation is wet. Replace wet insulation and insulate to proper levels.
- Openings caused by nails, fasteners, and light sockets 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 a reasonable range.
- Condensation on ceiling or wall when proper insulation and vapor retarder are installed. Check if cold air is being drawn or blown into the corrugations between the metal and insulation. The ends of the corrugations may not be sealed. Also check that insulation is in contact with roof sheathing so no gaps exist for cold air to accumulate.
- Also, see the causes under "High Relative Humidity".

Symptom: Drafts and uneven temperature distribution

Excessive drafts and/or hot spots at different locations in the building.

Possible causes and solutions:

- Poorly adjusted inlets. Adjust inlets to match the ventilating rate (cold, mild, and hot weather rates). Some "trial and error" adjustments are expected to obtain a completely balanced system. Use a manometer when adjusting inlets to match fan airflow rates. Maintain static pressure at about 0.04". Air distribution can sometimes be improved in winter by closing every other inlet section and adjusting remaining inlets for better distribution.
- Inlets deliver more air to one area than another. Adjust inlets or install an inlet that can uniformly distribute the air. Check if inlets are blocked.
- Airflow is short-circuited. Open windows and doors cause poor air distribution. Static pressure below 0.04" is a good indicator of this problem. Close large openings like doors, windows, hay chutes, and gutter cleaner ports.
- Cold air is leaking through summer ventilating fans. Disconnect power and cover them with insulated panels or plastic film.
- Animal densities are not uniform. Match airflow to animal density by adjusting inlet openings. Supplemental heat may be required. Where large and small animals are housed in the same building, divide into multiple rooms and ventilate each room separately.
- Insufficient fan capacity. See causes under "Warm Building".
- Draft baffles are required. Install hovers and/or solid pen partitions to reduce drafts on small animals.
- An air recirculation system can cause drafts, especially with small animals. Make sure it is properly designed and operated. Check if inlet air is going to the recirculation duct fan or falling directly to the floor causing a draft.
- Obstructions to airflow can cause inlet air 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".
- Fuse or circuit breaker is tripped or faulty. Replace fuse or reset breaker and switch on fan. If fuse blows or breaker trips again, look for a short circuit. Have wiring checked and repaired.
- 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 defective or improperly wired. Check motor for proper wiring and rewire if necessary. Repair or replace 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 units to measure and respond to conditions experienced by animals. A good location is near 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 only cold weather fans when supplemental heat is on. Adjust other fans to turn off at a temperature at least 5 F above the shut off temperature for the heating system. Place fan and heater thermostats close together. See the Controls chapter. Check 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 common problem with variable speed fans which do not always fit the desired range. Calculate minimum ventilating rates and install an appropriately 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 even air removal. Check for backdrafting of manure gases through manure sewer lines and pit annexes.
- Large floor area is covered with manure. Check for proper dunging habits. For swine, direct cold incoming air into the desired dunging area.

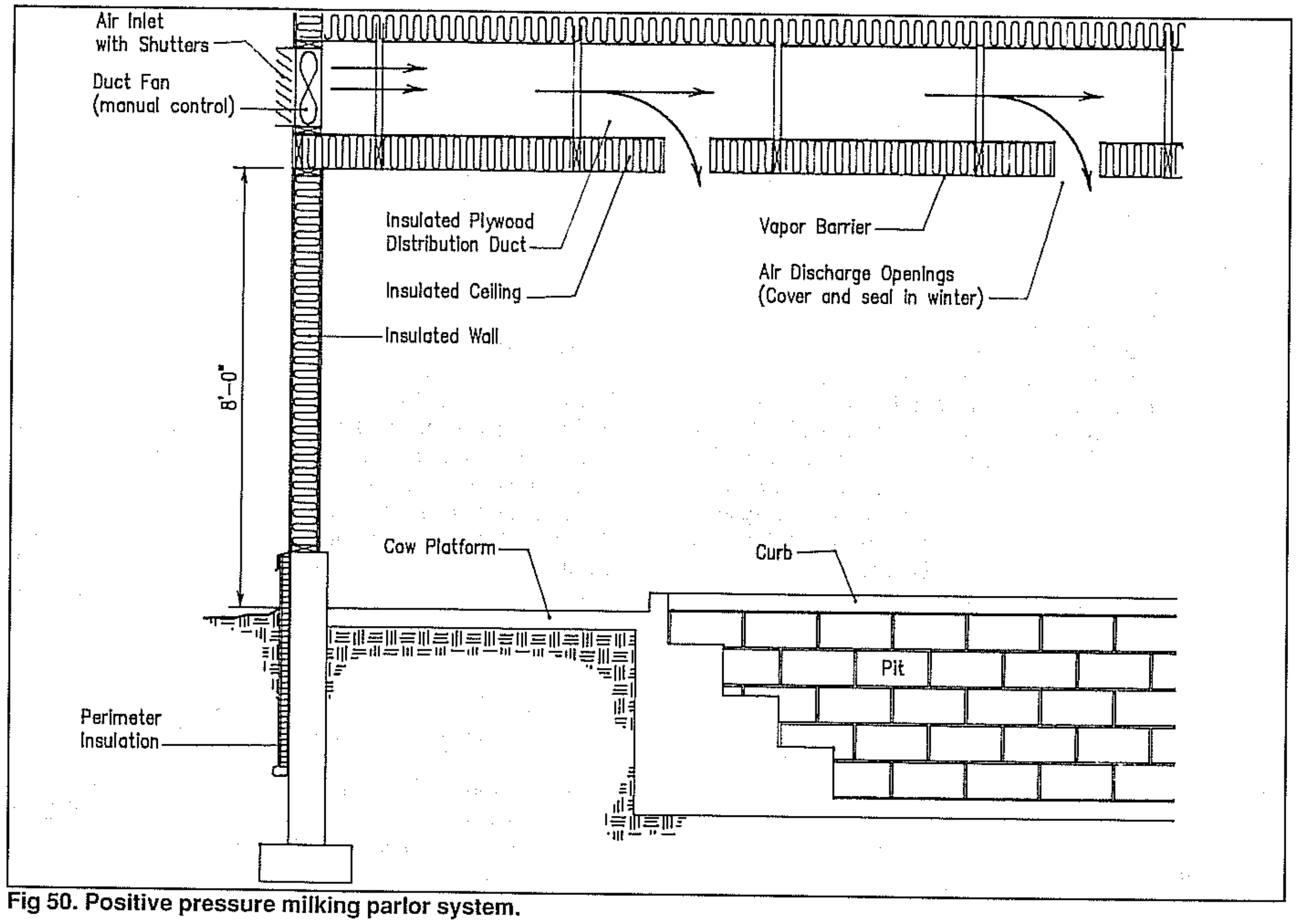


Fig 50. Positive pressure milking parlor system.

With mechanical ventilation, size fan capacity for the animal holding capacity and recommended ventilating rates. Install proper air inlets and controls. If doors between the holding area and cow housing are left open, use positive pressure ventilation.

Treatment-hospital area

The treatment-hospital area is usually a separate room with its own mechanical or natural ventilating system. Design the system to accommodate varying animal densities.

If water freezing or worker comfort are concerns, consider an individual space heater, central heating system, and heating tape. A frost proof water system allows this area to be unheated when not in use.

Milking parlor

Exhaust fans remove excess heat and moisture, circulating fans move air in the operator pit, and a heater controls temperature.

Provide 100 cfm/stall fan capacity for cold weather ventilation and 400 cfm/stall for warm weather ventilation. If doors to the holding area are left open, use a positive pressure ventilating system, Fig 50. Locate the fan in the gable end and duct air to the parlor. Size the duct based on required total cfm.

Control fans with an interval timer and a manual override switch for flexibility. During winter, set the timer to ventilate after milking to dry out the parlor. During summer, the manual switch provides continuous operation during milking and cleanup.

Locate exhaust fans on the leeward side of the parlor and exhaust directly outdoors, away from milkroom or office air intakes.

Ceiling fans that move air down across the operator or fans to blow air through the pit area increase summer operator comfort. Moving shadows from paddle fans installed below lights can bother cows and operators.

Parlor heating can be radiant, floor, unit space, or central heating systems. Consider total milking center heating needs when selecting the parlor heating system.

Hang radiant heaters to direct heat toward the cow's udder and the milker's hands. Turn on radiant heaters with a manual switch during milking.

Electric heating cable or hot water pipe is sometimes used in the milker's pit floor and on cow ramps where ice and snow are a problem. With heating cable, provide 20 to 30 W/ft^2 capacity on a manual switch.

A central hot air system is shown in Fig 51. A central hot water system can heat each room with convectors, Fig 52, and can allow for individual temperature control in each room. Local regulations may not permit this system if the same heat exchanger preheats washwater.

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. Duct hot air into the milker's pit about 8" above the floor; direct air toward the floor. Locate cold air returns 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 may need to be doubled for existing lightly insulated milking parlors.

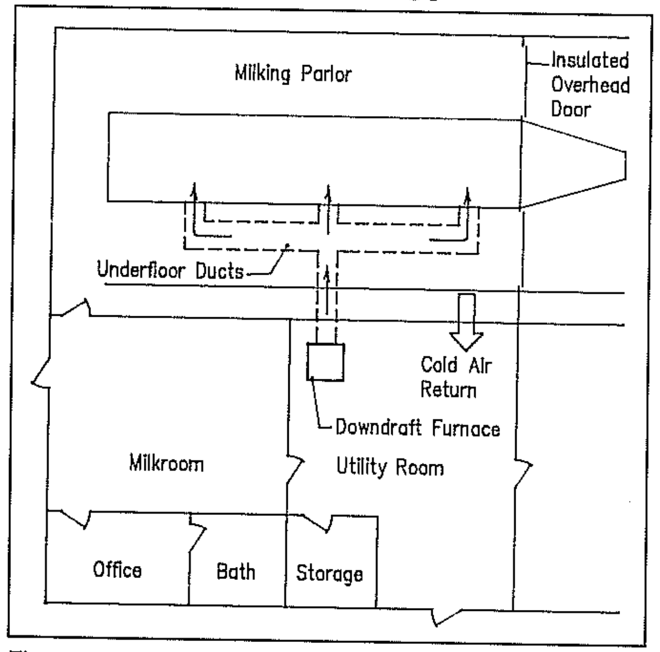


Fig 51. Forced air central heating system.
Cold air return can be ducted to the furnace.

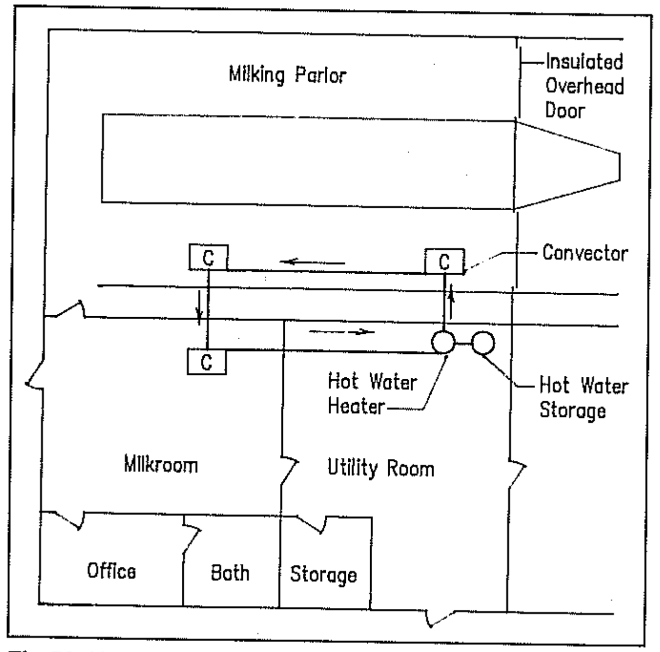


Fig 52. Hot water central heating system.

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 a 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-80 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 furnace 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 ft^2/air inlet/600 cfm fan capacity. Cover air inlets with gravity or motorized louvers 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.

Dairy Design Examples

Example 12:

A farmer in north eastern Ohio wants to improve the environment in a two story bank barn with a one story addition, Fig 53. The bank barn walls are 18" limestone and the addition walls are 8" masonry block. There is one 1'x1' metal ventilator on the ridge of the addition. The barn has one 18" direct drive fan with a small motor and one 24" belt drive fan with no motor. The barn houses 40 cows with an average

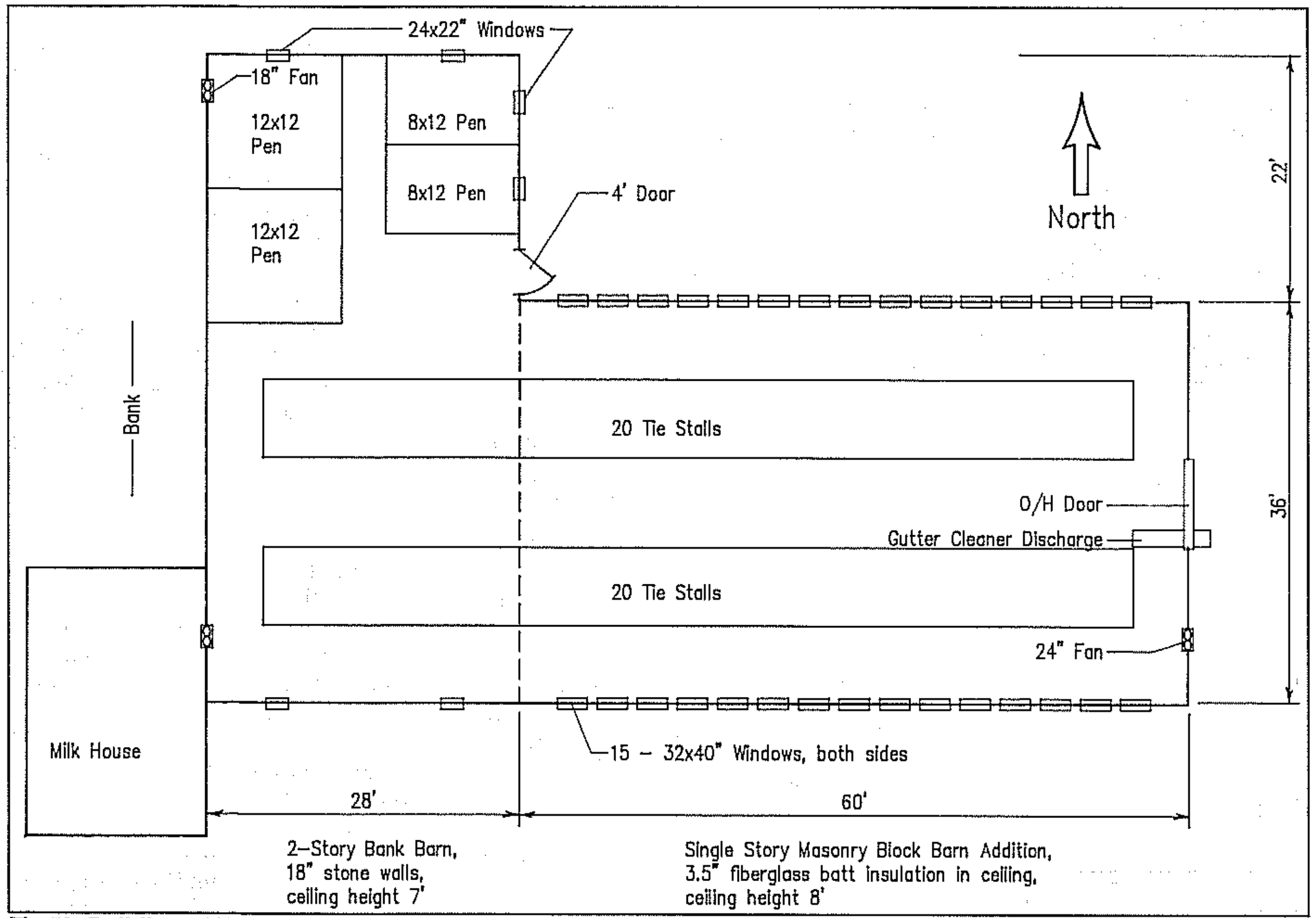


Fig 53. Building of Example 12.

weight of 1,225 lb, 6 to 12 calves with an average weight of 250 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 ventilating 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 18 calves = 360 cfm
Mild weather:
60 cfm/calf x 18 calves = 1,080 cfm
Hot weather:
130 cfm/calf x 18 calves = 2,340 cfm

Use the pressure distribution duct for cold and mild weather ventilation. Install a 2-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"x18" duct handles 1,080 cfm. One 3" diameter outlet hole can supply about 45 cfm: 24-3" 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 1,260 cfm, the difference between the mild and hot weather ventilating rates. Locate the fan in a separate duct along the north wall. From Table 4, an 18"x18" 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:
49 a.u. x 36 cfm/a.u. = 1,764 cfm
Mild weather ventilating rate:
49 a.u. x 120 cfm/a.u. = 5,880 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: 10,535 cfm, the difference between the hot and mild weather rates (16,415 cfm – 5,880 cfm).

Control the fan with a thermostat set at 60 F. In 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 176' (88' 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' (176' – 16') long.

Cold weather inlet opening:
Airflow = 1,690 cfm ÷ 160' = 10.6 cfm/ft of slot length.
From Table 3, ¼" slot is required.
Mild weather inlet opening:
Airflow = (4,290 + 1,690) cfm ÷ 176' = 34.0 cfm/ft.
¾" slot is required.
Hot weather inlet opening:
Airflow = (10,800 + 4,290 + 001,690) cfm ÷ 176' = 95.3 cfm/ft.
Slightly over 2" slot is required. Windows can provide additional summer inlets.

Make the building slot opening 2½"-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 inlet 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 chaff 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 = 93.5 cfm/ft

Required duct airflow from each end:

95.3 cfm/ft x 28' ÷ 2 = 1,334 cfm
From Table 4, duct is 18"x20", or
12"x30" if head room is limited.
Insulate the duct to prevent condensation.

Construct eave intakes (Fig 6c) at least 50% larger than the largest slot inlet opening. Minimum eave intake is 3.75" (2.5" x 1.5). Construct eave intakes on the south side of the 2-story barn to supply inlet air. Install doors on the north eave inlets to close in winter.

Attic ventilation

When north eave intakes are closed, inlet air comes from the attic; check for adequate attic openings in the one-story barn. Size attic openings for 200 fpm inlet air velocity at the mild weather ventilating rate. Determine required and available attic openings:

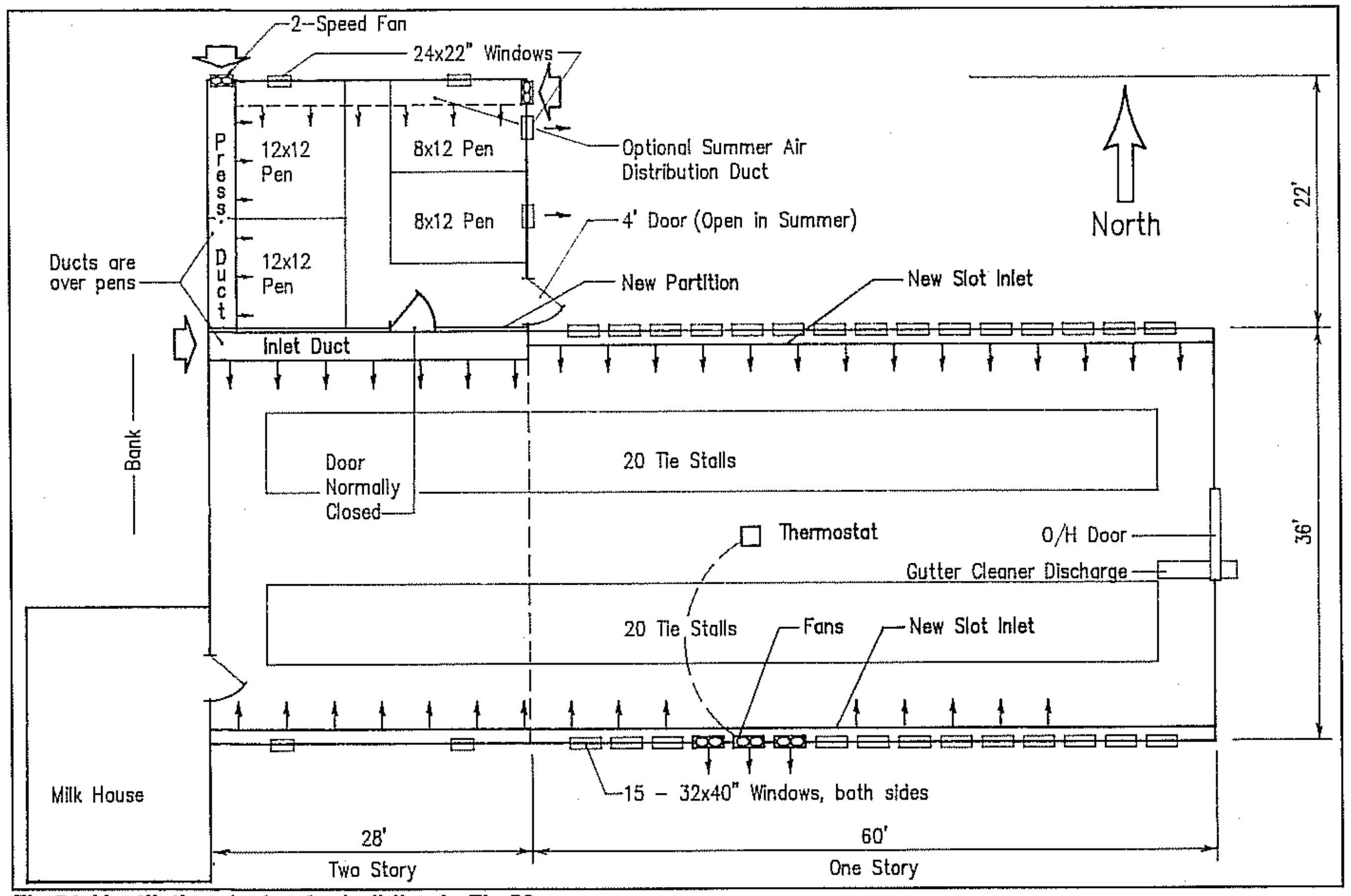


Fig 54. Ventilation design for building in Fig 53.

Mild weather airflow = 34.0 cfm/ft × (2 × 60') = 4,080 cfm.
Minimum attic opening = 4,080 cfm ÷ 200 fpm = 20.4 ft^2.
South eave attic opening = 60' × (3.75" ÷ 12 in/ft) = 18.8 ft^2.
1' × 1' roof ridge ventilator attic opening = 1' × 1' = 1 ft^2.
Total available opening = 18.8 ft^2 + 1 ft^2 = 19.8 ft^2.

Increase attic opening about 1 ft^2 with more ridge ventilators, gable louvers, or wider eave openings.

Other modifications

Increase ceiling insulation to at least R=33, 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 (0-2 mo) and 50 heifers (3-8 mo) in Madison, Wisconsin. See Fig 55. Two housing sections are needed. Calves are in 2' × 4' elevated crates; young heifers are on bedded pack.

Solution:

Young calf housing

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

Fans: 240 cfm continuous cold weather fan; 560 cfm mild weather fan (800 cfm – 240 cfm); 800 cfm hot weather fan (1,600 cfm – 800 cfm).

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 × 16' = 32'. During winter, close inlets 8'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/ft.
Nearly ½" slot is required for tight buildings.

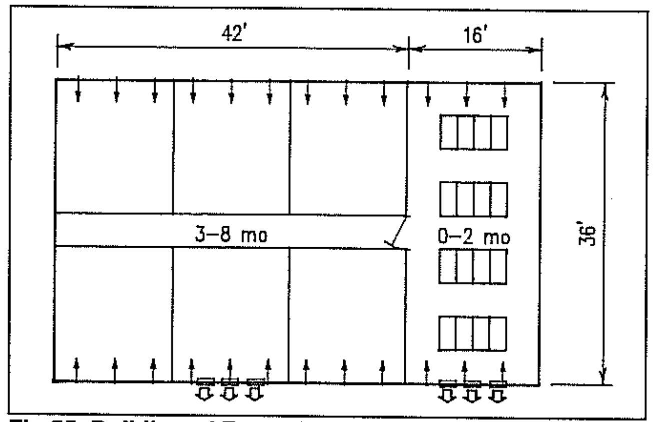


Fig 55. Building of Example 13.

Mild weather inlet: 800 cfm ÷ 32' slot length = 25 cfm/ft.
A little more than ½" slot is needed.
Hot weather inlet: 1,600 cfm ÷ 32' slot length = 50 cfm/ft.
1¼" slot is required.

Make the building slot opening about 1½" and cover with a baffle to adjust for different ventilating rates. Install a manometer in the room and adjust the baffle to maintain a static pressure of about 0.04".

Supplemental heat: Provide supplemental heat to keep the room at 60 F-70 F. Estimate the supplemental heater size from Table 26. For 16 calves at 1,000 Btu/hr-hd, 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 58 F.

Insulate 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/hd × 50 hd = 1,000 cfm
Mild weather rate: 60 cfm/hd × 50 hd = 3,000 cfm
Hot weather rate: 130 cfm/hd × 50 hd = 6,500 cfm

Fans: 1,000 cfm continuous cold weather fan; 2,000 cfm (3,000 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 84' (2 × 42'). Close 16' of inlet over the continuous cold weather fan in winter. Cold weather inlet length is 68' (84' – 16').

Cold weather inlet: 1,000 cfm ÷ 68' slot length = 14.7 cfm/ft.
From Table 3, ⅜" slot is required in a tight building.
Mild weather inlet: 3,000 cfm ÷ 84' slot length = 35.7 cfm/ft.
¾" slot is required.
Hot weather inlet: 6,500 cfm ÷ 84' slot length = 77.4 cfm/ft.
1¾" 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 2'x5' elevated wooden pens within the first week of age (100 lb). Start calves at 70 F and decrease the temperature 1 F every 3 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 calf heat helps warm the room. A gas valve modulating type furnace maintains constant temperature in air tempering corridors or use

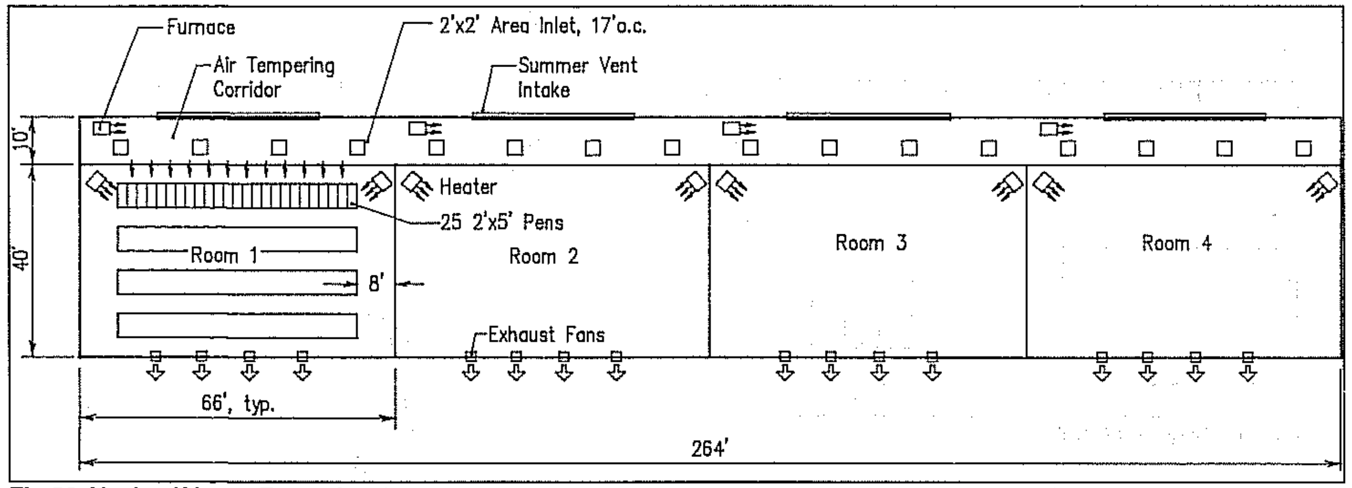


Fig 56. Veal calf barn, Example 14.

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 56. 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 × 100 calves × 100 lb/calf = 1,000 cfm

Cold weather, 400 lb calves:

10 cfm/100 lb × 100 calves × 400 lb = 4,000 cfm

Mild weather:

20 cfm/100 lb × 100 calves × 400 lb = 8,000 cfm

Hot weather:

50 cfm/100 lb × 100 calves × 400 lb = 20,000 cfm

Cold weather fan: 1,000 cfm continuous fan. Install a second fan for minimum ventilation for larger calves: 3,000 cfm (4,000 cfm – 1,000 cfm). Install a timer on this fan to adjust as calves grow.

Mild weather fan: 4,000 cfm (8,000 cfm – 4,000 cfm) fan on a thermostat set at 55 F.

Hot weather fan: 12,000 cfm (20,000 cfm – 8,000 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 inlet to the outside and pull air only from the air tempering corridor. In hot weather, open slot inlets on both sides. Total cold and mild weather slot length in each room is 66'. Total hot weather slot length in each room is 132' (2 x 66'). Required inlet opening:

Cold weather inlet (100 lb calves):

1,000 cfm ÷ 66' slot length = 15.2 cfm/ft.

From Table 3, ½" slot required.

Cold weather inlet (400 lb calves):

4,000 cfm ÷ 66' slot length = 60.6 cfm/ft.

1½" slot required.

Mild weather inlet:

8,000 cfm ÷ 66' slot length = 121.2 cfm/ft.

2¾" slot required.

Hot weather inlet:

20,000 cfm ÷ 132' slot length = 151.5 cfm/ft.

3½" slot required.

Make the slot opening on both sides about 5" and close down 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 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 ft^2 of inlet area per 540 cfm: 8,000 cfm/room × 4 rooms × 1 ft^2/1,000 cfm = 59 ft^2.

Provide 16-2'x2' 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.

Corridor furnace: Fans can deliver air about 50'; space four furnaces uniformly in the corridor. Run furnace fans continuously in winter. The furnaces must heat air from -10 F to 40 F. Size furnaces for the maximum cold weather ventilating rate of 4,000 cfm/room.

Heating capacity: 4,000 cfm/room × 4 rooms × 1.1 Btu-min ÷ F-hr-ft^3 × (40 F – (-10 F)) = 880,000 Btu/hr.

Use four 200,000 Btu/hr heaters (880,000 Btu/hr ÷ 4). Set heater thermostats at 38 F. Vent furnaces or increase ventilating rate by 3,200 cfm (2½ cfm/1,000 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 1,000 cfm/room.

Determine building surface heat loss with Eq 2, Appendix.

Ceiling heat loss + wall heat loss = building heat loss.

2,640 ft^2 × (70 – (-10))F ÷ (33 Btu/hr-ft^2-F) + 954 ft^2 × (70 – (-10))F ÷ 20 Btu/hr-ft^2-F = 10,216 Btu/hr.

Heat loss from water 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 ventilating rate is 1,000 cfm.

1,000 cfm × 1.1 Btu-min ÷ hr-ft^3-F × (70-40)F = 33,000 Btu/hr

Determine heat produced by the animals. From Table 25, a 100 lb Ayrshire calf produces 310 Btu/hr with 73 F room temperature.

100 hd × 310 Btu/hr/hd = 31,000 Btu/hr

Balance heat losses and production to find furnace size.

Furnace heat = Building loss + Evaporative loss + Ventilation loss – Animal heat production.

Furnace heat = 10,216 Btu/hr + 83,000 Btu/hr + 33,000 Btu/hr – 31,000 Btu/hr = 95,216 Btu/hr.

Note that about 65% of the total heat loss is to evaporate moisture in the room. With vented heaters additional ventilation capacity is not needed. 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 shut 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. Show horses can maintain a short hair coat down to 40 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 to an R-value of 3 or more reduces condensation in winter and solar heat gain in summer. For warm housing, insulate to recommended levels. See Fig 57 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 cable 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 for each 1,000 lb of animal weight. With 12'x12' box stalls and a 12' center alley, the animals provide only 9 to 14 Btu/hr-ft^2 per 1,000 lb, which is much lower than other typical animal housing. Because of low animal density, more supplemental heat is needed—about 5,000 Btu/hr per stall, Table 26. For a more accurate estimate, calculate building and ventilation heat losses using Chapter 11.

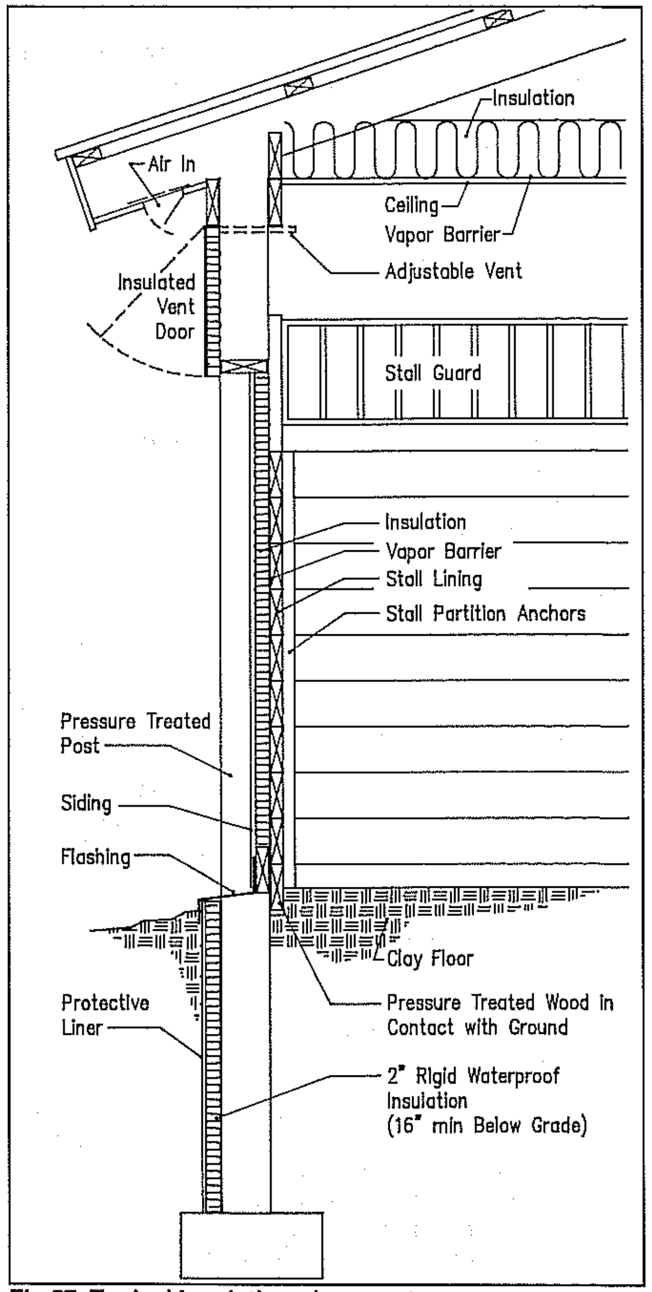


Fig 57. Typical insulation placement.

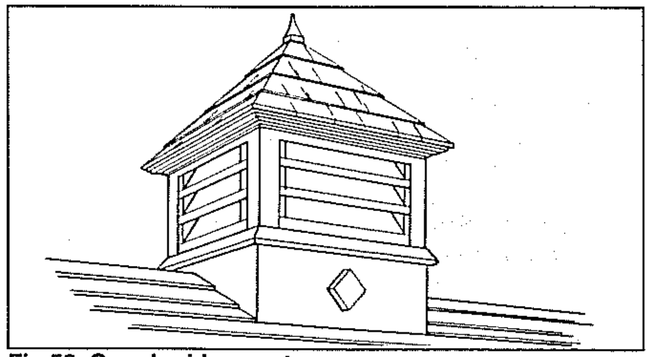


Fig 58. Cupola ridge vent.

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 brooding hover temperature.

Turkey poults: Provide the following temperatures: first 3 to 7 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 9 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 hovers (brooders) are common for supplemental heat. The hover promotes radiant heat transfer to chicks. A whole room 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 housing. Pull all incoming air through the wetted pads. Operate at or above hot weather ventilating rates to achieve the greatest production benefits. Pad systems operating at 80% 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. Line water pressure up to 600 psi. Cooling capacity is about half of pad systems at about 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 between cleanings. See Fig 59.

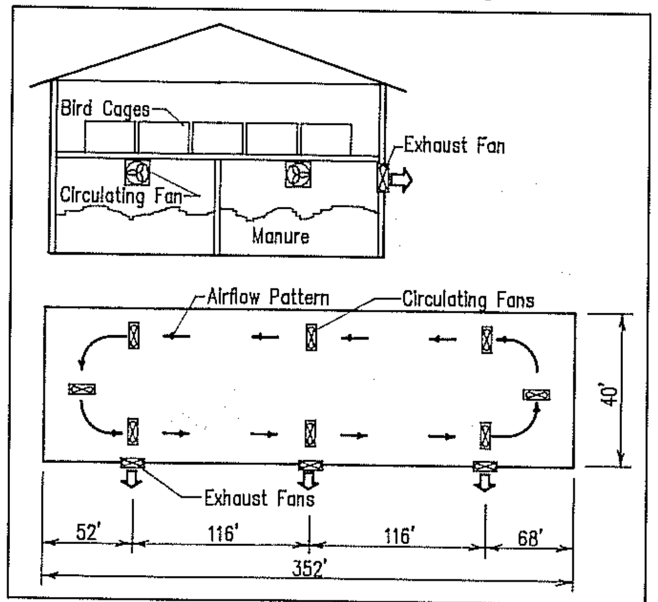


Fig 59. Deep pit ventilation.

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 3 birds/ft^2 in high-rise houses, manure dries to 50% moisture or less causing few odor and handling problems. With 5 or more birds/ft^2 in triple-deck systems, manure does not dry below 50% moisture unless pit air velocities are increased.

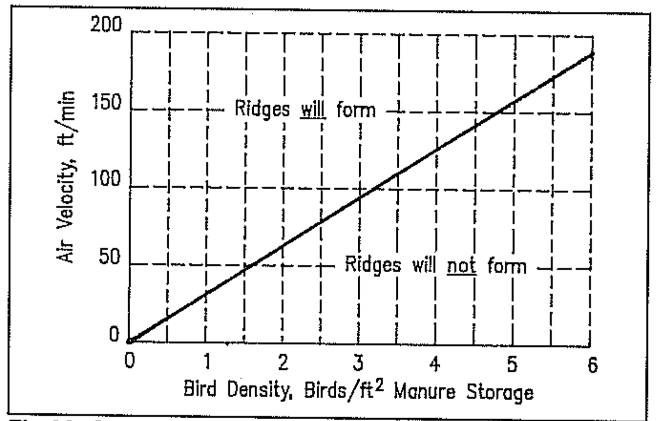


Fig 60. Conditions for manure ridge formation.
In high-rise poultry house.

Example 15:

Design the ventilating system and building to house 20,000 broilers to be marketed at 4 lb. Building is located in central Missouri. Bird density is 0.8 ft^2/bird.

Solution:

A mechanically ventilated building with brooders is needed.

Building dimensions: Determine house dimensions to maintain a bird density of 0.8 ft^2/bird. Required area is 16,000 ft^2 (20,000 birds × 0.8 ft^2/bird). Use a 40' wide house because wider houses are difficult to ventilate. Required house dimensions are 40' × 400' (16,000 ft^2 ÷ 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 3½" 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 × 0.1 cfm/lb × 4 lb = 8,000 cfm
Mild weather rate:
20,000 birds × 0.5 cfm/lb × 4 lb = 40,000 cfm
Hot weather rate:
20,000 birds × 1.0 cfm/lb × 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 temperature and moisture stratification.

Mild weather fans: Select one 32,000 cfm or two 16,000 cfm mild weather fans (40,000 cfm – 8,000 cfm). Set thermostats at 70 F.

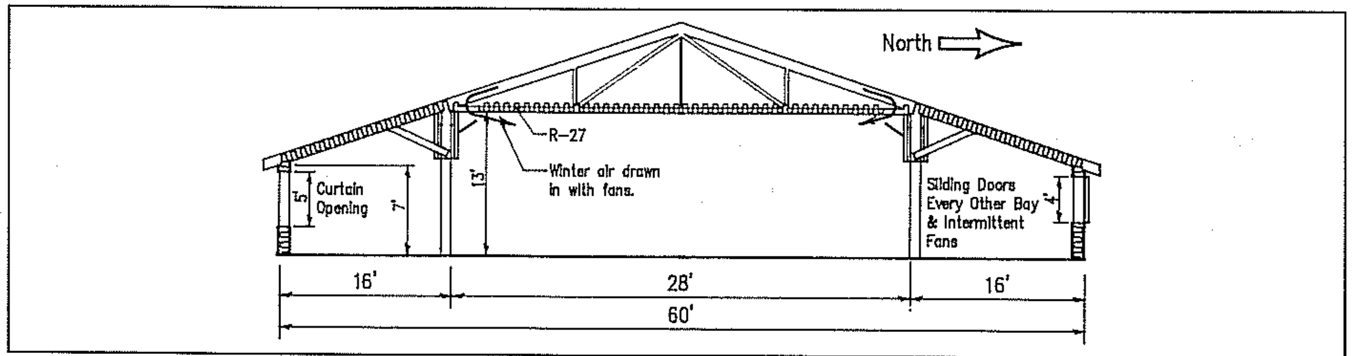


Fig 61. Brooder and grower building cross section (Example 16).

Hot 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 in 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 ½".
Mild weather inlet:
40,000 cfm ÷ 400' = 100 cfm/ft.
Slot opening is about 2¼".
Hot weather inlet:
80,000 cfm ÷ 400' = 200 cfm/ft.
Slot opening is 4½".

Adjust the continuous curtain to provide needed inlet size or install an 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 flocks is not necessary. Completely clean out at least once a year. Between flocks, remove caked litter around feeders, brooders, and drinkers. 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. Put chicks in half 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, 75 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: poults from one day to 8 weeks at 1 ft^2/tom; 10,000 toms × 1 ft^2/tom) = 10,000 ft^2. Growout building: 3.5 ft^2/tom; 10,000 toms × 3.5 ft^2/tom = 35,000 ft^2.

Make the brooder building 60'x167' (60' × 167' = 10,020 ft^2). Use two growout buildings, each 60'x290' (60' × 290' × 2 = 34,000 ft^2), Fig 61.

Insulation: Insulate the ceiling and roof to R=33 and the walls, endwalls, and doors to R=20, Table 9. Grower buildings are cooler and growers produce more heat, so insulate the ceiling and roof to R=25 and walls, endwalls, and doors to R=12.

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

Cold weather rate (Table 2):
10,000 birds × 0.2 cfm/hd = 2,000 cfm
Mild weather rate:
10,000 birds × 0.7 cfm/hd = 7,000 cfm
Hot weather rate:
10,000 birds × 2 cfm/hd = 20,000 cfm

Install two 2,000 cfm fans, two 3,000 cfm fans, and two 5,000 cfm fans. Space fans evenly in both sidewalls. One 2,000 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 4'x8' insulated sidewall doors 40' apart and at least 2' above outside grade.

Brooder inlets are continuous slots along both sides of the 28' center section. Bring air in through ducts from lean-to eaves or through ceiling inlets from the attic. Total slot inlet length is 334'.

Cold weather rate inlet:
2,000 cfm ÷ 334' = 6.0 cfm/ft.
From Table 3, slot opening is ⅛". As an option to the narrow slot, consider closing half the inlet and opening the other half to ¼" in winter.
Mild weather rate inlet:
7,000 cfm ÷ 334' = 21.0 cfm/ft.
Slot opening is ½".
Hot weather rate inlet:
20,000 cfm ÷ 334' = 59.9 cfm/ft.
Slot opening is just under 1½".

Size slot openings at about 2" and close down with an adjustable baffle to maintain static pressures of about 0.04" 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 pancake type hovers 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 poults per brooder ring. Maintain brooder temperatures at 90 F, 85 F, 80 F for the first, second, and third week respectively, and maintain room temperatures about 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 flocks and place new poults on fresh bedding. During brooding, replace wet litter around waterers. If relative humidity is too high or litter begins to feel damp, increase ventilation until the litter dries. Wet litter and fecal material sticking to poult footpads can cause serious health problems. Completely wash and disinfect building and equipment surfaces between flocks.

Grower ventilation: Provide for natural ventilation in hot weather, as described in MWPS-33, *Natural Ventilating Systems for Livestock Housing.*

Required ventilating rates depend on bird weight and outside temperature, Table 2. Table 22 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 curtains 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.

Table 22. Ventilating rates for grower building.
These ventilating rates are for one building with 5,000 birds. NAT = natural ventilation.

Bird weight, lb	Bird age, wk	Ventilating rate Cold weather	Mild weather	Hot weather
		------- cfm	--------	
6¼	8	2,500	10,940	NAT
14	13	5,600	24,500	NAT
25	19	10,000	43,750	NAT
32	23	12,800	56,000	NAT

Install 800,000 Btu/hr of heating capacity to preheat the grower barn before new poults 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 poults 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 60 F at 15 weeks of age.

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

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

Example 17:

Design ventilation for a 56,320 bird, 40'x352' building in New York for layer hens averaging 3.8 lb/bird. The building is high rise construction with an 8' high manure storage underneath. Bird density is 4 birds/ft^2.

Solution:

Insulate the ceiling to at least R=33 and the walls to at least R=20, 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:
56,320 birds × 0.1 cfm/lb × 3.8 lb = 21,400 cfm
Mild weather ventilation:
56,320 birds × 0.5 cfm/lb × 3.8 lb = 107,000 cfm

Hot weather ventilation:
56,320 birds × 1.0 cfm/lb × 3.8 lb = 214,000 cfm

Install two 11,000 cfm 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 cfm (107,000 cfm – 22,000 cfm). Four 22,000 cfm fans are needed in addition to cold weather fans. Hot weather ventilation fans must provide 104,000 cfm (214,000 cfm – 110,000 cfm). An additional four 20,000 cfm fans and one 25,000 cfm 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 two at a time 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' (352' × 2). 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 cfm ÷ 672' of slot length = 32.7 cfm/ft.
From Table 3, slot opening is ¾".

Mild weather inlet:
110,000 cfm ÷ 704' of slot length = 156.3 cfm/ft.
Slot opening is 3½".

Hot weather inlet:
215,000 cfm ÷ 704' of slot length = 305.4 cfm/ft.
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 procedures 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 59. From Fig 60, an air velocity **over** 125 fpm is required for a bird density of 4 birds/ft^2. 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 above 75 F. In cold climates, air make-up heaters may be needed. Typical lighting schedule is a 15 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 inlets 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 55 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. Temporary 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 heat costs, Table 9.

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 (frequently 1 lb/ft^2 or less) makes it difficult to control cold weather rates 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 ventilating system for a 100 doe rabbitry producing fryers. A 30'x120' building has R=14 sidewall and R=25 ceiling insulation.

Solution:

See Table 23.

Table 23. Rabbit cages and animal weight.
100 doe rabbitry.

Animal group	No. cages	Individual animal weight, lb	Total animal weight, lb
Doe + litter	100	10	1,000
Bucks	10	12	120
Replacement doe	30	7	210
Grow out (8 animals/group)	60	5	2,400
Total live weight			3,730 lb

Cold weather ventilation (Table 2):
3,730 lb × 0.1 cfm/lb = 373 cfm

Mild weather ventilation:
3,730 lb × 0.5 cfm/lb = 1,865 cfm

Hot weather ventilation:
3,730 lb × 1.0 cfm/lb = 3,730 cfm

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 15% 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 cfm of airflow—two 24"x24" shutters. Open one power shutter in mild weather and both in hot weather.

One single speed 400 cfm 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 cfm and high capacity of 3,500 cfm (or one 1,500 cfm and one 1,900 cfm fan) is for mild and hot weather. Set thermostats to provide low volume rate at 45 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/ft^2 to maintain 45-50 F inside when outside temperature is -10 F. Put a 25,000 Btu/hr heater near the inlet end of the recirculation tube.

Install both temperature and power failure alarms.

Example 19:

Design a mechanical/natural ventilating system for a 60 doe fryer production unit housed in a 20'x110' building with curtained sidewalls. The building is in southern Iowa.

Solution:

See Table 24.

Table 24. Rabbit cages and animal weight.

Animal group	No. cages	Individual animal weight, lb	Total animal weight, lb
Doe	60	10	600
Bucks	6	12	72
Replacement animals	18	7	126
Grow out (8 animals/group)	36	5	1,440
Total live weight			2,238 lb

Cold weather ventilation (Table 2):
2,238 lb × 0.1 cfm/lb = 223 cfm

Mild weather ventilation:
2,238 lb × 0.5 cfm/lb = 1,119 cfm

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 cfm exhaust fan (cold weather rate) in the wall opposite the tube inlet. Run this fan continuously with a low temperature shut off below 35 F. Cracks around curtain provide enough inlet area.

Install a 1,000 cfm 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'-6" roof overhang shades rabbits and protects from blowing rain.

Install a 30,000 Btu/hr 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 5 and warm buildings as in Table 9.

Ventilation and Heat

Naturally ventilated buildings are discussed in MWPS-33, *Natural Ventilating Systems for Livestock Housing*. Warm buildings often have mechanical winter ventilation. See Table 2. Circulation fans increase air speed over animals and reduce summer ventilating rates up to 40%. Consider evaporative cooling.

Supplemental heat (400 Btu/hr/ewe) 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: 20 ft^2/ewe. Average weight for a ewe and lamb: 225 lb. Use a negative pressure ventilating system for cold and mild weather ventilation and natural ventilation for hot weather.

Solution:

Building dimensions for 200 ewes: Floor space is 4,000 ft^2 (200 ewes × 20 ft^2/ewe). Select 40' width. Plan 40'x100' (4,000 ft^2 ÷ 40' = 100') building with solid floors and 10'-12' high sidewalls for good summer natural ventilation.

Insulate supplementally heated building in northern Illinois to R=33 in the ceiling and R=20 in the outside walls, Table 9. Insulate doors. Provide a 6-mil polyethylene plastic vapor retarder on the warm side of the ceiling and walls.

Ventilation: If possible, orient the building east-west to minimize summer heat gain and take advantage of summer breezes. Install continuous sidewall doors or panels at least 60" high along both sidewalls for summer.

Cold weather rate (Table 2):

25 cfm ÷ 1,000 lb × 225 lb/ewe × 200 ewes = 1,125 cfm

Mild weather rate:

100 cfm ÷ 1,000 lb × 225 lb/ewe × 200 ewes = 4,500 cfm

Select a 1,200 cfm fan for continuous cold weather ventilation and two 1,700 cfm fans for mild weather. Thermostats turn on mild weather fans as temperature rises.

Inlets: Install continuous slot inlets along the ceiling of both side walls. Total slot inlet length is 200' (100' × 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 ÷ 184' of slot length = 6.5 cfm/ft. From Table 3, slot opening is just over 1/8", 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-ewe of supplemental heat and 250 watt heat lamps for the lambing pens. 400 Btu/hr-ewe × 200 ewes = 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.

Swine

General

Farrowing: A new-born pig requires 90-95 F for the first three days, but a sow wants 60-75 F. Provide two zones by keeping the farrowing room at 65-75 F and supply supplemental heat in creeps for at least the first week after farrowing. Room temperature can be 60 F if bedding is used.

Nursery: For 3-week-old pigs in a prenursery, provide 85 F at pig level for the first few days after weaning. Lower the temperature 3 F/week to about 70 F for 8-week old pigs. Warm the floor with infrared heaters, heating pads, or floor heat. With only space heaters, maintain warm floors with higher thermostat settings. For prenursery, consider pre-heating ventilating air to reduce chilling drafts.

In a non-bedded sow-pig nursery, keep the room at 65-75 F with supplemental heat in the creeps. With bedding or hovers, room temperature can be 60 F.

Growing and finishing: For growing and finishing pigs, 60-70 F is recommended.

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 stillborns and abortions. Keep the room at 60 F or above for sows or gilts in crates or tethers or on total slotted floors. If the floor is partly slotted and if sows are in groups that can huddle together, temperature can be down to 50 F. Colder temperatures can be tolerated with bedding, but freezing temperatures with wind can be a problem.

Keep relative humidity at about 40%-60%.

Insulation, Table 9

Install minimum insulation in open front buildings and single sow farrowing huts: 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 F increments.

For natural ventilation, get 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 hover space 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, 24'x56', 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 perimeter.

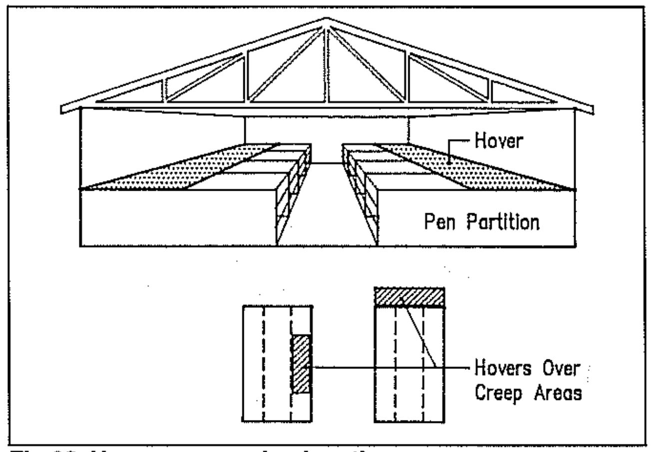


Fig 62. Hovers over animal resting areas.

Ventilation:

Cold weather rate (Table 2):

20 sows × 20 cfm/sow = 400 cfm

Mild weather rate:

20 sows × 80 cfm/sow = 1,600 cfm

Hot weather rate:

20 sows × 500 cfm/sow = 10,000 cfm

Supply the cold weather rate with one 400 cfm continuous fan. A 1,200 cfm fan on a thermostat plus the 400 cfm cold weather fan supply 1,600 cfm for mild weather. An additional 8,400 cfm with one or two additional fans on a thermostat to operate at a higher temperature, provides a total of 10,000 cfm in hot weather. Group the fans in the middle of the leeward wall.

Inlets: Provide continuous slot inlets along the ceiling of the long sides of the building. Total slot length is 112' (56' × 2). In winter, close 16' of inlets over the continuous fan. Winter baffle length is 96' (112' – 16').

Cold weather inlet:

400 cfm ÷ 96' of slot length = 4.2 cfm/ft. From Table 3, slot width is 1/8", which is too small to control, so close half the inlet sections and open the other half to about 1/4".

Mild weather inlet:

1,600 cfm ÷ 112' of slot length = 14.3 cfm/ft. From Table 3, a slot width of about 3/8" is required.

Hot weather inlet:

10,000 cfm ÷ 112' of slot length = 89.3 cfm/ft. Slot width is 2".

Make the ceiling opening about 3" wide and close down with a baffle for static pressures of about 0.04" at different ventilating rates.

Supplemental heat: From Table 26: 3,000 Btu/hr-sow are required for 70 F in a slotted floor farrowing building.

3,000 Btu/hr-sow × 20 sows = 60,000 Btu/hr

Locate two 30,000 Btu/hr unit heaters for good circulation and heat distribution. Determine heat load more accurately with the procedure in Chapter 11.

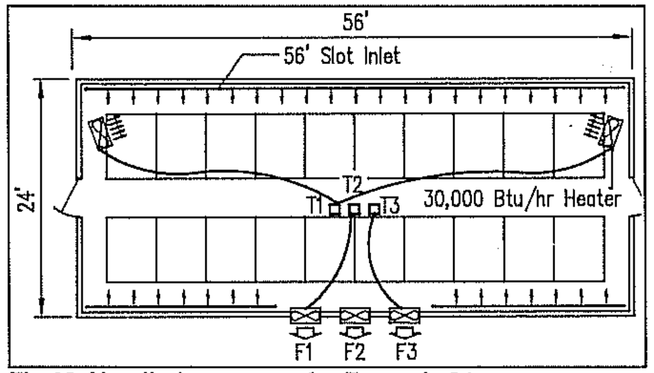


Fig 63. Ventilating system for Example 21.

For fire safety, put heaters beyond animal reach. Protect combustible materials with fire-resistant ones. Floor heat works well under hovers and reduces fire hazard.

11. APPENDIX

Animal Heat and Moisture Production

Table 25. Moisture and sensible heat from livestock.

For animals at weights not listed in the table, multiply the animal weights times the values in the per lb animal weight column. Unknown values shown as "—".

Animal	Building temperature F	Moisture production: lb water/ hr-hd	Moisture production: lb water/ hr-100 lb weight	Sensible heat loss: Btu/hr-hd	Sensible heat loss: Btu/hr-lb animal
Cattle:					
Dairy cow					
1,100 lb	30	0.65	0.08	3,200	2.9
1,100 lb	50	1.10	0.10	2,550	2.3
1,100 lb	60	1.43	0.13	2,050	1.9
1,100 lb	70	1.43	0.13	1,875	1.7
1,100 lb	80	1.98	0.18	1,025	0.93
Beef cattle					
1,100 lb	40	2.75	0.25	2,550	2.3
Calves:					
Ayrshire male					
85 lb	37	0.060	0.07	330	3.9
100 lb	37	0.070	0.07	400	4.0
85 lb	73	0.060	0.07	265	3.1
100 lb	73	0.070	0.07	310	3.1
Brown Swiss					
16 wk	50	—	0.20	—	3.6
32 wk	50	—	0.12	—	2.3
48 wk	50	—	0.10	—	2.3
16 wk	80	—	0.30	—	2.3
32 wk	80	—	0.22	—	1.7
48 wk	80	—	0.19	—	1.5
Jersey					
16 wk	50	—	0.24	—	3.9
32 wk	50	—	0.15	—	2.8
48 wk	50	—	0.13	—	2.5
16 wk	80	—	0.38	—	2.2
32 wk	80	—	0.25	—	1.5
48 wk	80	—	0.23	—	1.2
Shorthorn Brahman Santa Gertrudies					
25 wk	50	—	0.16	—	2.2
40 wk	50	—	0.11	—	1.5
55 wk	50	—	0.10	—	1.5
25 wk	80	—	0.28	—	1.1
40 wk	80	—	0.21	—	0.77
55 wk	80	—	0.18	—	0.77
Swine:					
Sow and litter					
390 lb (0 wk)	60-80	0.70	0.18	785	2.0
400 lb (2 wk)	60-80	0.96	0.24	1,050	2.6
410 lb (4 wk)	60-80	1.07	0.26	1,080	2.6
440 lb (6 wk)	60-80	1.19	0.27	1,160	2.6
500 lb (8 wk)	60-80	1.30	0.26	1,630	3.3
Nursery pigs					
10 lb	85	0.017	0.17	34	3.4
20 lb	75	0.044	0.22	96	4.8
30 lb	65	0.066	0.22	162	5.4
Growing-finishing pigs					
45 lb	40	0.11	0.25	290	6.5
	50	0.12	0.27	275	6.2
	60	0.14	0.31	205	4.6
	68	0.16	0.37	160	3.6
	77	0.21	0.47	110	2.5
	86	0.28	0.63	40	0.93
90 lb	40	0.13	0.15	410	4.6
	50	0.14	0.16	345	3.9
	60	0.17	0.19	275	3.1
	68	0.19	0.22	220	2.5
	77	0.25	0.28	165	1.9
	86	0.32	0.36	82	0.93
130 lb	40	0.16	0.12	510	3.9
	50	0.17	0.13	405	3.1
	60	0.19	0.14	345	2.6
	68	0.22	0.17	265	2.0
	77	0.26	0.20	200	1.5
	86	0.36	0.27	100	0.77
175 lb	40	0.19	0.11	600	3.4
	50	0.19	0.11	490	2.8
	60	0.21	0.12	405	2.3
	68	0.25	0.14	330	1.9
	77	0.30	0.17	230	1.3
	86	0.39	0.22	133	0.76
220 lb	40	0.21	0.094	682	3.1
	50	0.22	0.10	550	2.5
	60	0.24	0.11	440	2.0
	68	0.26	0.12	375	1.7
	77	0.31	0.14	270	1.2
	86	0.40	0.18	167	0.76
Gilts, sows, and boars					
300 lb	40	0.24	0.079	850	2.8
	50	0.24	0.079	710	2.3
	60	0.25	0.084	570	1.9
	68	0.28	0.093	475	1.5
	77	0.34	0.11	365	1.2
	86	0.40	0.13	255	0.84
400 lb	40	0.25	0.064	1,040	2.6
	50	0.25	0.063	860	2.2
	60	0.26	0.065	740	1.9
	68	0.28	0.070	600	1.5
	77	0.32	0.080	490	1.2
	86	0.38	0.096	390	0.98
Sheep:					
130 lb					
Fleece length:					
(Maintenance diet)					
Shorn	46	0.044	0.033	490	3.7
	68	0.053	0.040	305	2.3
	90	0.10	0.079	165	1.3
1"	46	0.045	0.034	245	1.9
	68	0.069	0.052	195	1.5
	90	0.17	0.13	92	0.70
2-14"	46	0.053	0.040	205	1.5
	68	0.10	0.076	140	1.1
	90	0.19	0.14	60	0.45
(13 × maintenance diet)					
434"	55	0.13	0.10	170	1.3
	73	0.20	0.15	110	0.84
Poultry:					
Layer (Leghorn)					
	46	—	0.21	—	7.0
	54	—	0.28	—	6.2
	64	—	0.29	—	6.0
	82	—	0.38	—	5.0
Broilers					
0.25 lb	85	0.00088	0.40	4.1	18.6
1.5 lb	85	0.015	1.0	14.3	9.3
	77	0.0046	0.30	16.7	10.8
	60	0.011	0.70	14.3	9.3
2.5 lb	85	0.024	1.0	15.0	6.2
	65	0.0044	0.18	26.3	10.8
	60	0.011	0.45	13.5	5.6

Table 25. Moisture and sensible heat (continued).

Animal	Building temperature F	Moisture production: lb water/ hr-hd	Moisture production: lb water/ hr-100 lb weight	Sensible heat loss: Btu/hr-hd	Sensible heat loss: Btu/hr-lb animal
3.5 lb	65	0.0071	0.20	31.1	8.8
4.5 lb	65	0.0062	0.14	32.8	7.4
Turkeys:					
Large white					
Toms					
0.22 lb	95	0.0034	1.56	2.08	9.4
0.44 lb	90	0.0043	0.98	4.30	9.8
0.88 lb	85	0.0064	0.72	7.37	8.4
1.32 lb	80	0.0054	0.41	12.08	9.1
2.20 lb	75	0.0053	0.24	21.50	9.8
33 lb	75	0.0562	0.17	56.32	1.7
Hens					
18 lb	75	0.0253	0.14	39.19	2.2
Beltsville White					
Toms					
19.5 lb	65	0.031	0.16	72.9	3.7
	78	0.039	0.20	51.6	2.6
Hens					
9.5 lb	65	0.014	0.14	36.0	3.7
	78	0.037	0.38	15.0	1.5
Broad Breasted Bronze					
Toms					
37.5 lb	50	0.013	0.035	110.3	2.9
	60	0.020	0.053	98.6	2.6
	65	0.025	0.066	92.8	2.5
35 lb	75	0.031	0.088	81.9	2.3
37.5 lb	85	0.041	0.11	47.0	1.3
35 lb	95	0.053	0.15	24.0	0.68
Hens					
21.5 lb	50	0.0067	0.031	70.2	3.3
21.0 lb	60	0.016	0.075	61.6	2.9
	65	0.015	0.070	51.9	2.5
20.5 lb	75	0.017	0.083	47.6	2.3
20.0 lb	85	0.020	0.10	31.1	1.5
19.0 lb	95	0.025	0.13	19.0	0.99

Table 26. Sizing supplemental heaters.

Use these peak loads only for rough estimates and only where winter degree days are greater than 5,000. These values are based on the minimum outdoor design temperature and twice the cold weather ventilating rate in a moderately well insulated building with normally accepted stocking densities. Reserve heater capacity can handle heating needs when only a few animals are present. Additional zone heat may be needed for young animals.

Animal unit	Inside temp, F	Supplemental heat per animal unit: Slotted floor (Btu/hr/unit)	Supplemental heat per animal unit: Bedded/scraped floor (Btu/hr/unit)
Swine			
Sow and litter	80	4,000	—
	70	3,000	—
	60	—	3,500
Prenursery pig (12-30 lb)	85	350	—
Nursery pig (30-75 lb)	75	350	—
	65	—	450
Growing-finishing pig (75-220 lb)	60	600	—
Gestating sow/boar	60	1,000	—
Dairy			
Calf housing		1,000 Btu/hr/calf	
Double 4-HB parlor		50,000 Total Btu/hr	
6- or 8-HB parlor		70,000 Total Btu/hr	
Milkhouse		10,000 Total Btu/hr	
Sheep, lambing		400 Btu/hr/ewe Plus heat lamps	
Horse, warm barn		5,000 Btu/hr/stall	

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 value (R_T) of the building surface; the higher the R_T value, the lower the heat flow rate. Heat loss from **each** building surface, BSL, is given by:

$$BSL = (A/R_T) \times (t_i - t_o) \quad \text{Eq 2.}$$

- BSL = Heat loss rate through a surface, Btu/hr
- A = Surface area, ft^2 (i.e. wall area)
- R_T = Total resistance of the surface to heat flow, F-ft^2-hr/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.

Heat loss through the floor perimeter is a special case. The surface area, A, in Eq 2, is replaced by the length (perimeter) of the exterior wall. The R_T value in Table 8 is given per foot of length.

Building heat loss through all surfaces, BHL, can be expressed as the sum of all surface area/resistance ratios (A/R) times inside-outside temperature difference (Δt).

$$BHL = (A/R) \times \Delta t$$

Where:

- BHL = Total building heat loss
- A/R = The sum of all (area/resistance) ratios of the building, Btu/hr-F
  - = Ceiling (A/R) + frame wall (A/R) + concrete wall (A/R) + perimeter (A/R) + window (A/R) + door (A/R)
- Δt = Difference between inside and outside temperature, t_i-t_o (F)

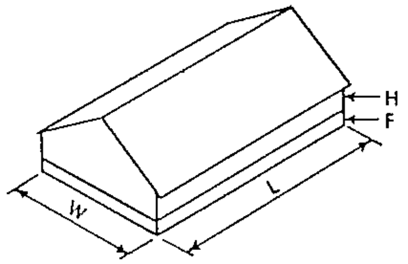
Example 22:

Find the heat loss from the 24'x36' building of Fig 64. Inside design temperature is 75 F, and outside is 0 F. The building has two 3'x7' doors, insulated with 1" of 1 pcf molded polystyrene. There are no windows.

Solution:

Step 1: Using the worksheet, fill in the blanks with the length, width, wall height, and foundation height. Calculate the perimeter, frame wall and concrete wall area (excluding windows and doors), ceiling area, window area, and door area. Find the insulation R-values in Table 8. Frame wall resistance is 12.47. The R_T for a 6" concrete wall with 2" polystyrene insulation is 9.33. The R_T for the ceiling is 13.98 and for the doors is 7.99. For 2"x24" polystyrene perimeter insulation, the R_T value is 2.22.

Worksheet – Heat loss through building surfaces



Step I

Building dimensions (ft), **Surface area** (ft^2)

Length (L) ____

Width (W) ____

Frame wall height (H) ____

Concrete wall height (F) ____

Perimeter ____

Ceiling area ____

Window area ____

Door area ____

Frame wall area

less window & door area ____

R_T values

Ceiling ____

Window ____

Door ____

Frame wall ____

Concrete wall ____

Perimeter ____

Design temperatures, F

t_o (outside temp.) = ____, t_i (inside temp.) = ____,

Δt = ____.

Step II

Building heat loss, q_b

Ceiling	$q_c = \dfrac{\Delta t \times \text{ceiling area}}{\text{ceiling } R_T}$	$q_c = \dfrac{\Delta_t \times (\quad)}{(\quad)}$	$= \Delta_t F \times ($ ____	Btu/hr-F)
Windows	$q_{wi} = \dfrac{\Delta t \times \text{window area}}{\text{window } R_T}$	$q_{wi} = \dfrac{\Delta_t \times (\quad)}{(\quad)}$	$= \Delta_t F \times ($ ____	Btu/hr-F)
Doors	$q_d = \dfrac{\Delta t \times \text{door area}}{\text{door } R_T}$	$q_d = \dfrac{\Delta_t \times (\quad)}{(\quad)}$	$= \Delta_t F \times ($ ____	Btu/hr-F)
Frame walls	$q_w = \dfrac{\Delta t \times \text{frame wall area}}{\text{frame wall } R_T}$	$q_w = \dfrac{\Delta_t \times (\quad)}{(\quad)}$	$= \Delta_t F \times ($ ____	Btu/hr-F)
Concrete walls	$q_f = \dfrac{\Delta t \times \text{concrete wall}}{\text{concrete wall } R_T}$	$q_f = \dfrac{\Delta_t \times (\quad)}{(\quad)}$	$= \Delta_t F \times ($ ____	Btu/hr- F)
Perimeter	$q_p = \dfrac{\Delta t \times \text{perimeter}}{\text{perimeter } R_T}$	$q_p = \dfrac{\Delta_t \times (\quad)}{(\quad)}$	$= \Delta_t F \times ($ ____	Btu/hr-F)
		Total, $q_b = \Delta_t \times A/R$	$= \Delta_t F \times ($ ____	Btu/hr- F)

Total, q_b = ____ × ____ = ____ Btu/hr

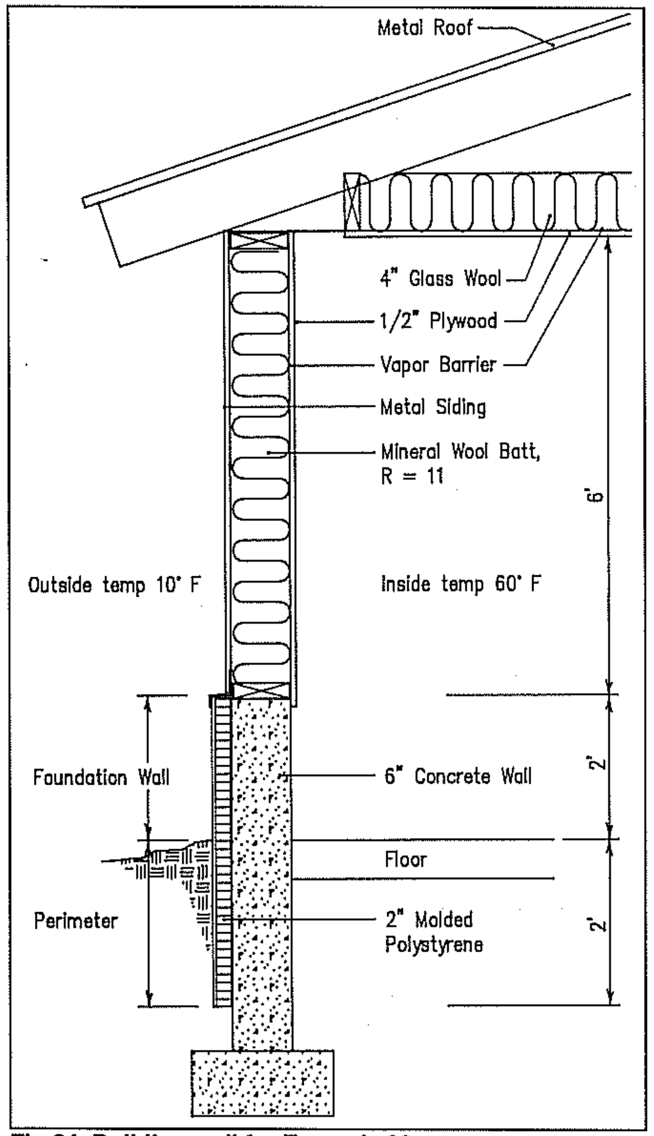


Fig 64. Building wall for Example 22.

Step 2: Determine A/R for the building by adding A/R values of each building surface. Determine building heat loss by multiplying the temperature difference (Δt) by the building A/R.

Worksheet example

Calculating Heat Loss by Ventilation

Heat loss by ventilating air is proportional to the ventilating rate and the difference between the inside and outside temperatures.

$VHL = 1.1 \times cfm_c \times (t_i - t_o)$ **Eq 3.**

VHL = Heat loss rate by ventilating air, Btu/hr
cfm_c = Cold weather ventilating rate, cfm
t_i = Inside temperature, F
t_o = Outside temperature, F
1.1 = Conversion factor, Btu-min/hr-ft^3-F

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.

$THL = BHL + VHL$ **Eq 4.**
$THL = (A/R + 1.1 \times cfm_c)(t_i - t_o)$

THL = Total rate of heat loss from building, Btu/hr

$HLF = (A/R + 1.1 \times cfm_c)$ **Eq 5.**

HLF = 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_d, with Eq 7.

$t_b = t_i - (SHL \div HLF)$ **Eq 6.**

t_b = Balance point temperature, F
SHL = Total livestock sensible heat loss, Btu/hr. Multiply value from Table 25 by number of animals or total weight
HLF = From Eq 5

$C_d = A + (B \times (t_b - 32))$ **Eq 7.**

C_d = Heating degree days correction factor
A,B = 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.

$E = C_d \times 24 \times HLF \times HDD$ **Eq 8.**

E = Annual energy consumption, Btu/year
C_d = Heating degree days correction factor for livestock buildings
HDD = Heating degree days, F-day, from Fig 24

Determine annual fuel cost, AFC:

$AFC = (FC \times E) \div (EFF \times V)$ **Eq 9.**

AFC = Annual fuel cost, $
FC = Fuel cost, $/unit
E = Annual heating load, Btu/year (Eq 8)
EFF = Efficiency of heating system, %/100
V = Fuel heat content, Table 28

Table 27. Coefficients for Eq 7.

State	Coefficients A	Coefficients B
Illinois	-0.3425	0.0440
Indiana	-0.3773	0.0451
Iowa	-0.1545	0.0375
Kansas	-0.4139	0.0462
Michigan	-0.3316	0.0436
Minnesota	-0.0498	0.0339
Missouri	-0.4852	0.0489
Nebraska	-0.1428	0.0386
North Dakota	-0.0156	0.0316
Ohio	-0.3730	0.0449
South Dakota	-0.1000	0.0354
Wisconsin	-0.1271	0.0365

Table 28. Approximate fuel heat content, V.

	Heat content Btu	Heating system efficiency Eff %
Natural gas	1,000 Btu/ft^3	70-90
LP gas	93,000 Btu/gal	70-90
Fuel oil	138,000 Btu/gal	50-80
Electricity	3,413 Btu/kw-hr	100

Example 23:

The 24'x36' building in Example 22 houses 200 pigs weighing 50 lb each. The building has a cold weather ventilating rate of 600 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 75% efficient heater. Find furnace size. Location is Grand Island, NE.

Solution:

Step 1:

Ventilation heat loss rate, VHL, Eq 3.

$$\begin{aligned} VHL &= 1.1 \times cfm_c \times (t_i - t_o) \\ &= 1.1 \text{ Btu-min/hr-F-ft}^3 \times 600 \text{ cfm} \times (75 \text{ F-0 F}) = 49{,}500 \text{ Btu/hr} \end{aligned}$$

Step 2:

Find the overall heat loss factor, HLF, using Eq 5. From Example 22, A/R = 201.45 Btu/hr-F.

$$\begin{aligned} HLF &= A/R + 1.1 \times cfm_c \\ HLF &= 201.45 \text{ Btu/hr-F} + 1.1 \text{ Btu-min/hr-F-ft}^3 \times 600 \text{ cfm} = 861.45 \text{ Btu/hr-F} \end{aligned}$$

Step 3:

Determine the total sensible heat loss (SHL) by animals. Find the sensible heat loss rate value 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/lb at 68 F and 2.5 Btu/hr/lb at 77 F. Interpolate to get the heat loss at 75 F.

$$3.6 \text{ Btu/hr-lb} - ((75-68) \text{ F} \times (3.6-2.5) \text{ Btu/hr-lb} \div (77-68) \text{F}) = 2.7 \text{ Btu/hr-lb}$$

$$SHL = 2.7 \text{ Btu/hr/lb} \times 200 \text{ pigs} \times 50 \text{ lb/pig} = 27{,}000 \text{ Btu/hr}$$

Step 4:

Determine the balance point temperature, t_b, from Eq 6.

$$\begin{aligned} t_b &= t_i - (SHL \div HLF) \\ t_b &= 75 \text{ F} - (27{,}000 \text{ Btu/hr} \div 861.45 \text{ Btu/hr/F}) \\ &= 43.7 \text{ F} \end{aligned}$$

Step 5:

Calculate heating degree days correction factor, C_d, using Eq 7.

$$\begin{aligned} C_d &= [A + B \times (t_b - 32)] \\ C_d &= -0.1428 + (0.0386/\text{F} \times (43.7-32)\text{F}) = 0.309 \end{aligned}$$

Determine annual heating load, E, from Eq 8. From Fig 24, HDD is about 6,500 degree days/yr.

$$\begin{aligned} E &= C_d \times 24 \times HLF \times HDD \\ E &= 0.309 \times 24 \text{ hr/day} \times 861.45 \text{ Btu/hr-F} \times 6{,}500 \text{ F-day/yr} \\ &= 41{,}525{,}336 \text{ Btu/yr} \end{aligned}$$

Step 6:

Determine annual fuel cost, AFC, from Eq 9.

$$\begin{aligned} AFC &= (FC \times E) \div (EFF \times V) \\ AFC &= (0.7 \text{ \$/gal} \times 41{,}525{,}336 \text{ Btu/yr}) \div (0.75 \times 93{,}000 \text{ Btu/gal}) \\ &= \$417/\text{yr} \end{aligned}$$

Determining Furnace Size

The equation for determining furnace size balances building heat loss against animal heat production.

$$FS = HLF \cdot \Delta T - SHL$$

FS = Furnace size (Btu/hr)
HLF = Building heat loss factor (Btu ÷ hr · F)
ΔT = t_i - t_o at design temperature
SHL = Sensible heat loss by animals (Btu/hr)

In our example, assume t_o = -10, then Δt = 85 F and furnace size becomes:

$$FS = 861.45 \times 85 - 27{,}000 = 46{,}223 \text{ Btu/hr}$$

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 from organic fibers, primarily paper. Often used as loose-fill.

Celsius (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, an 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-ft^2-F). Conductance 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 or running water over it, cooling an animal by blowing air on it.

Degree day method: Procedure for estimating energy needs based on a 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 at 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 manure pit.

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 and the boiling point at 212.

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/lb dry air or grains water/lb dry air (7,000 grains water/lb 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 permeability. One perm equals one grain of water/hr-ft^2-in of mercury pressure difference.

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

Polyisocyanurate: Plastic foam insulation. R-value is 7.2-8.0 (ft^2-hr-F)/Btu per inch of thickness.

Polystyrene: Plastic foam insulation. R-value is 4-5 (ft^2-hr-F)/Btu per inch of thickness. R-value is higher for extruded (styrofoam) than molded polystyrene (beadboard).

Polyurethane: Plastic foam insulation. R-value is 6 (ft^2-hr-F)/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 larger the resistance to heat flow through the material. R-values are additive. Units are (hr-ft^2-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 ft^3/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.

Vapor retarder: Material resisting vapor transfer through a wall or ceiling. Materials below a perm rating of 1.0 are considered good vapor retarders.

Velocity, inlet air: Speed at which air enters a livestock room through a designed inlet. Units are ft/min.

Ventilating doors: Doors used in naturally ventilated buildings to open sidewalls for summer airflow.

Ventilating rate: Airflow rate passing through a building. Usually controlled by ventilation fans in mechanically ventilated buildings. Units are cubic feet per minute (cfm).

Ventilation: Process of exchanging air. In livestock structures, air contaminants are removed from the structure. Ventilation is used to control temperature, moisture, odors, pathogenic organisms, and dust.

Wet-bulb temperature: Temperature measured by a thermometer whose bulb is covered by a wet wick and exposed to an air stream with a velocity of 1000 ft/min. The wet-bulb temperature is a function of the rate of water evaporation from the wet wick and its resultant cooling which depends on the water vapor content in the air. (See Sling psychrometer).

Wind rosettes: Graph of wind at a site: % of time, and how fast, it blows from each direction.

13. SELECTED REFERENCES

Gas Measuring Instruments: Numbers in parentheses refer to addresses, below.

Ammonia detectors (4, 5, 7, 10)

CO_2 detectors (7, 9)

Detector tubes for instantaneous readings or average readings over a long period (1, 7)

Electronic instruments for many gases (3, 6, 8)

Hydrogen sulfide detector (2, 7)

1. BGI Incorporated; 58 Guinan St, Waltham MA 02154
2. Fracor Atlas; 9441 Baythorne Dr, Houston TX 77041
3. MDA Scientific, Inc.; 405 Barclay Blvd, Lincolnshire IL 60069
4. Matheson Gas Products, Inc.; 30 Seaview Dr, Secaucus NJ 07094
5. Mine Safety Appliance Company; 36 Great Valley Pkwy, Malvern PA 19355
6. Sensidyne, Inc.; 12345 Starkey Rd, Suite E, Largo FL 33543
7. SKC, Inc.; 334 Valley View Rd, Eighty Four PA 15330-9614
8. Texas Analytical Controls; 4434 Blue Bonnet Dr, Stafford TX 77477
9. Unico Environmental Instruments, Inc.; P.O. Box 590, Fall River MA 02722
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.

MWPS-3 *Sheep Housing and Equipment Handbook.*

MWPS-6 *Beef Housing and Equipment Handbook.*

MWPS-7 *Dairy Housing and Equipment Handbook.*

MWPS-8 *Swine Housing and Equipment Handbook.*

MWPS-15 *Horse Housing and Equipment Handbook.*

MWPS-18 *Livestock Waste Facilitis Handbook.*

MWPS-23 *Solar Livestock Housing Handbook.*

MWPS-28 *Farm Buildings Wiring Handbook.*

MWPS-33 *Natural Ventilating Systems for Livestock Housing.*

MWPS-34 *Heating, Cooling and Tempering Air for Livestock Housing.*

Available from other sources:

1989 ASHRAE Handbook of Fundamentals. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.; 345 East 47th St, New York NY 10017.

Ventilation of Agricultural Structures, 1983. American Society of Agricultural Engineers; 2950 Niles Road, St Joseph MI 49085.

Design of Ventilating Systems for Poultry and Livestock Shelters. ASAE—Engineering Practice EP270.5. American Society of Agricultural Engineers; 2950 Niles Road, St Joseph MI 49085.

14. INDEX

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ERRATA SHEET

MWPS-32, *Mechanical Ventilating Systems Handbook*

MWPS-33, *Natural Ventilating Systems Handbook*

Following is revised Table 1 found on Page 3 of MWPS-32, *Mechanical Ventilating Systems*, and MWPS-33, *Natural Ventilating Systems Handbook*.

Please note that the "Maximum allowable concentrations" has been renamed "Threshold limit value" and has been revised to reflect both long-term and short-term exposure periods for noxious gases.

Table 1. Properties, limits and effects of noxious gases.
This table is based on adult humans. The effects of two or more gases tend to be additive.

			Threshold limit value		Concentration effects		
Gas	Odor	Odor threshold, ppm	Time-weighted average (8-10 hr) ppm	Short term exposure (15 min) ppm	Level ppm	Exposure period, min	Physiological effects
		(a)	(b)	(c)	(d)	(e)	
Carbon dioxide (CO_2)	None	—	5,000	30,000			Asphyxiant
					20,000	—	Safe
					30,000	—	Increased breathing
					40,000	—	Drowsiness, headaches
					60,000	30	Heavy, asphyxiating breathing
					300,000	30	Could be fatal
Ammonia (NH_3)	Sharp, pungent	5	25	35			Irritant
					400	—	Throat irritant
					700	—	Eye irritant
					1,700	—	Coughing and frothing
					3,000	30	Asphyxiating
					5,000	40	Could be fatal
Hydrogen sulfide (H_2S)	Rotten egg smell, nauseating	0.7	10	15			Poison
					100	Several hours	Eye and nose irritant
					200	60	Headaches, dizziness
					500	30	Nausea, excitement, insomnia
					1,000	—	Unconsciousness, death
Methane (CH_4)	None	—	—	30,000[f]	500,000	—	Asphyxiant Headache, nontoxic
Carbon monoxide (CO)	None	—	50	200			Poison
					500	60	No effect
					1,000	60	Unpleasant, but not dangerous
					2,000	60	Dangerous

[a]About the lowest concentration at which odor is detected.
[b]Threshold limit value for time-weighted average exposure concentration for a normal 8 to 10 hr workday. (Source: 1989 Guide to Occupational Exposure Values, American Conference of Govemmental Industrial Hygienists, Cincinatti, Ohio.)
[c]Short term exposure limit: 15 min time-weighted average exposure limit for any time during a workday even if the 8-hr threshold limit value is within limits. (Source: 1989 Guide to Occupational Exposure Values, American Conference of Govemmental Industrial Hygienists, Cincinatti, Ohio.)
[d]Parts of pure gas per million parts of atmospheric air. Divide by 10,000 for % volume. Example: 20,000 ppm ÷ 10,000 = 2% by volume.
[e]The time until immediate reaction to the gas.
[f]Value is based on air with 18% oxygen and 3% methane. This value for methane was not obtained from the American Conference of Govemmental Industrial Hygienists. Methane is explosive at concentrations of 5%-15%.