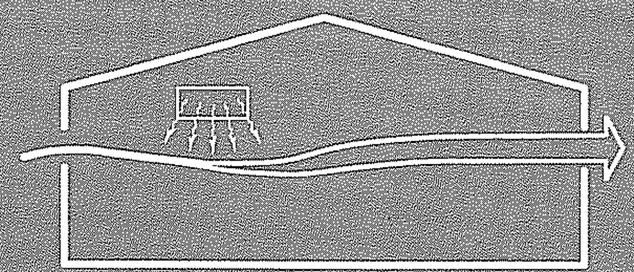
MWPS-34

Heating, Cooling and Tempering Air for Livestock Housing

First Edition, 1990



Engineering Program of 13 Universities
USDA Cooperating Member
...ce
...nowledge

ISBN 0-89373-076-9

under the direction of the following agricul-
n the ventilation subcommittee of the Mid-

/ of Wis, Madison
: Univ, E. Lansing
Univ, Columbus
v, Ames
of Ill, Urbana
Jeb, Lincoln
, Columbia
Univ, University Park
v, Manhattan
Minn, St. Paul
, St. Paul
/, W. Lafayette
Jniv, Wooster
niv, Manhattan
ustries Inc., Osborn, Ks
Ill, Urbana
Jniv, Ithaca
ate Univ, Columbus

r
vice Engineer
ervice Engineer
Service Engineer

esult of much work by many people. In-
ere used; each author's work was critically
easonable to recognize the following for their

airy design example.
r quality; gases, odors, and dust.
oubleshooting tools; troubleshooting
tural ventilation; dairy design example;
essary; significant contribution as com-
ttee chairman in development of book
ntent.
ultry design example.
dge, eave, and wall opening design and
e; wind, draft, and snow control; gas
easuring instruments.
orse design example.
abbit design example.
dge, eave, and wall opening size and
sign; swine design example; significant
ntribution as technical editor in develop-
ent of book content.
eep design example, significant contribu-
n as technical editor in development of
ok content.

...And Justice for All.
publications are available to all potential
rd to race, color, sex, or national origin.
iminated against should send a complaint
Secretary of Agriculture, Washington, DC
l opportunity employer.

MWPS Committee

The Midwest Plan Service prepares publications under the direction of agricultural engineers and consulting specialists. It is an official activity of the following universities and the U.S. Department of Agriculture. The Midwest Plan Service Committee is responsible for the selection and supervision of all projects:

A.J. Muehling; G.L. Riskowski
University of Illinois, Urbana, IL 61801
D.D. Jones; W.H. Friday
Purdue University, West Lafayette, IN 47907
V.M. Meyer; D.S. Bundy
Iowa State University, Ames, IA 50011
J.P. Murphy; A.J. Heber
Kansas State University, Manhattan, KS 66506
W.G. Bickert; T.L. Loudon
Michigan State University, East Lansing, MI 48824
L.D. Jacobson; K.A. Janni
University of Minnesota, St. Paul, MN 55108
D.L. Williams; N.F. Meador
University of Missouri, Columbia, MO 65211
D.N. Sasseville
Lincoln University, Jefferson City, MO 65101
G.R. Bodman; J.A. DeShazer
University of Nebraska, Lincoln, NE 68583
K.J. Hellevang; L.F. Backer
North Dakota State University, Fargo, ND 58105
M.A. Veenhuizen; H.M. Keener
The Ohio State University, Columbus, OH 43210
S.H. Pohl; G.A. Anderson
South Dakota State University, Brookings, SD 57006
D.W. Kammel; D.R. Bohnhoff
University of Wisconsin, Madison, WI 53706
L.G. Hahn
USDA
W.L. Harris
USDA-CRS

For additional copies of this book or other publications referred to, write: Extension Agricultural Engineer at any of the above institutions.

MWPS-34
First Edition, 1st printing, 10M, December 1990

Library of Congress Cataloging in Publication Data
Heating, cooling, and tempering air for livestock housing / [prepared under the direction of the Ventilation Subcommittee of the Midwest Plan Service]. — 1st ed.
48 p.
"MWPS-34."
Includes bibliographical references.
ISBN 0-89373-076-9
1. Livestock—Housing—Heating and ventilation. I. Midwest Plan Service. Ventilation Subcommittee.
SF91.H43 1990 90-34153
636.08'31dc20 CIP

TABLE OF CONTENTS

1 **1. PROVIDING A PROPER ENVIRONMENT**
1 Ventilating Process
1 Ventilating Systems

2 **2. AIR REQUIREMENTS**
2 Air Quality
3 Animal Heat Loss
4 Moisture Balance
4 Heat Balance
4 How Much Air

6 **3. HEATING**
6 Heating
7 Heaters
Radiant Heaters
Floor Heat
Thermostat
Hot water floor heat
Electric heating cable
Electrical plastic heat pads
Floor Heat with Sand for Heat Storage
Unit Space Heaters

12 **4. TEMPERING**
Air Make-up Heaters
Air Preheating Rooms
Reusing Exhaust Air
Air Blending
Air-to-Air Heat Exchangers
Heat exchanger efficiency
Airflow pattern
Integrating heat exchangers
Condensation and dust
Solar Heat
15 Controls

17 **5. EARTH TUBE HEAT EXCHANGERS**
Benefits
Principles
Layouts
19 Earth Tube System Design
Design Procedure and Example
Tube Installation

24 **6. COOLING**
Ventilation Cooling
Air Circulation
Water Cooling
Sprinkler cooling
Drip cooling of swine
Evaporative Cooling
Principles
Evaporative coolers
Design
Maintenance
Air Conditioning Systems
Zone Cooling

29 **7. INSULATION**
29 Where to Insulate
Insulation Levels
30 Moisture Problems
31 Fire Resistance
31 Birds and Rodents

32 **8. APPLICATIONS AND EXAMPLES**
32 Beef
32 Dairy
Milking Center
Milking parlor
Milk room
Other areas
Dairy Design Example
34 Veal Calves
General
Ventilation
Air tempering
Veal Calf Design Example
35 Horses
General
Supplemental Heat
36 Poultry
General
Ventilation
Supplemental Heat
Cooling
37 Rabbits
General
Ventilation
37 Sheep
General
Ventilation and Heat
38 Swine
General

39 **9. APPENDIX**
39 Animal Heat and Moisture Production
40 Calculating Heat Loss Through Building Surfaces
Worksheet example
Calculating Heat Loss by Ventilation
Annual Heating Costs
41 Worksheet: Heat Loss Through Building Surfaces
43 Determining Furnace Size

44 **10. GLOSSARY**

46 **11. SELECTED REFERENCES**

47 **12. INDEX**

1. PROVIDING A PROPER ENVIRONMENT FOR ANIMALS AND WORKERS

This is one of three handbooks on ventilation for livestock housing 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.

Mechanically ventilate where careful control of the environment is needed, as for young and smaller animals. See MWPS-32, *Mechanical Ventilating Systems for Livestock Housing.* Mature, "finishing", or large animals are often in naturally ventilated buildings. They are discussed in MWPS-33, *Natural Ventilating Systems for Livestock Housing.*

Heating and cooling are sometimes needed to maintain the desired environment. Young animals often need additional heat and breeding stock may require summer cooling. This book discusses adding supplemental heating and cooling to the ventilating system and changing room air temperature during the ventilating process in livestock housing. It helps evaluate existing systems and examines alternatives for new systems. Ventilating system type and desired inside environment depend on animal species and management system. Systems to satisfy the requirements of different livestock are shown.

Retaining animal body heat in a building 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. Contact your state's Extension Agricultural Engineer for these and other Midwest Plan Service publications.

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 levels.
- 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 other needs. High odor levels from under-floor manure storage may require higher air exchange rates.

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

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

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

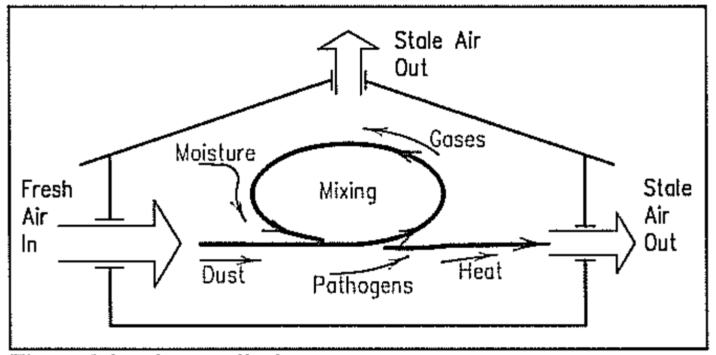


Fig 1. A basic ventilating process.

Ventilating Systems

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

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

2. AIR REQUIREMENTS

is 78% nitrogen, 21% oxygen, carbon dioxide, and smaller ses. Air composition is changed ngs. Breathing uses oxygen and de. Air oxygen content less than rt; less than 10% is dangerous. off from respiration, animals' ure. Anaerobic decomposition of litional noxious gases. Without xic gases and dust in enclosed an harm animals and operators. ıck buildings that may affect are ammonia, carbon dioxide, ydrogen sulfide, and methane.

See Table 1 for human responses to these gases. Decomposing wastes give off odorous gases such as amines, amides, mercaptans, sulfides, and disulfides. More details on these gases, their effects, and their controls are in other books in this series—MWPS-32, *Mechanical Ventilating Systems for Livestock Housing*, MWPS-33, *Natural Ventilating Systems for Livestock Housing*, and MWPS-18, *Livestock Waste Facilities Handbook.*

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

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

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

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

nits and effects of noxious gases.

ans. The effects of two or more gases tend to be additive.

		Threshold limit value		Concentration effects		
	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
	—	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
	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
g	0.7	10	15	100	Several hours	Eye and nose irritant
ıg				200	60	Headaches, dizziness
				500	30	Nausea, excitement, insomnia
				1,000	—	Unconsciousness, death
						Asphyxiant
	—	—	30,000[f]	500,000	—	Headache, nontoxic
						Poison
	—	50	200	500	60	No effect
				1,000	60	Unpleasant, but not dangerous
				2,000	60	Dangerous
				4,000	60+	Fatal

ı at which odor is detected.

weighted average exposure concentration for a normal 8 to 10 hr workday. (Source: 1989 Guide to Occupational Exposure Values, American dustrial Hygienists, Cincinatti, Ohio.)

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 es, American Conference of Governmental Industrial Hygienists, Cincinatti, Ohio.)

arts of atmospheric air. Divide by 10,000 for % by volume. Example: 20,000 ppm ÷ 10,000 = 2% by volume.

ion to the gas.

oxygen and 3% methane. This value for methane was not obtained from the American Conference of Governmental Industrial Hygienists. Methane f 5%-15%.

Animal Heat Loss

A ventilating system is used to control the environment. Ventilating capacity is based primarily on the amount of air exchange needed to remove moisture in winter and excess heat in summer.

Farm animals try to maintain a constant body temperature, so they either lose metabolic heat to their surroundings at the rate it is produced, or their body temperature changes. An animal overheats if it cannot lose heat fast enough and chills if it loses heat too fast. Heat loss rate depends considerably on the environment. Air and room surface temperatures, relative humidity, air velocity, and solar radiation are important factors of animal heat loss. These factors combine into an effective temperature. At air temperatures below pig body temperature, increasing air velocity past a pig from 0-90 ft/min can decrease the effective temperature about 13 F. This effect is the wind chill factor.

How heat is lost is important. With an understanding of the different methods of heat loss, proper corrective measures can be taken. 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 skin 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. Fig 2 shows that temperature affects what portion of a pig's heat loss is from each of the four methods. Fig 3 shows that increasing air velocity changes how pigs lose heat.

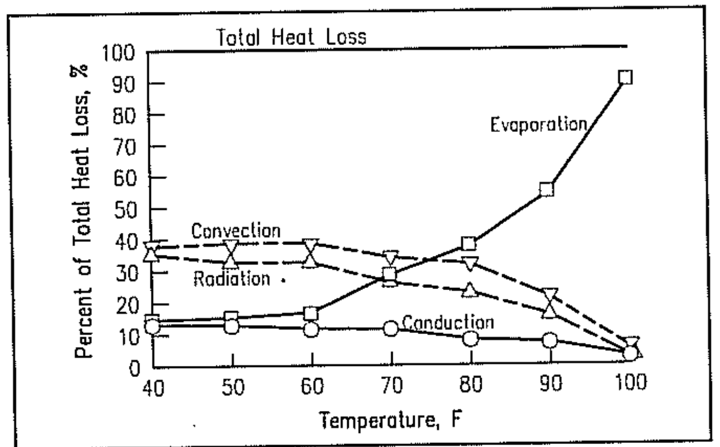


Fig 2. Temperature affects how pigs lose heat.

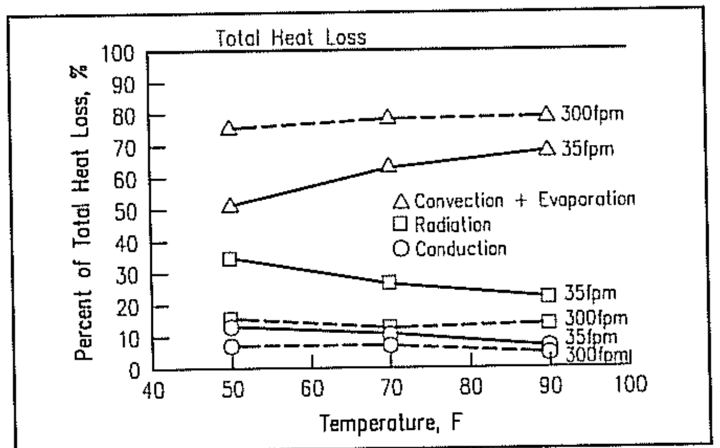


Fig 3. Air velocity affects pig heat loss.
Air velocity in feet per minute (fpm). 35 fpm is nearly still air (0.4 mph); 300 fpm is about 3.4 mph.

As air temperature increases, an animal cannot lose as much sensible heat, so it pants and sweats to increase evaporation and latent heat loss, Fig 4. As the temperature increases, even more moisture is produced. As relative humidity rises, an animal loses less heat by evaporation. If temperature and relative humidity are both high, the animal becomes heat stressed. See Table 20 in the Appendix for animal heat and moisture production rates.

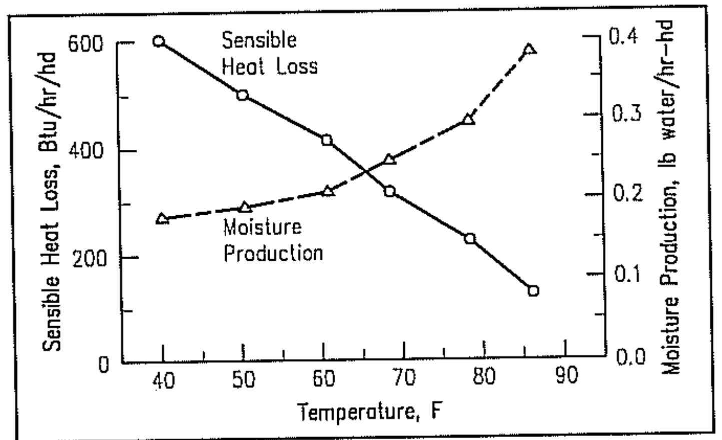
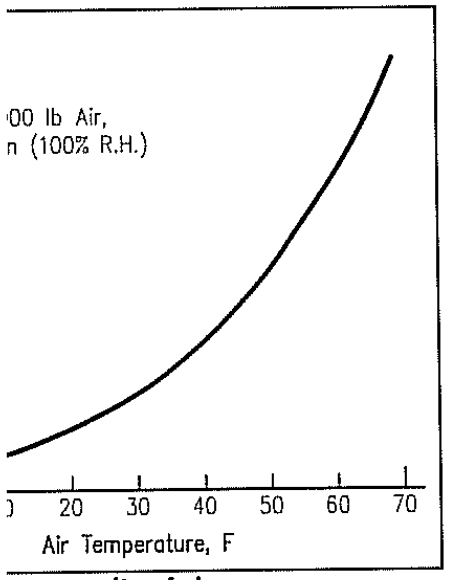


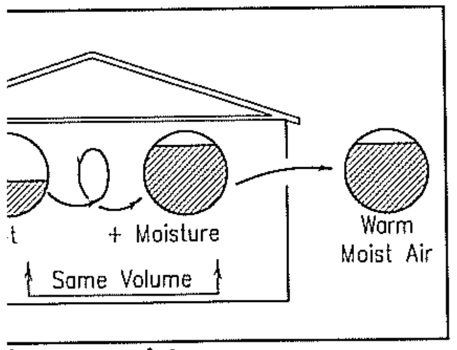
Fig 4. Heat and moisture loss vary with air temperature.
Typical sensible heat loss and moisture loss of a 175 lb pig.

e

r vapor enter the environment
d evaporation from surfaces and
er vapor is removed by ventila-
moisture to be removed depends
ize and on the manure handling
rger animals give off more mois-
re moisture control ventilation.
her, ventilation brings cold, rela-
building. The air is warmed by
electrical equipment, and sup-
As air temperature rises, air can
re and its relative humidity
holding capacity of air nearly
F rise in temperature. Ventilat-
isture and removes it from the
perties are shown schematically



ıg capacity of air.



ds more moisture.
d can absorb more moisture.

intain room air between 40% and
idity. Higher humidities tend to
ıtion; lower humidities increase
40%-60% relative humidity is
borne bacteria found in livestock

Heat Balance

To maintain constant room temperature, heat **produced** by animals and heaters has to equal heat **lost** through building walls, windows and doors, ceiling/roofs, and ventilation. If heat loss exceeds animal heat production, provide supplemental heat. If heat production exceeds heat loss, increase the ventilating rate or use other cooling methods. Incoming air that is warmer than room air cannot cool or effectively dry inside conditions.

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

$$VHL = cfm_c \times 1.1 \times (t_i - t_o) \qquad \text{Eq 1.}$$

VHL = Heat loss rate by ventilation air, Btu/hr
cfm_c = Cold weather ventilating rate, cfm (ft^3/min)
1.1 = Conversion factor, a constant, Btu-min/hr-ft^3-F
t_i = Indoor temperature, F
t_o = Outdoor temperature, F

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

Solution:
Using Eq 1, find the heat removal rate.

cfm_c = 1,000 cfm
t_o = 20 F
t_i = 70 F

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

How Much Air

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

Design the system to provide **at least** three seasonal ventilating rates—cold, mild, and hot weather.

Cold weather ventilation provides oxygen and removes moisture. When supplemental heaters are running, do not exceed the cold weather rate. Supplying heat at higher ventilating rates wastes fuel. Protect pipes from freezing or provide an alarm and a safety thermostat to shut off cold weather fans if the building temperature drops to near freezing. See "Alarm" section in Chapter 7, MWPS-32, *Mechanical Ventilating Systems for Livestock Housing.*

Mild weather ventilation modifies temperature and removes moisture. Fans to provide this additional air are usually turned on by thermostats when building temperature exceeds a desired level.

Hot weather ventilation reduces heat buildup and increases air velocity in the building. Thermostats turn on maximum rate fans when the indoor temperature exceeds a set level.

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

Example 2:
Determine the required cold, mild, and hot weather ventilating rates for a 1,200 lb dairy cow.

Solution:
From Table 2, the recommended ventilating rates for a 1,000 lb cow are:

Cold weather = 36 cfm
Mild weather = 120 cfm
Hot weather = 335 cfm

To calculate ventilating rates for a 1,200 lb cow:

Cold weather = (36 cfm/1,000 lb) × 1,200 lb = 43 cfm
Mild weather = (120 cfm/1,000 lb) × 1,200 lb = 144 cfm
Hot weather = (335 cfm/1,000 lb) × 1,200 lb = 402 cfm

Provide a cold weather fan rated at 43 cfm/cow, a mild weather fan to add about 101 cfm/cow, and hot weather fans to provide another 258 cfm/cow.

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

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

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

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

[a]Where unvented heaters are used, provide at least an additional 2½ cfm continuous ventilating capacity per 1,000 Btu/hr of heater capacity.
[b]If mechanical, earth tempered, or wet-skin cooling is provided for **mature animals,** the hot weather rate may be reduced. See Chapter 6.
[c]400 cfm/1,000 lb cow is recommended in the mid-Atlantic and southeastern states.
[d]If air circulation fans are provided, hot weather ventilating rates can be reduced up to 40%.

3. HEATING

ıat is needed where heat from
ep the building at a desired
. weather. Heat is lost through
s and by exhausting ventilating
ed livestock building, as much as
d in the building is used to warm
vaporate moisture.
ig 7 show how ventilation and
equirements are affected by out-
ıe "moisture control ventilation"
tilation needed to maintain rela-
a certain level. The "temperature
ıows ventilation needed to main-
ture below a certain level. Curve
ther ventilation rate discussed
dbook.
ures (below 30 F, Fig 7):
ol ventilation reduces relative
ı reduces fogging, wet floors, and
ɔn walls, windows, and other
es.
ɔn is usually needed to control
to control temperature, so room
end to drop. Additional ventila-
o help control odors and manure
ols the room even more.
ntal heat to maintain desired
ıre. See Table 3 for recommended
ıg temperatures.
entilation rates to below the cold
. Table 2.
eratures (30 F and above, Fig 7):
ɔntrol requires higher ventilation
ıre control is not a problem.
eather and without air condition-
ı maintains the indoor tempera-
ees above the outdoor tempera-

lating rate curve is shown in Fig
g system is designed to meet or
relative humidity is controlled
, inside temperature is only 1 F-5
side during warm weather, and
comfort are maintained.
culation provides a more uniform
lative humidity eliminating cold
cing condensation, and distribut-
in through building inlets and
tion cannot replace inadequate

to reduce drafts in cold weather,
ll animals.
protection, e.g. solid wall pens,
and/or solid floors.

- Increase air temperature with air heaters.
- Provide radiant or floor heaters to warm the animals.
- Provide deep bedding so animals can nestle.

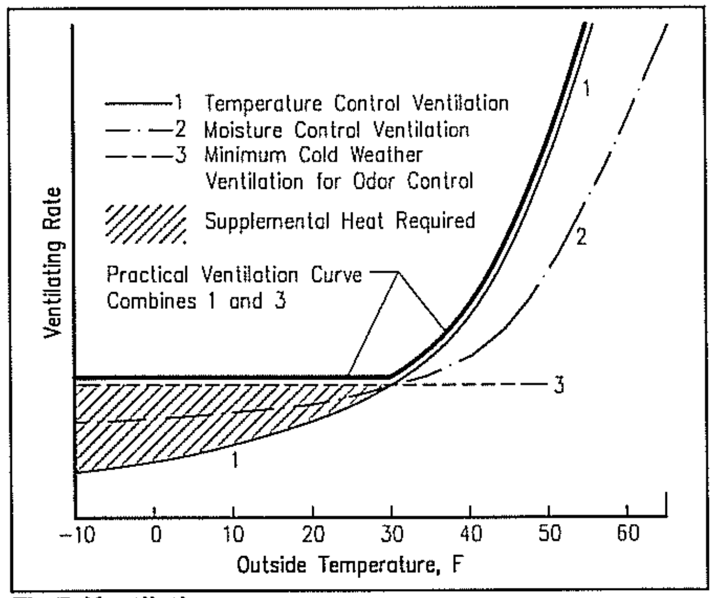


Fig 7. Ventilation curves.
Ventilation curves shown are for a specific building. Higher building insulation levels lower the intersection point of the temperature and moisture control curves; lower insulation levels raise it. Increasing the cold weather ventilating rate above the moisture control curve improves air quality and distribution but also increases operating costs.

Table 3. Temperatures for livestock housing.
Optimum temperature depends on air velocity, humidity, floor type, insulation level, and outdoor temperature. The temperatures listed assume reasonable humidity control.

Animal	Desirable temperature, F
Lactating sow	50-70
Litter-newborn	90-95
Litter 3 weeks old	75-85
Pre-nursery (12-30 lb)	75-85
Nursery (30-50 lb)	70-80
Nursery (50-75 lb)	60-70
Growing-finishing (75-220 lb)	50-70
Gestating sows	50-70
Boars	50-70
Dairy cows	40-60
Calves, floor level, bedded	40-60
Calves, raised stalls	60-70
Beef cows	40-60
Horses	50-70
Rabbits	40-60
Layers	55-70
Broilers and turkeys	
Brooding (to 4-5 weeks)	95 brooder; 70 room
Growers	65-70

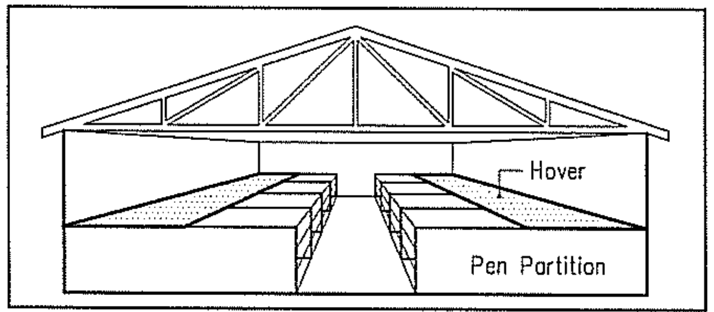


Fig 8. Hovers over animal resting areas.

Table 4. Sizing supplemental heaters.
Use these peak loads only for rough estimates and only where winter degree days are greater than 5,000. Refer to Chapter 9 for a design procedure. These values are based on the minimum outdoor design temperature and twice the cold weather ventilating rate in a moderately well insulated building with typical stocking densities. The supplemental heat recommended provides reserve heater capacity to handle heating needs when only a few animals are present. Additional zone heat may be needed for young animals.
Example: A 20-sow farrowing house kept at 80 F requires about 20 × 4,000 = 80,000 Btu/hr heating capacity.

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

Heaters

Heating systems include radiant, floor, unit space, and air make-up heaters. Space heaters heat room air and maintain room temperature. Radiant and floor heat provides localized animal comfort. Table 4 gives supplemental heat requirements for typical livestock housing in the North Central U.S.

Radiant Heaters

Radiant heaters work well for zone heating of young animals. Animals find comfort by moving closer to or farther from the heater. Energy from a radiant heater passes through air without warming it. When the energy strikes an animal or other surface, it is absorbed and the object warms. The warmed object then warms the air around it.

Infrared heaters produce radiant heat from natural gas, propane, or electricity. Available types range from heat lamps for zone heating to fan-driven pipe units for providing heat in an entire building.

With floor heat in a farrowing creep area, provide a 250 watt (852 Btu/hr) overhead heat lamp for the first few days after farrowing. If no floor heat is used, provide 2,200 Btu/hr of overhead radiant heat per litter (especially in cold climates, a heat lamp may not be enough).

Heat lamps are a potential fire hazard. Suspend them on chains and make the lamp cord 1' shorter than the floor-to-ceiling height, so it unplugs before the lamp hits the floor. For pigs, mount lamps at least 30" above pen floors and 18" above creep floors. Place no more than seven 250 watt heat lamps on one 20 amp circuit. Consider manual or automatic voltage controllers to regulate heat lamps when full wattage is not required.

Gas catalytic radiant heaters are flameless and have relatively low surface temperatures. Catalytic heaters are usually not thermostatically controlled, which makes them less efficient. They require no chimney in a properly ventilated building. Radiating surfaces of catalytic heaters must be kept clean to maintain heating efficiency.

Unvented gas heaters are **not** recommended. If they must be used, increase the ventilating rate by 2.5 cfm/1,000 Btu-hr of heater capacity to prevent buildup of moisture and poisonous combustion gases. When vented heaters are used with negative pressure ventilation systems, use vent dampers and a fan powered vent.

Floor Heat

Floor heat is used primarily for localized heating. Possible uses of floor heat are in farm shops or small animal housing, pit in the milking parlor pit, and other heated work areas.

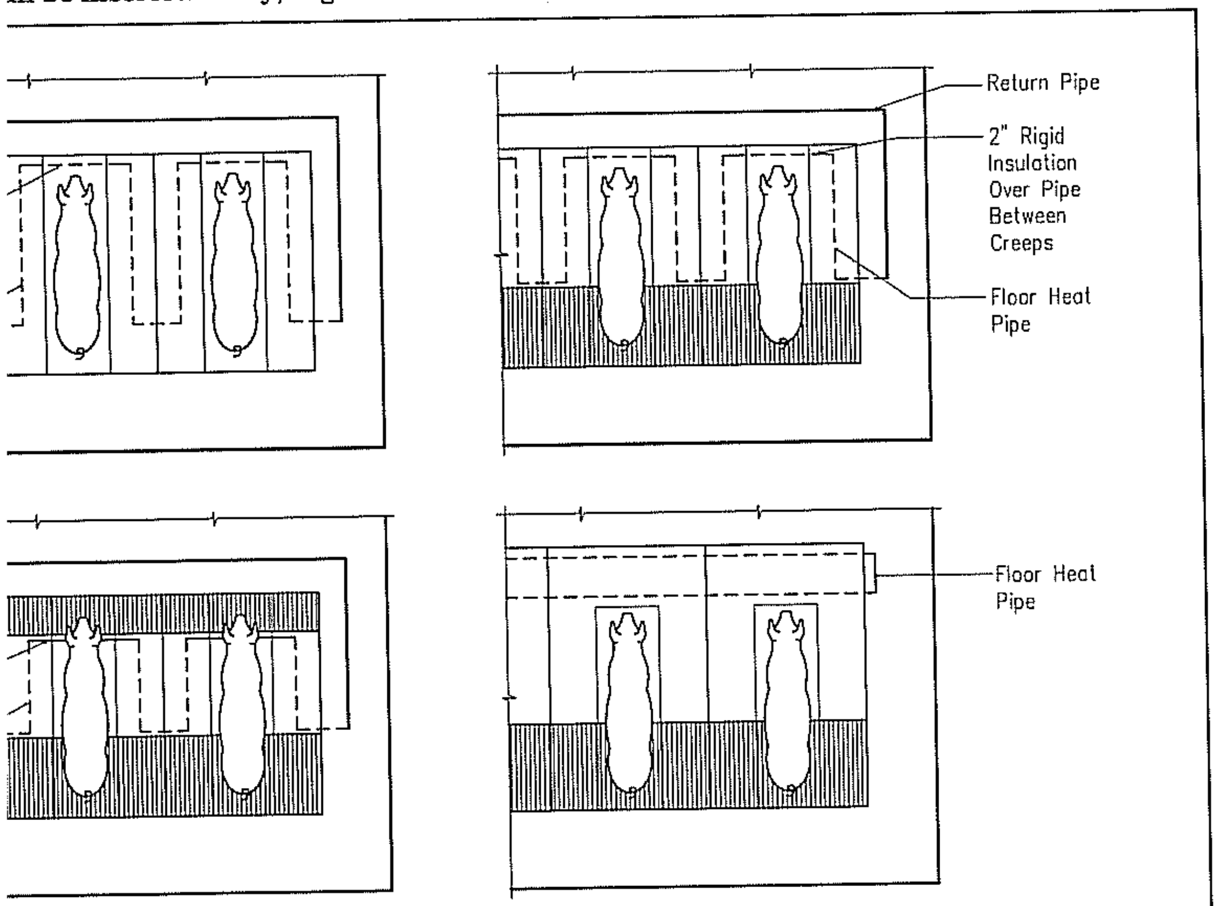
Common floor heaters are electric resistance cables or hot water pipes buried in concrete, Figs 9 and 10, or electric heating coils in fiberglass pads placed over an existing floor. Arrange resting areas, waterers, and dunging areas so the heated area is seldom wet. Floor heat evaporates liquid from the floor, which uses heat and increases the building relative humidity.

Too much heated area wastes heat; too little encourages animals to pile, Table 5. Use waterproof insulation under a heated floor but do not lay heating elements directly on plastic insulation. Perimeter insulation is especially important if the heated slab is near an outside wall. Uniform concrete thickness above hot water pipes or electric heat cables prevents hot spots.

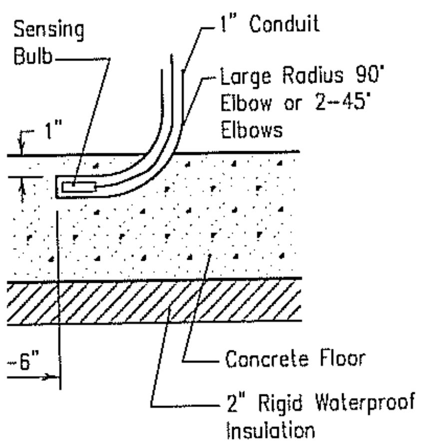
Thermostat

Locate the temperature sensing bulb about 1" below the heated floor surface and 4"-6" from a heat electric heat cable. Install the bulb and connecting tube in a 1" pe so they can be removed for large radius bend in the conduit ın be inserted easily, Fig 9.

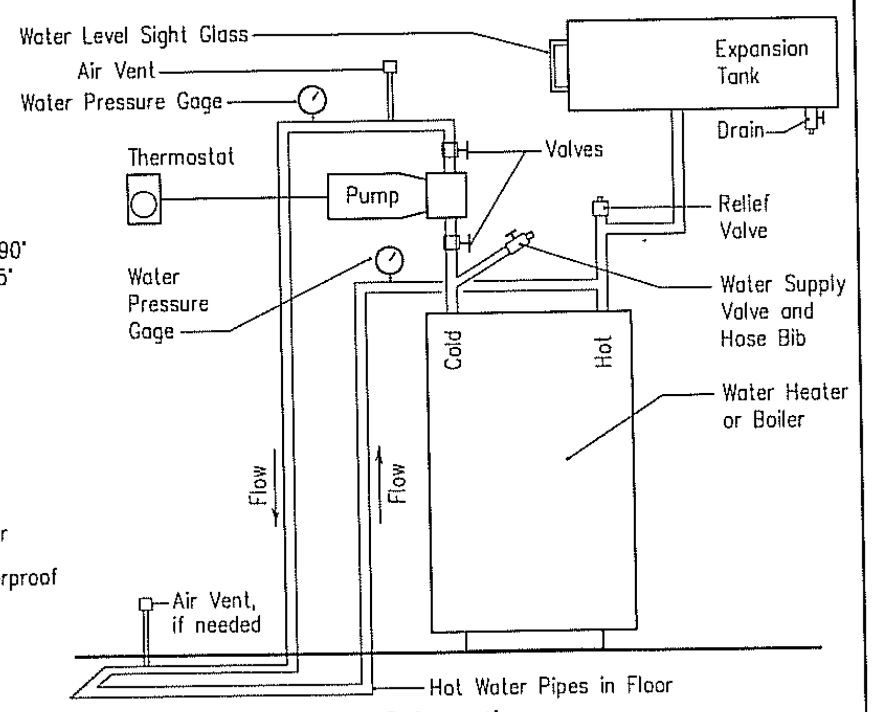
To check the thermostat, which controls internal instead of surface slab temperature, use a thermometer or other temperature sensor laid on the floor. Adjust to obtain desired environmental conditions.



ɪrnative Plan Views



ısor



Plumbing Schematic

ɪr heat.

Do not heat the floor under sows in farrowing buildings. Floor heat is occasionally installed in swine nursery buildings and naturally ventilated growing-finishing buildings.

Warm a concrete floor at least 2 days before use. Do not use insulation or excessive bedding on top of heated areas. Floor heat alone seldom provides the total heat requirements of a building.

Table 5. Heated floor design criteria for swine.
For swine farrowing buildings, provide 95 F slab surface temperature at farrowing. Gradually lower to 85 F when pigs are 3 weeks old. Also provide heat lamps or hovers for 3 to 5 days after farrowing.

Pig weight, lb	Heated floor space, ft²	Floor surface temperature, F	Hot water pipe spacing, in. Plastic	Iron	Electric heat W/ft²	Btu/hr-ft²
Birth-30	6-15/litter	85-95	See Fig 9	30-40	102-136	
30-75	1-2/pig	70-85	10	20	25-30	85-102
75-150	2-3/pig	60-70	10	20	25-30	85-102
150-220	3-3½/pig	50-60	12	24	20-25	68-85

Hot water floor heat

Hot water floor heat uses wrought iron, black iron, or high temperature (180 F) plastic pipe. Do not use galvanized steel or cold water plastic pipe, Fig 9.

Plastic pipe can supply 35 Btu/hr for each foot of pipe at an inlet water temperature of 150 F—iron can supply 70 Btu/hr-ft. Multiply the linear feet of pipe times these values to get the required output of a water heater. Use rated boiler output or multiply the rated input capacity of gas heaters by 0.75 to approximate actual heat output.

Space pipes per Table 5. Place pipes within 6" of the concrete slab edge. If a heated pipe passes under a sow, insulate between the sow and pipe. Pressurize the pipes with water to check for leaks before placing concrete. Cover the pipes with 2½"-3" of concrete. Contact an experienced plumbing contractor to plan and install hot water systems to allow for pipe expansion, vents, etc.

Electric heating cable

Electric heating cable usually has a lower installation cost than hot water pipes, avoids freezing problems, and permits individual control for each pen or stall.

Use heating cable approved for use in concrete. The most common type of heating cable is covered with polyvinylchloride (PVC) and is rated from 2-7

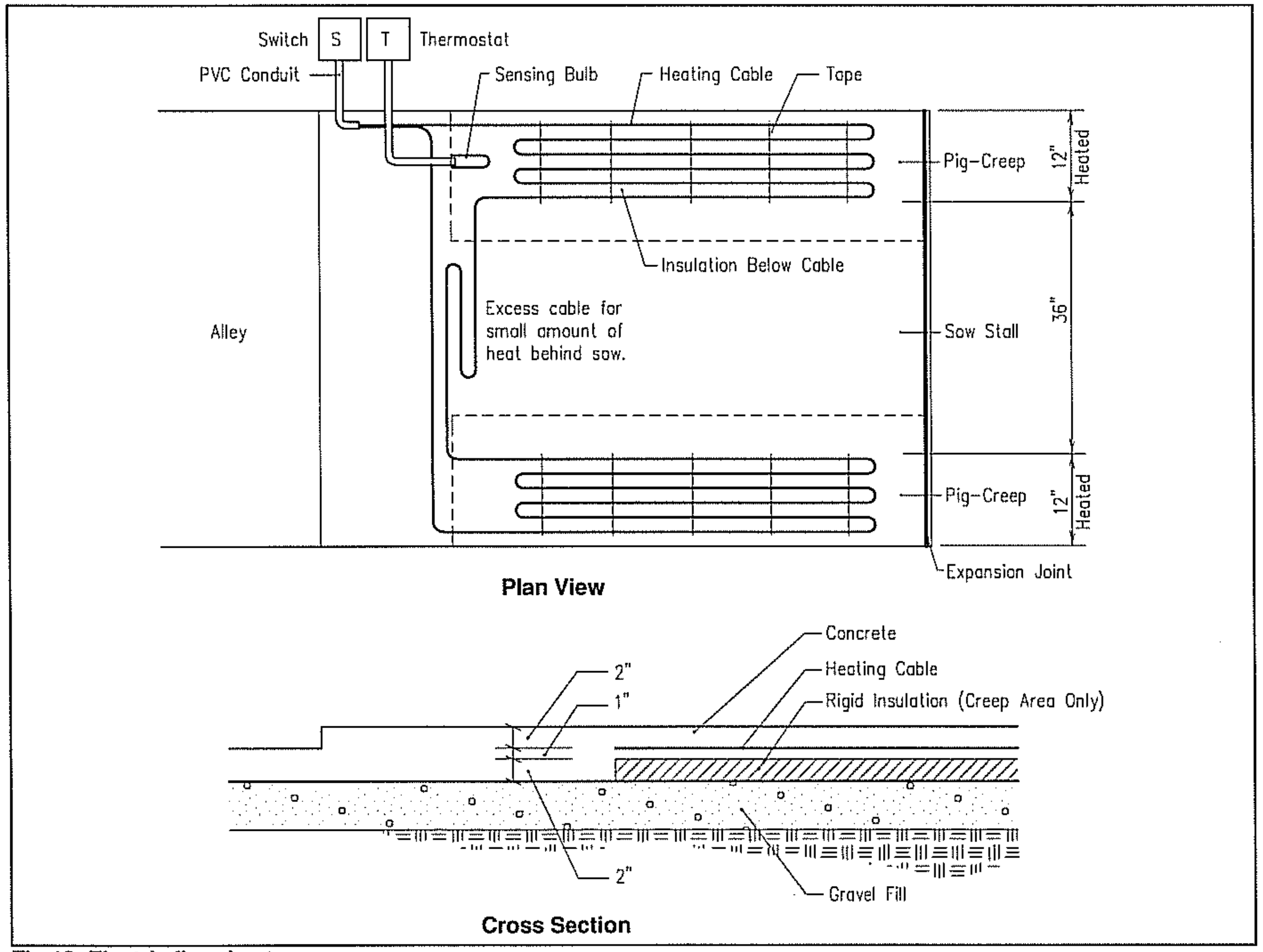
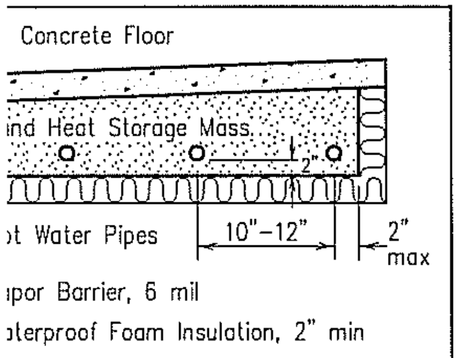


Fig 10. Electric floor heat.

ɔt. Prefabricated pads have cables
mesh to simplify installation.
; the heating cable in place, per-
ıst to ensure the cable will operate.
½"-2" into the concrete and space
ıre it is completely surrounded by
t burnout. Use a thermostat for
talls. Protect wiring and thermo-
ıbuse. A fused switch on each pen
sconnecting them when they are
ıtray voltages, electrically ground
vaterers to an equipotential plane,
rcement in concrete floors. Electri-
ıforcement and ground it to the
ıe entrance panel. See MWPS-28,
ɪring Handbook, for more details.

ıt pads

.c heat pads offer an alternative to
They can be placed on top of an
otted floor and are removable for
ɜ available in sizes suitable for
ırsery decks, and larger animals.
ɹith a factory set heat level while
ɜrmostat to permit changes in pad
'e. Protect the electrical cable from
a rigid conduit at animal level.



ɔr heat with sand mass.

Floor Heat with Sand for Heat Storage

Sand under concrete floors can store heat from animals, solar heated air, hot water pipes, or off-peak electricity to reduce floor surface temperature fluctuations. Hot water pipes placed in sand, rather than concrete, are less likely to be damaged by shifting concrete.

Advantages include:

- Heat system and concrete can be installed separately.
- Less surface temperature fluctuation.
- Reduced heating system damage from cracking or shifting concrete.
- Full pressure test of water pipes can be done before concrete is installed.

Design and installation of hot water floor heating with storage is similar to one without storage. Differences are:

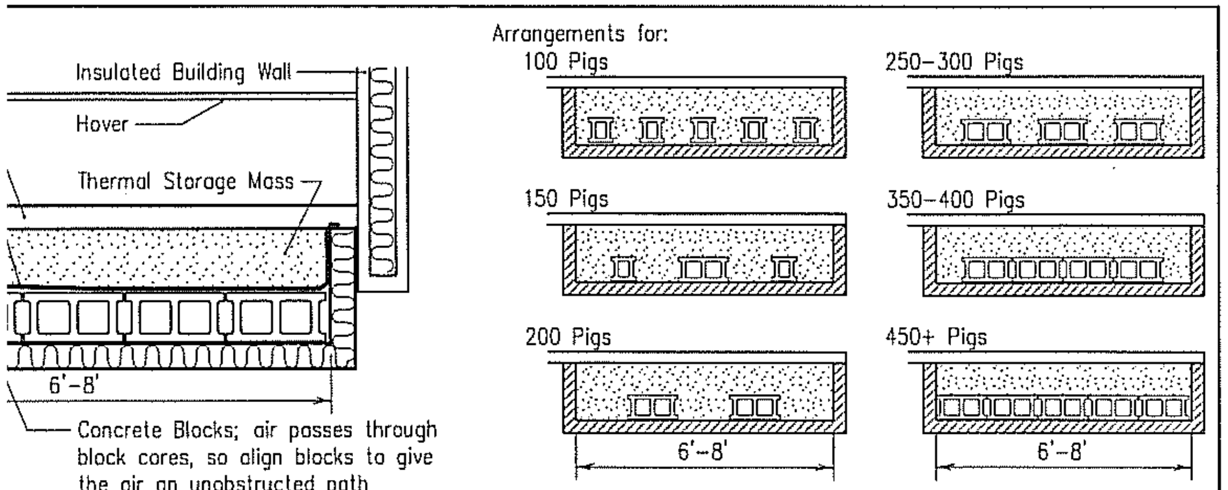
- Place insulation and a vapor barrier around the sand to reduce heat loss. 2" waterproof foam insulation is effective.
- Place 4"-8" of sand below the floor.
- Place hot water pipes in the sand about 2" above the bottom insulation, Fig 11. Place sand around the pipes so there are no air pockets.
- See Table 6 for recommended watt per ft² (W/ft²) for floor heat with storage systems in swine nursery buildings. Hot water pipes spaced 10"-12" apart provide about 10 W/ft² of heat in the floor.

Table 6. Floor heating levels with sand mass.
Continuous floor heating levels can use as much energy as higher electric floor heating levels, but impose a lower peak load.

Room air temperature, F:	60	65	75	85
W/ft²:	8	8-11	0-4	0

Warm air floor heat with storage works with solar systems for heating swine nursery facilities. Consider this system in sunny areas where solar heat may be an economical heat source. Air ducts for transferring heated air from a solar collector to the heat-storage sand can be concrete blocks laid on edge, Fig 12. Cover the top of the blocks with polyethylene plastic and 4"-8" of sand. A 6" deep sand layer causes about a 12 hr thermal lag between maximum solar air temperature and maximum floor surface temperature. The time lag keeps the floor surface warm until early morning, when pigs need the heat most. Each additional inch of sand increases the lag about 1½ hr, so the time of maximum floor surface temperature can be controlled.

The heated floor area is typically 6'-8" wide (five 8" concrete blocks). Air velocity through the cores is 90-180 fpm. A smaller nursery requires less solar collector length and less airflow, so fewer blocks are needed to maintain the air velocity in the cores. Therefore, block arrangement depends on the number of nursery pigs, Fig 12.

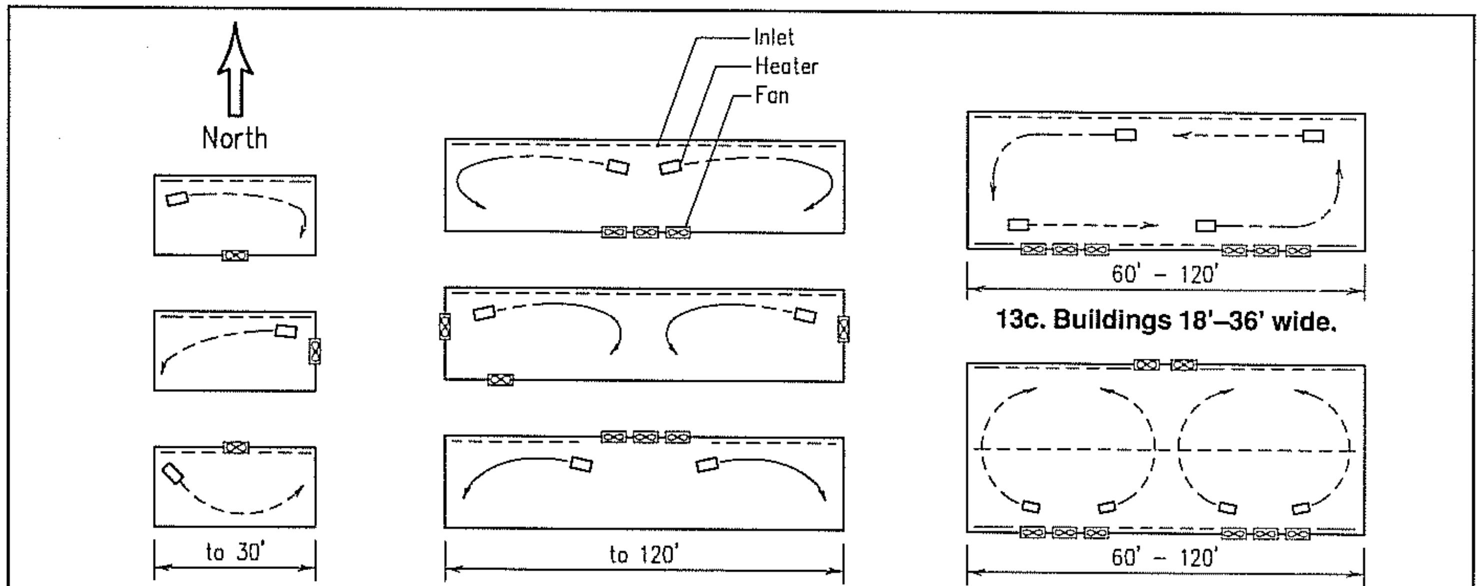


12b. Block duct arrangements.

ɦeat with sand mass.
ɪeeded air rate against a pressure drop of about 0.2" of water column, which is typical with these systems.

Unit Space Heaters

Unit space heaters are common and relatively inexpensive for supplemental heat. They heat room air directly and recirculate it. Room air containing dust, moisture, and corrosive gases, often increase fan maintenance. Clean and lubricate unit heaters once a month during the heating season and more often in a very dusty environment such as a growing-finishing building. Make sure gas orifices are clean. Unvented heaters are **not** recommended. If they must be used, increase the cold weather ventilating rate by 2.5 cfm/1,000 Btu-hr of heater capacity. With 1 heater in a room, locate it under an air inlet so it blows along the inlet. With more than 1 heater, arrange them to create a circular air pattern within the room. See Fig 13 for recommended space heater location.



13a. Buildings up to 12' wide. **13b. Buildings up to 18' wide.** **13c. Buildings 18'–36' wide.** **13d. Buildings 36'–48' wide.**

Fig 13. Inlet, heater, and exhaust fan locations.

4. TEMPERING

ıs or cools ventilating air before oom. Tempering systems include ;, air blending systems, heat ex- ectors, earth tubes (Chapter 5), olers (Chapter 6). Warmed-air help most in small animal hous- luce drafts by improving air dis- higher temperature ventilating varm and cold air blending.

ıpering also simplifies air inlet pered air is warmer and less farther into a room, mixes better e entering the animal zone, and ough some tempered air systems sometimes cooling requirements, stify their purchase on energy

:ed air systems usually provide ıtion. Use a conventional ventilat- d and hot weather ventilation. ed to outside air when the outside high enough so animals are not

duct can deliver tempered air in conventional slot inlets with ex- ə in mild and hot weather. orce air into the building with 1 r from the building with another sure systems are discussed in *ical Ventilating Systems for Live-* ıe system only supplies incoming ɔh as most solar and earth tube ather exhaust fan is needed in the cold weather fan capacity to pro- cold weather airflow rate.

rs

ıaters are unvented and heat in- air. They require less service than late room air. When exposed to ɔnditions, controls may malfunc-

ə is usually constant and fuel flow ries to maintain room inlet air ıeated air is usually blown directly lepends on room air circulation for ɔt install ducts on the heater ex- ısulting the manufacturer.

heater airflow capacity smaller ather exhaust fan. If the heater ıan the cold weather ventilating lriven into the attic where it con- and drips on the insulation. Back- ılets from the attic help reduce this

ə-up heaters exhaust combustion building, which seems more effi- cient than vented heaters, but is not recommended. Water vapor is one of the gases emitted (about 1 lb water/lb propane burned), so increase the ventilating rate to remove this extra moisture, which tends to offset the initial efficiency gain. Add an extra 2.5 cfm to the cold weather ventilating rate for each 1,000 Btu/hr of heater capacity.

Air Preheating Rooms

Ventilating air can be heated in a separate room or hallway before entering animal rooms, Fig 14. Outside air is brought into the preheating room or hallway, heated to a preset temperature, and distributed to the animal rooms. Keep the preheating room temperature lower than the desired animal room temperature because animals and equipment also provide heat. Set the preheating room temperature at or below the balance point temperature of the animal room. See the section on calculating heat loss through building surfaces in Chapter 9 to determine balance point temperatures. If the preheating room supplies animal rooms with different temperatures (e.g. swine farrowing and nursery rooms), base the preheating room temperature on the balance point temperature, Fig 7, of the coolest animal room. Install a supplemental heater in the warmer room to maintain the desired temperature. In practice, air is usually preheated in the preheating alley or room to within 20 F-30 F of the desired room temperature. The ventilating rate is often increased to about 50% above the recommended cold weather minimum rate.

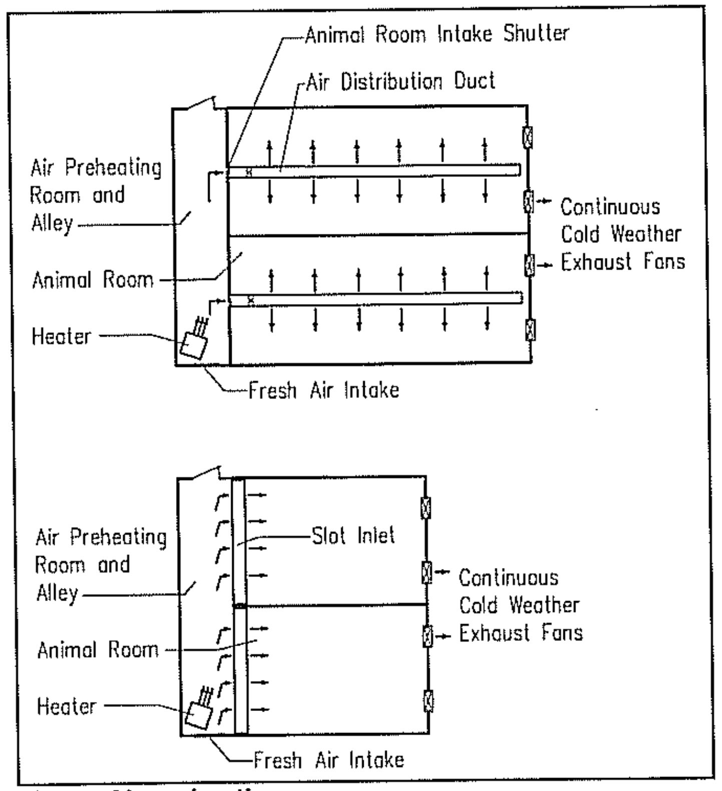


Fig 14. Air preheating rooms.

Reusing Exhaust Air

Do not reuse exhaust air from one livestock room or building to ventilate an adjacent one. Unless the first building is overventilated, its exhaust air is nearly saturated with water and has little capacity to remove moisture from the second building. Overventilating creates drafts and wastes fuel. Veterinarians and animal scientists discourage reusing ventilating air because of increased possibility of spreading disease, particularly for young animals.

Air Blending

Air blending systems mix some of the room air with incoming ventilating air to temper the air before entering the animal room, Fig 15. The following are advantages of mixing room air with incoming ventilating air:

- Cold incoming air blends quickly with inside air for more uniform air temperatures.
- Room air mixes more thoroughly to reduce temperature stratification.

Disadvantages include:

- Possible drafts from higher air velocity in cold weather.
- If not enough units are installed, incomplete blending occurs and air distribution in the building may not be uniform.
- Recirculation ducts accumulate dust, which is not desirable for all-in/all-out production systems.

Air blending systems are sometimes advertised as heat exchangers but are not, unless exhaust air transfers heat across some surface to incoming air without mixing. See "Heat Exchangers" section.

Some circulation systems allow air mixing with the option to totally close off incoming fresh air. These systems pose more danger of malfunction or mismanagement than ventilation providing fresh air.

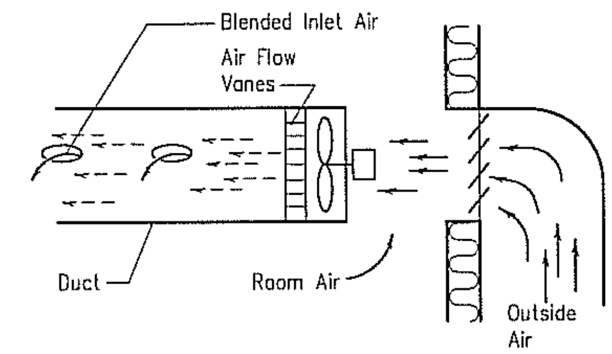
Air-to-Air Heat Exchangers

Heat exchangers:

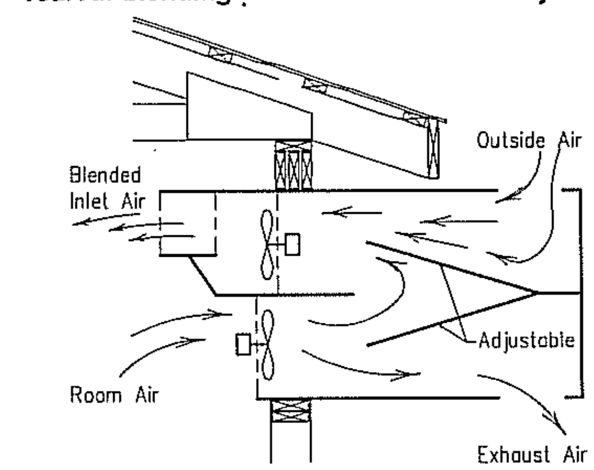
- Can save energy.
- Allow higher cold weather ventilating rates to dry a building without an increase in heating fuel costs.
- Provide higher inlet temperatures so there are fewer drafts.

Traditional ventilating systems remove moisture by exhausting warm stale air directly outside. About 70%-90% of heat loss from animal confinement buildings during winter is lost through the ventilating system.

Warm air exhausted through a heat exchanger transfers some of its heat to cold incoming ventilating air. The air entering the building is preheated by the heat exchanger to reduce supplemental heating requirements. The amount of heat saved depends on the heat exchanger efficiency.

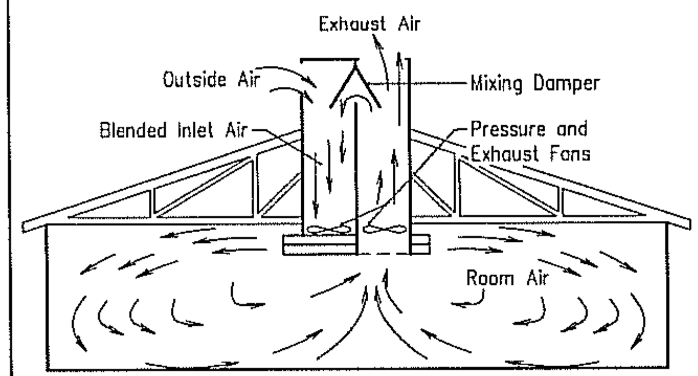


15a. Air blending with tube recirculation system.



15b. Wall mounted unit air blender.

An air distribution duct may be required for better air distribution.



15c. Ceiling mounted unit air blender.

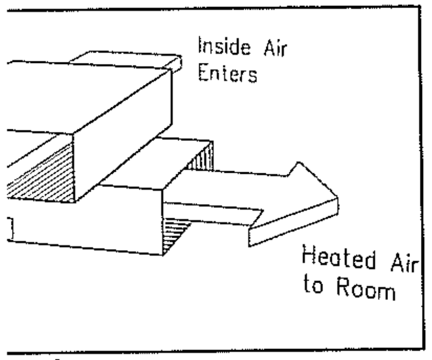
Fig 15. Air blending systems.

Heat exchanger efficiency

The following factors affect heat exchanger efficiency:

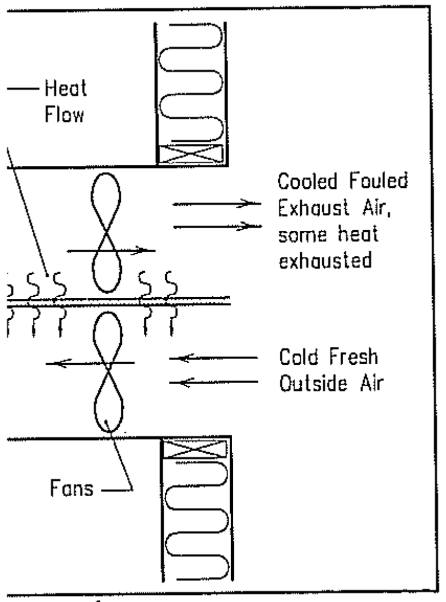
- Airflow pattern through the heat exchanger.
- Thermal conductivity of the material between the warm and cold air—the metal or plastic and, more importantly, the air film and dirt on the surfaces.
- Ratio of exhaust air volume to intake air volume.
- Difference between inside and outside air temperatures. The greater the temperature difference, the greater the efficiency. Outside air temperature varies, so heat exchanger efficiency also varies.
- Length of defrost cycle.

nt building heat exchangers are ›unterflow.
exchangers, Fig 16, warm and ngles to each other. Their major ; size. However, field tests indi- icult to clean and frost up easily.



exchanger.

ıat exchangers, Fig 17, exhaust ; parallel through the heat ex- site directions. A major disad- :. Counterflow heat exchangers t in existing buildings—they are ruction. Counterflows are more flows because heat transfer is ;hout the exchanger.
can be tempered by passing it ted duct in a heated room before the room. Condensation falling a major problem. For an effective aterial must be conductive and



eat exchanger.

angers into ventilating systems

; can help with cold weather ven- for young animals, but not with er ventilation. Integrate an ex- and inlets to create a system for

proper environment throughout the year. Most heat exchangers operate at neutral pressure, so it is not necessary to tightly seal other air inlets in the building. Make sure inlets from the attic have antiback-draft baffles or curtains to keep warm moist air from entering the attic.

Some safeguards are needed. Wire mild weather fans to cycle on and off for minimum ventilation if the heat exchanger breaks down. Air for emergency operation of mild weather fans can come through antiback-draft curtains on conventional slot inlets that are left slightly open during cold weather. Some air can come in through the heat exchanger itself.

To reduce heating costs, size the heat exchanger to supply fresh air at the cold weather ventilating rate. However, for improved room air quality during cold weather, heat exchanger airflow capacity can be greater than the cold weather rate without higher heating costs than a conventional ventilating system. Many manufacturers of variable flowrate heat exchangers recommend that the exchanger provide 50%-100% more ventilation than the minimum cold weather rate. Table 7 shows possible increases in ventilating rates with a heat exchanger at about the same heating cost as a conventional ventilating system.

Condensation and dust

Condensation within a heat exchanger increases efficiency, but dust accumulation can decrease heat transfer and increase pressure loss. So, the effects of condensation and dust tend to offset each other. However, if condensation freezes, it can plug the heat exchanger, increase pressure loss, and require a defrosting cycle. Defrosting time decreases energy savings. Frequent cleaning is necessary for efficient operation. Manure gases and moisture are very corrosive. Select a corrosion resistant heat exchanger that is easy to clean.

Table 7. Ventilating rate increases possible with heat exchangers.
With a heat exchanger, ventilating rates can be increased above cold weather ventilating rates without increasing heating costs. Neutral pressure is assumed and latent heat is ignored in the calculations. Typical seasonal heat exchange efficiency is 40%-50%.

Heat exchanger efficiency, %	Possible ventilating rate increase, %
10	10
20	25
30	45
40	65
50	100
60	150
70	230

Cold duct surfaces during winter create large amounts of condensation on the duct surface and floor below. Locate ducts away from tethered animals or animals in stalls. If possible, locate ducts over a gutter or slotted floor where wet floors are not a problem.

Solar Heat

Solar heat can be cost effective. There are two types of solar collection systems:

- Passive systems have transparent or translucent panels that allow the sun to shine directly into the building.
- Active systems transport heat in air or water from a solar collector to the animal environment.

Passive systems are relatively inexpensive, but have high heat losses and moisture can condense on poorly insulated solar panels. Active systems are more expensive to build, but operate more effectively.

A masonry wall collector combines both energy collection and storage. Paint a south-facing concrete masonry wall black to collect and store solar heat. Draw ventilating air past or through the sun-heated blocks to preheat air before entering the building, Fig 18.

There are many variations of air-type solar collectors for new or retrofit building construction and for freestanding and portable units. Refer to MWPS-23, *Solar Livestock Housing Handbook,* for more information.

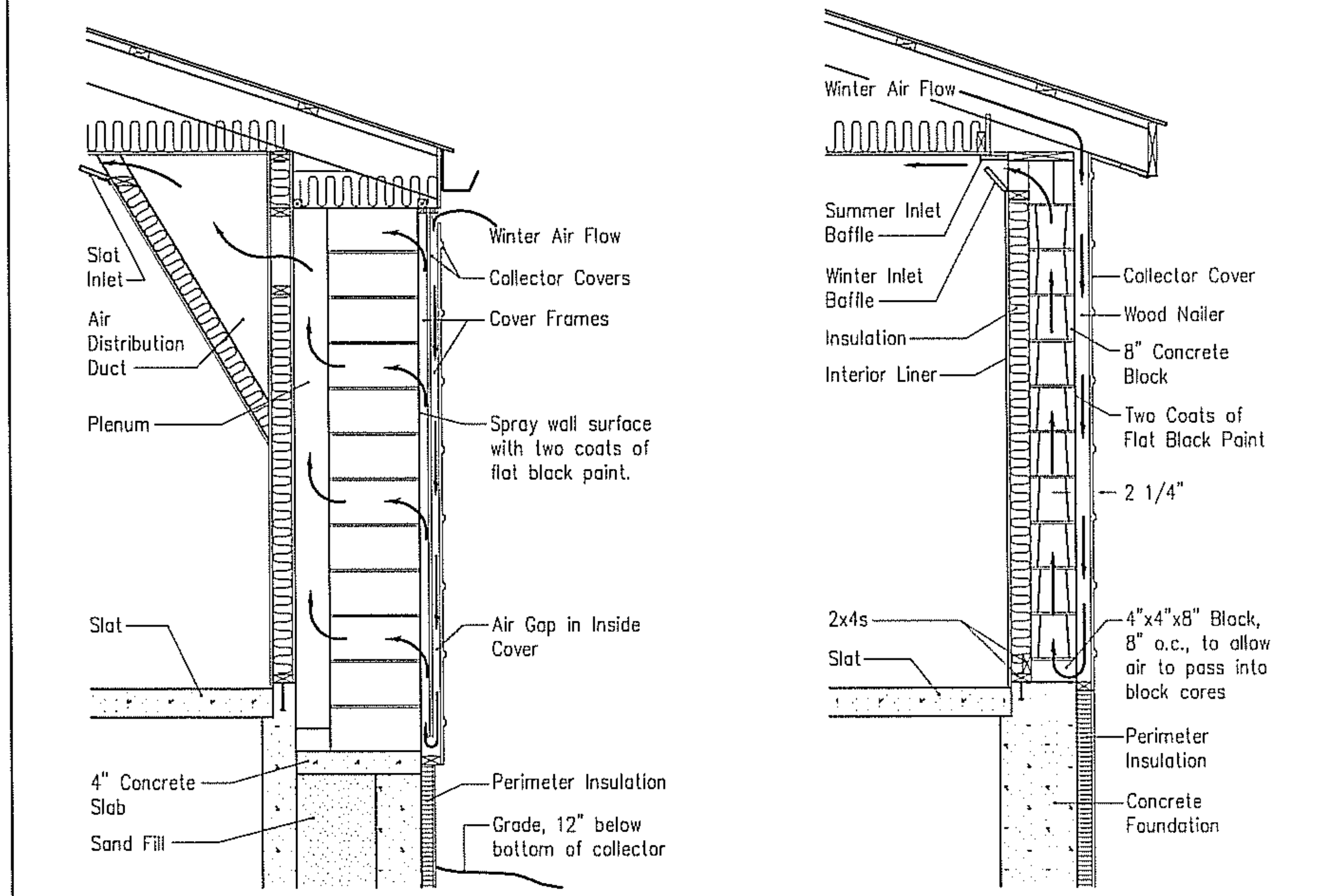
Controls

This section is a summary of a more complete discussion of controls in Chapter 7, MWPS-32, *Mechanical Ventilating Systems for Livestock Housing.* See that handbook for wiring circuits and alarm systems.

Controls automatically adjust fans, heaters, inlet baffles, and vent doors to maintain desired environmental conditions. Ventilating equipment is adjusted according to temperature, humidity, static pressure, and time. Ammonia concentration can also be monitored.

Some systems have manual switches to override automatic controls. Be careful to keep environmental conditions within acceptable limits when using manual overrides.

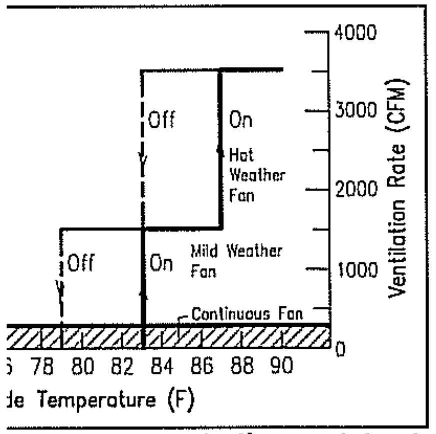
Thermostats sense air temperature and help control heaters, fans, and vent doors. Humidistats sense air moisture level (humidity), but are not common in livestock buildings because they become inaccurate after exposure to dust and gases. Static pressure sensors automatically control inlet baffles and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



18a. Air passage between concrete blocks. **18b. Air passage through concrete block cores.**

Fig 18. Masonry wall solar collectors.

a heater and multiple fans, set
ent temperatures to turn fans on
times to approximate a con-
entilating rate. It is critical that
oprocessors can control animal
urately as sensors permit and
urately as sensors permit and
ystem management. Provide
stats as back-up control over



stem response to thermostat set-

ermostat setting (71 F) and stays on until room
ntial (71 + 4 = 75 F). Fans use cooling thermostats
re. In this example, fan settings are 79 F and 83 F
fan runs continuously. Set thermostats so heater
un at the same time.

l settings for a heated room with
as for cold, mild, and hot weather
room temperature is 75 F. As-
age for each thermostat.

stat for each fan and the heater.
runs continuously; provide only
set at 45 F to shut off the fan to
ng.
hermostat at 71 F. The heater
emperature drops below 71 F and
raised the room temperature to

Set the mild weather fan thermostat so the heater and mild weather fan do not run at the same time. Set the mild weather fan at 79 F. With a 4 F on-off range, the fan turns on at 83 F and off at 79 F.

Set the hot weather fan at 83 F so it comes on at 87 F and shuts off at 83 F.

Example 4:

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

Solution:

The 3-speed fan is for cold and mild weather ventilation. Provide a safety thermostat to shut off the low speed at 45 F to prevent excess cooling.

Set the heater thermostat at 71 F to turn the heater on when the air temperature drops below 71 F and shuts off at 75 F.

Set multi-speed fan thermostat to switch to middle speed at 81 F and back to low speed at 77 F. Switch the multi-speed fan to high speed at 85 F. With a 4 F on-off range the multi-speed fan switches back to the middle speed at 81 F.

Provide a thermostat set at 87 F on the single-speed fan to provide hot weather ventilation. The fan comes on at 87 F and shuts off at 83 F.

Example 5:

Determine the control setup for a heated room maintained at 75 F. One variable speed fan is used for cold and mild weather ventilation. One single-speed fan is used for hot weather ventilation. Assume the thermostat on-off range is 4 F.

Solution:

Provide a safety thermostat set to shut off the variable speed fan at 45 F.

Set heating unit thermostat at 71 F. The heater comes on when the air temperature drops below 71 F and shuts off at 75 F.

Use a manual variable speed controller to change fan speed. Gradually increase fan speed at 79 F and continue increasing to maximum speed at 85 F.

Provide a thermostat set at 87 F on the single-speed fan to provide hot weather ventilation. The fan comes on at 87 F and shuts off at 83 F.

5. EARTH TUBE HEAT EXCHANGERS

Some livestock producers pass ventilating air through buried plastic tubing to temper inlet air. Average soil temperatures 6'-12' below grade are higher than the average air temperature in winter and lower in summer. Therefore, earth tube systems remove heat from the soil in winter to heat ventilating air and deliver heat to the soil in summer to cool ventilating air.

Benefits

The benefits of earth tubes cannot be accurately predicted. Earth tube performance varies with soil type, depth, soil moisture content, airflow, climate, etc. Table 8 has example systems based on computer simulations and field studies to give an idea of their performance. Specific systems may vary considerably from these values.

On warmer days, earth tubes may collect more energy than is needed so some energy is wasted. Only the heat that reduces fuel consumption saves money.

To get the most benefit from a system, use it for summer cooling and winter heating and always operate it at full capacity. Instead of reducing airflow through the tubes between mild and cold weather, ventilate an adjoining building with the extra air capacity. For example, if 1,000 cfm were needed in mild weather but only 400 cfm in cold weather, the extra 600 cfm of tube capacity in cold weather could ventilate another building.

Earth tube systems are usually designed to supply only part of the supplemental heating needs of a building. It may be relatively inexpensive to eliminate 60% of a building's supplemental heat needs, but costly to eliminate the last 40%.

Whether an earth tube system should be installed depends on the size and shape of the available land, whether summer cooling is beneficial, and installation costs.

Principles

The soil temperature 6'-12' below the ground surface does not vary much throughout the year, Fig 20. The amount of air temperature modification from earth tubes is directly affected by soil temperature variations. From Table 9, the deeper the tube is placed, the smaller the annual temperature variation, and therefore the better the tube performance. At 6' deep, yearly variation is about 11 F above to 11 F below mean soil temperature at that depth for an average soil; total variation is about 22 F. At 12' deep, the variation is only ±6 F or a total of 12 F.

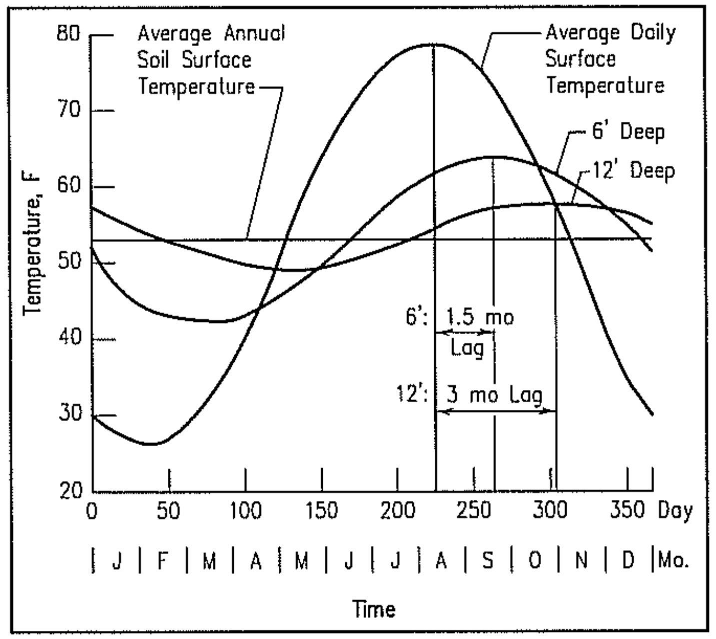


Fig 20. Soil temperature variation.
The deeper the soil, the less its temperature varies over the year. Maximum and minimum soil temperatures lag about 1½ months behind surface temperatures for a 6' depth and about 3 months behind for a 12' depth. Temperatures shown are for Burlington, IA.

Table 8. Example benefits from earth tube systems.
Table values are based on computer simulations and field studies. Combustion efficiency for gas furnaces assumed to be 80%. The data are all for farrowing houses.

System	Tube dia., in.	Airflow rate cfm/tube	Number of tubes	Tube length, ft	Energy saved per heating season: Million Btu	Energy saved per heating season: Gal of LP gas
20 sows, 26 cfm/crate Depth = about 6' Soil = silty clay loam Location = Ohio	6 8 10 12	53 106 177 265	10 5 3 2	100-130 130-165 165-200 200-250	16 15 13 12	215 202 175 161
30 sows, 31 cfm/crate Depth = 10' Soil = silt loam Location = Illinois	12 Cooling capacity = 16,000 Btu/hr = 4.7 kW	184	5	260	70	941
32 sows, 22 cfm/crate Depth = 11' Soil = silty clay loam Location = Illinois	12	200	4	200	41	551

ɜmperature variation with depth.
the yearly temperature variation.

Typical annual temperature change	
From mean degrees F	Total degrees F
±18	36
±14	28
±11	22
±9	18
±6	12
±4	8

average annual soil temperature , is 54 F, so the soil temperature (54 – 11) = 43 F to (54 + 11) = 65 2' deep, soil temperature varies to (54 + 6) = 60 F over a year. riations at a 6'-12' depth lag 1-3 ace temperatures in a silty clay peratures are warmest in fall and This lag increases the system's ability.

rmance is affected by soil charac- ɪe parameters. ɪstics include soil type, soil mois- vater table elevation. Generally, ter the soil, the better the system dry sand do not store or transfer void these soils. If tubes must be ɪdy soil, increase tube lengths or ee "Earth Tube System Design"

le is at or above the earth tubes, the tubes and block airflow. In a seal joints carefully or consider ɪts—some come in 300' lengths.

Seal any joints (e.g. tubing-to-air inlet) according to the manufacturer's recommendations and place concrete around the joints. Drain tubing to a sump.

Air-tube parameters include diameter, length, depth, spacing, and airflow rate. Nonperforated corrugated plastic tubing is readily available and relatively inexpensive. The corrugations increase strength and air turbulence. Air turbulence increases heat transfer slightly, but also increases airflow resistance.

Layouts

An earth tube system has several lines of tubing buried 6'-12' below grade, usually with one tube per trench. Tubes run horizontally from vertical inlet pipes to a collection sump. Air is drawn down the inlets, through horizontal tubes to a collection sump, and distributed in the livestock building, Figs 21 and 22.

Radial tube layouts are common but have these disadvantages:

- The arc of inlet pipes can obstruct farmstead traffic.
- Excavation near the collection sump can be difficult.
- The number of possible tubes is limited due to space constraints at the central hub.

Lateral patterns are rectangular and may fit better in limited space. Inlets in a straight line are easier to locate out of the way. Lateral systems usually cost more because they require large manifolds to carry air from the individual lines to the collection sump.

Wide trenches may have several tubes each. Excavate like a strip mine, using earth from one trench to fill the previous trench, Fig 23. Save the topsoil for the final covering for each trench. This method is usually more economical and faster to install than individual trenches. However, tubes in wide trenches carry more soil weight. Place air tubes carefully to avoid settling. Trapped water can restrict airflow and can damage the tubes. Backfill carefully so tubes are not damaged or pushed out of line.

Another installation option is to use a shallower wide trench with two layers of tubes. Place the top layer of tubes in the shallow trench and a second layer of tubes in 3'-4' deep narrow trenches excavated in the bottom of the wide trench, Fig 24. Separate all pipes at least 4' (6' is better) to maintain satisfactory system performance.

Do not confuse this method with that shown in Fig 25 where many closely spaced small diameter tubes replace one large tube in an individual trench.

Make the air inlets high enough so they are visible above surrounding vegetation and snow—usually 3'-4'. Risers are often PVC pipe because it is rigid, durable, and visible.

Earth Tube System Design

This procedure sizes tubes for 2.5 times the cold weather ventilation rate. Therefore, heat will be adequate for milder weather and for improved cold weather room environment.

Design Procedure and Example

Example 6:

Design an earth tube system for a 20-sow farrowing building.

Solution:

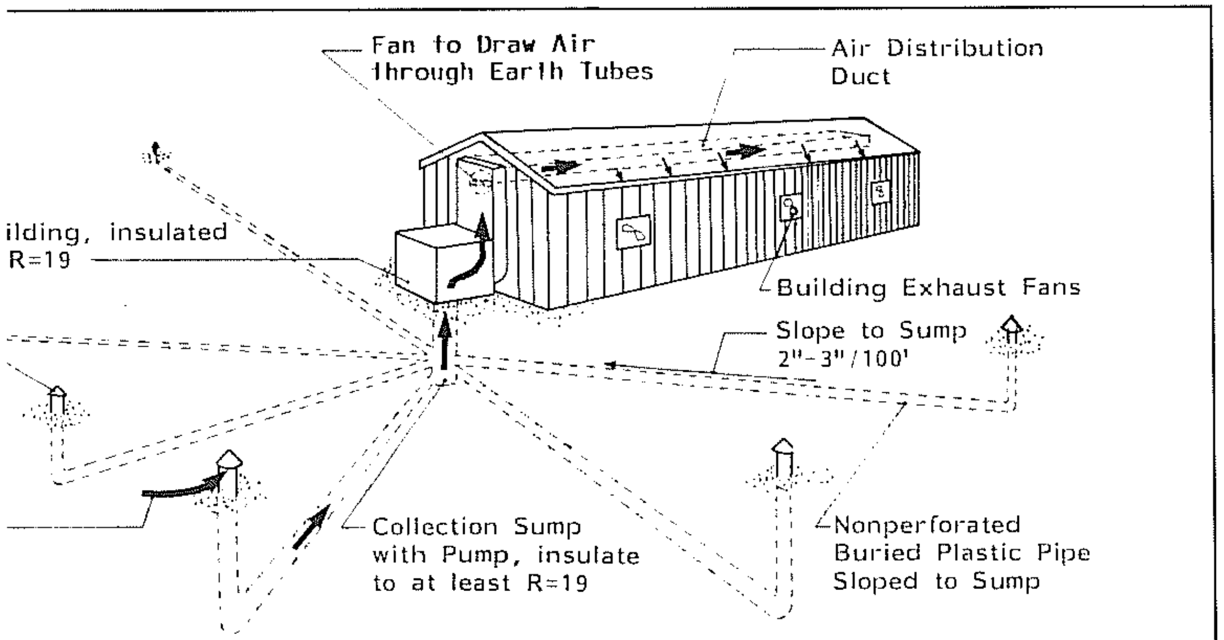
Step 1:

Determine the **maximum airflow rate** through the earth tube system.

Swine: (Maximum airflow rate, cfm) = (Number of animals) x (Values from Table 10)

Other animals: (Maximum airflow rate, cfm) = (Number of animals) x (Cold weather ventilating rate, cfm) x 2.5

From Table 10, the airflow rate/animal is 50 cfm/sow. (Maximum airflow rate, cfm) = 20 sows x 50 cfm/sow = 1,000 cfm.



stem with radial pattern.

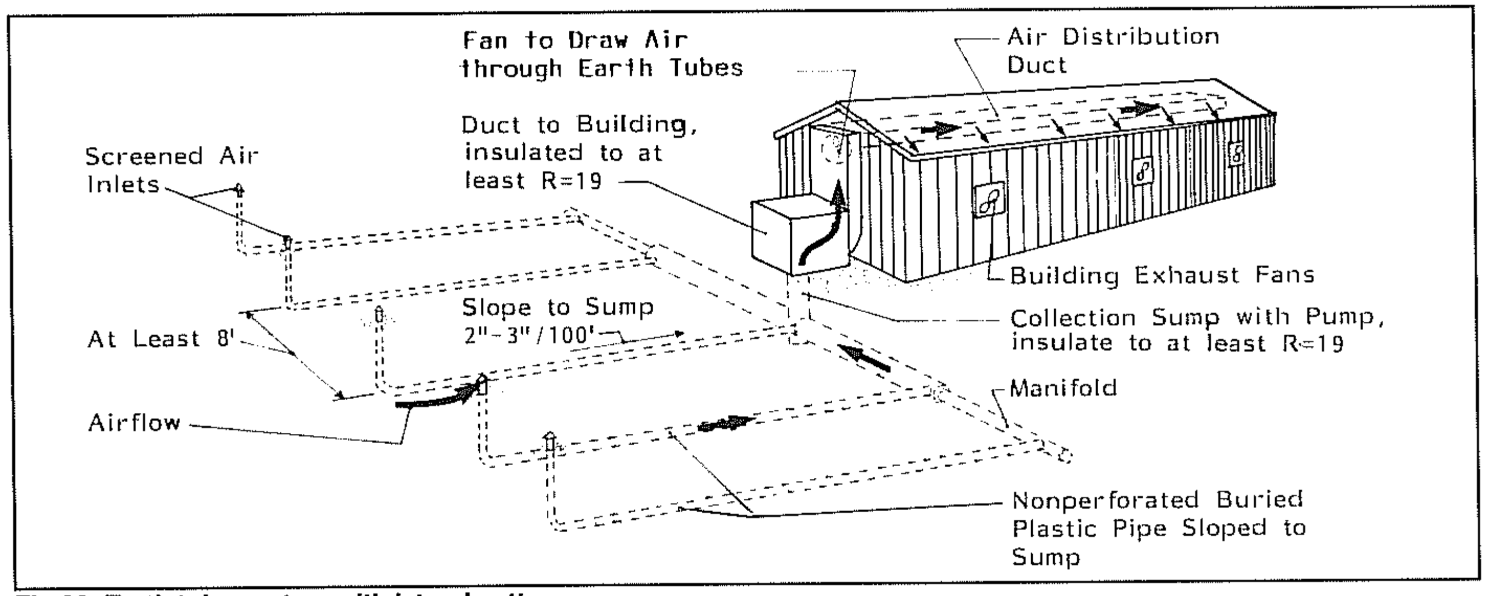


Fig 22. Earth tube system with lateral pattern.

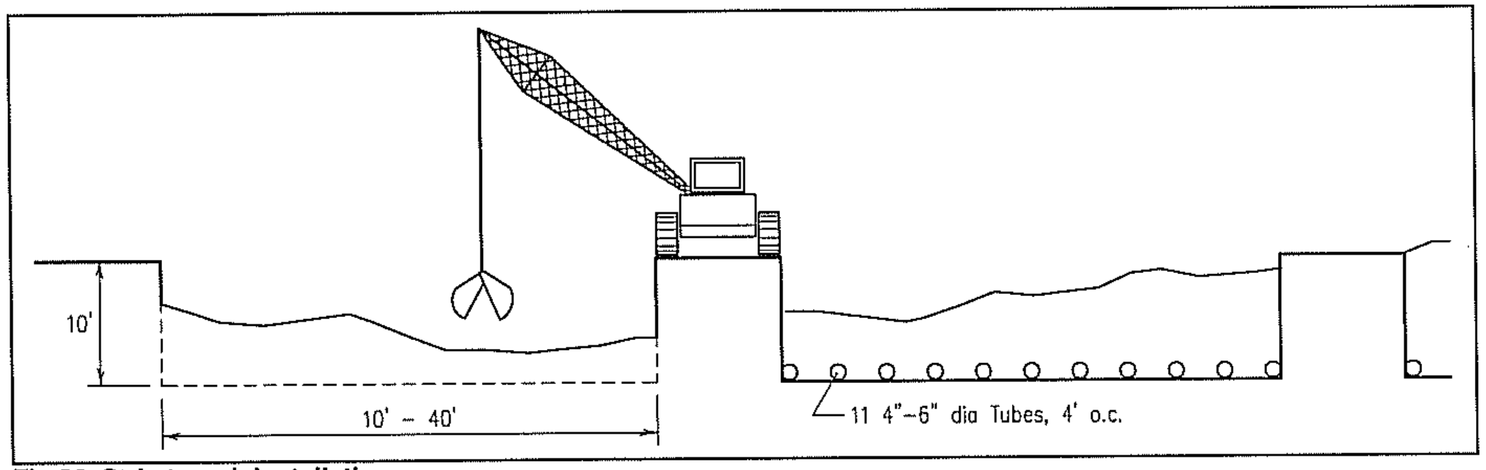
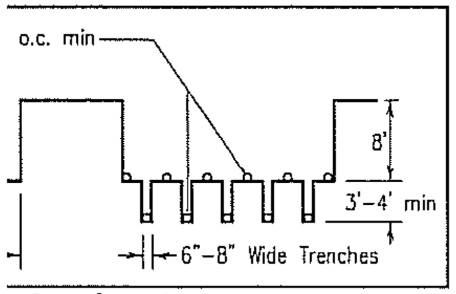
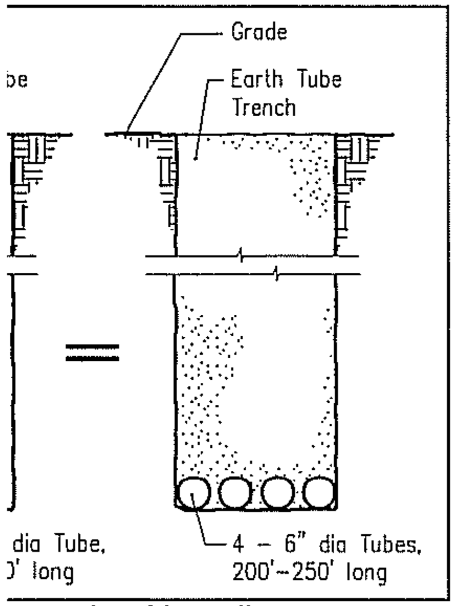


Fig 23. Strip trench installation.



p trench system.



arge tube with smaller ones.
umber of 4"-6" diameter tubes in one trench in place of
gh smaller tubes to about equal the airflow capacity
er tube. For example, the capacity of four 6" tubes is:

ube at 450 cfm. Make the 6" tubes the same length
: 200'-250'.

design airflow rates.
size the earth tubes at 2.5 times their cold weather

Airflow rate cfm/hd
50
5
8
18
25
30
40

number of tubes for three tube
um airflow/tube is in Table 11.
have 8"-12" diameter tubes for the
tubes for manifolds. The 4"-6"
seldom economical with only one
umber of 4"-6" tubes in one trench
one larger tube, Figs 23, 24, and

Table 11. Earth tube dimensions and capacities.
These values are based on an economic analysis by The Ohio State University and field trials by the University of Illinois. Airflows are based on a tube air velocity of 500-600 ft/min. The length ranges are based on an air contact (heat exchange) surface of about 1.3 to 1.8 ft² tube surface/cfm air, assuming smooth pipe. Relative cost is initial cost of one foot of installed tube. 1984 prices.

Tube dia., in.	Maximum airflow capacity cfm/tube	Tube length, ft	Relative cost* $/ft
4	50	65-85	0.25
5	80	80-105	0.35
6	110	100-130	0.55
8	200	130-170	0.90
10	300	160-210	1.85
12	450	200-250	2.30
15	700	250-320	3.80
18	1,000	300-380	6.30
24	1,800	400-500	14.40

*Initial cost of installed tube per foot of length. 1984 prices.

Up to a point, adding extra tubes or making them longer reduces airflow/tube, which increases temperature modification. See Figs 26 and 27.

By using fewer tubes than recommended, operating costs are increased. For example, with only ⅓ of the original number of tubes, air velocity increases by three times and fan operating costs increase about 27 times.

Divide the maximum airflow rate by the maximum airflow/tube to get the required number of tubes.

For 8"-12" tube diameters, determine the maximum airflow per tube from Table 11. Divide the maximum system airflow by the airflow/tube to get the required number of tubes.

Tube dia., in.	Maximum airflow/tube (from Table 11) cfm	Required number of tubes (maximum airflow rate=1,000 cfm)
8	200	1,000 cfm/200 cfm = 5
10	300	1,000 cfm/300 cfm = 3.33 or 4
12	450	1,000 cfm/450 cfm = 2.22 or 3

Step 3:

Determine the required **tube lengths** from Table 11. Tube length partly depends on soil type. The shorter length is for wet clay soil; the longer length is for dry sand. Another option for dry sand is to use more, but shorter, tubes. Make all the tubes the same length to help assure equal airflow through each tube.

It is not economical to increase tube length beyond the range recommended in Table 11.

Tube dia., in.	Tube length, ft
8	130-170
10	160-210
12	200-250

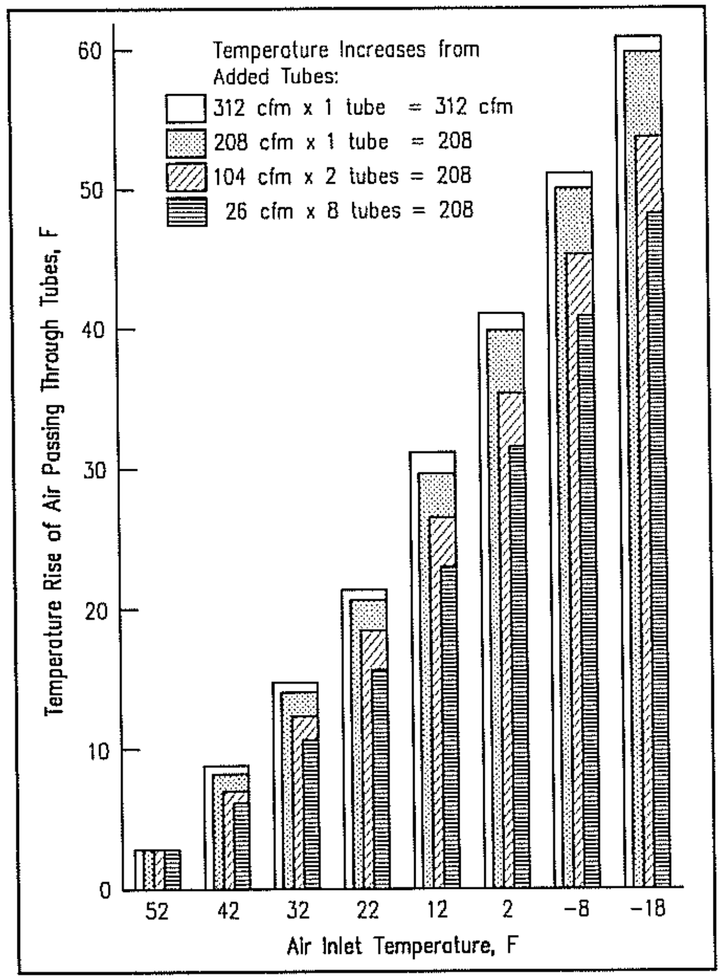


Fig 26. Airflow/tube affects thermal performance.
Airflow/tube rates other than those in Table 11 are generally not economical. Adding tubes reduces airflow/tube which increases temperature modification, but after a point the added benefit does not pay for the added cost. In this case, decreasing airflow/tube from 208 cfm to 104 cfm by doubling the number of tubes added only 1 F-6 F. Decreasing airflow from 104 cfm to 26 cfm with four times as many tubes (eight times enough for 208 cfm) increases temperature only 1 F-2 F. Increasing airflow in one tube by 50% (208-312 cfm) reduced temperature rise 1 F-5 F and also increased fan energy requirements. Source: Computer analysis of a 20-sow farrowing building in Ohio for 8"x164' tubing about 6' deep.

Step 4:

Select the best **tube diameter** for your system based on installation costs and space constraints.

Step 5:

Determine **tube depth.** The minimum recommended depth is 6', but depths down to 12' perform better. The best thermal performance may not be at the most economical depth. The most economical depth depends on trencher type, geographic location, and soil type.

Trenching costs may increase dramatically from one depth to another. For example, a modified trencher may reach 8', but a more expensive backhoe may be required if the tubes should be deeper. With higher installation costs for greater depths, less depth may give a better economic return. In northern latitudes, you can afford to pay more to bury the tubes deeper. See "Tube Installation" section for a safety warning.

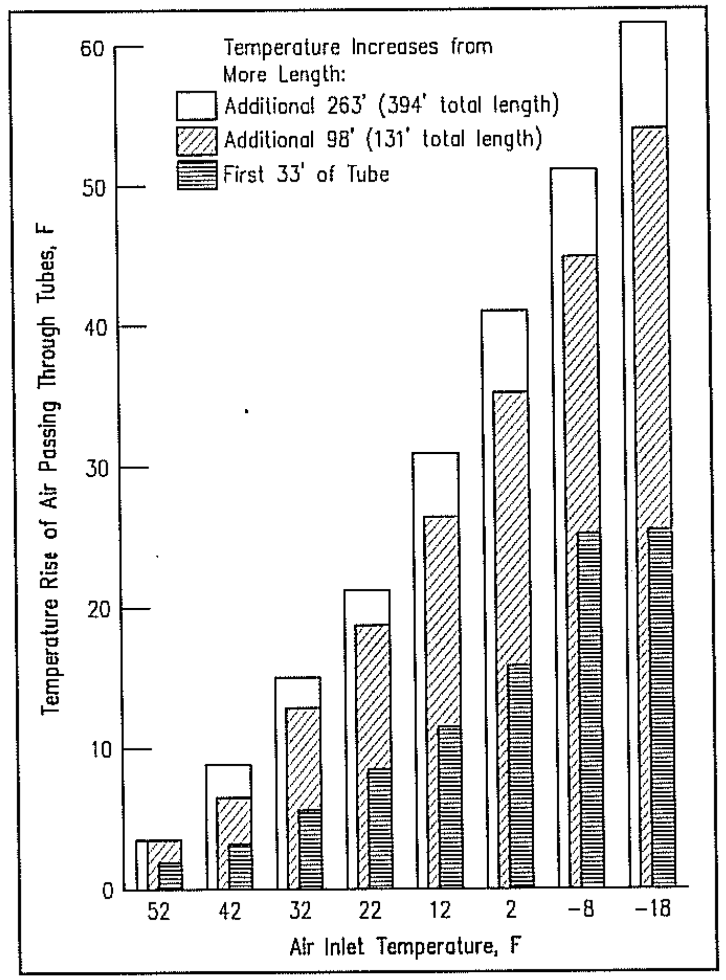


Fig 27. Tube length affects thermal performance.
In this case, four times as much length (33'-131') doubled air heating and 12 times as much length (33'-394') did not triple heating. Making tubes longer than recommended adds only a few degrees of temperature and is seldom economical.
Source: Computer analysis of a 20-sow farrowing building in Ohio for 8"x164' tubing about 6' deep.

Step 6:

Determine **tube spacing.** Space radial tubes as far apart as possible. Space lateral tubes at least 4' apart to ease installation and improve soil heat storage. Smaller diameter tubes replacing one larger tube in a trench, Fig 25, can be close together.

Tube spacing can vary and the tubes can be curved somewhat, but avoid abrupt turns.

Step 7:

For lateral tube systems, determine **manifold sizes.** Size manifolds to carry the combined airflow of all the tubes that connect to them. See Table 11.

If five 8" diameter tubes are installed as in Fig 22, with one tube entering the sump directly, two manifolds carry a maximum airflow of:

2 tubes × 200 cfm/tube = 400 cfm

From Table 11, select a 12" manifold to carry 400 cfm and 8" to carry the 200 cfm to the outermost tubes.

p. Build the sump from large culverts, reinforced concrete, or w for connecting all the tubes to ımp cross-sectional area to keep ׀00 fpm:

:tional area, ft² = airflow, cfm ÷

sides, and bottom of the sump ›of insulation to at least R=19. n with a rodentproof liner. mp cross-sectional area for 1,000

) fpm = 3.33 ft²

ıp-to-building duct. Insulate R=19. Make the duct's cross-sec- as big as the sump's. **Make all and duct airtight to prevent f the air.**

fan. Do not depend on negative ıilding's exhaust fans to pull air :ound tubes. Install the tube fan -building duct connects to the r through the tubes and blow it is fan must deliver the maximum .tic pressure. flow rates, the earth tube system he cold weather rate. To get the .e earth tube system, try to run it v rate even during cold weather. another room or building during additional air capacity cannot be speed tube fan. Try to get a fan ıt the cold weather rate (Table 2) at the tube design rate (Table 10

farrowing building, the tube :ulated earlier at 1,000 cfm. The :

fm/sow (Table 2) = 400 cfm
: 1,000 cfm; low volume = 400 cfm

ing's **air distribution duct.** Use ıe air distribution duct for the rate. The duct may be slightly ler. Insulate the duct to at least nsation on the outside of the duct. .be design rate of 1,000 cfm and size is 16"x16", 8"x30", or 18"

Table 12. Ventilating duct sizes.
Based on a duct air velocity of 600 fpm.

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

Step 12:

Design the **building's ventilating system.** The amount of air moved through the building by the ventilating system varies with outside temperature, so Table 2 gives three rates: cold, mild, and hot weather rates. At the cold weather rate, pass all the inlet air through the earth tubes and distribute it in the building through a zone cooling system, Fig 34.

At the mild weather rate, pass most of the building inlet air through the earth tubes at the tube design rate, Table 10. Distribute the earth tube air to the animals through a zone cooling system. Bring the remaining inlet air in through conventional ventilating inlets.

At the hot weather rate, pass some of the building inlet air through the earth tubes at the tube design rate, Table 10. Distribute this air through a zone cooling system. The tube design airflow rate for each sow is 50 cfm. From Table 13, the required downspout size is 3"x3" or 4" diameter. Bring the remaining inlet air into the building through conventional ventilating inlets.

From Table 2, the ventilating rates for a 20-sow farrowing building with a zone cooling system are:

Cold weather rate: 20 sows × 20 cfm/sow = 400 cfm
Pass all 400 cfm of the inlet air through the earth tubes and distribute the air throughout the room.

Mild weather rate: 20 sows × 80 cfm/sow = 1,600 cfm
Pass 1,000 cfm of the inlet air through the earth tubes and distribute it in the building through the zone cooling system. Bring the remaining 600 cfm of inlet air in through conventional ventilating inlets and control with thermostats.

Hot weather rate: Because a zone cooling system is used, the hot weather rate can be halved:
20 sows × 500 cfm/sow × ½ = 5,000 cfm

Pass 1,000 cfm of the inlet air through the earth tube and distribute it in the building through the zone cooling system. Bring the remaining 4,000 cfm of inlet air in through conventional ventilating inlets and control with thermostats.

Table 13. Downspouts for zone cooling.
Sized for 800 fpm air velocity.

Airflow cfm	Area in²	Inside dimensions WxH, in.	Dia., in.
10	1.8	1½x1½	1½
15	2.7	1¾x1¾	2
20	3.6	2x2	2½
25	4.5	2x2¼	2½
30	5.4	2x2¾	3
35	6.3	2x3¼	3
40	7.2	2x3¾	3
45	8.1	3x2¾	4
50	9.0	3x3	4
55	9.9	3x3½	4
60	10.8	3x3¾	4
65	11.7	3x4	4
70	12.6	3x4¼	4
75	13.5	3x4½	4
100	18.0	4x4½	6
125	22.5	4x5¾	6
150	27.0	4x6¾	6

Tube Installation

Slope tubes 3"/100' toward a sump at the building. Drain the sump with a pump—usually a typical basement sump pump. In field tests, about 5 gal water/hr were removed from a 1,000 cfm nonperforated tube system. The tubes can be sloped away from the building and drained by gravity if there is a natural drainageway nearby. Install a pipe to drain water from the bottom of the air inlet end of the tube to the natural drainageway. Form a "U" trap in the drainage pipe near the outlet to prevent animals and air from entering..

Constant slope is critical because any dips in the tube could fill with water and reduce or block airflow. Small diameter tubes are more susceptible to this than the larger ones. Carefully check the slope of each line before backfilling.

Trenchers equipped with laser plane grade guides ensure a constant slope. Most trenchers are restricted to depths of less than 6', but some trenchers have been modified to reach an 8'-10' depth. If modified trenchers are not available, remove a few feet of topsoil before trenching to allow the trencher to reach depths greater than 6'. However, this additional cost reduces the economic benefit. Larger backhoes are normally more expensive but can, with care, maintain a constant slope at depths down to 12'.

Caution: trenches deeper than 4' pose a potential hazard from the collapse of the earth walls on workers. Use wall shoring where danger of collapse exists.

Occasionally, the tubes or the T-connectors on the manifold collapse during backfilling, making the entire tube useless. Round the bottom of the trench to fit the tubing. Install the tubing according to ASTM F449 specifications. You can obtain a copy from the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103. Before backfilling, check the integrity of all tube couplings. Consider covering the T-connectors with concrete and letting the concrete set before backfilling.

6. COOLING

.y limited to mature animals. Hot ıimal feed intake and decreases ɔductive capability. For example, .rt feeling heat stress at about 70 s above 85 F may cause substan- ıe pigs are kept cool. Dairy cow ops off rapidly at temperatures ·elative humidities and reproduc- evelop above 80 F.
w air temperatures (60 F and e most of their heat by sensible ɔn (airflow past the body), conduc- . Fig 4, Chapter 2. Sensible heat high air velocity (wind chill), cold ı bedding), and cold building sur- ɔn levels). A relatively large dif- ly and surrounding temperatures e heat loss.
emperatures, however, livestock ɔtal heat by evaporative cooling-- porative cooling is from the lungs. ıd evaporative skin cooling can ınd to a lesser extent with cattle ; will wet their body surfaces when ɜ evaporative skin cooling.
ntilation helps prevent excessive ıre increases. Animal comfort can d with:
ıs to increase air velocity past the

:er on the animals to increase :at loss.
ıg and earth tube heat exchangers l the air and partially dry it to ırative cooling.
ɔoling of ventilating air.

ȷ

ntilation cools animals by:
air with cooler air.
gh humidity respired air from imal.
ɔm the air to evaporate moisture ing and animal surfaces, creating ɜ cooling effect.
' velocity around the animals and ɜasing evaporative and convective he skin.
:ather ventilation is designed to :mperatures 1 F-5 F higher than .res. The hot weather ventilating ıapter 2, allow for removing excess a well insulated building and pro- ities around the animals. At least y is needed to achieve hot weather animals. With mature animals, :o the animals.

Air Circulation

During summer, air circulation helps distribute inlet air and provide higher air velocities past animals. In naturally ventilated buildings, circulation fans can help on still days.

Research has shown no improvement in milk production with high air velocities (790 ft/min) past cows at 65 F and 80 F. At 95 F, milk production was higher with high air velocity than with low air velocity (about 300 ft/min). In growing swine, increased air velocity does not improve productivity. For young pigs, it may decrease rate of gain. However, mature pigs benefit from high air velocity at temperatures above 85 F. Poultry appear to benefit from high air velocity, especially broilers.

Air circulation cannot replace a good ventilating system. Before installing air circulating fans, evaluate the ventilating system.

If air circulation fans or ducts are provided, hot weather ventilating rates in Table 2 can be reduced as much as 40% for boars, breeding sows, mature dairy and beef cows, horses, and sheep.

Circulate air with axial flow fans to circulate air horizontally or paddle fans to direct air either up or down across animals. Locate axial flow fans within the building to create a rotational "racetrack" airflow pattern, Fig 28. Direct airflow down toward the animals in summer and upward in winter. Space circulation fans no more than 25 fan diameters apart. For example, space 24" fans no more than 50' apart. Circulation fans can be rated for free air and should have sealed motors. Unit heater fans can be run continuously to help improve circulation.

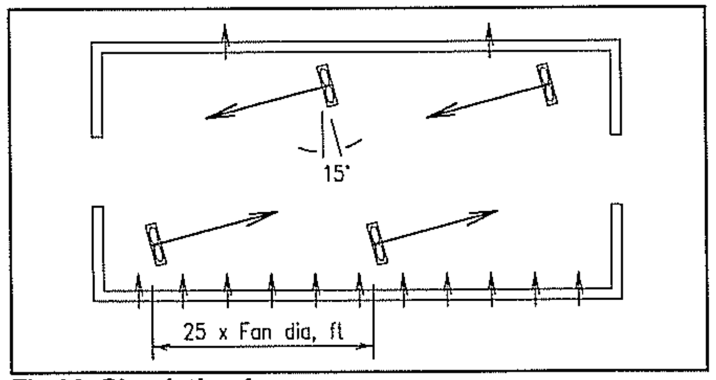


Fig 28. Circulating fans.

Large diameter paddle fans can direct air downward or upward across animals, Fig 29. The greatest influence is directly below the fan. Follow manufacturer's recommendations for fan spacing. If this information is not available, space fans 25' apart.

With some breeds of poultry, slow moving shadows created by lights near paddle fans are interpreted as flying predators. Enclosed fan blade housings are recommended. Contact your extension poultry specialist for more information.

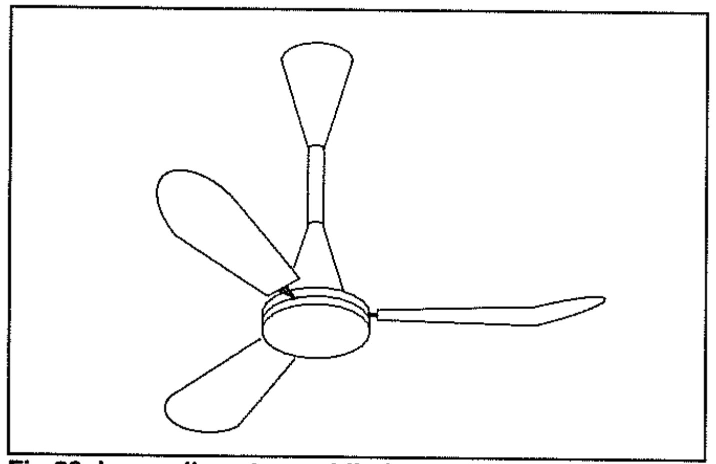


Fig 29. Large diameter paddle fan.

A negative pressure with recirculation duct system can provide air mixing and increased velocity past animals.

Water Cooling

Wetting an animal's skin and allowing the moisture to evaporate can provide substantial cooling. A slight breeze or forced air movement increases the evaporation rate and improves cooling.

Pasture wallows provide good wet-skin cooling for swine. Shade wallows to reduce solar heat, maintain cooler water temperatures, and improve effectiveness. Do not sprinkle water on concrete without a shade or swine may sunburn. Provide drainage away from concrete in a dirt lot to avoid creating a mud hole next to the concrete.

Sprinkler cooling

The best sprinkler cooling systems wet the animal, then allow moisture to evaporate. For swine, a thermostat connected in series with a timer-controlled solenoid provides automatic wetting. Adjust the time interval and nozzle size to deliver 1 gal of water/hr/10 pigs. Start sprinkling when temperature reaches 85 F and sprinkle long enough to wet all the swine. Knowledge of the water system flowrate and pressure is necessary to size nozzles and water lines. Tables 14 and 15 give example water nozzle and line sizes. Select non-corrosive nozzles designed to provide a solid cone of water droplets, **not** a fog. A fogger cools the air; a sprinkler directly cools the animal.

Holding and feeding areas for dairy cattle can be effectively cooled by spraying from above. Use either sprinklers or misters with droplets large enough to wet cows' skin. Use sprinklers in windy or high air velocity situations. Sprinklers and misters are preferred because they wet the animal more than foggers. If possible, shade the sprayed area. Open the sprayed area to prevailing breezes to improve evaporative cooling. Use circulating fans where natural breezes are not sufficient. Allow animals to circulate freely between sprinkled areas and dry areas.

Size sprinkler nozzles and water lines for 0.5 gal/min. Locate sprinklers 10' above the ground and 10' o.c. Operate sprinklers when the air temperature is above 80 F. If possible, direct the spray toward the middle of the cow's back. Control the sprinkler on-off cycle with a timer.

Do not spray dairy cattle in free stalls, alleys directly adjacent to free stalls, and loafing areas. Spraying in these areas can cause wet conditions in the cow resting area which can increase mastitis problems.

Sprinkling beef cattle in feedlots to suppress dust and heat is practical when it is dry and hot. The optimum effect is obtained when air temperature is above 80 F and relative humidities below 40%. When relative humidities are above 40%, the effectiveness is reduced but some cooling is still accomplished. Operate sprinklers when the air temperature is 85 F-90 F and control the sprinkler on-off cycle with a timer. The recommended cycle is on for 2-3 min. every 15-20 min.

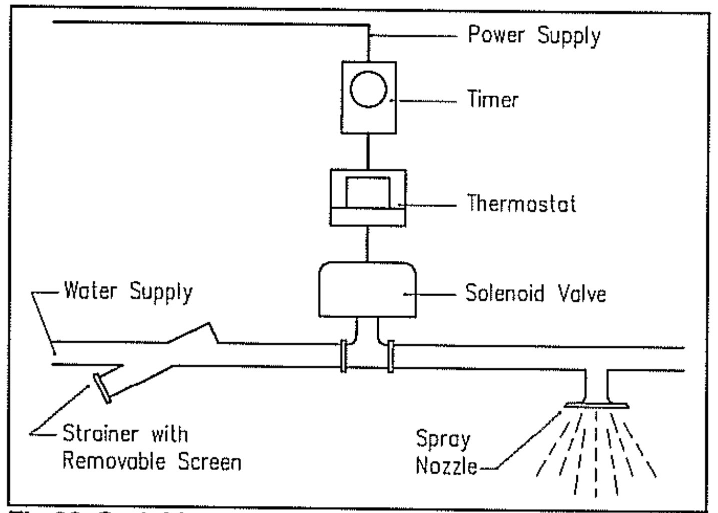


Fig 30. Sprinkler with solenoid valve control.

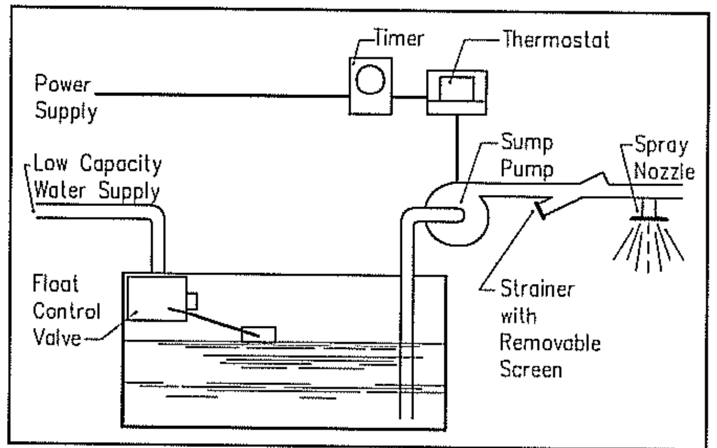


Fig 31. Sprinkler with float valve control.
Use this system where the rate of water supply is limited. The water supply fills the tank almost continuously while the large capacity sprinkler runs intermittently. Select a sump pump for at least 30 psi pressure.

Drip cooling of swine

Drip cooling systems emit small water droplets directly on the neck and shoulders of farrowing sows. This area has a high blood flow which enhances heat transfer from the skin. Only a small portion of the

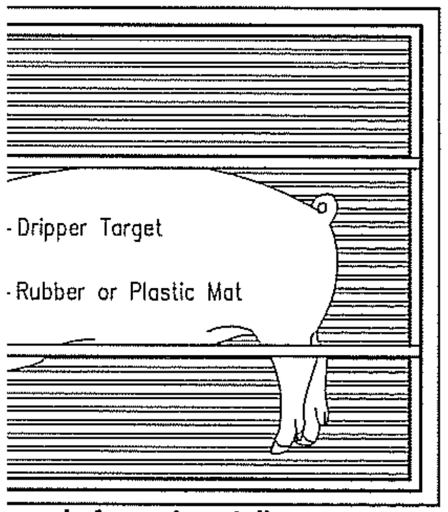
ɩzzles for swine groups.
ɀzle per pen at least 6' above floor, centered over the provide a solid cone, low drift, and large droplets. For 5 min. out of each hour. In larger systems, flowrate ɀzle size and time to achieve 1 gal/hr for 10 pigs.

	Nozzle size, gpm
	0.20
	0.40
	0.60
	2 nozzles at 0.40
	2 nozzles at 0.50

ɾr lines for sprinklers.
ɪ' maximum pressure drop and 4 ft/second maximum

	Maximum flow gpm
	3
	6
	10
	18
	25
	40
	50
	90
	140

ɜ wetted floor area is minimized · dry.
zles are commercially available. ate at low pressure. Obtain drip- 1.0 gal/hr at the manufacturer's ıtrol the drippers with a thermo- alve. Operate drippers when air s 85 F.
ɾr supply pipe, ½" polyethylene, ıe stall about 20" behind the front tion reduces feed wetting, keeps ı provides effective sow cooling. er the sow's neck and shoulder install drippers where water can ırea.
ɾip systems can be used in in- ıs boar pens. Locate the nozzle in



ows in farrowing stalls.

Evaporative Cooling

Principles

Evaporative coolers use heat from air to vaporize water. This lowers the air temperature, but increases the relative humidity.

Lower relative humidity of incoming air to increase the effectiveness of the evaporative cooling process. Evaporative coolers are more effective in dry western states but can be helpful in the Midwest during the hottest part of the day by providing up to 20 F of cooling.

Evaporative coolers

Commercial evaporative coolers are available for livestock buildings. Air is drawn through wet pads or foggers into the animal area. Most units pump water from a sump to a fibrous pad. One commercial unit rotates a drum-mounted pad through a pan of water. Pads can be mounted on the sidewalls, endwalls, or roof. Wall-mounted units are easier to maintain than roof units.

Provide airflow through the evaporative unit at the hot weather ventilating rate given in Table 2. For boars, breeding sows, mature dairy and beef cows, horses, and sheep, airflow rates in Table 2 can be reduced up to 40% because of evaporative cooling. On hot, humid days evaporative cooling is not as effective. If the hot weather ventilating rate is reduced, install circulation fans to help cool animals. If the pads do not cover the full length of the building, use circulation fans to distribute the cooled air. See the "Circulating Fans" section.

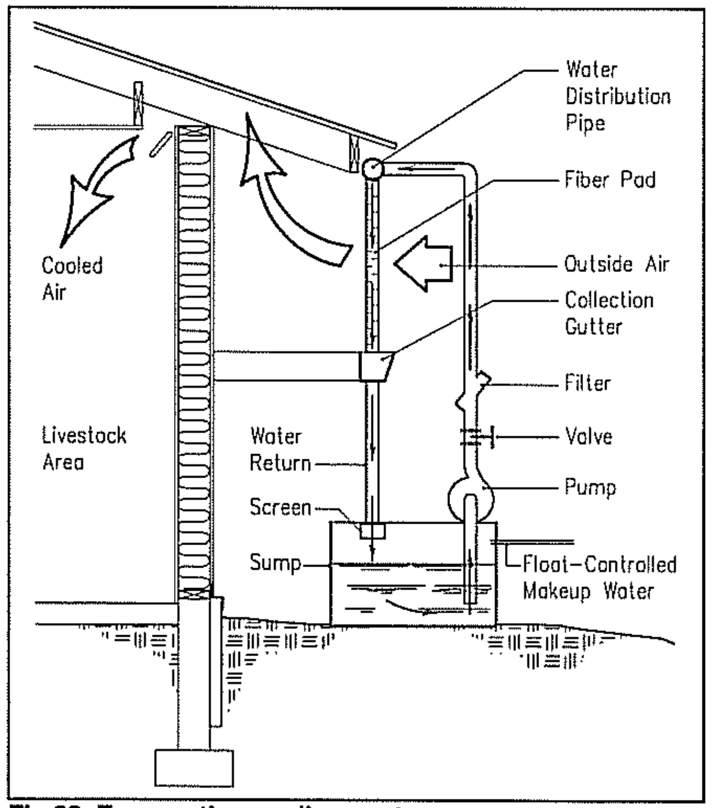


Fig 33. Evaporative cooling system.
Ventilating exhaust fans pull hot air through wet fiber pads. Air heat evaporates the water and lowers air temperatures.

Design

Table 16 gives pad size and water requirements for a wall evaporative cooler, Fig 33. Cover pads with insulated doors during winter.

Supply water to the pads with a water sump and overhead distribution system. Rigid plastic pipes or open rain gutters with evenly spaced holes allow water to drip uniformly over the pads. Pipe size, hole size, and spacing depend on water flowrate and are sized for each system. For best evaporative efficiency, more water is supplied than is evaporated. To conserve unevaporated water, provide a return to the sump. A sloped gutter below the pads collects and conveys unevaporated water back to the sump. Control make-up water line with a shut-off float valve.

Protect the water distribution system from insects and debris. Screen recirculated water before it returns to the sump. Also, install a filter between the pump and the distribution pipe or gutter.

Control the system with a thermostat set to begin wetting pads at about 78 F. To reduce algae growth on the pad, stop the pump several minutes before the fans to dry pads after each use.

Example 7:

Size the pads, sump tank, and pumps for a 24'x54' building housing 48 gestating sows. Aspen pads will be placed along one sidewall as shown in Fig 33.

Solution:

The hot weather ventilating rate cannot be reduced 40% for gestating sows. Size the pad for the hot weather ventilating rate in Table 2.

Total airflow: 48 sows × 150 cfm/sow = 7,200 cfm

Required pad area is: 7,200 cfm × 6.67 ft^2 (Table 16) ÷ 1,000 cfm = 48 ft^2

Required pad length, assuming 2' high pads: 48 ft^2 ÷ 2' = 24'

Use four 6' long pads spaced evenly along the sidewall opposite the fans. Block off the area between the pads and other inlets so all the incoming air passes through the pad. Install circulation fans in the building to distribute the cooled air.

Sump tank size: 48 ft^2 × 0.5 gal/ft^2 of pad (Table 16) = 24 gal

Pad water pump capacity: 24' long × 0.33 gal/linear ft of pad (Table 16) = 8 gpm

Maximum rate for make-up water on a hot, dry day: 48 ft^2 × 1 gpm ÷ 100 ft^2 (Table 16) = 0.48 gpm

Maintenance

Evaporative cooling systems require regular maintenance for proper operation. Develop a maintenance schedule from the following guidelines:

- Replace woven aspen fibers annually.
- Cellulose pads have a life of about five years. Replace within five years.
- If the pad settles, add more pad material so air does not short-circuit.
- Hose pads off at least once every two months to wash away dust and sediment.
- Control algae buildup with a copper sulfate solution in the water. Light-tight enclosures around pads and water sump also help control algae.
- As water evaporates, salts and other impurities buildup. Bleed off 5%-10% of the water continuously to remove salts or flush the entire system every month. **Caution,** bleed off water can be toxic--dispose of properly.

Air Conditioning Systems

Corrosive gases and dust in livestock environments do not allow cooled air to be reused. Livestock building air conditioners must continually cool hot air in a one pass process. Livestock buildings are seldom air conditioned because of cost. Air conditioning systems are sometimes used to cool expensive breeding animals such as AI boars and bulls.

Zone Cooling

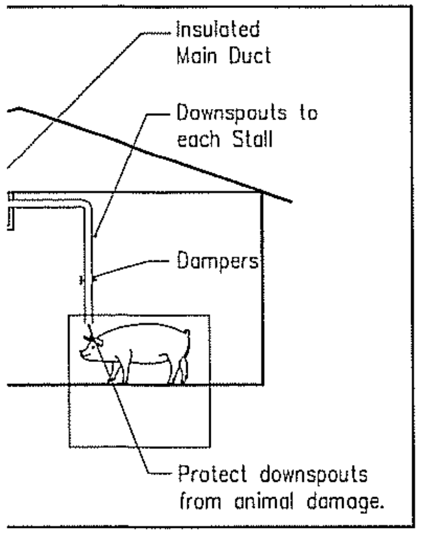
In hot weather, most animals lose 60%-70% of their heat through evaporation from the respiratory tract. Zone cooling the area around the head helps improve cooling. Zone cooling is generally used for stall- or tether-restrained animals and occasionally for animals in individual pens. In swine farrowing buildings, zone cooling makes the sow more comfortable while allowing higher temperatures in the pig creep.

Air for zone cooling can be unconditioned outside air, mechanically conditioned air, or earth tube tempered air. Use only fresh air. Do not use evaporatively cooled air with a relative humidity above 80% for snout cooling—mechanical cooling works best be-

Table 16. Evaporative cooling design criteria.

Pad type	Pad area ft^2/1,000 cfm	Sump tank size gal/ft^2	Pad pump capacity* gpm/linear ft	Maximum make-up water rate, gpm/100 ft^2
Aspen	6.67	0.50	0.33	1
Cellulose	4.00	0.75	0.50	1

*Maximum height of 6'.



stem.

lifies the air. Because air from :oach 100% relative humidity, the animal's body rather than

stem has a main air duct and lucts) located as needed, Fig 34.)se to the animal; mixing cooled :eases its effectiveness. Protect e. Provide dampers to close lls or pens are empty. duct to an R-value of 6 to reduce ıting of duct air. With plywood . 1½" of polyisocyanurate or ion board on the inside of the :ts are difficult to insulate. ecommended zone cooling ven- :ommended main duct and given in Tables 13 and 12. The ger, but not smaller. Consider izing ducts. Properly sized ɔrtant to maintain desired air

Table 17. Swine zone cooling airflows.
With non-mechanically conditioned air (i.e. earth tubes), ventilate the room at the hot weather rate from Table 2 in addition to zone cooling. With mechanically conditioned or cooled air, no additional hot weather ventilation is required because air is cooled and dehumidified in one pass.

	Non-mechanically conditioned air		Mechanically conditioned air
Swine type	Zone	Room	Zone
	---------- cfm/animal ----------		
Farrowing sow	70	500	40
Gestating sow	35	150	20
Boar	55	300	30

Example 8:

Determine the airflow and duct size requirements of a zone cooling system for a 20-sow farrowing building. Use non-mechanically conditioned air.

Solution:

Step 1:

Determine recommended downspout and main duct airflow. From Table 17, 70 cfm/downspout is required. Main duct airflow is 1,400 cfm (70 cfm/sow x 20 sows).

Step 2:

Determine size of downspout from Table 13. Use a 4" diameter downspout.

Step 3:

From Table 12, size the main duct. A 12"x30" plywood duct (interior dimensions) is adequate for 1,500 cfm if insulation is outside the duct. Increase duct's dimension to allow for insulation placed inside of the duct.

Step 4:

In addition to zone cooling, ventilate the room with a conventional ventilating system. Provide the hot weather ventilating rate from Table 2. Total ventilating capacity is 10,000 cfm (500 cfm/sow x 20 sows).

7. INSULATION

Insulation is any material that reduces heat transfer from one area to another. The resistance of a material to heat flow is indicated by its R-value. Good insulators have high R-values, Table 18.

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

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

In a poorly insulated building, inside ceiling and wall surfaces become cold in winter. If the surface temperature is below the dew point temperature, air next to the surface becomes saturated and moisture condenses, Fig 35. If the surface temperature is below freezing, frost occurs.

Five common forms of insulation are:

1. **Batt and blanket.** The most common.
2. **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.
3. **Rigid insulations.** Provide rigidity and strength that other insulation types do not.
4. **Foam or foamed-in-place insulation.**
5. **Reflective materials.** Like aluminum foil, reflect most of the radiant heat that strikes it if an air space is provided. Radiant heat loss is a small part of the total heat loss. Several air spaces are needed to resist heat flow by conduction and convection. Dust and corrosion greatly reduce reflective insulation values.

Insulating effectiveness of an air space depends on its position, and thickness. A ¾"-4" thick non-reflective dead air space has a maximum R-value of about R=0.9. See Table 18 for R-value of reflective air space.

Where to Insulate

Use insulation in all spaces that are heated in winter or cooled in summer. In addition to walls, ceilings, and foundation perimeters, consider insulating:

Under metal roof surfaces in cold housing where winter or summer weather conditions are severe, to reduce radiant heat gain and moisture condensation.

- Under heated floors.
- Heating or ventilating ducts passing through unheated spaces.

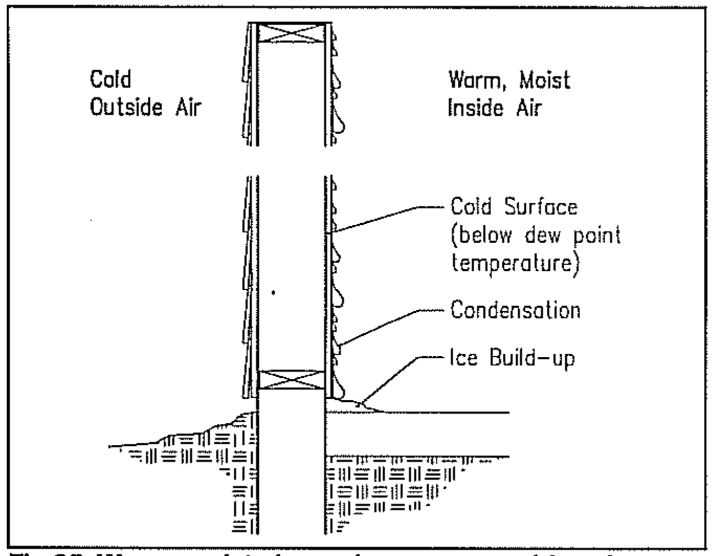


Fig 35. Warm, moist air condenses on a cold surface.

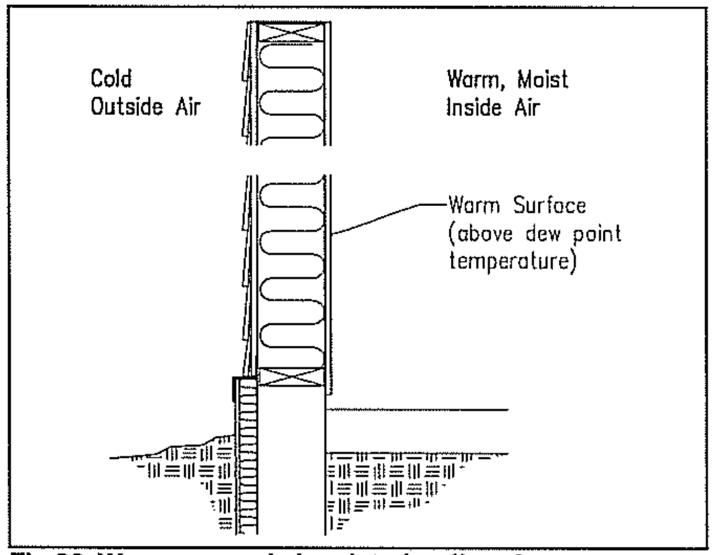


Fig 36. Warm, properly insulated wall surfaces.
The warmer the surface, the less likely it will have condensation.

- Raised floors with an unheated space below.
- In winter, windows and summer ventilating fan openings.

Insulation Levels

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

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

ıes.
ıdbook of Fundamentals. Values do not include ıerwise. All values are approximate.

	R-value: Per inch (approximate) 1/k	R-value: For thickness listed 1/C
	2.75-3.67[a]	
	3.13-3.70	
	2.20-3.00	
	2.13-2.27	
	2.22	
	1.50	30+
	5.00	
	3.85	
	4.35	
	4.55	
ıfaced	5.56-6.25	
	4.00	
	2.50	
	7.20[b]	
	5.26-6.25	
	0.08	
	8"	1.11
		2.00
		5.03
	0.31-0.45	
	0.11-0.19	
	0.00	
		0.61
		1.82
	0.89-1.00	
	0.99-1.06	
	1.11-1.35	
	0.8-0.89	
	0.82-0.87	
	0.84-0.94	
	0.88-0.94	
	1.25	0.47
	1.25	0.62
	1.06	
	1.00	0.25
		2.06
		0.45
		0.81
		0.44
		0.94
ions)		
		0.91
		2.00
		1.69
		2.56
ɔnditions)		
		3.03
nal break		5.88
ıermal break		2.50
		0.90
		1.25
		2.20
		3.40
h)		0.68
mph)		0.17
wall length)		
ın		1.23
lation		2.22

att thickness and manufacturer—check the label.
k with gas-retarder quality aluminum foil facers on
ɔe on each side is required.

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

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

Recommended minimum insulation levels for degree-day zones are in Table 19. More insulation may be justified with increasing energy costs in supplementally heated buildings.

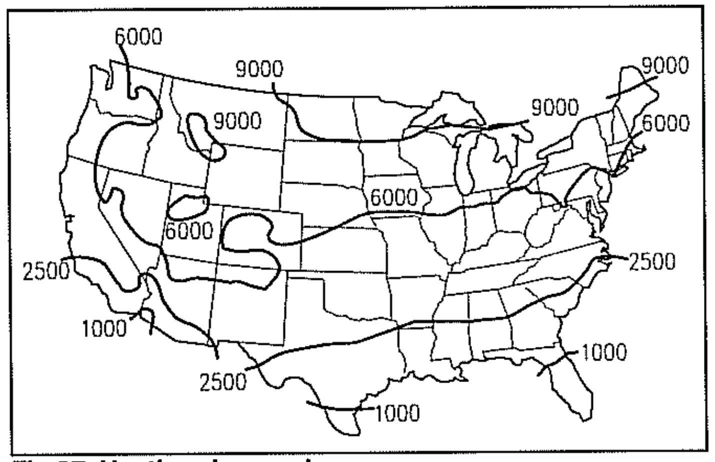


Fig 37. Heating degree days.
These values can vary considerably in mountainous areas. Check local records.

Table 19. Minimum insulation levels for animal buildings.
R-values are for building sections. In cold barns with mature animals, no insulation is needed in the walls or roof. In severe climates, insulation (R=5) in the roof helps control condensation and frosting and reduces summer heat load.

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

Moisture Problems

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

One of the best vapor barrier materials 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 commonly used, but 6-mil (0.006") is easier to handle without tearing. Aluminum foil can also act as a vapor barrier.

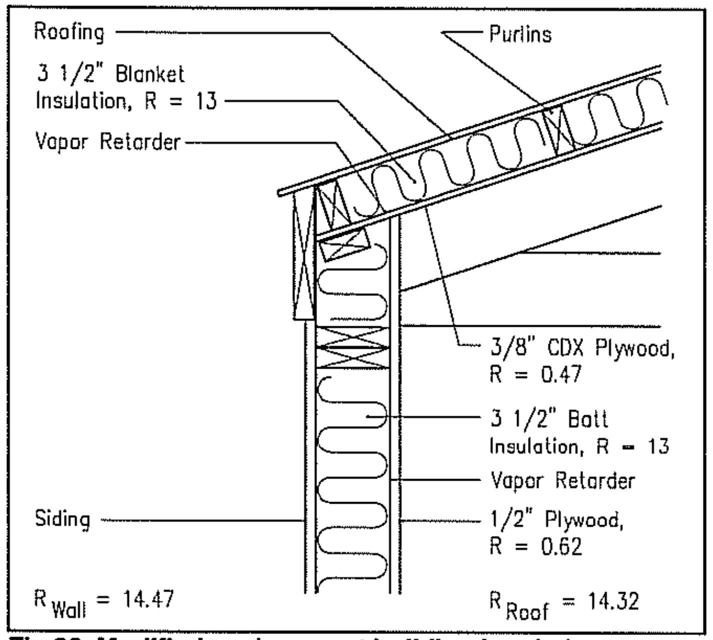


Fig 38. Modified environment building insulation.
R-values of batt insulation can vary—check the label.

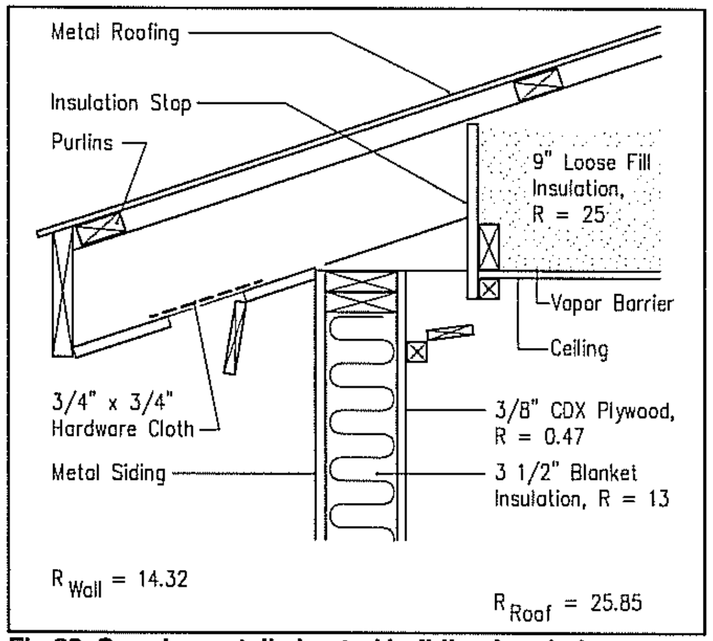


Fig 39. Supplementally heated building insulation.
For areas where winter degree days are less than 6,000. R-values of batt insulation can vary—check the label.

Use vapor barriers with sheet metal ceilings and walls. Although metal is a good vapor barrier, joints and screw holes create many openings for moisture to pass through. With rigid board insulation, moist air passes through board joints and condenses. Follow manufacturer's instructions for sealing board joints.

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

Fire Resistance

Many plastic foam insulations have high flame spread rates. Insulation in farm buildings that have high flame spread rates must be protected from potential fire. If plastic foam insulations are not protected from potential fire, your insurance company may refuse to cover the structure.

To reduce risk, protect plastic foam insulation with fire-resistant coatings. Do not use fire rated gypsum board (sheet rock) in high moisture environments such as animal housing. Materials that provide satisfactory protection include:

- Fire rated ½" exterior plywood.
- ½" thick cement plaster.
- ¼" thick sprayed-on magnesium oxychloride (60 lb/ft³) or ½" of the lighter, foam material.

Birds and Rodents

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

Cover exposed perimeter insulation with a protective liner and maintain a rodent control program. High density fiberglass reinforced plastic is preferred. Foundation grade plywood, ⅜", resists physical and moisture damage but is not rodentproof. Seal holes and cracks in walls and ceilings to limit rodent access. Screen eave vent openings with ¾" hardware cloth to exclude birds.

8. APPLICATIONS AND EXAMPLES

ents example systems. Only
tempering references are in-
plete examples of ventilation
?S-32, *Mechanical Ventilating*
:k Housing, and MWPS-33,
ystems for Livestock Housing.

ıdoor temperatures about the
lequate for beef cattle. Ventila-
movement and supplemental
occasional use of heaters for
for newborn calves in cold
al heat may be needed to main-
res in warm barns.

s no change in production for
emperatures between 10 F and
eclines above 75 F. Jersey cows
ı0 F and above 80 F.
;ally controlled dairy buildings
from November through April.
ıf 40%-60% are common. Sup-
ıe required to maintain desired
.
ventilation is common in most
ıg and freestall barns are often

ement heifers: Naturally venti-
ften in calf hutches, is usually
es and heifers (0-8 mo) can also
echanically ventilated housing.
eas.

parlor, milk room, office, toilet,
lry floors and prevent freezing.
; parlor temperature at about 50
supplementing animal heat if
ıe milking center to reduce heat
ensation.
ı compressor, water heater, and
uipment heat outside in warm
0 lb of milk from 98 F to 40 F
Btu of heat. This added to about
ompressor motor is equal to a 2
ınning for 1 hr. A system to use
eating or preheating water can
a cost. See Fig 40.
uipment is practical for almost
es less economical with smaller
consumption of 100 gal/day of
ter is required to make heat
economical. Check with equip-
he utility company for sizing and potential energy savings. Heat exchangers are available to heat air and water with refrigeration systems. Heat air with an air-cooled condensing unit or water with a water-cooled unit.

The treatment-hospital area is usually a separate room with its own mechanical or natural ventilating system. Design the system to accommodate varying animal densities. If water freezing or worker comfort is a concern, consider an individual space heater, central heating system, or heating tape on pipes. A frost proof water system allows this area to be unheated when not in use.

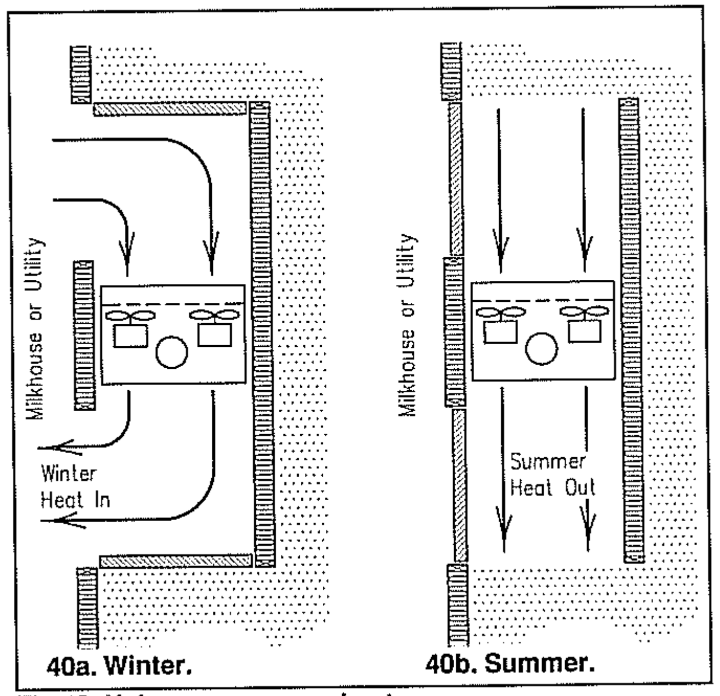


Fig 40. Using compressor heat.
Retain compressor heat in cold weather and remove it in warm weather. Size the cross-sectional area of all air passages at least 1½ times the condenser area. Consider ducting utility room heat to milking parlor during cold weather.

Milking parlor

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

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

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

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

A central forced air system is shown in Fig 41. A central hot water system can heat each room with convectors, Fig 42, which allow for individual temperature control in each room. Local regulations may not allow this system if the same heat exchanger is used in preheating the washwater.

With a central forced air system, use a down draft furnace with easily changeable filters. Use an induced draft or powered vent furnace to force exhaust gases out powered dampers. Duct hot air into the milker's pit about 8" above the floor; direct air toward the floor. Locate cold air returns high on the wall.

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

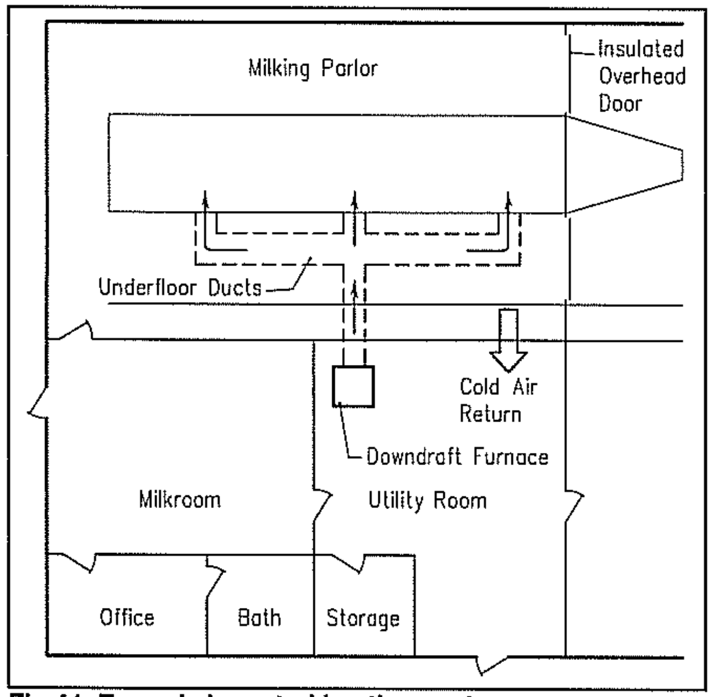


Fig 41. Forced air central heating system.
Cold air return can be ducted to the furnace.

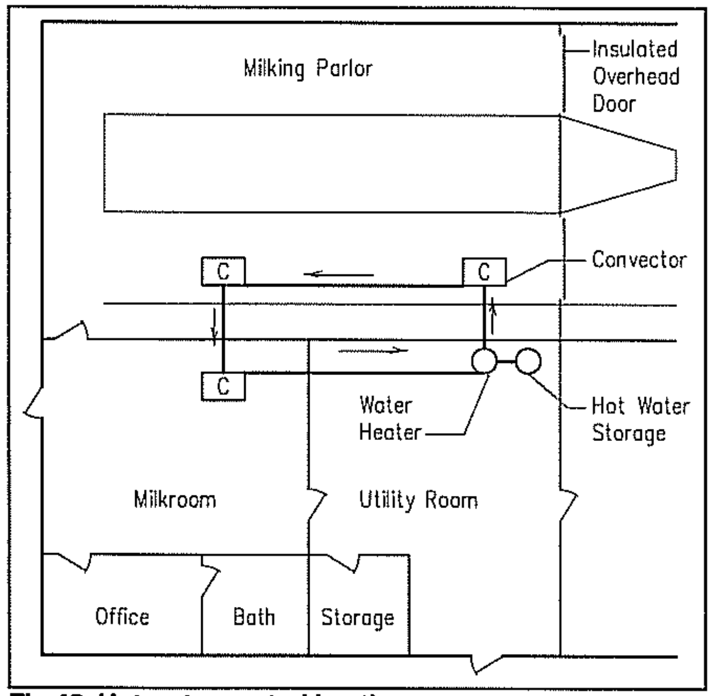


Fig 42. Hot water central heating system.

Milk room

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

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

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

Other areas

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

Maintain a storage room between 40 F-80 F. Freezing can damage medical supplies, while high temperatures can accelerate rubber component deterioration. Maintain safe storage temperatures with a supplemental heater or duct from a central heating system. Do not use air exhausted from the utility room or that room may get too cold.

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

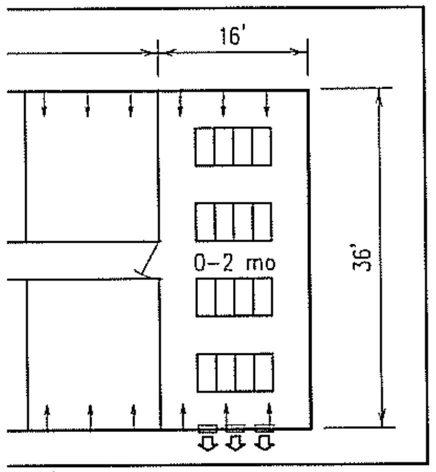
Locate the compressor, vacuum pump, water heater, and furnace in a utility room kept above freezing with equipment heat.

Ventilate for efficient equipment operation. Provide a thermostatically controlled exhaust fan to control temperature rise. Size the fan for one air exchange per minute. Provide 1 ft^2 air inlet/600 cfm fan capacity. Cover air inlets with gravity or motorized louvers that open when the fan turns on. In winter, move excess heat to other rooms with a fan and duct. During summer, exhaust excess heat outside, Fig 40.

Dairy Design Example

Example 9:

Design warm housing ventilation for 16 calves (0-2 mo.) near Madison, Wisconsin for the youngstock barn of Fig 43. Calves are in 2'x4' elevated crates; young heifers are on bedded pack.



ımple 9.

ɜing:
ate: 15 cfm/hd × 16 hd = 240 cfm

ate: 50 cfm/hd × 16 hd = 800 cfm

ıte: 100 cfm × 16 hd = 1,600 cfm

ɔntinuous cold weather fan; 560
ı (800 cfm-240 cfm); 800 cfm hot
fm-800 cfm).
)ne is not needed for the con-
the other two fans with thermo-
veather fan thermostat at about
ather one at about 70 F.
ıeat: Provide supplemental heat
; about 60 F. Estimate the sup-
ze from Table 4, Chapter 3. For
Btu/hr-hd, estimated heater is
ulate heater size more precisely
ıt procedure includes conduction
ɔuilding parts, ventilation heat
ion heat loss, as well as heat

rmostat has an on-off range of 4
ɔom temperature is 60 F, set the

ɔ R=20 and the ceiling to R=33.
vapor barrier.

usually in 2'x5' elevated wooden
; week of age (100 lb). Start calves
the temperature 1 F every 3 days
re reaches 50 F.
ıir relative humidity at 50%-60%
40%-50% for smaller calves.

ıther fans. The lower capacity fan
ventilation when calves weigh
ıher capacity fan for winter ven-

tilation for 400 lb calves. Increase airflow with a timer as calves grow. Operate the lower capacity fan continuously.

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

Air tempering

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

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

Supplemental heat is needed to maintain desired room temperature. Size heaters as in Chapter 9 and Example 10.

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

Veal Calf Design Example

Example 10:

Design the ventilating system for a four room veal barn with 100 calves per room in southern Wisconsin. The building is 50'x264' with a side air tempering corridor, Fig 44. Ceiling height is 9'.

Solution:

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

Ventilating rates for each room:

Cold weather, 100 lb calves:
10 cfm/100 lb × 100 calves × 100 lb/calf = 1,000 cfm
Cold weather, 400 lb calves:
10 cfm/100 lb × 100 calves × 400 lb = 4,000 cfm
Mild weather:
20 cfm/100 lb × 100 calves × 400 lb = 8,000 cfm
Hot weather:
50 cfm/100 lb × 100 calves × 400 lb = 20,000 cfm

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

Mild weather fan: 4,000 cfm (8,000 cfm – 4,000 cfm) fan on a thermostat set at 77 F.

Hot weather fan: 12,000 cfm (20,000 cfm – 8,000 cfm) on a thermostat set at 82 F.

Locate exhaust fans in the outside wall opposite the corridor. Cover and insulate the hot weather fan

during winter to reduce drafts. See MWPS-32, *Mechanical Ventilating Systems for Livestock Housing*, for inlet design.

Corridor inlets: Box inlets in the corridor ceiling bring air from the attic. Provide 16-2'x2' area inlets evenly spaced along the corridor. A slot at least 6" wide is needed for enough outlet area. Open windows or doors in the outside wall of the corridor for more summer ventilating inlet areas.

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

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

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

Calf room heaters: Size room heaters to maintain desired room temperature when calves are first put in the room. Determine the heat losses due to evaporation, ventilation, and through building surfaces and heat produced by animals to determine furnace size. Use the minimum cold weather ventilating rate of 1,000 cfm/room.

Determine building surface heat loss with Eq 2, Appendix.

Ceiling heat loss + wall heat loss = building heat loss
2,640 ft^2 × (70 – (-10))F ÷ (33 Btu/hr-ft^2-F) + 954 ft^2 × (70 – (-10))F ÷ 20 Btu/hr-ft^2-F = 10,216 Btu/hr

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

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

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

Determine heat produced by the animals. From Table 20, a 100 lb Ayrshire calf produces 310 Btu/hr with 73 F room temperature.

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

Balance heat losses and production to find furnace size.

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

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

Note that about 65% of the total heat loss is to evaporate moisture in the room. With vented heaters additional ventilation capacity is not needed. Use two 50,000 Btu/hr heaters in each room. Operate heater fans continuously to improve air circulation.

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

Horses

General

In mild or moderate climates, horses can be in uninsulated, naturally ventilated buildings. Horses conditioned to cold weather with long hair coats can withstand temperatures below 0 F with adequate shelter and nutrition. Show horses can maintain a

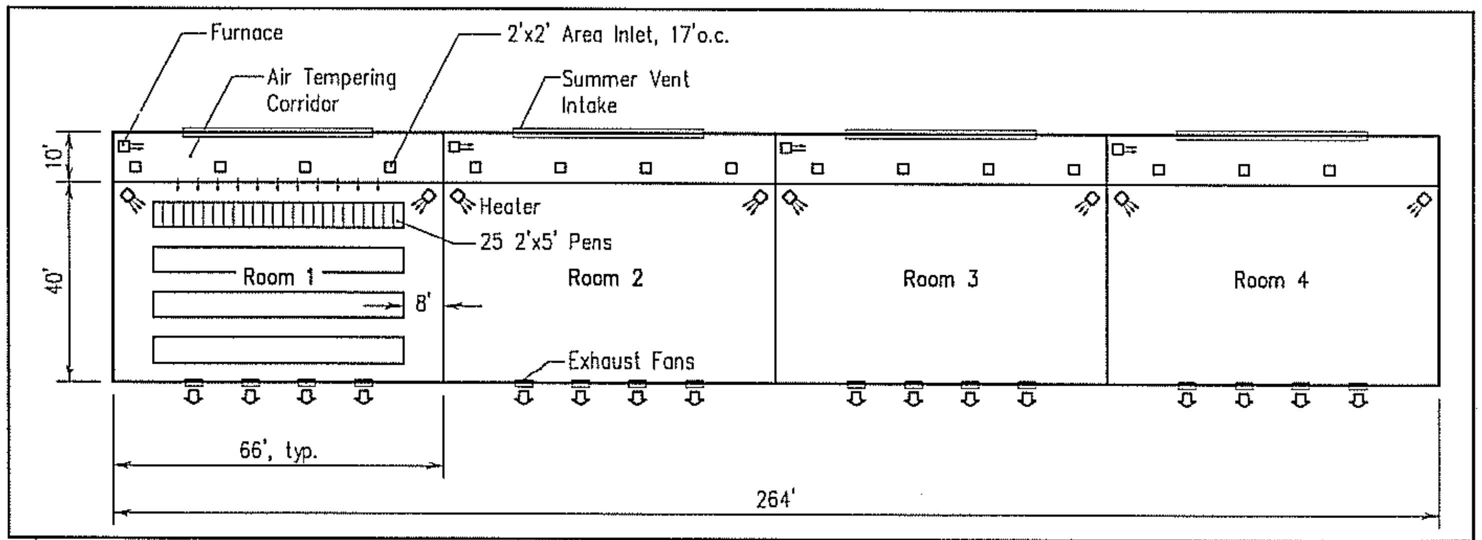


Fig 44. Veal calf barn, Example 10.

to 40 F if kept in dry indoor
ankets, hoods, and leg wraps.
s, insulated buildings heated to
ese buildings are mechanically
winter and often naturally ven-
nmer. In warm buildings, rela-
ɜen 40% and 70% are satisfac-

ıg, insulate to recommended
ılation is recommended in cold

ıtion is required for warm horse
continuous fan for minimum
ıtion and additional fans on
and hot weather.
ıre often solid 4' high and open
e solid above 4', provide an inlet
ıll for adequate air movement,
m weather.
ystems automatically combine
ical ventilation. During warm
ıse building temperature and
hes adjust inlets. As weather
rols close ventilating doors and
ilate during cold periods. Fan
ısure proper air exchange on

ıduce 2,000-3,000 Btu/hr of heat
nimal weight. With 12'x12' box
alley, the animals provide only
1,000 lb, which is much lower
ıimal housing. Because of low
supplemental heat is needed--
ɔer stall. For a more accurate
ıilding and ventilation heat los-

ıture depends on bird age.
ınd starter pullets: Maintain
ɔeratures: First 3 to 7 days—85
', and third week—75 F. Main-
he entire house or provide zone
hovers. With brooders, room
ıbout 10 F cooler than brooding

Provide the following tempera-
—90 F, second week—85 F, and
rooder hovers can provide zone

ıyers, and turkeys: Minimum
For poultry, maintain air rela-
-70% to control litter moisture
wet basis). At higher relative
is and other disease outbreaks

can occur. Lower humidities can cause dusty litter. Short periods of up to 90% humidity can be tolerated.

In warmer climates, consider rigid insulation (up to R=10) in the roof and walls and fibrous insulation above a flat ceiling. Install a vapor barrier to control moisture migration.

Ventilation

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

Supplemental Heat

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

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

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

Cooling

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

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

Use evaporative pad cooling only with mechanically ventilated housing. Pull all incoming air through the wetted pads. Operate at or above hot weather ventilating rates to achieve the greatest production benefits. Pad systems operating at 80% evaporative efficiency can give up to 20 F sensible cooling in humid climates. Pad systems usually cool breeding and egg laying birds but also cool commercial broilers subject to extreme heat stress.

High pressure foggers create a very fine smoke-like fog with excellent distribution with line water pressures up to 600 psi. Cooling capacity is about half of pad systems at about half the cost. Fogging is applicable to naturally ventilated broiler houses. Low pressure fogging is not recommended because of limited effectiveness and problems with wet litter.

Example 11:

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

Solution:

A mechanically ventilated building with brooders is needed.

Building dimensions: Determine house dimensions to maintain a bird density of 0.8 ft^2/bird. Required area is 16,000 ft^2 (20,000 birds × 0.8 ft^2/bird). Use a 40' wide house because wider houses are difficult to ventilate. Required house dimensions are 40'x400' (16,000 ft^2 ÷ 40'). Provide 10' ceiling clearance for broiler loading near the house center.

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

Base ventilation rate on maximum bird size, i.e. 4 lb.

Cold weather rate (Table 2):
20,000 birds × 0.1 cfm/lb × 4 lb = 8,000 cfm
Mild weather rate:
20,000 birds × 0.5 cfm/lb × 4 lb = 40,000 cfm
Hot weather rate:
20,000 birds × 1.0 cfm/lb × 4 lb = 80,000 cfm
(Up to 1.5 cfm/lb may be desirable.)

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

Mild weather fans: Select three fans at about 10,500 cfm each for mild weather (40,000 cfm – 8,000 cfm). Set thermostats at 70 F.

Hot weather fans: Use two 20,000 cfm fans for hot weather (80,000 cfm – 40,000 cfm). Set thermostats at 75 F.

Wire controls so fans shut off when curtains are open.

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

Supplemental heat: Install about 24 brooders, preferably with electronic ignition, in the brooding end of the building. Maintain chick hovers at 85 F, 80 F, 75 F for the first, second, and third weeks. Install 4 to 6 additional brooders in the non-brooding end for cold weather after brooding.

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

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

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

Rabbits

General

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

Temperature for optimum feed conversion for rabbits is about 55 F. Most systems maintain minimum winter temperature at 40 F-45 F.

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

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

Insulate to moderate summer temperatures and reduce winter supplemental heat costs, Table 19.

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

Ventilation

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

Periodically remove rabbit hair from cages because it restricts airflow.

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

Sheep

General

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

Insulate cold buildings as recommended in Chapter 7 and warm buildings as in Table 19.

Ventilation and Heat

Naturally ventilated buildings are discussed in MWPS-33, *Natural Ventilating Systems for Livestock*

ildings often have mechanical
ꞩee Table 2. Circulation fans in-
ꞅr animals and reduce summer
ı to 40%. Consider evaporative

eat (400 Btu/hr/ewe) may be
ı heat lamps for mothering pens.
ꞓe pen partitions solid or provide
ʼafts and install 250 watt heat

ew-born pig requires 90 F-95 F
ıys, but a sow wants 50 F-70 F.
ɪ keeping the farrowing room at
supplemental heat in creeps for
week after farrowing. Room
30 F if bedding is used.
week-old pigs in a prenursery,
evel for the first few days after
temperature 3 F/week to about
gs. Warm the floor with infrared
s, or floor heat. With only space
arm floors with higher thermo-
ʼenursery, consider pre-heating
uce chilling drafts.
sow-pig nursery, keep the room
ıpplemental heat in the creeps.
ꞅrs, room temperature can be 60

ıishing: For growing and finish-
꞉ recommended.
tion: Temperatures above 85 F
reduce fertility of boars, sows,

and gilts. Maintain the room below 85 F for sows during the first 2 or 3 weeks of gestation for maximum litter size and during the last 2 or 3 weeks to reduce stillborns and abortions. Keep the room at 60 F or warmer for sows or gilts in crates or tethers or on total slotted floors. If the floor is partly slotted and if sows are in groups that can huddle together, temperature can be down to 50 F. Colder temperatures can be tolerated with bedding, but freezing temperatures with wind can be a problem.

Keep relative humidity at about 40%-60%.

Insulation: Install minimum insulation in open front buildings and single sow farrowing huts: have indoor temperatures only slightly higher than outside conditions.

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

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

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

Draft control: Solid pen partitions around animal sleeping areas reduce drafts.

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

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

9. APPENDIX

Animal Heat and Moisture Production

Table 20. Moisture and sensible heat from livestock.

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

Animal	Building temperature F	Moisture production: lb water/ hr-hd	Moisture production: lb water/ hr-100 lb weight	Sensible heat loss: Btu/hr-hd	Sensible heat loss: Btu/hr-lb animal
Cattle:					
Dairy cow					
1,100 lb	30	0.85	0.08	3,200	2.9
1,100 lb	50	1.10	0.10	2,550	2.3
1,100 lb	60	1.43	0.13	2,050	1.9
1,100 lb	70	1.43	0.13	1,875	1.7
1,100 lb	80	1.98	0.18	1,025	0.93
Beef cattle					
1,100 lb	40	2.75	0.25	2,550	2.3
Calves:					
Ayrshire male					
85 lb	37	0.060	0.07	330	3.9
100 lb	37	0.070	0.07	400	4.0
85 lb	73	0.060	0.07	265	3.1
100 lb	73	0.070	0.07	310	3.1
Brown Swiss					
16 wk	50	—	0.20	—	3.6
32 wk	50	—	0.12	—	2.3
48 wk	50	—	0.10	—	2.3
16 wk	80	—	0.30	—	2.3
32 wk	80	—	0.22	—	1.7
48 wk	80	—	0.19	—	1.5
Jersey					
16 wk	50	—	0.24	—	3.9
32 wk	50	—	0.15	—	2.8
48 wk	50	—	0.13	—	2.5
16 wk	80	—	0.38	—	2.2
32 wk	80	—	0.25	—	1.5
48 wk	80	—	0.23	—	1.2
Shorthorn Brahman Santa Gertrudis					
25 wk	50	—	0.16	—	2.2
40 wk	50	—	0.11	—	1.5
55 wk	50	—	0.10	—	1.5
25 wk	80	—	0.28	—	1.1
40 wk	80	—	0.21	—	0.77
55 wk	80	—	0.18	—	0.77
Swine:					
Sow and litter					
390 lb (0 wk)	60-80	0.70	0.18	785	2.0
400 lb (2 wk)	60-80	0.96	0.24	1,050	2.6
410 lb (4 wk)	60-80	1.07	0.26	1,080	2.6
440 lb (6 wk)	60-80	1.19	0.27	1,160	2.6
500 lb (8 wk)	60-80	1.30	0.26	1,630	3.3
Nursery pigs					
10 lb	85	0.017	0.17	34	3.4
20 lb	75	0.044	0.22	96	4.8
30 lb	65	0.066	0.22	162	5.4
Growing-finishing pigs					
45 lb	40	0.11	0.25	290	6.5
	50	0.12	0.27	275	6.2
	60	0.14	0.31	205	4.6
	68	0.16	0.37	160	3.6
	77	0.21	0.47	110	2.5
	86	0.28	0.63	40	0.93
90 lb	40	0.13	0.15	410	4.6
	50	0.14	0.16	345	3.9
	60	0.17	0.19	275	3.1
	68	0.19	0.22	220	2.5
	77	0.25	0.28	165	1.9
	86	0.32	0.36	82	0.93
130 lb	40	0.16	0.12	510	3.9
	50	0.17	0.13	405	3.1
	60	0.19	0.14	345	2.6
	68	0.22	0.17	265	2.0
	77	0.26	0.20	200	1.5
	86	0.36	0.27	100	0.77
175 lb	40	0.19	0.11	600	3.4
	50	0.19	0.11	490	2.8
	60	0.21	0.12	405	2.3
	68	0.25	0.14	330	1.9
	77	0.30	0.17	230	1.3
	86	0.39	0.22	133	0.76
220 lb	40	0.21	0.094	682	3.1
	50	0.22	0.10	550	2.5
	60	0.24	0.11	440	2.0
	68	0.26	0.12	375	1.7
	77	0.31	0.14	270	1.2
	86	0.40	0.18	167	0.76
Gilts, sows, and boars					
300 lb	40	0.24	0.079	850	2.8
	50	0.24	0.079	710	2.3
	60	0.25	0.084	570	1.9
	68	0.28	0.093	475	1.5
	77	0.34	0.11	365	1.2
	86	0.40	0.13	255	0.84
400 lb	40	0.25	0.064	1,040	2.6
	50	0.25	0.063	860	2.2
	60	0.26	0.065	740	1.9
	68	0.28	0.070	600	1.5
	77	0.32	0.080	490	1.2
	86	0.38	0.096	390	0.98
Sheep:					
130 lb					
Fleece length:					
(Maintenance diet)					
Shorn	46	0.044	0.033	490	3.7
	68	0.053	0.040	305	2.3
	90	0.10	0.079	165	1.3
1"	46	0.045	0.034	245	1.9
	68	0.069	0.052	195	1.5
	90	0.17	0.13	92	0.70
2¼"	46	0.053	0.040	205	1.5
	68	0.10	0.076	140	1.1
	90	0.19	0.14	60	0.45
(1.3 × maintenance diet)					
4¾"	55	0.13	0.10	170	1.3
	73	0.20	0.15	110	0.84
Poultry:					
Layer (Leghorn)					
	46	—	0.21	—	7.0
	54	—	0.28	—	6.2
	64	—	0.29	—	6.0
	82	—	0.38	—	5.0
Broilers					
0.25 lb	85	0.00088	0.40	4.1	18.6
1.5 lb	85	0.015	1.0	14.3	9.3
	77	0.0046	0.30	16.7	10.8
	60	0.011	0.70	14.3	9.3
2.5 lb	85	0.024	1.0	15.0	6.2
	65	0.0044	0.18	26.3	10.8
	60	0.011	0.45	13.5	5.6

d sensible heat (continued).

loisture production		Sensible heat loss	
ɔ water/ hr-hd	lb water/ hr-100 lb weight	Btu/hr-hd	Btu/hr-lb animal
).0071	0.20	31.1	8.8
).0062	0.14	32.8	7.4
).0034	1.56	2.08	9.4
).0043	0.98	4.30	9.8
).0064	0.72	7.37	8.4
).0054	0.41	12.08	9.1
).0053	0.24	21.50	9.8
).0562	0.17	56.32	1.7
).0253	0.14	39.19	2.2
).031	0.16	72.9	3.7
).039	0.20	51.6	2.6
).014	0.14	36.0	3.7
).037	0.38	15.0	1.5
).013	0.035	110.3	2.9
).020	0.053	98.6	2.6
).025	0.066	92.8	2.5
).031	0.088	81.9	2.3
).041	0.11	47.0	1.3
).053	0.15	24.0	0.68
).0067	0.031	70.2	3.3
).016	0.075	61.6	2.9
).015	0.070	51.9	2.5
).017	0.083	47.6	2.3
).020	0.10	31.1	1.5
).025	0.13	19.0	0.99

t Loss Through Building

te through each building surface
; area and the difference between
temperatures. The rate of heat
ned by the total heat resistance
ilding surface; the higher the R_T
ə heat flow rate. Heat loss from
.ce, BSL, is given by:

t_o) **Eq 2.**

ıs rate through a surface, Btu/hr
area, ft² (i.e. wall area)
ɛsistance of the surface to heat
ft²-hr/Btu
əmperature, F
temperature, F

ss from a building, add the losses
ng surface.
;h the floor perimeter is a special
ʼea, A, in Eq 2, is replaced by the

length (perimeter) of the exterior wall. The R_T value in Table 18 is given per foot of length.

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

BHL = (A/R) × Δt

Where:

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

Example 12:

Find the heat loss from the 24'x36' building of Fig 45. Inside design temperature is 75 F, and outside is 0 F. The building has two 3'x7' doors, insulated with 1" of 1 pcf molded polystyrene. There are no windows.

Solution:

Step 1:

Using the worksheet, fill in the blanks with the length, width, wall height, and foundation height. Calculate the perimeter, frame wall and concrete wall area (excluding windows and doors), ceiling area, window area, and door area. Find the insulation R-values in Table 18. Frame wall resistance is 12.47. The R_T for a 6" concrete wall with 2" polystyrene insulation is 9.33. The R_T for the ceiling is 13.98 and for the doors is 7.99. For 2"x24" polystyrene perimeter insulation, the R_T value is 2.22.

Step 2:

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

Worksheet Example

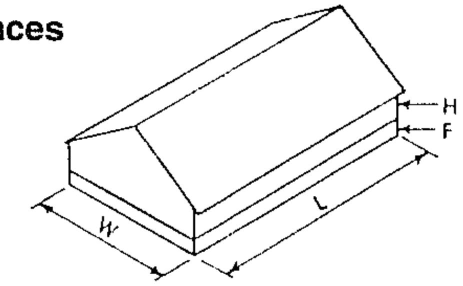
Calculating Heat Loss by Ventilation

Heat loss by ventilating air is proportional to the ventilating rate and the difference between the inside and outside temperatures. Eq 1 presented in Chapter 2 gives the governing equation.

Annual Heating Costs

Total building heat loss is heat loss through building surfaces plus ventilating air. Eqs 1 and 2 can be combined to get Eq 3 for calculating total heat loss rate.

Worksheet: Heat Loss Through Building Surfaces



Step I

Building dimensions (ft),
Surface area (ft²)

Length (L) ______
Width (W) ______
Frame wall height (H) ______
Concrete wall height (F) ______
Perimeter ______

R_T values

Ceiling ______
Window ______
Door ______
Frame wall ______
Concrete wall ______
Perimeter ______

Ceiling area ______
Window area ______
Door area ______
Frame wall area
less window & door area ______

Design temperatures, F

t_o (outside temp.) = ______, t_i (inside temp.) = ______,
Δt = ______.

Step II

Building heat loss, q_b

Ceiling $qc = \frac{\Delta t \times \text{ceiling area}}{\text{ceiling } R_T}$ $qc = \frac{\Delta_t \times (\quad)}{(\quad)} = \Delta_t F \times (\_\_\_\_\_ \text{ Btu/hr-F})$

Windows $qwi = \frac{\Delta t \times \text{window area}}{\text{window } R_T}$ $qwi = \frac{\Delta_t \times (\quad)}{(\quad)} = \Delta_t F \times (\_\_\_\_\_ \text{ Btu/hr-F})$

Doors $qd = \frac{\Delta t \times \text{door area}}{\text{door } R_T}$ $qd = \frac{\Delta_t \times (\quad)}{(\quad)} = \Delta_t F \times (\_\_\_\_\_ \text{ Btu/hr-F})$

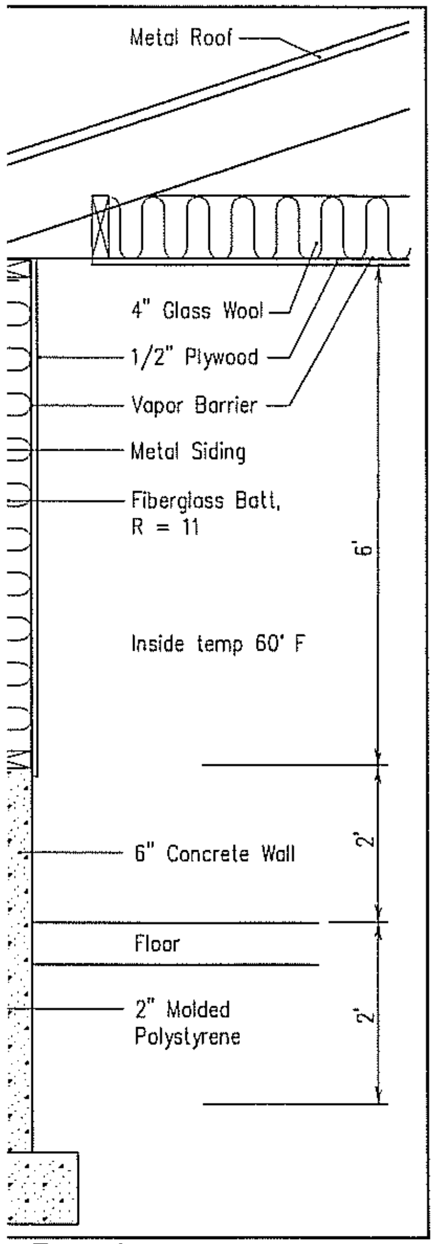
Frame walls $qw = \frac{\Delta t \times \text{frame wall area}}{\text{frame wall } R_T}$ $qw = \frac{\Delta_t \times (\quad)}{(\quad)} = \Delta_t F \times (\_\_\_\_\_ \text{ Btu/hr-F})$

Concrete walls $qf = \frac{\Delta t \times \text{concrete wall}}{\text{concrete wall } R_T}$ $qf = \frac{\Delta_t \times (\quad)}{(\quad)} = \Delta_t F \times (\_\_\_\_\_ \text{ Btu/hr-F})$

Perimeter $qp = \frac{\Delta_t \times \text{perimeter}}{\text{perimeter } R_T}$ $qp = \frac{\Delta_t \times (\quad)}{(\quad)} = \Delta_t F \times (\_\_\_\_\_ \text{ Btu/hr-F})$

Total, $q_b = \Delta_t \times A/R$ $= \Delta_t F \times (\_\_\_\_\_ \text{ Btu/hr-F})$

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



r Example 12.

Eq 3.

fm$_c$)($t_i - t_o$)

te of heat loss from building,

fm$_c$) Eq 4.

s factor, Btu/hr–F

g degree days from residential
: buildings, calculate the balance
b using Eq 5. It is the minimum
: required to maintain the build-
iperature with no supplemental
nce point temperature, t_b, calcu-
gree days correction factor, C_d,

$$t_b = t_i - (SHL \div HLF) \quad \textbf{Eq 5.}$$

t_b = Balance point temperature, F
SHL = Total livestock sensible heat loss, Btu/hr. Multiply value from Table 20 by number of animals or total weight
HLF = From Eq 4

$$C_d = A + (B \times (t_b - 32)) \quad \textbf{Eq 6.}$$

C_d = Heating degree days correction factor
A,B = Coefficients from Table 21

The annual energy required, E, to heat a building is determined by Eq 7. Supplemental heating requirements are reduced by heat produced by livestock or increased by high room temperatures.

$$E = C_d \times 24 \times HLF \times HDD \quad \textbf{Eq 7.}$$

E = Annual energy consumption, Btu/year
C_d = Heating degree days correction factor for livestock buildings
HDD = Heating degree days, F-day, from Fig 37

Determine annual fuel cost, AFC:

$$AFC = (FC \times E) \div (EFF \times V) \quad \textbf{Eq 8.}$$

AFC = Annual fuel cost, $
FC = Fuel cost, $/unit
E = Annual energy consumption, Btu/year (Eq 7)
EFF = Efficiency of heating system, %/100
V = Fuel heat content, Table 22

Table 21. Coefficients for Eq 6.

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

Table 22. Approximate fuel heat content, V.

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

Example 13:

The 24'x36' building in Example 12 houses 200 pigs weighing 50 lb each. The building has a cold weather ventilating rate of 600 cfm. Find the heat loss through ventilating air at the outside design temperature. Find annual heating cost with LP gas at $0.70 per gallon and a 75% efficient heater. Find furnace size. Location is Grand Island, NE.

Solution:

Step 1:

Ventilation heat loss rate, VHL, Eq 1.

VHL = $1.1 \times cfm_c \times (t_i - t_o)$
= 1.1 Btu-min/hr-F-ft^3 × 600 cfm × (75 F-0 F) = 49,500 Btu/hr

Step 2:

Find the overall heat loss factor, HLF, using Eq 4. From Example 12, A/R = 201.45 Btu/hr-F.

HLF = $A/R + 1.1 \times cfm_c$
HLF = 201.45 Btu/hr-F + 1.1 Btu-min/hr-F-ft^3 × 600 cfm = 861.45 Btu/hr-F

Step 3:

Determine the total sensible heat loss (SHL) by animals. Find the sensible heat loss rate value from Table 20. Because 50 lb is close to 45 lb, use the per-lb value for 45 lb and multiply by 50 lb. However, you will need to interpolate for temperature. From Table 20, a 45 lb pig loses 3.6 Btu/hr/lb at 68 F and 2.5 Btu/hr/lb at 77 F. Interpolate to get the heat loss at 75 F.

3.6 Btu/hr-lb – [(75 – 68) F × (3.6 – 2.5) Btu/hr-lb ÷ (77 – 68)F] = 2.7 Btu/hr-lb

SHL = 2.7 Btu/hr-lb × 200 pigs × 50 lb/pig = 27,000 Btu/hr

Step 4:

Determine the balance point temperature, t_b, from Eq 5.

t_b = t_i – (SHL ÷ HLF)
t_b = 75 F – (27,000 Btu/hr ÷ 861.45 Btu/hr/F) = 43.7 F

When the building air temperature is above 43.7 F, the furnace will not be needed.

Step 5:

Calculate heating degree days correction factor, C_d, using Eq 6.

C_d = [A + B × (t_b – 32)]
C_d = -0.1428 + [0.0386/F × (43.7 – 32)F] = 0.309

Determine annual heating load, E, from Eq 7. From Fig 37, HDD is about 6,500 degree days/yr.

E = C_d × 24 × HLF × HDD
E = 0.309 × 24 hr/day × 861.45 Btu/hr-F × 6,500 F-day/yr
= 41,525,336 Btu/yr

Step 6:

Determine annual fuel cost, AFC, from Eq 8.
AFC = (FC × E) ÷ (EFF × V)
AFC = (0.7 $/gal × 41,525,336 Btu/yr) ÷ (0.75 × 93,000 Btu/gal)
= $417/yr

Determining Furnace Size

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

$$FS \quad (HLF \times \Delta T) - SHL \quad \textbf{Eq 9.}$$

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

In our example, assume t_o = -10 F, the design temperature for the furnace. Then Δt = 85 F and furnace size becomes:

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

10. GLOSSARY

ıg: A method of filtering air and ımidity and temperature. Usually ɜration equipment.

ır delivery rate usually expressed as nute (cfm).

ıemperature: Outside temperature losses from a building equal energy pplemental heat.

ırmal Unit. Quantity of heat energy 1 lb of water by 1 F.

ation: Insulation made from organic paper. Often used as loose-fill.

ımperature scale with the freezing t zero and the boiling point at 100.

on for cubic feet per minute, unit for ıw, e.g. through ducts, tubes, fans.

Process by which a change of phase apor to a liquid. Examples include nulating on building surfaces in ıting dehumidifier, and moisture on ater in summer.

Thermal conductance is a measure of ity to conduct heat energy. Units are Conductance is the inverse of resis- reviated C.

ıat transfer: Process by which heat om one location to another in a body ıture gradient in the body. The ener- s from the high-temperature region ɜrature region. Two bodies in contact ct heat. Examples include the hot ted pan, metal heated by welding.

at transfer: Process by which heat ·om a body to a fluid by passing the ły. The fluid may or may not be forced ıg in forced or natural convection. le cooling a hot object by blowing air ır over it, cooling an animal by blow-

ıthod: Procedure for estimating ener- on a difference between the daily ɜ air temperature and the balance ıre.

ıration: Ratio of the weight of water ıturated weight of water vapor per ṛ at the same temperature and pres- ısed interchangeably with relative

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

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

Dry-bulb temperature: Temperature of air or a body measured with a conventional thermometer.

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

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

Energy: Capacity for doing work.

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

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

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

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

Fan: Mechanical device to move air—usually electric.

Heat: Form of energy. Heat energy can be transferred from a body of higher temperature to one of lower temperature. Heat energy cannot be seen or measured, but the effects of heat gain or loss can be observed (i.e. evaporation, condensation, temperature rise or decline.)

Heat transfer: Process of heat energy transport. (See Conductive, Convective, Radiant, Evaporative heat transfer, and Condensation).

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

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

Inlet: Structural opening through which ventilation air enters.

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

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

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

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

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

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

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

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

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

Polyurethane: Plastic foam insulation. R-value is 6 (ft^2-hr-F)/Btu per inch of thickness (aged).

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

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

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

R-value: Resistance value of an insulation material to heat flow. The higher the R-value the larger the resistance to heat flow through the material. R-values are additive. Units are (hr-ft^2-F)/Btu.

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

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

Specific volume: Space occupied by a given mass of a gas or gas mixture. In ventilation, units are expressed as ft^3/lb dry air.

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

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

Temperature: Temperature is a measure of warmth or coldness of an object or substance with reference to some standard value.

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

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

Vapor pressure: Pressure exerted by a gas in a given space. It is a function of the amount of gas present and its temperature. In ventilation, water vapor pressure is the pressure exerted by the water vapor in a given space of air and water vapor. Units are expressed as inches of mercury.

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

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

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

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

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

Wet-bulb temperature: Temperature measured by a thermometer whose bulb is covered by a wet wick and exposed to an air stream with a velocity of 1,000 ft/min. The wet-bulb temperature is a function of the rate of water evaporation from the wet wick and its resultant cooling which depends on the water vapor content in the air.

11. SELECTED REFERENCES

ailable from the Extension Agricul-
ɜny of the institutions listed on the in-
r from Midwest Plan Service.

Iousing and Equipment Handbook.

ıusing and Equipment Handbook.

Iousing and Equipment Handbook.

Iousing and Equipment Handbook.

Housing and Equipment Handbook.

ock Waste Facilities Handbook.

Livestock Housing Handbook.

Buildings Wiring Handbook.

MWPS-32 *Mechanical Ventilating Systems for Livestock Housing*

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

Available from other sources:

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

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

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

12. INDEX

Air
Blending 13
Circulation 24
Preheating rooms 12
Reusing exhaust 13
Air conditioning systems 27
Air requirements 2
Dust 14
Gases and odors 2
Lethal situation 2
Quality 2
Quantity 4
Airflow pattern 14
Appendix 39
Calculating heat loss 40
Heat and moisture production 39
Applications and examples 32
Beef 32
Dairy 32
Design example 33
Milking center 32
Milking parlor 32
Milk room 33
Other areas 33
Horses 35
Poultry 36
Rabbits 37
Sheep 37
Swine 38
Veal calves 34

Balance
Heat 4
Moisture 4

Central heating system 32
Forced air 33
Hot water 33
Condensation 14
Controls 15
Cooling 24
Evaporative 26
Design 27
Equipment 26
Maintenance 27
Principles 26
Ventilation 24
Water 25
Drip cooling of swine 25
Sprinkler 25
Zone 27

Fan
Circulating 24
Location 24
Paddle 25
Fuel heat content 42

Glossary 44

Heat
Compressor 32
Electric heating cable 9
Electrical plastic heat pads 10
Floor 7
Hot water floor 9
Sand for heat storage 10
Solar 15
Heat exchanger 13
Air-to-air 13
Counterflow 14
Crossflow 14
Earth tube 17
Benefits 17
Design procedure 19
Installation 23
Layouts 18
Principles 17
System design 19
Efficiency 13
Integrating into ventilating systems 14
Heaters 7
Air make-up 12
Radiant 7
Supplemental 7, 36, 38
Unit space 11
Heating 6
Heating degree days 30
Hovers 7

Insulation 29
Birds and rodents 31
Fire resistance 31
Moisture problems 30

Selected references 46

Tempering 12

Ventilation
Duct size 22
Rates 5