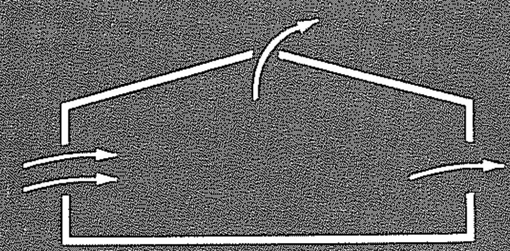
MWPS-33

Natural Ventilating Systems for Livestock Housing

First Edition, 1989



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This handbook is the result of much work by many people. Innumerable resources were used; each author's work was critically reviewed by others. It is reasonable to recognize the following for their contribution.

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.
K.A. Janni	Poultry design example.
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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 availability.

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. Refer to the Midwest Plan Service *Structures and Environment Handbook,* MWPS-1, for additional design information.

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 is important in cold weather to maintain desired room temperature and to evaporate excess moisture. A chapter on selection and use of building insulation to reduce heat loss is included.

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 fresh 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.

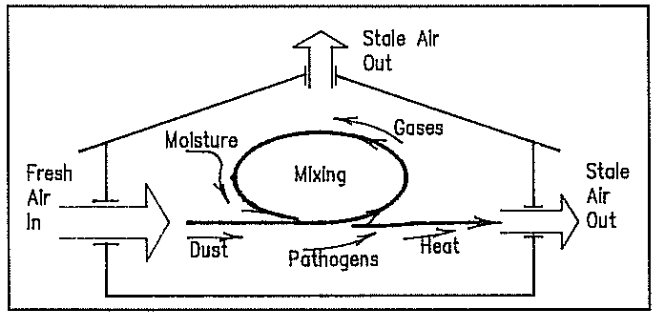


Fig 1. A basic ventilating process.

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.

Mechanically ventilate where careful control of the environment is needed, as for young and smaller animals. They are discussed in MWPS-32, *Mechanical Ventilating Systems for Livestock Housing.* Mature or large animals or animals in the "finishing" growth stages are often in naturally ventilated buildings.

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 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%.

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.

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.

H_2S can rapidly destroy the sense of smell; lack of an H_2S odor is not an adequate warning. See the Potentially Lethal Situations section. As much as 8,000 ppm (0.08%) 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) 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.

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 to 10 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.

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

Potentially Lethal Situations

Ventilating system failure can cause death by asphyxiation from lack of oxygen and increased carbon dioxide, by heat prostration, by poisoning 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.

Agitation of liquid manure releases large quantities of noxious gases and creates possible lethal conditions. If possible, remove animals and workers 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 naturally ventilated building, choose a windy day and open all ventilating doors. Stop agitation immediately if problems occur and ventilate well before entering a building.

Entering a storage pit can cause death from hydrogen sulfide or lack of oxygen. Enter a manure storage 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, 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.
- 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.
- 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.

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 have reduced feed dust.

Smaller dust particles, like those in swine nurseries, tend to stay suspended longer and can deposit deeper in the lungs. Larger 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

Farm animals 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.

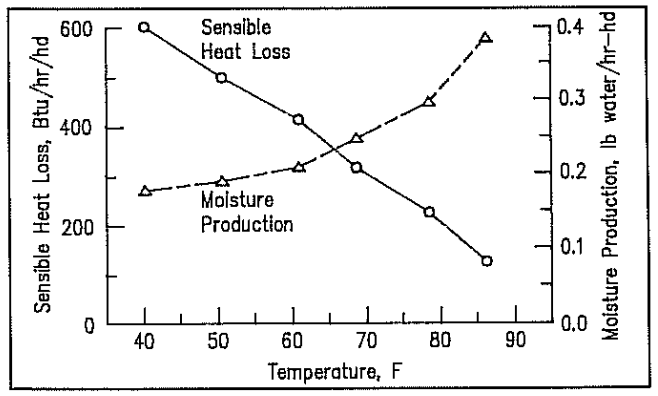


Fig 2. Heat and moisture loss vary with air temperature.
Typical sensible heat loss and moisture loss of a 175 lb pig.

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 (which increases its humidity ratio) and removes it from the building. These properties are shown schematically in Fig 3 and 4.

Even though humidity control is difficult with natural ventilation, it is desirable for room air to be at 50%-70% relative humidity. Higher humidities increase condensation; lower humidities increase dustiness. Also, 50%-70% relative humidity is detrimental to airborne bacteria found in livestock buildings.

How Much Air

Air requirements vary with animal size and outside environmental conditions. Ideally, ventilating air varies from just enough air to maintain air quality in very cold weather, up to a maximum rate to reduce heat stress in 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.

Mild weather ventilation modifies temperature and removes moisture.

Hot weather ventilation reduces heat buildup and increases air movement.

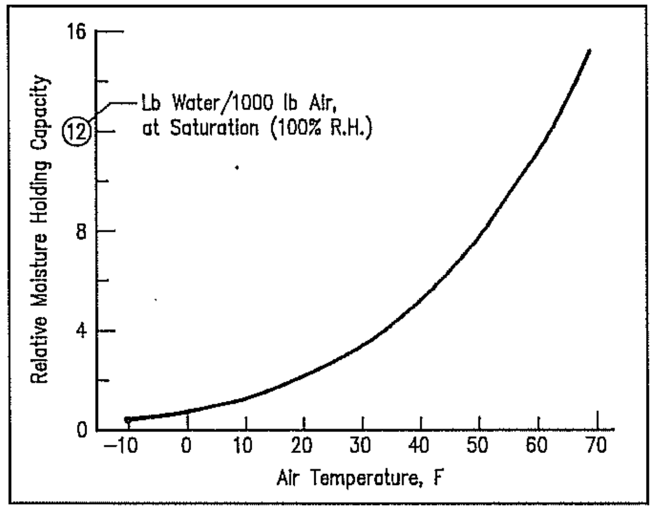


Fig 3. Moisture holding capacity of air.

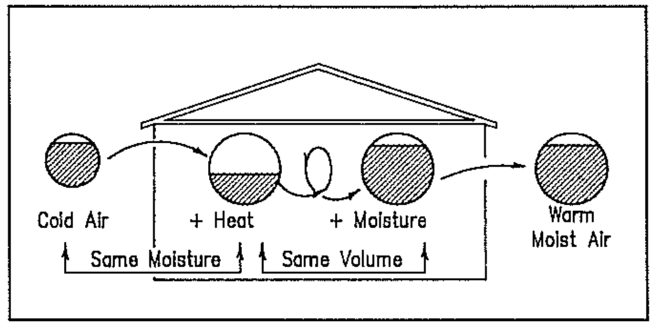


Fig 4. Heated air holds more moisture.
Air expands as it is heated and can absorb more moisture.

3. System Selection and Design

Natural ventilation moves air through adjustable and fixed openings. The openings include windows, eave openings, wall panels, vent doors, and ridge openings. Fixed openings include open building fronts and continuous eave and ridge slots.

Natural ventilation is usually more economical for mature animals than mechanical ventilation. Control of air flow and distribution is generally not precise enough for young animals, unless the building is well insulated and managed. Bedding, zone heat, and/or hovers may be needed for comfort and draft protection.

Building Types

Naturally ventilated buildings are either:
- "Cold" buildings, or
- "Modified-environment" buildings.

And in this book, they are either:
- Gable roof buildings, or
- Monoslope roof buildings.

"Cold" buildings are designed to maintain winter indoor temperatures within a few degrees of outdoor temperature. Dairy and beef animals, sheep, finishing and gestating swine, poultry, horses, and rabbits do satisfactorily in cold buildings if kept dry and adequately fed. Bedding is usually provided. These buildings are usually uninsulated or lightly insulated, often have an open front, and have limited control over airflow.

"Modified-environment" buildings are insulated and designed for higher winter indoor temperatures than cold buildings. They provide better winter performance for finishing swine and gestating sows and have fewer problems with manure freezing. Ventilation control is critical to prevent large temperature fluctuations and drafts. Without supplemental heat, freezing temperatures can occur with small animals or low animal density.

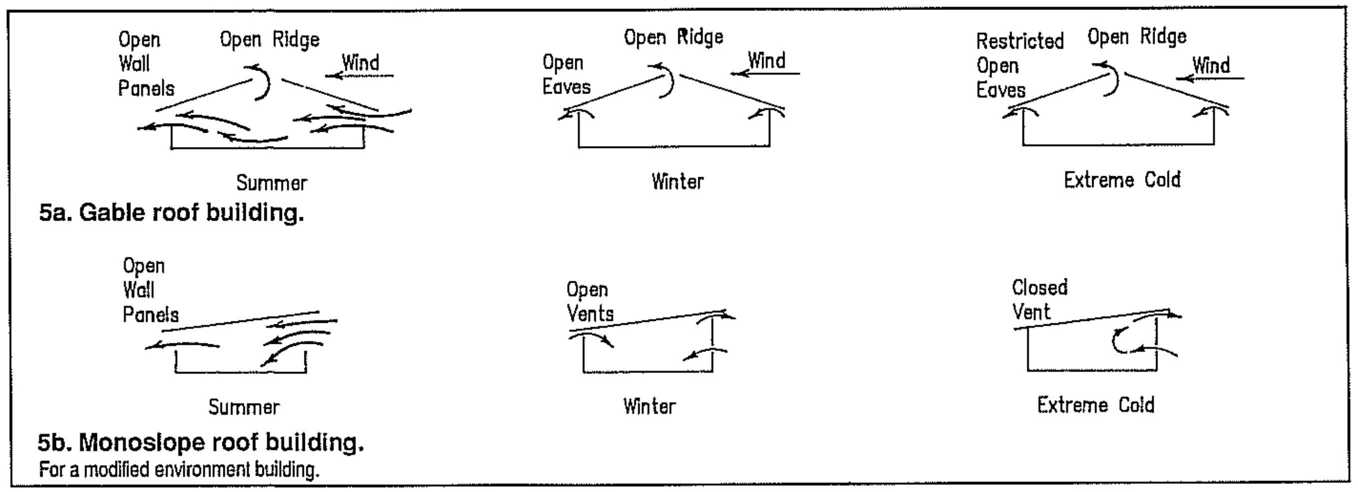
Gable buildings are best ventilated naturally with a continuous ridge opening, large sidewall openings, no ceiling, smooth roof underside, continuous eave openings, and a 3/12 or greater roof slope.

Wind across the open ridge and indoor/outdoor temperature differences exhaust air out through the ridge; fresh air enters through eave or sidewall openings, Fig 5a. Some ventilation occurs even on calm days because warm, moist air rises, causing a chimney effect. Large, adjustable sidewall openings allow increased air movement due to wind in summer.

In winter, air enters **cold buildings** through open eaves and open front walls. In **modified environment** gable buildings, winter air inlets high on sidewalls or in the eaves reduce cold drafts. Downwind eave openings usually act as air outlets. A gable-roof building with ceiling operates like a monoslope, especially in a modified environment system.

Monoslope buildings ventilate with cross flow of air both winter and summer, because these buildings have no ridge. **Cold monoslopes** are operated like open-front gable buildings. During winter, air enters through back wall eave openings or the open front and exits at the top of the front wall.

In **modified environment monoslopes,** winter ventilating air enters through small openings in the bottom of the front wall and moves 10'-15' back into the animal area, Fig 5b. Except for extremely cold periods, the back wall eave is left partly open. Air warmed by the animals rises and travels up the sloped roof to exit through the front eave opening. As outside temperatures rise, open the back eave and then the front wall panel. In summer, completely open back and front wall panels.



5a. Gable roof building.

5b. Monoslope roof building.
For a modified environment building.

Fig 5. Airflow in naturally ventilated buildings.
Airflow patterns vary with wind direction and velocity.

Other Factors

Natural ventilation moves air through a building with wind pressure differences between inlets and outlets, and differences between inside and outside temperatures.

Roof slope

Warm air rises, so steeper roofs help upward warm airflow. However, incoming air rises too rapidly along roof slopes over 6/12, and does not drop into the animal zone. The steeper and smoother the roof underside up to 6/12, the better the airflow.

Avoid roof slopes less than 3/12 for gable roofs and 2/12 for monoslope roofs. Condensation and high interior summer temperatures are a problem with flatter slopes because of reduced air movement. Roof slopes of 3/12 for gable buildings and 2/12 for monoslope buildings less than 30' wide are satisfactory. Roof slopes of 4/12 to 6/12 work very well.

Deep purlins reduce air movement along the roof and trap warm, moist air which increases condensation. Avoid exposed purlins deeper than 4". With flat ceilings, provide cold weather ventilation with pit or sidewall fans.

Openings

Properly sized ridge and eave openings and large, adjustable sidewall openings are important parts of a natural ventilating system.

Cold buildings: Ridge and eave openings are usually fixed. Make sidewall openings adjustable for different weather and season requirements.

In severe climates, adjustable eave vents reduce airflow and snow blow-in. Close eave vents only part way and then only during severe winter weather. Do not leave closed all winter. Sleeping areas near inlets can be drafty. A fascia can protect eave openings from direct wind gust and reduce drafts.

Gable roof buildings. Ridge openings are either continuous or evenly spaced along building length.

In cold climates, minimum ridge opening width is 6" to prevent the opening from freezing shut. Less than 6" can be used in warmer climates for buildings less than 30' wide. With adjustable ridge closures, increase the ridge opening 50% to improve hot and mild weather ventilation.

Protect exposed rafters or trusses with flashing. Extend the flashing 1" on each side of the truss member or rafter, Fig 9.

With a properly sized ridge opening and proper animal density, precipitation entering the building is not a serious problem. Air exiting through the ridge prevents most rain and snow from entering.

If the amount of precipitation coming through the ridge is objectionable, it is better to protect areas below the ridge than to build a cap. Cover critical components, such as a feeder motor or feeder belt, or place an internal trough 2'-3' below the open ridge to collect rain water and channel it out of the building, Fig 10. When possible, locate scraper alley or other less critical areas under the ridge.

Raised ridge caps are not recommended because they reduce airflow, can trap snow, are expensive, can corrode, and require maintenance. A ridge vent upstand, Fig 11, can help keep out snow and rain and increase the chimney effect when wind is perpendicular to the ridge. With commercial ridge ventilators, be sure the effective opening is equal to or greater than the required area.

Closures on **modified environment** building ridge openings control airflow and indoor temperature during cold periods, Fig 14. Commercial roof ventilators are available. Check and clean dust, bird nests, or frost from ventilators regularly to maintain good airflow. Size roof ventilators to provide the minimum ridge opening recommended in Table 3.

Eave openings

Construct continuous eave openings along both sides of the building. Size **each** opening of gable roof buildings for at least ½ as much open area as at the ridge. See Table 3. Note that eave openings at the high side of monoslope roofs act the same as gable roof ridge openings.

Wall openings. Larger sidewall openings give warm weather cross ventilation. Provide openings in the back of open front buildings and both long walls in enclosed buildings. For good airflow at the animal level, put the lower edge of the opening not more than 4' above the floor for cattle or 32" for swine and sheep. If construction details and animal access allow, lower openings improve airflow through the animal zone. Have vent doors open to a full horizontal position so none of the opening is constricted, or increase door size to provide the recommended open area.

With large sidewall openings, provide an overhang at the eave to shade and partly shield the opening from blowing rain. In wide buildings, provide endwall openings, such as alley doors, ventilating panels, or removable wall sections.

Building orientation

Orient naturally ventilated buildings perpendicular to prevailing summer winds to maximize airflow through large sidewall openings. Greater wind pressure differences occur when air strikes the sidewall rather than the endwall. Because air enters at the eave or sidewall and exits at the ridge, it is best if the building is also perpendicular to winter winds.

In much of the Midwest, open-front buildings with the long axis east-west are best for summer cooling, winter sun penetration, and winter wind control. The greater solar heat load on north-south oriented roofs is not a big concern for well insulated modified environment buildings. Depending on prevailing summer breezes in your area, consider turning the open front toward the SSE or SSW, especially if it also helps fit the building on the site.

Site selection

Building location is critical in a natural ventilation. Locate buildings on high ground, where trees or structures do not disturb airflow around or through the building.

Trees, silos, and other structures disturb airflow for 5 to 10 times their height downwind. Locate naturally ventilated buildings at least 50' (in any direction) from such structures or trees. As a rule, even greater separation is needed if the upwind structure is more than 80' long. Also, 75' separation between buildings for fire safety is recommended, especially for major buildings or complexes.

The wind rose maps, Fig 22 and 23, at the end of this chapter suggest winter and summer prevailing winds.

Determine required spacing between naturally ventilated buildings with Table 2. Upwind shelterbelts and buildings and seasonal prevailing winds affect minimum separation distance. In a building complex, locate naturally ventilated structures upwind in prevailing summer wind, so mechanically ventilated buildings do not interfere with prevailing wind, Fig 6.

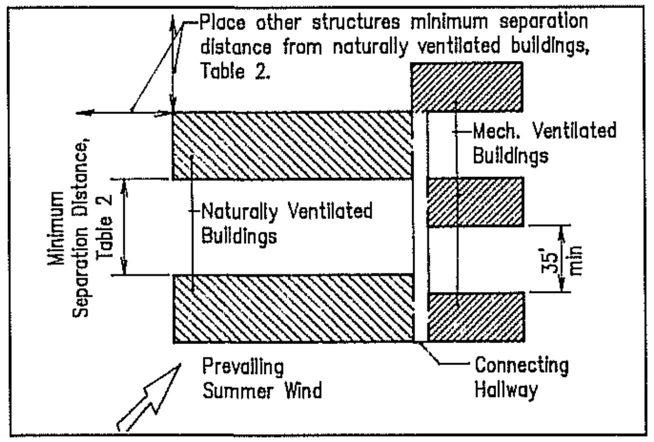


Fig 6. Layout of naturally and mechanically ventilated buildings.
Locate naturally ventilated structures upwind in prevailing summer wind, so mechanically ventilated buildings do not interfere with prevailing wind.

Table 2. Minimum natural ventilation separation distances.
Minimum separation from trees and structures for uninterrupted airflow is 50'. Recommended separation between buildings for fire protection is 75' or more.

	Windward building or obstruction Length, ft					
Height, ft	50	75	100	150	200	250
	- - - - ft of separation- - - -					
8	50	50	50	50	50	51
10	50	50	50	50	57	63
12	50	50	50	59	68	76
14	50	50	56	69	79	89
16	50	55	64	78	91	101
18	51	62	72	88	102	114
20	57	69	80	98	113	126
22	62	76	88	108	124	139
24	68	83	96	118	136	152
26	74	90	104	127	147	164
28	79	97	112	137	158	177
30	85	104	120	147	170	190

DSD = 0.4 × HGHT (ft) × √LGTH (ft)
DSD = design separation distance between buildings, ft; = 50' min.
HGHT = total building height to the ridge, ft
= Sidewall height, ft + (Bldg width, ft ÷ 2) × Roof slope
LGTH = total length of building, ft

Example 1:

Determine the minimum separation distance between a 40'x120' naturally ventilated building located south of a 32'x72' machinery storage with 14' sidewalls and a 4/12 gable roof. See Fig 7.

Solution:

Determine the minimum separation distance with Table 2 and the dimensions of the machinery storage for the windward building. Calculate the building ridge height:

14' + ((32' ÷ 2) × (4 ÷ 12)) = 19.33'. Use 20' for building height. The total length is 72'.

From Table 2, provide a minimum separation distance between buildings of about 69'.

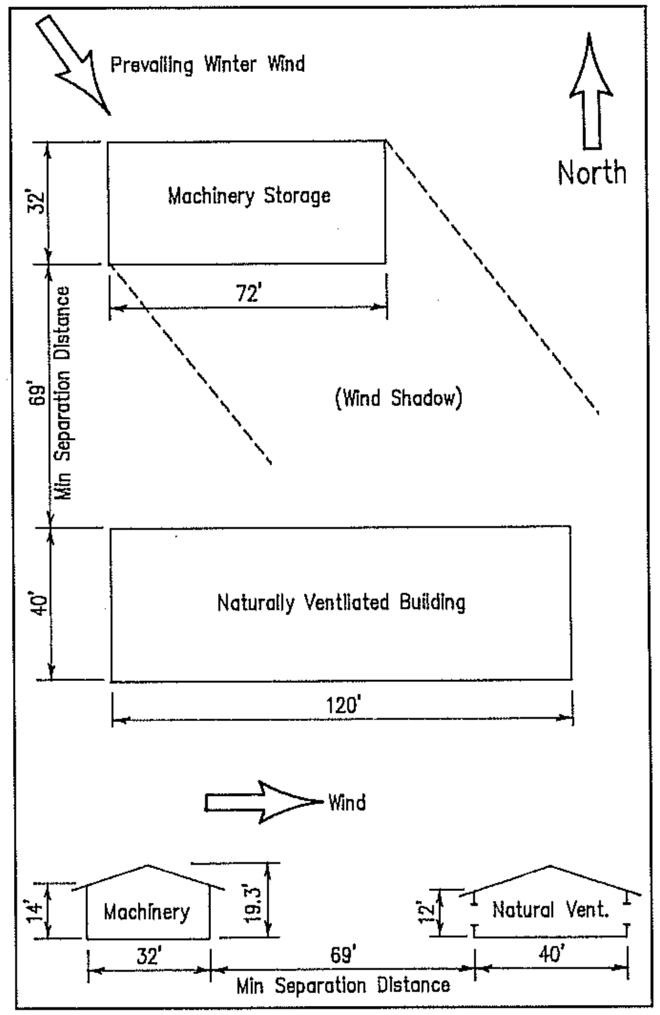


Fig 7. Minimum separation distance, Example 1.

Insulation

Insulation is not needed to conserve winter heat in cold buildings, but it can help control condensation and frost on roof surfaces and help reduce the radiant heat load on animals from solar roof heating in summer.

High insulation levels help maintain higher indoor temperatures in modified environment buildings. See Table 5.

Protect insulation from rodent, bird, and fire damage. A building with unprotected insulation may be uninsurable for fire.

Avoid translucent roofing panels that increase summer solar heat gain. Usually, enough light is available from vent openings.

Bird control

Bird numbers in buildings can often be reduced in enclosed buildings by screening ventilation openings. Cover the openings with ¾" hardware cloth and increase the open vent area proportionally. Screened ridge openings tend to freeze shut in cold weather; you may need to knock ice from the screen regularly. Also consider blocking nesting areas on truss chords, framing, etc.

For eave inlets, horizontal screening under the eave keeps birds from roosting or nesting in the eave area. Vertical screening above the siding may plug less. Consider the location that is easier or cheaper to install, which depends on the framing system.

Cold Buildings

Design

See Table 3 for ventilation opening sizes and Fig 8 for opening locations.

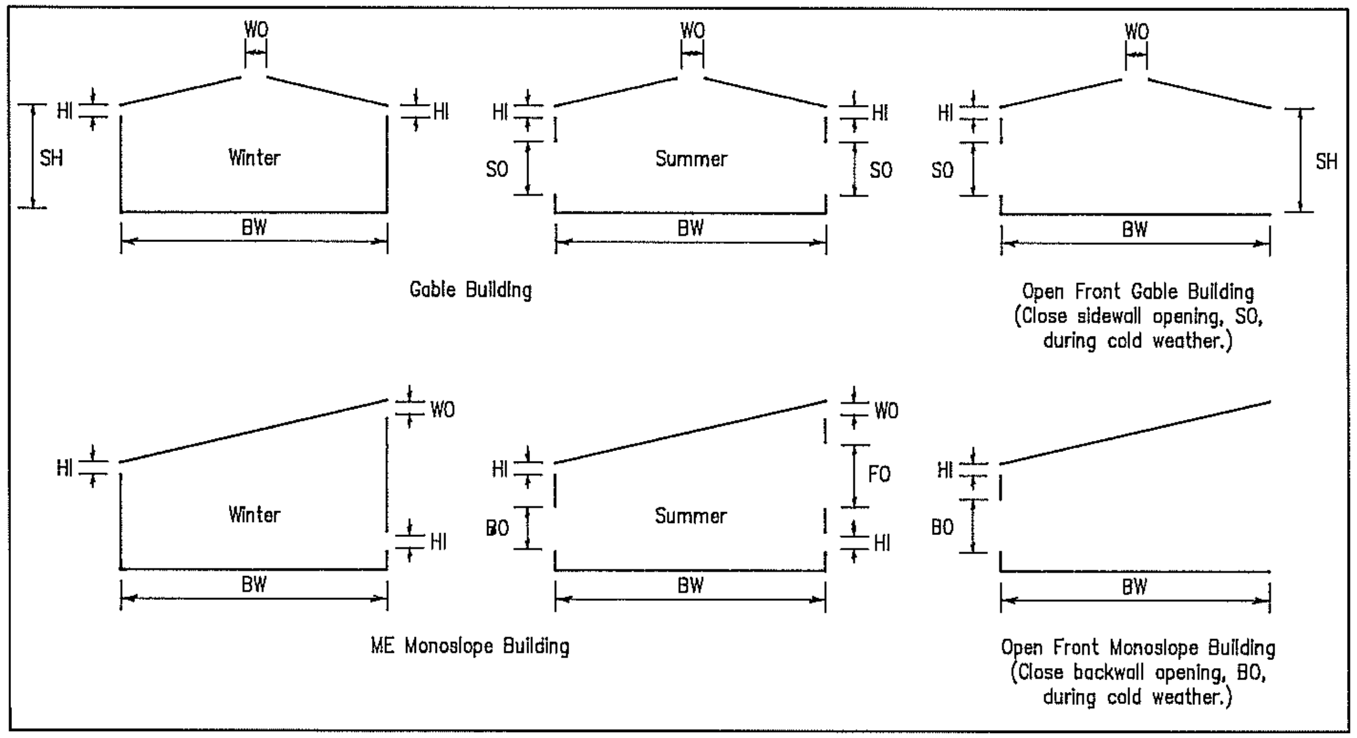


Fig 8. Natural ventilation openings.
ME = Modified environment. See Table 3 for opening size.

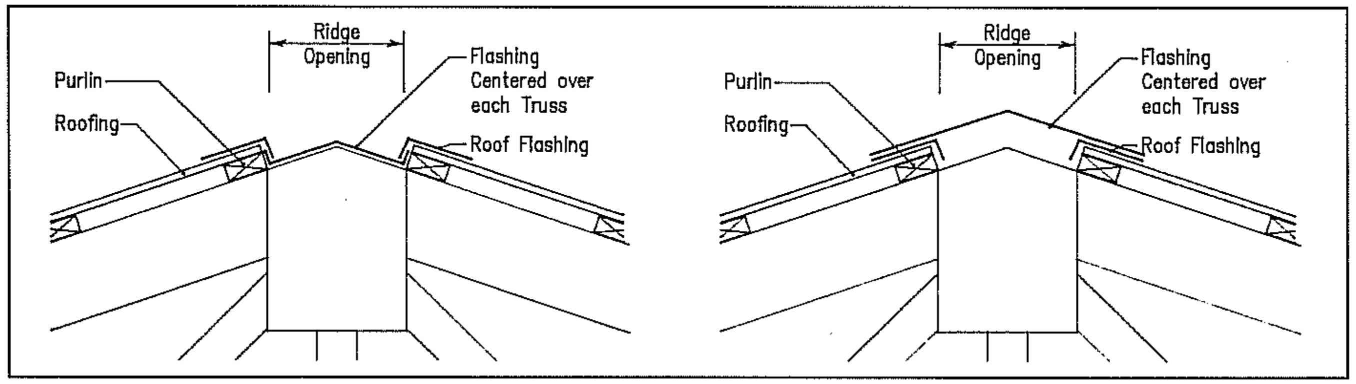


Fig 9. Flashing for ridge openings.

Table 3. Minimum openings for naturally ventilated buildings.

Openings are defined in Fig 8. Openings are continuous along building length. Front wall heights of monoslope buildings may be excessive in wide buildings. A 6" minimum ridge opening prevents freeze up. Less than 6" can be used in warmer climates for buildings less than 30' wide.

Modified environment (ME) swine and sheep buildings need adjustable winter outlets, 6' minimum backwall height, and at least 2/12 roof slope (3/12 on gable buildings).

3a. Beef and dairy.

	Winter		Summer		
Bldg width BW, ft	Outlet width WO, in.	Inlet width HI, in.	minimum sidewall opening SO, in.	Sidewall height SH, ft	
				Dairy	Beef
to-20	4-6	2	60	10	10
22	5-6	3	60	10	10
24	5-6	3	72	10	12
26-30	6	3	72	10	12
32-34	7	4	72	10	12
36-40	8	4	72	10	12
42-44	9	5	72	10	12
46-48	10	5	72	10	12
50	10	5	84	12	14
52-54	11	6	84	12	14
56-60	12	6	84	12	14
62-64	13	7	84	12	14
66-68	14	7	84	12	14
70	14	7	96	14	16
72-74	15	8	96	14	—
76-80	16	8	96	14	—
82-84	17	9	96	14	—
86-90	18	9	96	14	—
92-94	19	10	96	14	—
96-100	20	10	96	14	—

3b. Swine finishing and sow gestation.

For winter, install adjustable closures on WO and HI openings and regulate to maintain desired conditions.

	Winter		Summer			
	Gable or Monoslope		Gable		ME Monoslope	
Bldg width BW, ft	Outlet width WO, in.	Inlet width HI, in.	Sidewall opening SO, in.	Sidewall height SH, ft	Front wall opening FO, in.	Back wall opening BO, in.
to-20	4-6	2	30	8	48	16
22-24	5-6	3	36	8	60	18
26-30	6	3	42	8	66	24
32-34	7	4	48	8	—	—
36-40	8	4	60	9	—	—
42	9	5	60	9	—	—
44	9	5	72	10	—	—
46-50	10	5	72	10	—	—
52-54	11	6	84	12	—	—

3c. Sheep.

	Winter		Summer			
	Gable or Monoslope		Gable		ME Monoslope	
Bldg width BW, ft	Outlet width WO, in.	Inlet width HI, in.	Sidewall opening SO, in.	Front wall height SH, ft	Back wall opening FO, in.	opening BO, in.
16-20	4-6	2	48	8	48	16
22-24	5-6	3	48	8	48	16
26-30	6	3	48	8	48	16
32	7	4	48	8	48	16
34	7	4	48	8	60	24
36-40	8	4	60	9	60	24
42	9	5	60	9	—	—
44	9	5	72	10	—	—
46-48	10	5	72	10	—	—
50	10	5	84	12	—	—
52-54	11	6	84	12	—	—
56-60	12	6	84	12	—	—
62-64	13	7	84	12	—	—
66-68	14	7	84	12	—	—
70	14	7	96	14	—	—

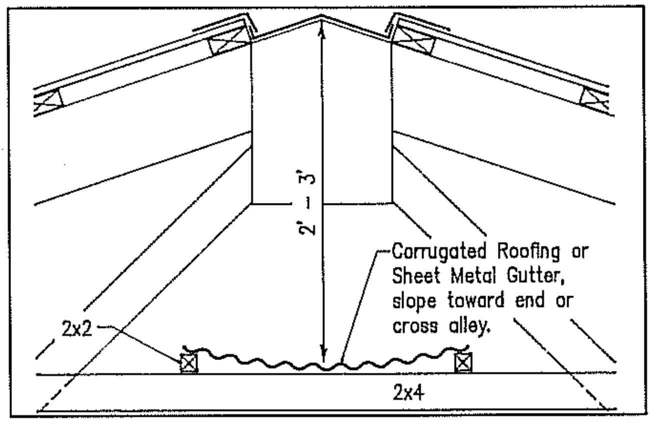


Fig 10. Rain trough below an open ridge.

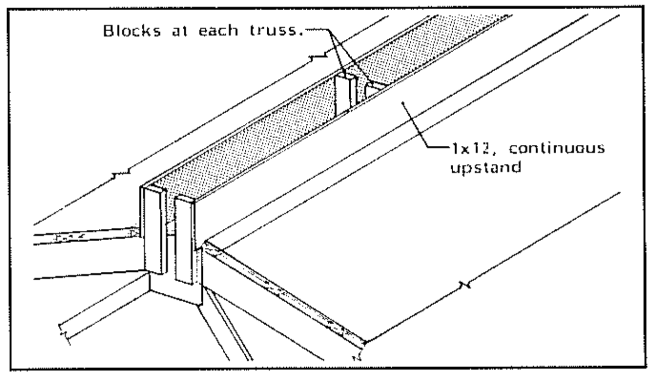


Fig 11. Upstand.

A 12" upstand reduces snow blow in and increases chimney effect when wind is blowing perpendicular to the ridge.

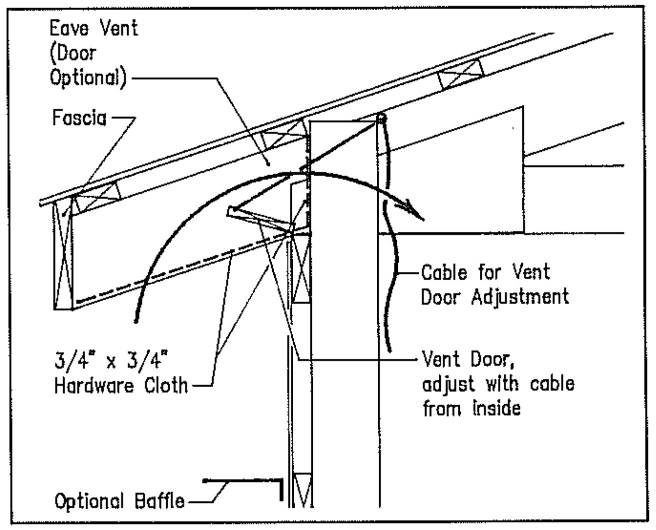


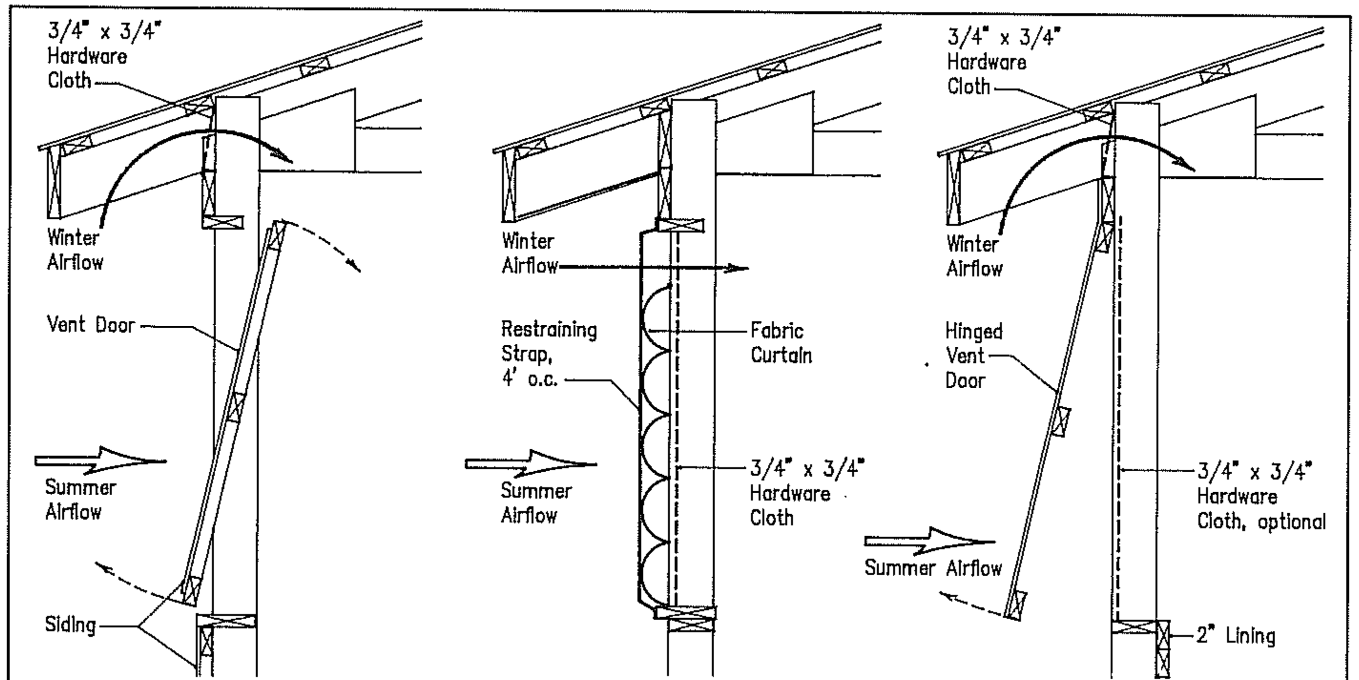
Fig 12. Eave openings.

Make eave vent doors no larger than 75% of the opening width. Vertical screen is less likely to plug than screen under the eave. When air is flowing up the wall, a baffle deflects the wind away from the inlet.

Eave openings

Size eave openings along both sides of the building so each has at least ½ as much open area as at the ridge.

In severe climates, adjustable eave vents reduce airflow and snow blow-in. Close eave vents only part way and then only during severe winter weather. Do not leave closed all winter. Sleeping areas near inlets can be drafty. To reduce drafts, protect eave openings from direct wind gusts with a fascia, Fig 12.



13a. Pivoting vent door. **13b. Plastic curtains.** **13c. Top hinged vent door.**

Fig 13. Sidewall openings.

See also Fig 15 and 16.

Wall openings

Adjustable summer vent openings include pivot doors, top- or bottom-hinged doors, sliding doors, and plastic or nylon curtains, Fig 13.

On a double track, doors can slide to one end for storage. Or, remove the doors in hot weather. Opening the full sidewall is helpful in wide buildings.

Management

Winter

In cold buildings, freeze-proof waterers and pipes. During cold weather, remove manure often—twice a day if necessary. Scrape in the afternoon when conditions are usually warmer.

Poor winter ventilation and high humidity can cause animal health problems and fog, condensation, or frost. Attempts to warm the building by closing ventilation openings increases the problem. In severely cold weather, eave openings can be partly closed. **Do not** close completely, but leave at least ½" continuous opening per 10' of building width.

Summer

Hot, humid summer weather is critical for animal health, comfort, and productivity. Often there is little air movement. Solar heat load on an uninsulated roof radiates more heat to the animals. Provide recommended sidewall openings at animal level for good cross ventilation. See the handbook on heating and cooling for more cooling methods.

Modified Environment Buildings

Design

Modified environment buildings are typically well insulated to help control indoor air temperature. See section on insulation for recommended insulation values.

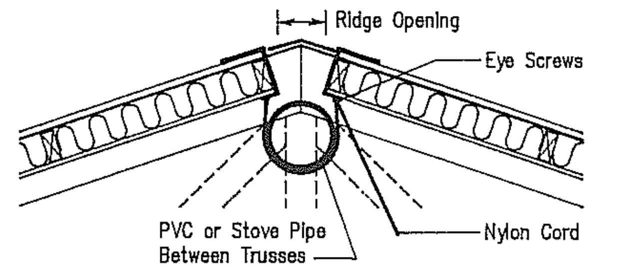
Provide two sizes of adjustable inlets—large openings for summer and slot openings for winter. In gable roof buildings, locate winter inlets at the eaves or high on the building wall and outlets at the high point of the roof. In single-slope buildings, locate winter inlets along the back sidewall eave and along the lower part of the front wall, Fig 18. Openings along the high part of the front wall are outlets.

Ridge Openings

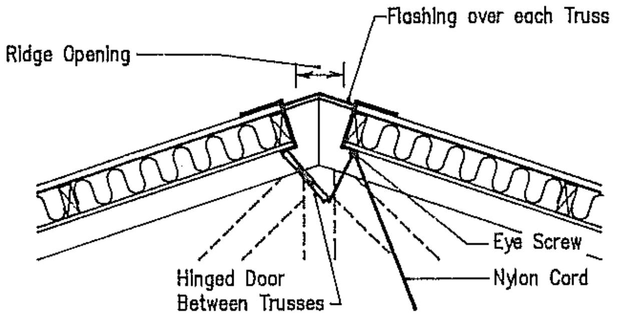
If closures are not provided, size ridge openings the same as for cold buildings. Closures are recommended on modified environment building ridge openings to control airflow and indoor temperature during cold periods, Fig 14.

Eave Openings

Locate continuous eave openings high along each sidewall to reduce drafts from incoming air in a resting area. With swine, direct air so it falls in the intended dunging area. Size eave inlets so each side has at least half the minimum recommended ridge opening, Table 3.



14a. With pipe.



14b. With door.

Fig 14. Adjustable opening for modified environment buildings.
With adjustable closures, increase opening width at least 50% for more airflow on calm days. Extend truss flashing at least 1" on each side of the truss.

In severe climates, provide adjustable eave openings to reduce but not completely block airflow. Closures need periodic adjustment to control indoor temperatures.

Sidewall Openings

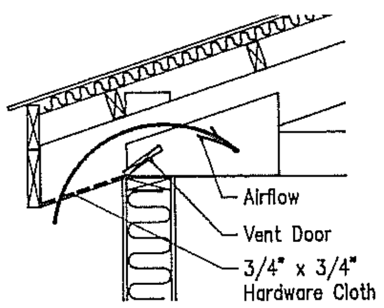
Summer vent openings include pivot doors, top- or bottom-opening doors, and plastic curtains, Figs 15b and 16. See Table 3.

Curtains work well in modified environment buildings during mild and hot weather. Some curtain materials crack if folded while cold, so do not open or close them during cold weather. When curtains are folded for an extended time, as during hot weather, rodents and birds can cause damage; a timed controller can briefly close and open curtains every day. Uninsulated curtains work well for larger animals even in cold climates. Insulated vent doors may be needed at least on the north or west sides of buildings to reduce heat loss and allow higher ventilating rates for swine below 150 lb or animals in crates or tethers.

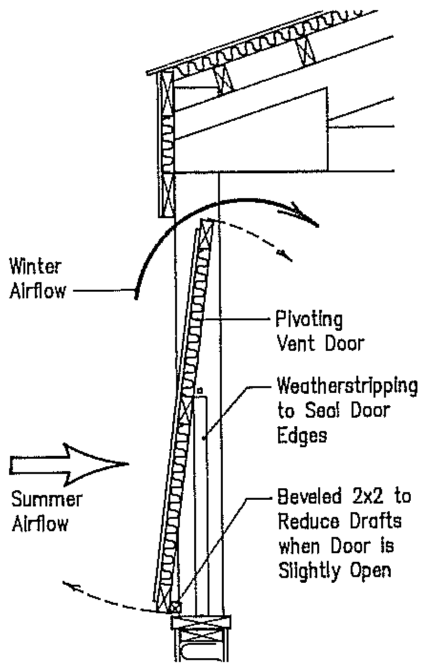
Management

Vent Doors

Adjust vent openings several times a day during changing weather to avoid wide temperature fluctuations. Install a winch and cable system to adjust several doors or other vents at once—some systems are automatic. Locate the controller at the center of building. Connect main cables to pull from opposite directions to reduce stress on the controller supports.



15a. Opening between rafters or trusses.



15b. Opening at top of pivot door.
Permit winter air to enter only at the top of slightly opened doors by weatherstripping the door sides and adding a beveled 2x2 along the door bottom.

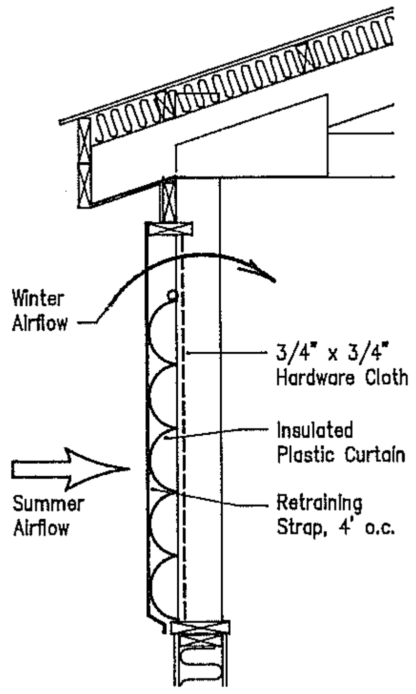
Fig 15. Typical eave openings.

Prestretched cable minimizes future adjustments. During cool weather, disconnect unwanted doors and control only needed doors. Provide different controllers for each room or group of animals by size.

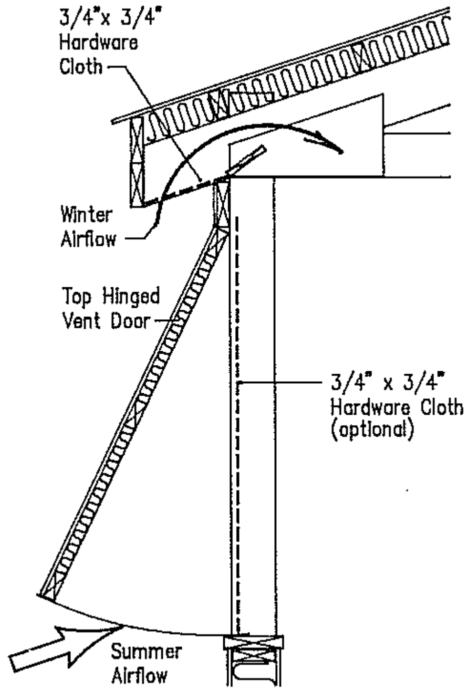
Gable Buildings

In cold weather, adjust ridge and eave openings to maintain desired room air conditions. Do not completely close the ridge opening except during very cold periods or blowing snow. Keep large sidewall vent doors closed unless they serve as eave openings. Adjust ridge openings based on seasonal differences.

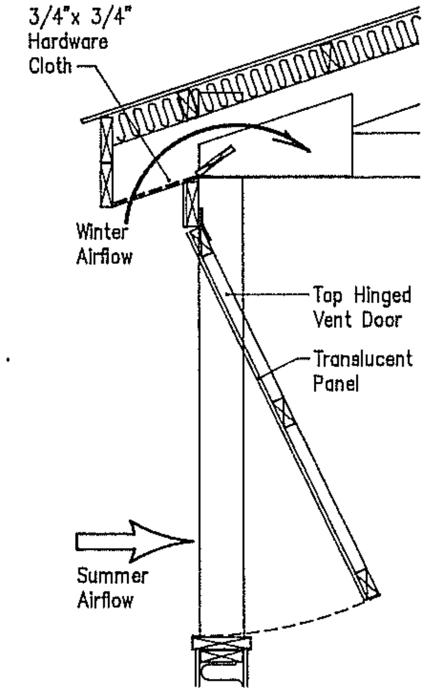
As the weather warms, gradually open the downwind vent doors. When downwind doors are about half open, start opening the upwind doors. Completely open all vent doors in hot weather. As temperatures decrease, close upwind doors first.



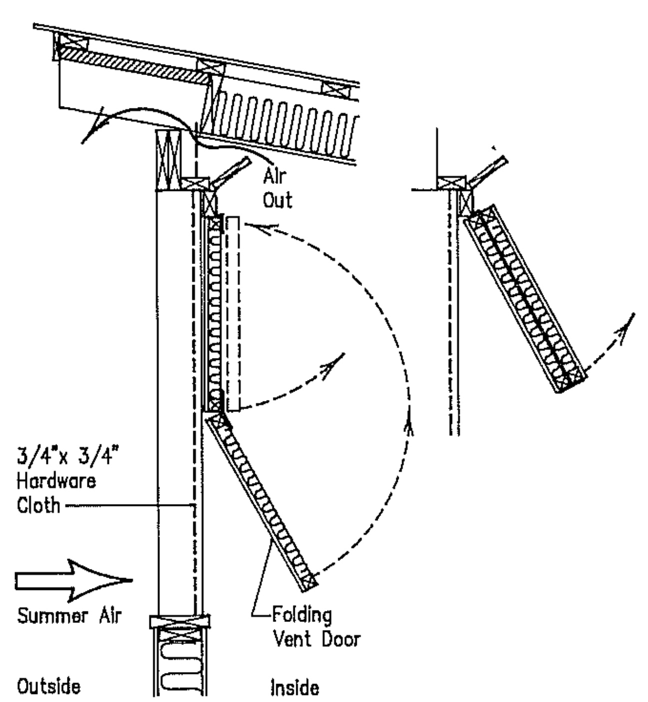
16a. Plastic curtain.



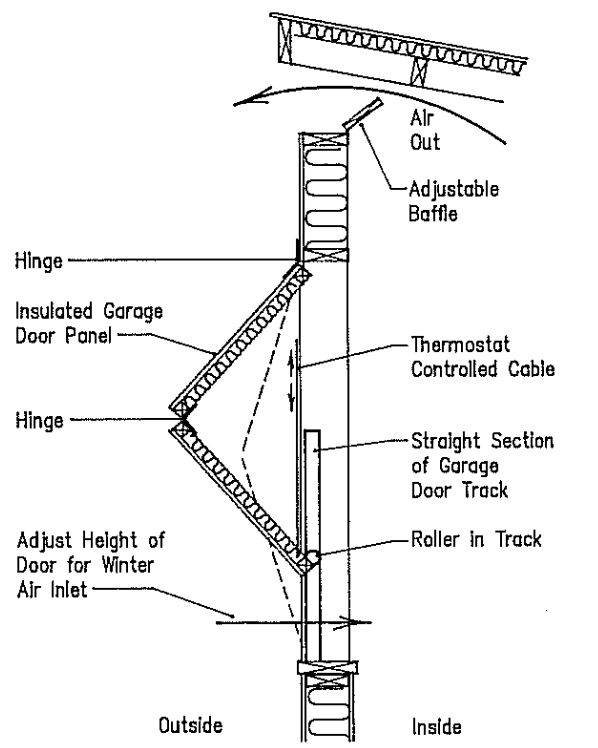
16b. Top hinged door.



16c. Translucent door panel.



16d. Folding vent door.



16e. Bifold vent door.

Fig 16. Sidewall openings for modified environment building.
See also Fig 15b. Buildings are insulated.

Monoslope Buildings

Modified environment monoslopes have large, adjustable openings in the front (high) and back sidewalls. The back openings are usually insulated tilt doors; front openings are usually plastic fabric curtains, fiberglass panels, or insulated tilt doors in cold climates. Smaller adjustable openings are along both eaves and along the lower part of the front wall, Fig 18.

As fall approaches, close the large back doors, then the large front doors. When the outside temperature is below 20 F, close the back eave openings. Ventilating air enters the small lower front openings and moves 10'-15' back into the animal area. As air warms, it rises and travels up the sloped roof to the front eave opening. The back sleeping area is not ventilated directly during very cold periods.

Wind, Draft, and Snow Control

Wind can cause drafts and deposit snow in naturally ventilated buildings, Fig 19. Drafts are from wind swirling around an endwall, over the roof, or off an adjacent structure.

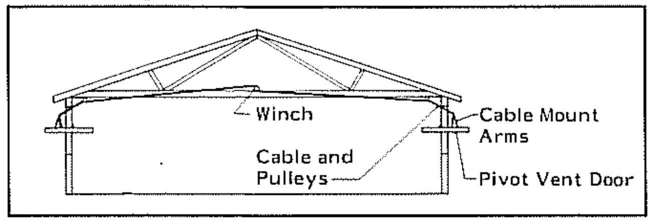


Fig 17. Cable-controlled pivot doors.
Cables on outside arms bring doors fully open. Hinge pivot doors slightly above center so they close when cable tension is released.

Reduce interior drafts in cattle and sheep buildings with one or more of the following options. Construct solid floor-to-eave partitions every 50' in buildings over 30' wide. In narrow buildings, space the partitions at a distance equal to building width. Close the front wall 16' from the corner on each end. Put summer vent doors in these wall sections or make them removable. To reduce drafts and snow deposits, build a 16'x16' swirl chamber of snow fencing from ground to eave as in Fig 20a. In open front buildings, if snow blows under the eave on the leeward side, make sure windward wall eaves are open, and then hang a snow fence just under the eave.

In swine buildings, see the solutions in Fig 20b. Construct solid floor-to-eave partitions every 75' in long buildings. Make pen partitions solid over slat areas in every third pen (i.e. attach plywood to gate). Make all pen partitions solid between back wall and slat area. Construct a solid front wall 16' long from the front corners to reduce wind and snow blow-in. Put summer vent doors in these walls or make them removable. Snow swirl chambers reduce blow-in.

To reduce drafts in modified environment buildings, make the partition over slats solid every sixth pen (about every 50'). During winter, the central alley fence can be solid. See Fig 21. During summer, make the central alley fence porous for cross ventilation. Use hovers (Fig 35) during cold weather; remove them during mild and hot weather.

Do not completely close eave openings on the windward side during blowing snow. Closed openings can reduce inside building pressure and draw snow in the open ridge and building front.

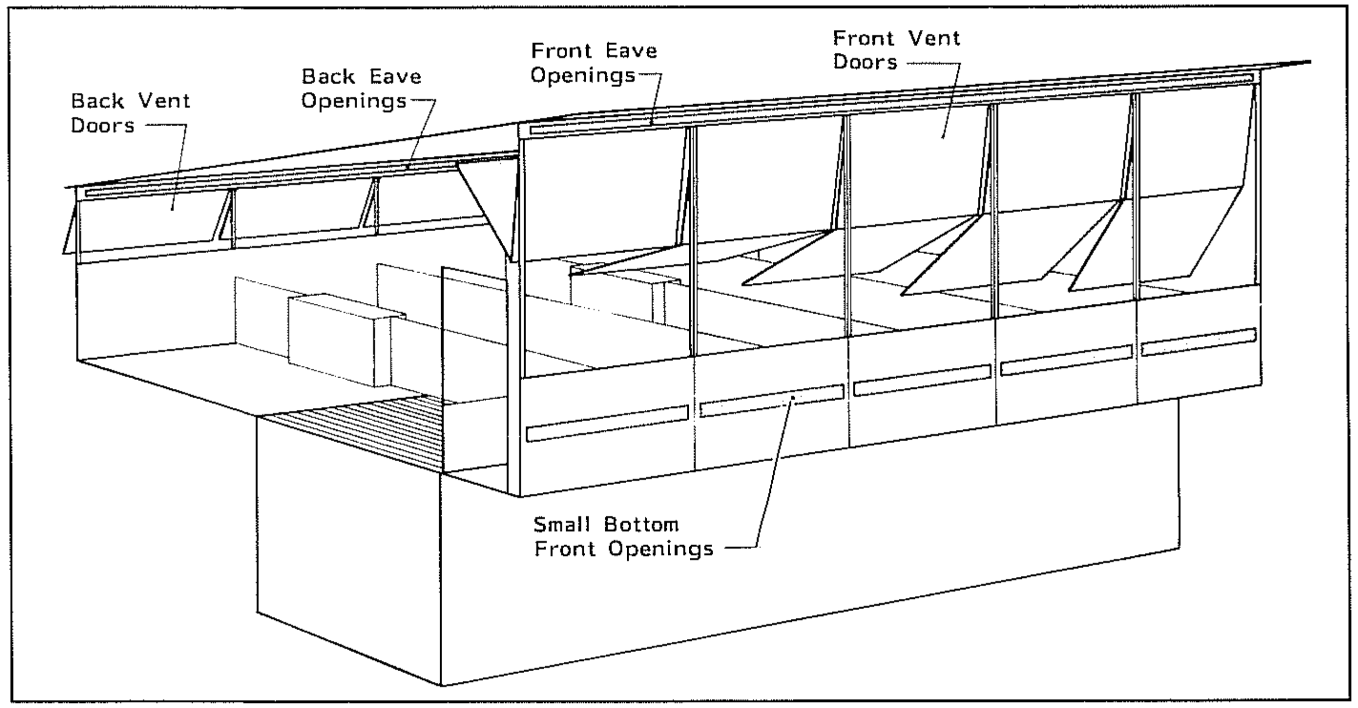


Fig 18. Modified environment monoslope swine building.

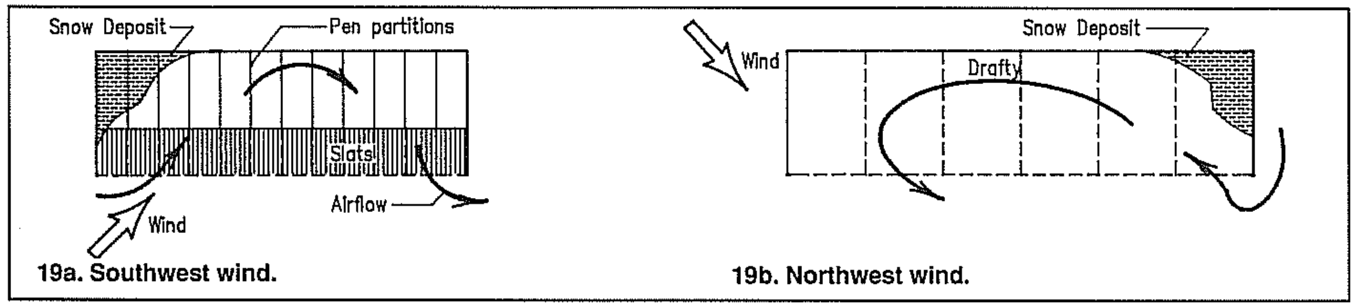


Fig 19. Drafts and snow deposit patterns in open-front building.

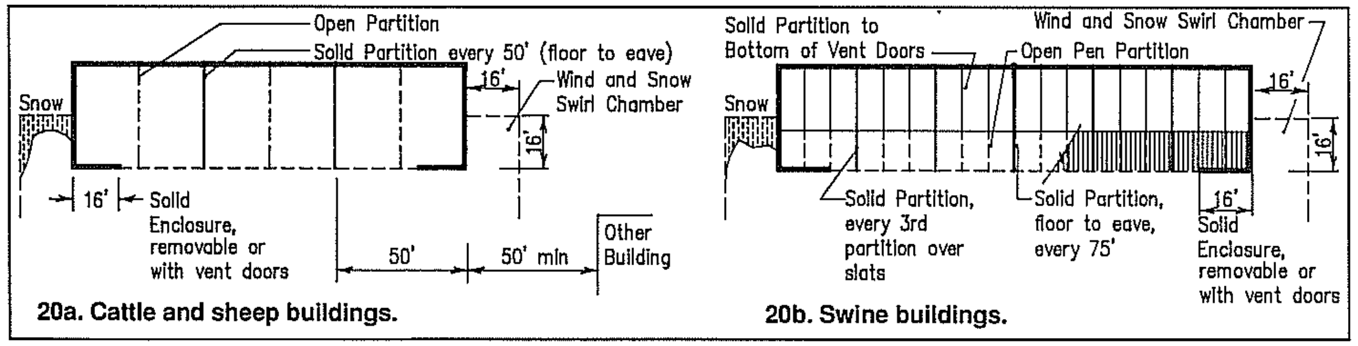


Fig 20. Snow and wind control for open front buildings.
Not all these options may be needed.

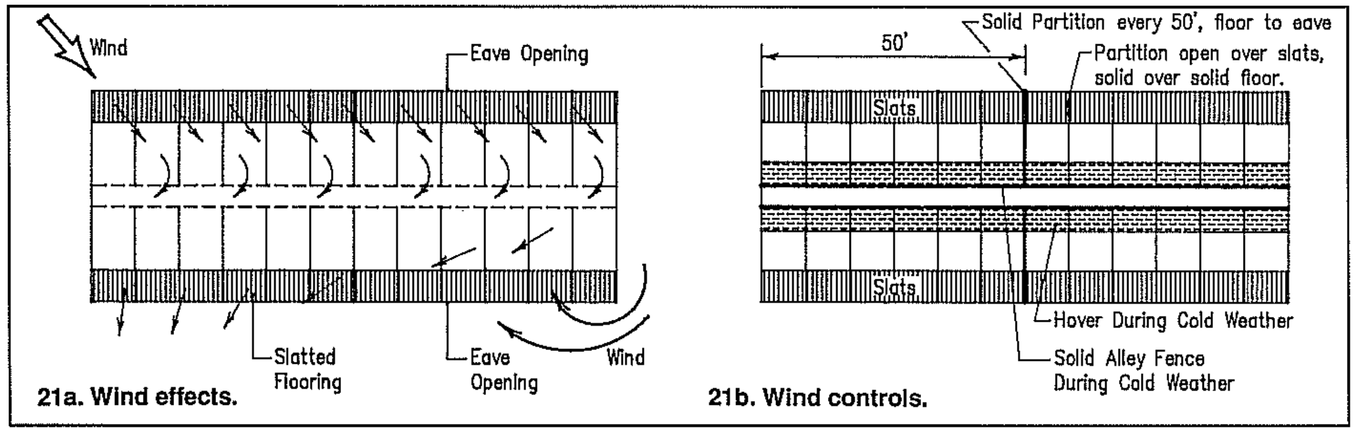


Fig 21. Wind in gable roof modified environment buildings.

Wide Ridge Building

Some naturally ventilated buildings less than 40' wide, have an automated wide ridge opening. A 24" open ridge has two interior doors operated by a door controller and thermostat. Adjustable openings help maintain indoor building temperature. Buildings with wide ridge ventilation are usually well insulated—R14 in the roof and R12 in the wall.

The ridge is both the air inlet and outlet. During windy conditions, air enters the ridge at one end and exits at the other. During still weather, circulation fans or adjustable winter eave inlets may be needed to maintain adequate air movement. Proper air distribution or drafts may be a problem.

With some conditions, air tends to drop from the ridge, so locate dunging area, slotted manure gutters, or storages directly below the ridge vent. Solid partitions from floor to ridge every 30'-40' along the building length reduce drafts. Hang weighted curtains in scraper or flush gutters between rooms. Install partitions in manure storages below solid partitions.

Provide large sidewall openings for summer cross ventilation. Provide insulated vent doors, as for cold or modified environment naturally ventilated buildings.

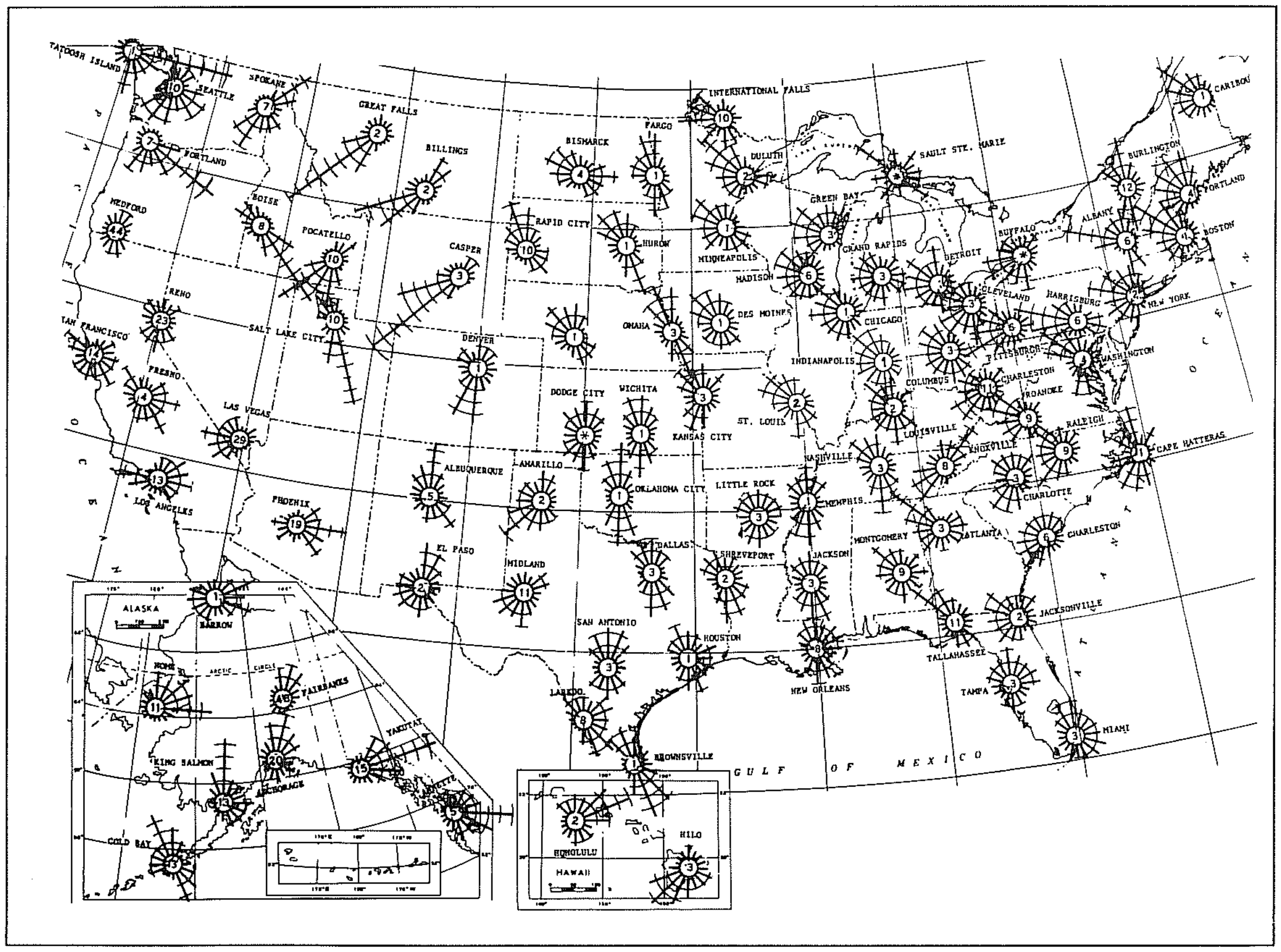


Fig 22. Surface wind roses for the United States, January.
U.S. Weather statistics from hourly observations, 1951-1960. Wind roses show % of time wind blew from the 16 compass points or was calm. Number in circle is % calm; *=less than 0.5% calm.

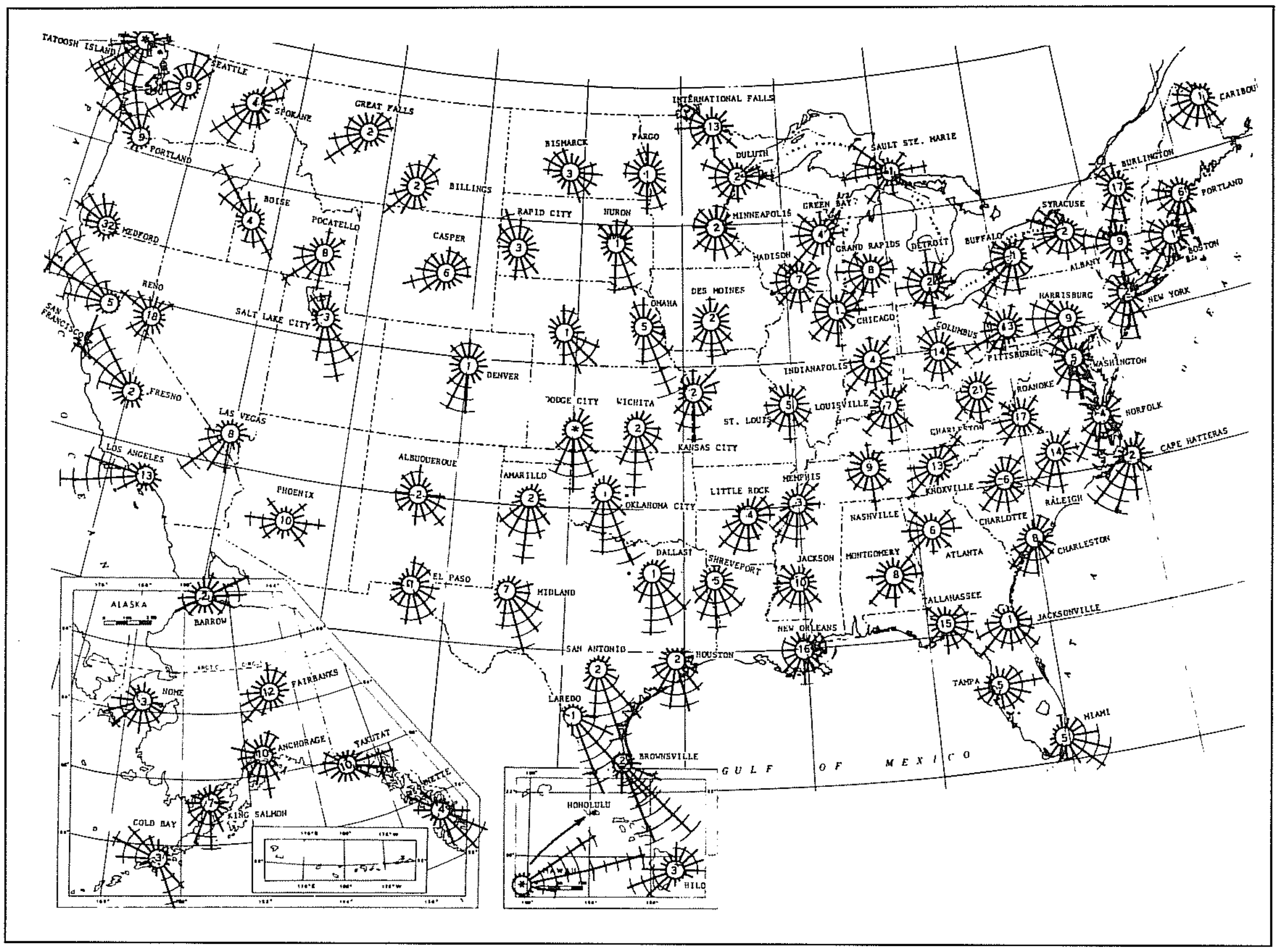


Fig 23. Surface wind roses for the United States, July.
U.S. Weather statistics from hourly observations, 1951-1960. Wind roses show % of time wind blew from the 16 compass points or was calm. Number in circle is % calm; *=less than 0.5% calm.

4. Insulation

Insulation is any material that reduces heat transfer from one area to another. R-value measures the resistance of a material to heat flow. Good insulators have high R-values. See Table 4.

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

During summer months, insulation reduces heat gain, improves comfort, and reduces cooling costs. Walls and roofs exposed to direct sunlight can be hotter than 50 F above air temperature.

With poor insulation, inside ceiling and wall surfaces become cold in winter. If the surface is below the dew point temperature, air next to the surface becomes saturated and moisture condenses, Fig 24. If the surface temperature is below freezing, frost occurs.

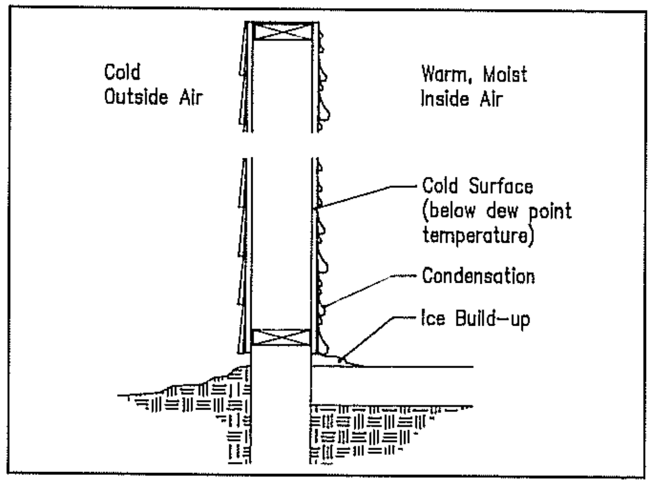


Fig 24. Poorly insulated wall.
Warm, moist air condenses on a cold surface.

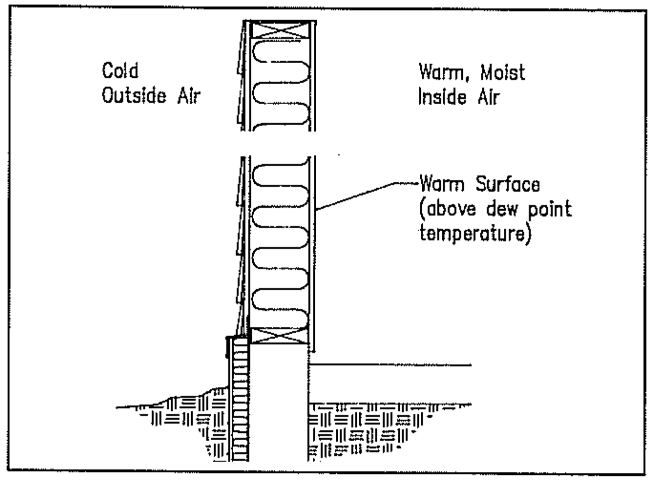


Fig 25. Warm, properly insulated wall surfaces.
The warmer the surface, the less likely it will have condensation.

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.

Table 4. Insulation values.
Adapted from *1985 ASHRAE Handbook of Fundamentals*. Values do not include surface conditions unless noted otherwise. All values are approximate.

Material	R-value Per inch 1/k	R-value For listed thickness 1/C
Batt and blanket insulation		
Glass or mineral wool, fiberglass	3.00-3.80	
Fill-type insulation		
Cellulose	3.13-3.70	
Glass or mineral wool	2.50-3.00	
Rigid insulation		
Expanded polystyrene		
Extruded, plain	5.00	
Molded beads, 1 pcf	3.85	
Molded beads, over 1 pcf	4.20	
Expanded rubber	4.55	
Expanded polyurethane, aged	6.25	
Glass fiber, varies; read label	4.00	
Wood or cane fiberboard	2.50	
Polyisocyanurate, aged, foil on 2 faces	7.20	
Windows (includes surface conditions)		
Single glazed window		0.91
With storm windows		2.00
Insulating double-pane glass, ¼" air space		1.69
Doors (exterior, includes surface conditions)		
Wood, solid core, 1¾"		3.03
Metal, urethane core, 1¾", no thermal break		2.50
Air space (¾"-4") Values vary with many factors. See ASHRAE.		
Non-reflective Horizontal		0.90
Non-reflective Vertical		1.25
Reflective Horizontal		2.20
Reflective Vertical		3.40
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

- Rigid insulations provide rigidity and strength that other insulation types do not.
- **Foam or foamed-in-place** insulation.
- **Reflective materials,** such as aluminum foil, reflect most of the radiant heat that strikes it in an enclosed air space. Radiant heat is a small part of total heat loss. Several air spaces are needed to resist heat flow by conduction and convection. Dust and corrosion greatly reduce reflective insulation values. Reflective insulation exposed to the room results in little insulation value.

Insulating effectiveness of an air space depends on its position, and thickness. A ¾" to 4" thick non-reflective dead air space has a maximum R-value of about R=0.9.

Insulation Levels

The amount of insulation needed in farm buildings depends on whether the space is naturally or mechanically ventilated, and 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, roof insulation reduces 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.

Recommended insulation levels are in Table 5. More insulation may be justified with increasing energy costs in supplementally heated buildings.

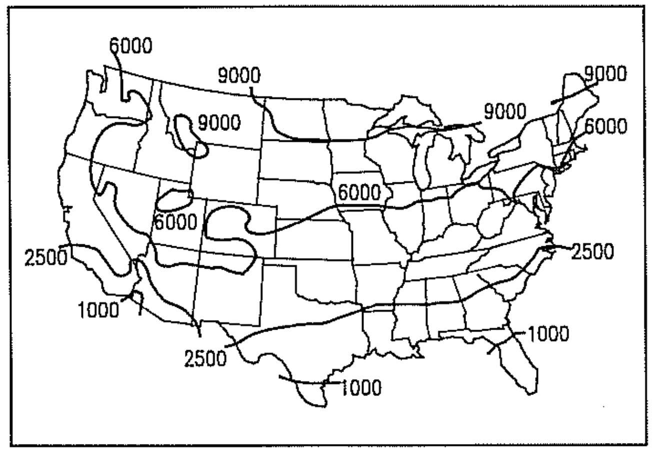


Fig 26. Winter degree days.
These values can vary considerably in mountainous areas. Check local records.

Table 5. 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 help control condensation, frost, and 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	19	20	33

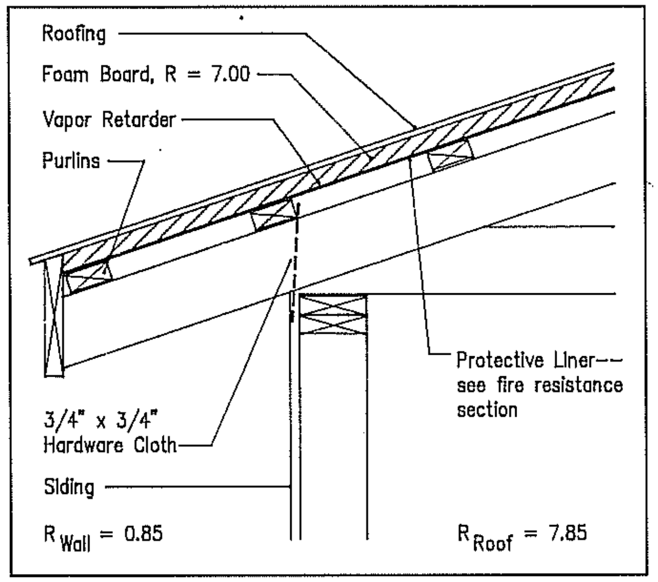


Fig 27. Optional cold building insulation.
Insulation in cold buildings can control roof condensation, frosting, and summer radiant heat load. Install a vapor retarder to prevent moist air from passing through insulation board joints and condensing. Protect insulation and vapor retarder from birds, rodents, and fire with an inside liner.

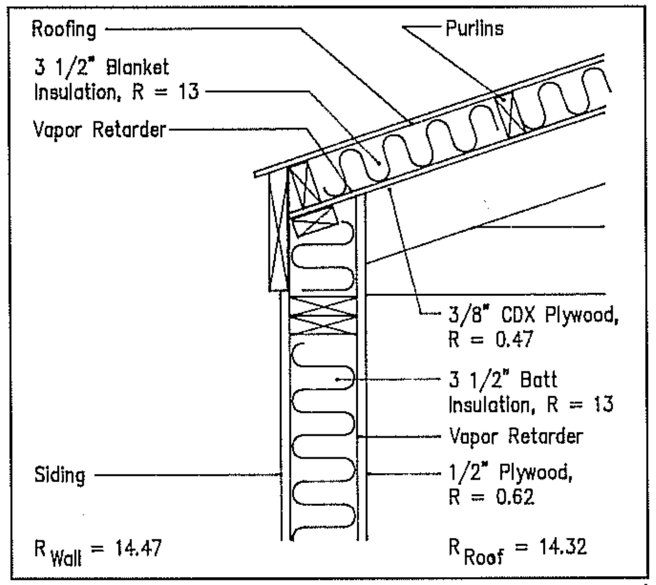


Fig 28. Modified environment building insulation.
R-values vary—check the label. Example illustrates insulation for up to 6000 winter degree days.

Moisture Problems

Reduce moisture problems in building sections by installing a separate vapor retarder on the warm side of all insulated walls, ceilings, and roofs.

One of the best vapor retarders for farm structures is polyethylene film. It is low cost, easily installed, and not affected by corrosive agents normally found in farm building environments. A 4-mil (0.004") thickness is common, but 6-mil (0.006") is better and easier to handle without tearing.

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, vapor retarders help prevent moist air passing through board joints and condensing. Follow manufacturer's instructions for sealing board joints.

Vapor leaks through joints, holes for electric boxes, windows, augers, nail holes, etc. Tape joints and seal other air leaks to reduce moisture movement.

Fire Resistance

Many plastic foam insulations have high flame spread rates, including urethane and polystyrene insulations common in farm buildings. If foam plastic 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. Check with your insurance company for materials that provide satisfactory protection. Some examples are:

- ½" thick cement plaster.
- 1/4" thick sprayed-on magnesium oxychloride (60 lb/ft^3) or ½" of the lighter, foam material.
- Fire rated ½" exterior plywood.
- Do not use fire rated gypsum board (sheet rock) in high moisture environments such as animal housing.

Birds and Rodents

Protect insulation from bird and rodent damage with an inside liner. Aluminum foil is not enough protection.

Cover exposed perimeter insulation—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. Maintain a rodent bait program.

Construct buildings so birds cannot roost near insulation and consider screening all vent openings. Use ¾" hardware cloth for air vent openings. Screened vent outlets are very susceptible to freezing shut. You may need to de-ice screens regularly during cold periods.

5. Troubleshooting

A properly designed and operating natural ventilating system provides an acceptable environment for livestock, but not thermal comfort for workers who may think the building is too cold. In fact, the system may be operating as designed. A cold and dry environment is better for most livestock than a warm wet one.

Troubleshooting Tools

Several simple tools aid system diagnosis. Contact suppliers of ventilating equipment or local heating contractors.

Thermometer

Natural ventilating systems rely mainly on a manager's judgement to control airflow rates. A good thermometer is essential for checking actual conditions and for calibrating thermostats which control vent openings and heaters. Maximum/minimum thermometers make it easier to monitor building temperature fluctuations, Fig 29. Calibrate thermostats at least twice a year place a thermometer near the thermostat and check thermostat "range"—points at which it turns on and off.

A maximum/minimum thermometer can monitor air temperature changes when you are not there. It is not uncommon to find 15 F between minimum and maximum temperatures in naturally ventilated buildings. Adjust openings or ventilating rates to maintain desired temperatures.

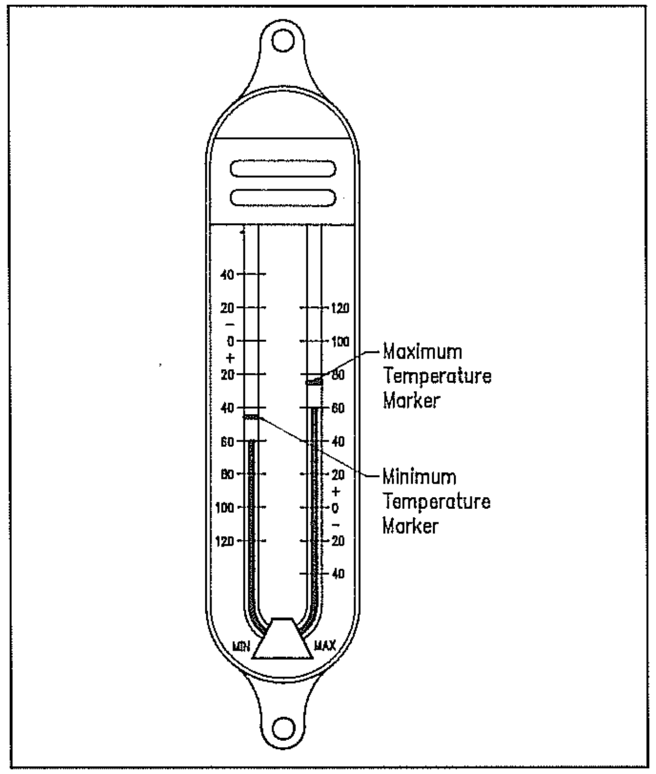


Fig 29. Maximum/minimum thermometer.

Psychrometer

A psychrometer has two thermometers, Fig 30. The sensing bulb on one thermometer is in an absorbent sock dipped in clean water. The instrument is whirled to get "wet bulb" and "dry bulb" temperatures—read the relative humidity from a chart furnished with the psychrometer.

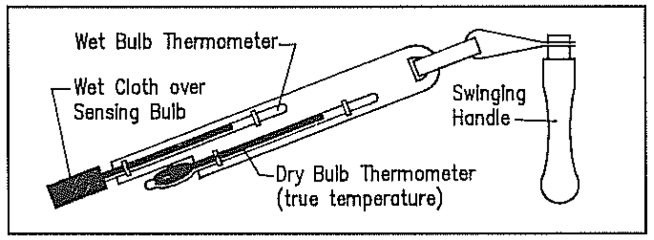


Fig 30. Sling psychrometer.

Smoke generator

Smokers show air movement patterns to help locate **dead** or **drafty** spots.

Smoke from a heated source (insect fogger, bee smoker, cigar, cigarette, burning rubber) may not accurately show airflow patterns because warm smoke tends to rise instead of following the air stream. Commercial 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.

Hold a smoke generator near a fresh air inlet. Air velocities farther from inlets are often erratic and low. By releasing smoke at the air inlet, you can move the smoke generator along the incoming air and slowly trace the air stream from inlet to outlet.

Troubleshooting Natural Ventilation

Ventilation and/or moisture problems occur in cold and modified environment housing when improperly designed. Some possible causes are:

- Natural ventilating openings are improperly designed or operated.
- Vent openings are closed to increase inside temperatures. Do not totally close ventilation openings. The result is usually a severe moisture buildup, condensation on the roof and walls, animal respiratory illness, and only a slight temperature rise.
- Attached sheds and roof extensions that block ventilation openings and prevent good air exchange.

- Poor sanitation and housekeeping leave extra moisture sources (manure, wet bedding, leaky waterers).
- High silos, trees, or other buildings are too close.

Symptom:
Excessive odors and high relative humidity.
Possible cause:
Insufficient air exchange or excessive odor or moisture sources.
Possible solutions:
- For a warmer environment, add insulation to walls and roof (rather than reduce ventilation).
- Provide recommended ridge, eave, and sidewall openings.
- Check for blocked ventilation openings. Remove dirt and debris.
- Consider a positive pressure mechanical ventilating system if adequate natural ventilation openings cannot be installed.
- Raise or remove a ridge cap that restricts the ridge opening.
- Check recommended animal stocking density. Overcrowding or understocking can cause problems.
- Keep area clean of manure and wet bedding. Fix leaking waterers.

Symptom:
Excessive condensation on inside roof and wall surfaces.
Possible cause:
Inside building surface temperature is below the air dew point temperature.
Possible solutions:
- Provide sufficient air exchange to remove excess moisture.
- In modified environment buildings, check that sufficient insulation (Table 5) is installed and in good repair.
- In cold buildings, where purlins more than 4" deep restrict airflow along the roof and adequate ventilation openings are provided, install insulation in the roof (R-value of 5 or more). Line the bottom of purlins to provide a smooth surface and improve airflow.
- Maintain indoor temperature within 10° to 20° of outside temperature.

Symptom:
Excessive inside summer temperatures.
Possible causes:
- Insufficient air exchange and/or air circulation across the animals.
- Excess radiant heat from the roof.

Possible solutions:
- Provide adequate summer ventilating openings located to allow airflow through the animal zone. See Table 3.
- Remove obstructions (if possible) that restrict crossflow summer ventilation—trees, buildings, silos, and other tall structures; solid partitions.
- If summer ventilation openings cannot be added or obstructions cannot be removed, use circulating fans or install a positive pressure ventilating system.
- Add insulation to roof, R=5.
- Avoid translucent roofing.

Symptom:
Excessive drafts during windy conditions.
Possible cause:
Inadequate draft control baffles and hovers.
Possible solutions:
- Close and seal summer ventilating openings.
- Install interior baffles, partitions, and walls. See the wind, draft, and snow control section.
- Install hovers for young animals.
- Keep windward eave vents at least partly open.
- If wind is blowing in the ridge, reduce the opening. **Do not completely close the ridge.**
- Hang a section of snow fence or solid baffle from the back eave of an open front building to reduce wind entering the building.

Symptom:
Excessive snow blow-in.
Possible cause:
Inadequate snow control; high silos, trees, or other obstructions are too close.
Possible solutions:
- Check spacing between building and tall obstructions. Obstructions too close can force snow into the building. Consider a windbreak. See the wind, draft, and snow control section.
- Install interior baffles, partitions, and walls.
- If windward eave openings are closed, snow may be pulled in through the ridge or leeward eaves. Open windward openings some.
- In modified environment buildings, use eave opening closures to restrict airflow and reduce snow blow-in. **Do not close completely.**
- Provide fascia boards to reduce direct wind gusts.
- Provide a baffle below the eave inlet (Fig 12).

6. Example Ventilating Systems

This section shows systems with elements unique to beef, dairy, horse, poultry, rabbit, sheep, and swine buildings. Adapt to local climate and management practices before adopting example designs.

Some systems have both mechanical and natural ventilation. The examples here deal only with natural ventilation. A companion handbook, *Mechanical Ventilating Systems for Livestock Housing*, MWPS-32, is expected late in 1989.

The following material does not repeat recommendations given earlier, such as insulation needs or affects of openings. Design tables are in Chapters 3 and 4. Ventilation rates for mechanical systems are at the end of this chapter.

Beef

General

"Cold" housing (indoor temperatures about the same as outdoors) is adequate for beef cattle. Ventilation is by natural air movement; some newborn calves get supplemental heat in cold weather.

Maintain room air at 50%-70% relative humidity.

Insulation is not common in cold housing for mature beef cattle. Reduced cost and fewer bird and rodent problems offset the inconvenience of some condensation. Roof insulation may be beneficial where winters and summers are severe.

Example 2:
Design a naturally ventilated 50' wide, gable roof, open front building for beef cattle.

Solution:
From Table 3a, a 50' wide gable roof beef building requires a 10" ridge opening and a 5" opening at each eave. The building has an open front, so only the backwall eave opening is needed. Have ridge and eave openings the entire building length.

From Table 3a, install vent doors at least 84" high along the entire backwall and make building sidewalls at least 14' high. Endwall doors improve summer ventilation.

Locate the building with the open front facing away from prevailing winter winds. If drafts and snow blow-in are problems, see Fig 19a.

Avoid translucent roofing, because it increases solar heat gain in summer. Adequate light enters through front, ridge, and sidewall openings.

Dairy

General

Research indicates no change in production for Holsteins housed at temperatures between 10 F and 70 F, but production declines above 75 F. Jersey cows show declines below 30 F and above 80 F.

Most environmentally controlled dairy buildings are kept at 40 F-60 F from November through April. Relative humidities of 60%-80% are common.

Insulate to at least the levels recommended in Table 5, Chapter 4.

Cows

Dry cow housing and freestall barns are often naturally ventilated. Circulating fans can improve air distribution in a poorly performing naturally ventilated building.

Calves and replacement heifers

Naturally ventilated cold housing is usually adequate for calves and heifers. Unweaned calves grow well in calf hutches. Separate calves from heifers, and young heifers (3-8 mo) from the milking herd for disease control. Young calves and heifers are susceptible to drafts. Provide draft protection and bedding during cold weather.

Young calves and heifers (0-8 mo) can also be housed in warm, heated, mechanically ventilated housing.

Holding area

Either natural or mechanical ventilation can remove excess moisture and heat. With natural ventilation during cold weather, consider either radiant or floor heat to remove ice from floors. Provide floor heat in entry doorways and ramps.

Treatment-hospital area

This area is usually a separate room with its own ventilating system. Design the system to accommodate varying animal densities.

Mechanical ventilation, at least in winter, is common in colder climates. If the area is part of a holding area, it may be naturally ventilated.

Example 3:
A farmer in southeastern Pennsylvania wants to build a 200 stall drive-through freestall barn with four groups and a milking center. Assume the barn is 84'x236' and the milking center and holding area are 40'x94'.

One possible location is about 125' from a nearby highway on top of a small hill. The other location is farther from the highway behind the hill.

One possible layout places the milking center parallel to the main barn about 20' away. Another layout places the milking center at right angles off the center of the main barn.

Three different building types are being considered.

- A steel rigid frame building with 7.5' or 9' sidewalls, 16' frame spacing, and a 2.5/12 roof slope.
- A laminated wood gothic arch building with 4' arch spacing.
- A post frame building with 8' truss spacing, 4/12 roof, and sidewall heights up to 16'.

Recommend building location, layout, type, and ventilating system.

Solution:

Location. Select a naturally ventilated building. Locate on top of the hill for better exposure to wind, especially breezes during critical warm periods. If the site permits, orient the barn's long dimension at right angles to prevailing summer breezes.

Put the milking center at right angles to the barn to reduce blocking summer breezes, Fig 31.

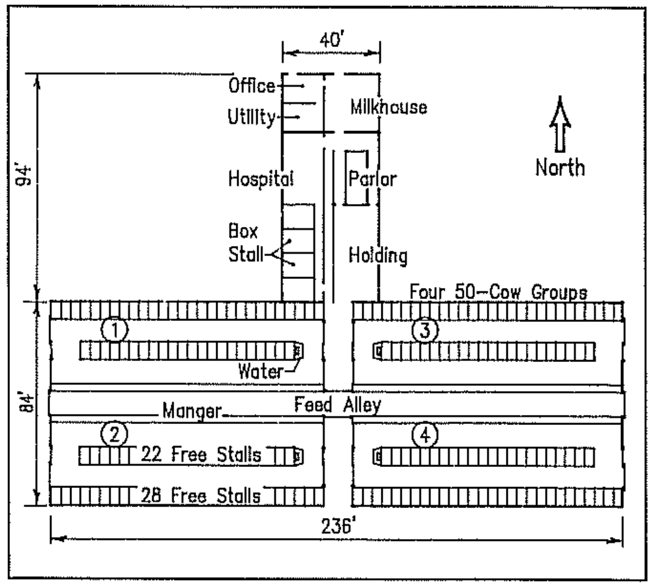


Fig 31. Building of Example 3.
200-cow dairy free-stall barn; drive-through feeding.

Building selection. Do not choose the steel frame building because:

- Roof slope is less than the desirable 4/12 slope for natural ventilation.
- The wide frame spacing requires deep roof purlins which can trap warm, moist air along the roof. With metal purlins, condensation and building deterioration are critical.
- Sidewalls high are lower than the 16' recommended for good wind exposure.

A laminated gothic arch building could be used. Advantages include:

- Little or no framing members for bird roosting or nesting.
- 4' arch spacing for shallow purlins.
- Adequate roof slope and high inside clearance.

However, traditional laminated arch construction does not allow adequate sidewall openings for summer ventilation. Rafter tails, as used for hay mow door openings, could be added and large summer openings installed along both sides of the barn, but at considerable cost increase.

A post frame building has the recommended roof slope and 14' high sidewalls. However, 8' truss spacing requires a deep purlin which interferes with airflow along the roof underside and allows birds to nest and roost on the truss top chord.

The best option is a post frame building with 4' truss spacing to allow flat purlins or an arch building with high sidewall openings.

Ventilation design is for the post frame building.

For **winter ventilation,** provide a continuous ridge opening and continuous eave openings along both sidewalls. From Table 3b, an 84' wide gable roof building requires a 17" ridge opening and a 9" opening at each eave. A ridge cap is not necessary. Protect trusses with flashing.

For **summer ventilation,** and from Table 3b, provide at least 96" high sidewall openings along both sides of the building. Locate ventilation openings at cow level. Endwall doors improve summer ventilation.

Space planks in free stall fronts along interior and exterior walls. Close spaces between planks along outside walls in winter with removable planks or a hinged sidewall panel. An adjustable curtain allows easy opening and closing of the upper portion of the sidewall.

Construct the roof with a reflective light colored material to minimize underside temperature. Insulate under the roof. Protect the insulation from birds. Avoid translucent roofing.

Some additional cow cooling may be required; consider circulation fans and sprinklers. Spray cows in holding and feeding areas, but not in free stalls, free stall alleys, or loafing areas.

Design milking parlor and size groups so cows spend no more than 1 hr in the holding area during hot weather. For this example, a parlor to handle 60 cows/hr is required. With a smaller parlor arrange to have only part of each group in the holding area at a time. Make the holding area sides completely removable for summer. Use high speed fans, directed across the cows' backs, to increase cooling and remove excess moisture, gases, and odors. Misting or sprinkling in this area can effectively cool cows.

Example 4:

Design a naturally ventilated barn to house dairy replacements for 100 mature cows. The barn houses 8 to 14 calves (0-2 mo), 25 heifers (3-8 mo), 17 heifers (9-12 mo), 12 heifers (13-15 mo), and 38 heifers (16-24 mo). Building layout is shown in Fig 32. Note: three separate housing sections are provided for calves, young heifers, and older heifers. The calf and young heifer sections have sidewalls on both sides and the older heifer section is open front with an outside lot.

Solution:

From Table 3a, a 7" wide continuous ridge opening and 4" eave openings are required for the 32' wide building. Provide eave openings along both sidewalls of the 0-2 mo and 3-8 mo sections. No eave opening is needed on the south side of the open front section. A rain gutter under the ridge in the calf section (0-2 mo) can protect the center row of pens, Fig 10.

Construct sidewalls 12' high and install 72" high vent doors the full length of enclosed north and south walls for summer ventilation.

Roof insulation (R-values = 5) will reduce condensation and summer heat gain.

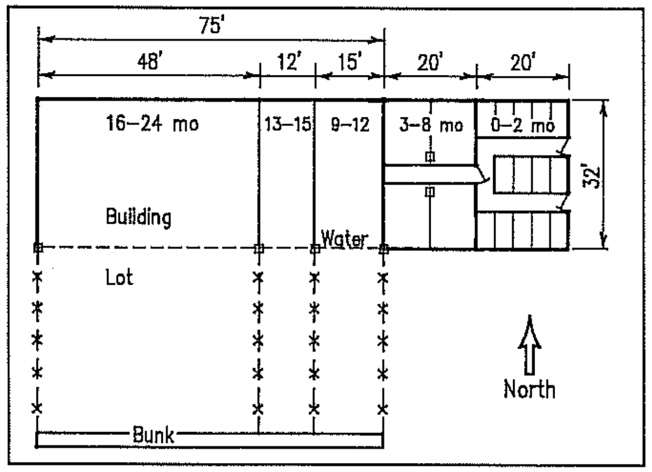


Fig 32. Building of Example 4.
Dairy replacement housing.

Horses

General

In mild or moderate climates, horses can be in uninsulated, naturally ventilated housing. Horses conditioned to cold weather and with long hair coats can withstand temperatures below 0 F with adequate feed and shelter. Show horses can maintain a short hair coat down to 40 F if given dry indoor facilities, blankets, hoods, and leg wraps.

In northern regions, insulated buildings and supplemental heat are common during the winter. Perimeter insulation reduces heat loss and prevents frozen bedding. In cold housing, solid wood sheathing insulates to R-3.

In cold naturally ventilated housing, provide at least 1 ft^2/stall of ridge and eave openings and at least 6 ft^2/stall of adjustable wall opening. Cupolas provide ridge vents that can be styled to match building construction. Circulation fans improve summer animal comfort.

Make openings adjustable and space them to maintain good air distribution. Horse stall sides are often solid 4' high and open above. If stall partitions are solid above 4', provide an air inlet and outlet in each stall.

Some ventilating systems combine natural and mechanical ventilation. In warm weather, thermostats trigger cable winches to adjust vent doors. As weather becomes colder, controls close ventilating doors and turn on ventilating fans. Warm horse housing requires mechanical ventilation. Because of low animal density, supplemental heat is usually needed.

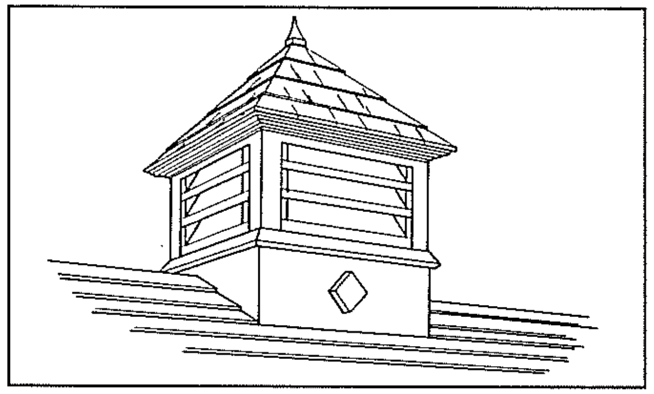


Fig 33. Cupola ridge vent.
Provide 1 ft^2/stall of free opening.

Example 5:

Design a natural ventilating system for a 36'x48', eight stall horse barn with a center alley, no flat ceiling, and 4/12 roof slope.

Solution:

Determine required ridge opening.

1 ft^2/stall × 8 stalls = 8 ft^2

A continuous ridge opening width is only 2" (8 ft^2 opening × 12 in/ft ÷ 48' building roof). Minimum width is 6" to prevent freeze up. Space 4 openings, 6" wide and 4' long, over the center alley. Alternative: two cupola ridge vents with a net airflow opening of 4 ft^2 each, Fig 33.

Provide an adjustable eave inlet:

1 ft^2/stall × 8 stall = 8 ft^2 of inlet.

Continuous eave opening is 2 × 48' = 96' long.

8 ft^2 × 12 in/ft ÷ 96' = 1" wide eave inlet along both sidewalls.

Summer vent doors: 6 ft^2/stall, or one 2'x3' vent door in each stall.

Poultry

General

Natural summer ventilation of turkey grower buildings is included here. Poultry buildings are often mechanically ventilated, especially in winter.

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.

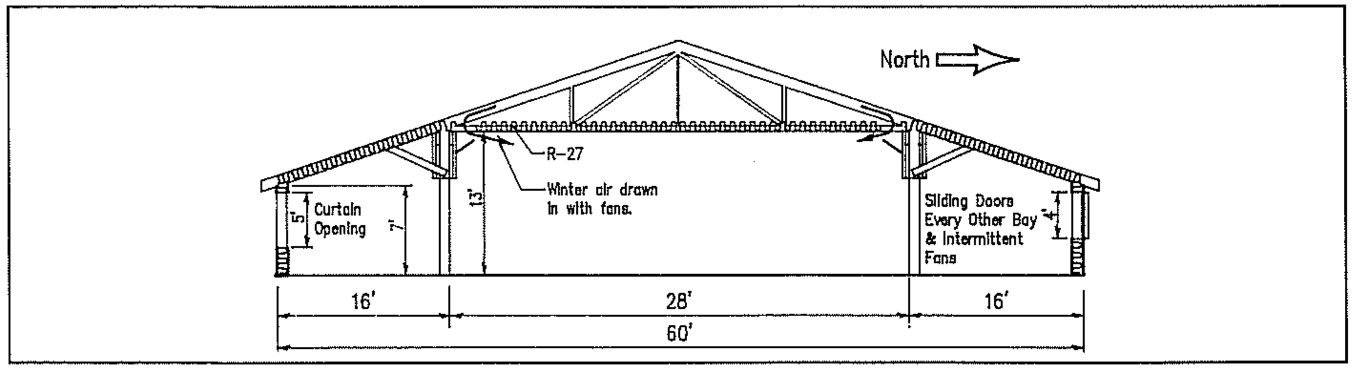


Fig 34. Brooder & grower building cross section.

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. Use R values shown in Table 5; install a vapor retarder.

Example 6:

Design a ventilating and management system 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 requires mechanical ventilation. Growing facilities are typically mechanically ventilated in cold and mild weather and naturally ventilated in hot weather. Only hot weather ventilation is presented here.

Two growout buildings, each 60'x290' (60' × 290' × 2 = 34,800 ft^2), Fig 34, provide for 10,000 toms at 3.5 ft^2/tom. South wall: provide continuous sidewall doors or 5' curtains. North wall: install continuous insulated 4'x8' doors at least 2' above the floor.

Move poults to the grower barn when 6 to 8 weeks old. Pre-warm the barn to 70 F before placing the birds. Reduce temperatures to 65 F when 9 weeks old. Some growers lower temperatures to 60 F at 15 weeks of age.

Circulation fans. In hot weather, air movement across birds reduces heat stress. Use four 36" fans hung vertically in the building or several paddle fans for mixing.

Rabbits

General

Cold, natural ventilation is adequate for mature rabbits, provided there are few drafts. Young rabbit housing is typically mechanically ventilated. Relatively low animal density (frequently 1 lb/ft^2 or less) makes it difficult to control cold weather rates without creating drafts.

Temperature for optimum feed conversion 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 85 F or more for 4 to 5 days can sterilize mature bucks for up to 60 days. All rabbits are subject to heat prostration at temperatures above 92 F.

Relative humidities below 35% can cause respiratory problems.

Insulation for rabbit buildings is required to moderate summer temperature extremes and reduce winter supplemental heat costs. See Table 5. Periodically remove rabbit hair from cages, because it restricts airflow.

Consider evaporative cooling in climates that frequently have potentially damaging high temperatures. For temporary relief for breeding bucks place 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 which is caustic to the animal's skin.

Example 7:

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

Solution:

Natural summer ventilation is included here. Mechanical ventilation is discussed in MWPS-32. The cages needed are in Table 6.

During hot weather, open both long sidewalls by adjusting curtains. Provide a 2'-6" roof overhang to shade rabbits and provide protection from blowing rain.

Table 6. Rabbitry cages and animal weight.
60-doe fryer production unit.

Animal group	No. cages
Doe	60
Bucks	6
Replacement animals	18
Grow out (8 animals/group)	36

Sheep

General

Open-front, naturally ventilated, cold buildings are common in moderate climates, especially for ewes and feeder lambs. Enclose buildings with ventilating doors. Control drafts and snow blow-in in more severe climates. Warm buildings are common for cold weather lambing.

In hot weather, circulation fans increase air speed over animals. Consider insulating cold sheep buildings to R=5.

Example 8:

Design a naturally ventilated 30' wide gable roof open front ewe and lamb building. The building is not closed in winter.

Solution:

Ventilation openings. From Table 3c, a 30' wide gable roof sheep building requires a 6" ridge opening and 3" eave opening in the closed wall. Install continuous ridge and eave openings.

Install at least 48" high vent doorsor curtains, continuous along the closed sidewall. Make the sidewalls at least 8' high. Protect lambing areas with temporary interior walls or drop curtains during cold weather.

Swine General

Natural ventilation is rare in farrowing and in nursery units.

Growing and finishing: For growing and finishing pigs, a temperature of 60 F-70 F is recommended. Although finishing swine can thrive in lower temperatures, they grow faster with less feed in the recommended temperature range.

Breeding-gestation: Temperatures above 85 F with high humidity reduce fertility. Maintain temperatures below 85 F for sows during the first 2 or 3 weeks of gestation to ensure maximum litter size and during the last 2 or 3 weeks to reduce stillborns and abortions. Temperatures of 60 F-85 F are recommended for sows or gilts confined on slotted floors or in crates or tethers. Colder temperatures in bedded pens can be tolerated, but freezing temperatures with wind can be a problem.

Relative humidities of 50%-70% are desired.

Consider minimum insulation (R=5).

Solid pen partitions around animal sleeping areas reduce drafts. Hovers reduce vertical drafts better than boards covering floor slots. Hovers can be tempered hardboard, sheet metal, or exterior plywood. Heavy clear plastic on a frame allows you to observe the animals. Provide enough hover space for all animals at one time—about half of a farrowing creep area or a third of a nursery pen. Mount hovers between solid partitions at no more than twice animal height.

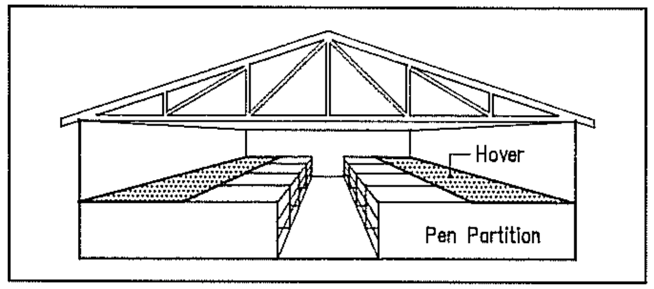


Fig 35. Hovers over animal resting areas.
For growing swine or calves. Reduce drafts with solid pen partitions and hovers.

Example 9:

Design a naturally ventilated 28' wide monoslope modified environment swine finishing building.

Solution:

Ventilation openings: From Table 3b, a 28' width requires a 6" opening under the eave of the front (south) wall. A 3" opening is required under the eave of the back wall and under the large vent doors of the front wall. Install adjustable baffles over these openings. Make the front wall vent doors at least 66" high and the back ones 24" high. Make all openings continuous along the building length.

Table 7. 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. [a]Where unvented heaters are used, provide an additional 4 cfm/1,000 Btu of heater capacity.
[b]If wet-skin cooling is provided for mature animals, the hot weather rate may be reduced.

Animal	Weight	Unit	Cold weather rate[a]	Mild weather rate	Hot weather rate[b]
			--- cfm/unit ----		
Swine					
Sow and litter	400 lb	hd	20	80	500
Prenursery pig	12-30 lb	hd	2	10	25
Nursery pig	30-75 lb	hd	3	15	35
Growing pig	75-150 lb	hd	7	24	75
Finishing pig	150-220 lb	hd	10	35	120
Gestating sow	325 lb	hd	12	40	150
Boar/Breeding sow	400 lb	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
Horse					
Warm 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	1.0
Turkeys					
Poults		hd	0.2	0.7	1-4
Growers		lb	0.08	0.35	0.8
Breeders	20-30 lb	lb	0.05	0.15	0.5
Rabbits		lb	0.1	0.5	1.0
Sheep					
Warm barn		1,000 lb	25	100	335

7. Glossary of Terms

AIr Conditioning: Cooling of air usually with 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: Temperature scale with zero as the freezing point of water and 100 as the boiling point of water. 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.

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. Often used interchangeably with relative humidity.

Dewpoint Temperature: Temperature at which moisture begins to condense from air.

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 Wet-bulb Temperature).

Duct: Structure used to conduct air from one place to another. Often used to distribute air within a structure 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.

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.

Fan: Mechanical device to move air—usually electric.

Fahrenheit: Temperature scale with 32 as the freezing point of water and 212 as the boiling point of water. Abbreviated F.

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 Conduction, Convection, Radiation, Evaporation, Condensation).

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

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

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 of a livestock structure which allows warm moist air to leave the building.

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

Perm: Measure of permeability. One perm equals one grain of water/hr/ft^2/in of mercury pressure difference.

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 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 expressed as a percent.

R-Value: Resistance value of an insulation material. 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: Condition where air can hold no additional water vapor. Condition of 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. A psychrometric chart is used to convert the two temperature readings 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 or on either side of a ventilating fan or inlet. Units measured in inches of water.

Supplemental Heat: 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.

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 Retarder: Material that resists vapor transfer through a wall or ceiling section. Materials below a perm rating of 1.0 are considered good vapor retarders.

Velocity, Inlet Air: Speed 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 with a thermometer with a wet wick on the bulb. The wet-bulb temperature represents the temperature at which ambient air would be saturated if it were cooled. (See Dry-bulb Temperature And Sling Psychrometer).

Wind Rosettes: Graph of wind at a site: how many hours, and how fast, it blows from each direction.

8. 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; Lyndhurst NJ 07071
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-1 *Structures and Environment Handbook.*

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-23 *Solar Livestock Housing Handbook.*

MWPS-28 *Farm Buildings Wiring Handbook*

MWPS-32 *Mechanical Ventilating Systems for Livestock Housing.* (To be published.)

MWPS-34 *Heating, Cooling and Tempering Air for Livestock Housing.* (To be published.)

AED-25 *Earth Tube Heat Exchange Systems.*

Available from other sources:

1985 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.

9. INDEX

December 1990

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)	
							Asphyxiant
Carbon dioxide (CO_2)	None	—	5,000	30,000	20,000	—	Safe
					30,000	—	Increased breathing
					40,000	—	Drowsiness, headaches
					60,000	30	Heavy, asphyxiating breathing
					300,000	30	Could be fatal
							Irritant
Ammonia (NH_3)	Sharp, pungent	5	25	35	400	—	Throat irritant
					700	—	Eye irritant
					1,700	—	Coughing and frothing
					3,000	30	Asphyxiating
					5,000	40	Could be fatal
							Poison
Hydrogen sulfide (H_2S)	Rotten egg smell, nauseating	0.7	10	15	100	Several hours	Eye and nose irritant
					200	60	Headaches, dizziness
					500	30	Nausea, excitement, insomnia
					1,000	—	Unconsciousness, death
							Asphyxiant
Methane (CH_4)	None	—	—	30,000[f]	500,000	—	Headache, nontoxic
							Poison
Carbon monoxide (CO)	None	—	50	200	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 Governmental 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 Governmental 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 Governmental Industrial Hygienists. Methane is explosive at concentrations of 5%-15%.