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Design of Ventilation Systems for Poultry and Livestock Shelters



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Design of Ventilation Systems for Poultry and Livestock Shelters

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1 Purpose and cope

1.1 This information is provided for the convenience of agricultural engineers and other professional persons serving the agricultural industry. It includes basic information and technical data, supported by research, for use in designing and/or evaluating ventilation systems for livestock or poultry shelters. Much of the information presented in Section 3 General Design Information will apply to the design of ventilation systems for any structure housing livestock or poultry.

1.2 In addition to the design and configuration of equipment, hazard control and accident prevention are dependent upon the awareness, concern, and prudence of personnel involved in the operation, transport, maintenance, and storage of equipment or in the use and maintenance of facilities.

2 Definition

2.1 Ventilation as used herein is defined as a system of air exchange which accomplishes one or more of the following:

2.1.1 Provides a desired amount of fresh air, without drafts, to all parts of the shelter. A draft is an air speed in excess of 0.15–0.3 m/s (29.5–59 ft/min) in cool weather (speed depends on animal size). In summer these limits may be exceeded except for small animals. High air speeds, besides causing wind chill, may also create excessive dust levels.

2.1.2 Maintains temperatures in the shelter within desired limits.

2.1.3 Maintains relative humidity in the shelter within desired limits for the animal species (see Section 4 Ventilation for Dairy Cows and Calves, Section 5 Ventilation for Beef Cattle, Section 6 Ventilation for Swine, Section 7 Ventilation for Broiler Chickens and Young Turkeys, Section 8 Ventilation for Laying Hens, through Section 9 Effect of Environment on Sheep for relative humidity requirements by species) unless ammonia levels are beyond desired limits for operating personnel.

2.1.4 Maintain ammonia levels in the shelter at less than 25 mg/m³ for operating personnel. This limit was set by the American Conference of Government Industrial Hygienists for personnel working no more than four intervals of 15 min each per day in the shelter. The 8 h threshold limit is 18 mg/m³.

3 General design information

3.1 Weather data

3.1.1 Design temperature. The outdoor design temperature should be selected for the particular area where the animal shelter will be located. The cold weather temperature is normally used for determining heat loss from a building, insulation requirements, minimum continuous air exchange rate and supplemental heating requirements. The summer design temperature is used to determine the maximum required ventilation capacity.

3.1.2 Cold weather conditions. Cold outdoor air contains relatively small amounts of moisture. As the cold ventilating air enters the building and warms up, it has the capacity to absorb relatively large quantities of vaporized moisture from within the building. Outside design temperature suitable for calculating winter minimum air exchange rates and heat loss through the building components are shown in Fig. 1. Tabular data on outside winter design temperatures can be found in several books and periodicals. Most are derived from the American Society of Heating, Refrigerating and Air-Conditioning Engineers Handbook of Fundamentals or other ASHRAE publications. The 97.5% values are recommended for animal shelter use.

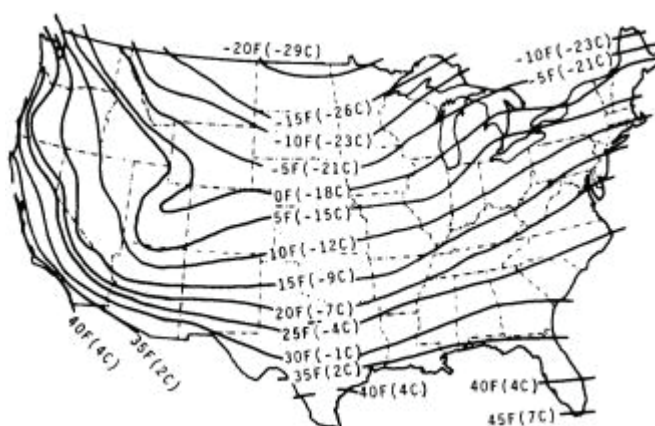


Figure 1 – Winter (Dec.-Feb.) temperature that is exceeded more than 97.5% of the time

3.1.3 Hot weather conditions. In buildings which depend upon mechanical ventilation during hot weather, air exchange must be sufficient to keep the inside temperature only slightly warmer than the outside temperature. Summer design temperatures suitable for calculating maximum air exchange rates are shown in Fig. 2. The design maximum ventilation capacity can be computed using equation 3.3.1.-6 and an assumed temperature difference of 1-2°C (2-4°F) or equation 3.3.1-4, whichever gives the greater exchange rate.

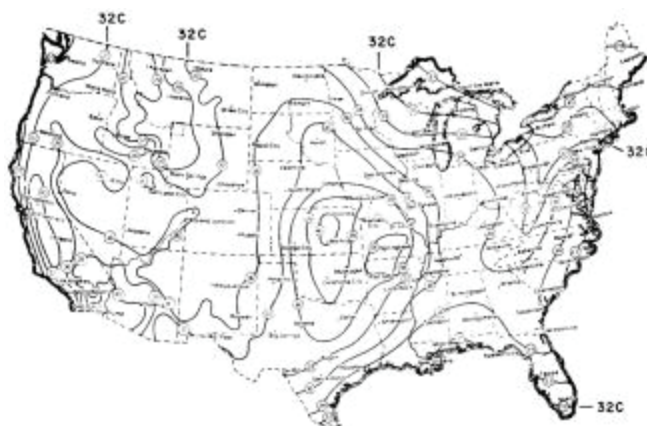


Figure 2 – Summer dry-bulb temperature data. The dry-bulb temperatures shown will be exceeded not more than 5% of the 12 h during the middle of the day in June to September inclusive (Ausburger, et al.).

3.2 Building requirements

3.2.1 Heat transmission through building materials. The rate of heat transmission through building materials depends upon the characteristics of the material. A comprehensive list of heat transmission coefficients of building materials is given in the ASHRAE Handbook of Fundamentals.

3.2.2 Need for vapor barriers. Animal shelters of the totally enclosed and ventilated type may be subjected to high moisture conditions. For example, a shelter with inside air temperature of 10°C (50°F) and relative humidity of 75% and with outside air temperature of -12°C (10°F) and relative humidity of 85% will be subjected to a winter vapor pressure difference of approximately 0.746 kPa (3 in. H₂O). A vapor pressure difference of this magnitude forces water vapor out through the components of the enclosure. Water vapor transfer is not a problem so long as the saturated vapor pressure gradient within the enclosure components remains above the actual vapor pressure gradient. Condensation will occur at or near the point in the building component where these gradients intersect. The condensate may migrate to other parts of the enclosure due to gravitational force or capillary attraction. Condensed water vapor promotes decomposition of building components and reduces the insulating capacity of many insulations. This situation increases structural heat loss which in turn hinders moisture control by ventilation. To keep insulation dry and free from condensed vapor, a vapor barrier should be applied on or near the side of the insulation with the highest vapor pressure, which is usually the warm side. A vapor barrier is a material with a high resistance to water vapor flow. Vapor barriers should be as continuous as possible. Thus, joints and holes in the vapor barrier should be minimized.

3.3 Ventilation requirements

3.3.1 Livestock and poultry produce best when their environment is within an optimum zone. The housing and environmental control system should be arranged to achieve these conditions. Design of the environmental control begins with analysis of the heat flows in the building using equation 3.3.1-1.

$$Q_S + Q_E + Q_{supp} = Q_M + Q_B + Q_V + Q_{stored} \quad (3.3.1-1)$$

where

Q_S = sensible heat loss rate from animals, J/s

Q_E = heat production rate by equipment, i.e., motors, lights, etc., J/s

Q_{supp} = supplemental heat production rate, J/s

Q_M = heat required to evaporate moisture, J/s

Q_B = rate of heat loss by conduction through walls, floor and ceiling, J/s

Q_V = rate of sensible heat exchanged in ventilation air, J/s

Q_{stored} = rate heat is stored or released by building material, especially by concrete floors, J/s
(This term is zero in steady state analysis.)

When a building is ventilated, heat is added or removed. This heat flow rate can be expressed as:

$$Q_V = Mc_p \Delta T \quad (3.3.1-2)$$

where

M = mass flow rate, kg/s

c_p = specific heat of air, 1005 J/kg·K (approx)

ΔT = temperature difference between the inside and outside, K

Fans are rated by volumetric flow rate, and equation 3.3.1-2 is based on mass flow rate. Ventilation rate should be obtained by multiplying the mass flow rate by the specific volume obtained from a psychrometric chart with conditions chosen to represent those on the intake side of the fan.

Each animal produces heat and moisture. Tables 1 and 2 show the production of these constituents for beef cattle, dairy cattle, swine, sheep and poultry. Moisture in the form of latent heat (vapor) and liquid in the waste is produced. Moisture in the liquid form must be vaporized for removal by ventilation, and the heat required for this process is given by:

$$Q_M = mN h_{fg} \quad (3.3.1-3)$$

where

m = rate of moisture production in ventilated space, kg/s·animal

N = number of animals

h_{fg} = latent heat of water vaporization, J/kg

The mass flow rate of dry air required to remove moisture is found using

$$M = \frac{mN}{W_i - W_o} \quad (3.3.1-4)$$

where

M = ventilation rate, kg/s

W_i = humidity ratio of inside air, kg water vapor/kg dry air

W_o = humidity ratio of outside air, kg water vapor/kg dry air

The rate of sensible heat produced by the animals, Q_s , is found using data in Tables 1 and 2. Multiply the sensible heat loss rate per animal unit by the number of animal units. Electrically generated heat, Q_E , is generally small and can often be neglected. The rate of supplemental heating, Q_{supp} , is either known from the capacity rating of any heaters within the airspace, or it is the unknown to be solved for in equation 3.3.1-1 (when the ventilation rate is known).

The rate heat that is conducted through the walls, floor and ceiling of a building can be calculated for steady state conditions using the following expression:

$$Q_B = UAT \quad (3.3.1-5)$$

where

U = overall heat transmission coefficient, J/(m²·k·s)

A = area of surface to which U and T apply, m²

T = temperature difference between inside and outside, K

Performing a heat balance of all sources and sinks of sensible and latent heat is a necessary first step in design of any environmental control system. The mass flow rate of dry air required to remove heat is found using:

$$M = \frac{Q_S + Q_E + Q_{supp} - Q_M - Q_B - Q_{stored}}{c_p T} \quad (3.3.1-6)$$

Table 1 – Moisture production (MP), sensible heat loss (SHL) and total heat loss (THL) of livestock based on calorimetric and housing systems studies

Livestock	Building Temperature °C	MP g H ₂ O/ kg·h	SHL W/kg	THL W/kg	Reference
Cattle					
Dairy cow					(Yeck and Stewart, 1959)
500 kg	-1	0.77	1.9	2.4	
500 kg	10	1.0	1.5	2.2	
500 kg	15	1.3	1.2	2.1	
500 kg	21	1.3	1.1	2.0	
500 kg	27	1.8	0.6	1.9	
Beef cattle					(Hellickson et al., 1974)
500 kg	4	2.5	1.5	2.8	
Calves					
Ayrshire male*					(Gonzalez-Jimenez and Blaxter, 1962)
39 kg (8 days)	3	0.7	2.5	2.9	
40 kg (14 days)	3	0.7	2.4	2.8	
45 kg (25 days)	3	0.7	2.6	3.0	
39 kg (8 days)	23	0.7	2.0	2.4	
40 kg (14 days)	23	0.7	1.9	2.3	
44 kg (24 days)	23	0.7	2.0	2.4	
British Friesian male*					(Holmes and Davey, 1976)
47 kg	20	-	-	2.3	
Jersey*					(Holmes and Davey, 1976)
28 kg	20	-	-	2.6	
British Friesian male*					(Webster and Gordon, 1977)
2 days to 8 wk	5	-	-	(7.9) [†]	
2 days to 8 wk	10	-	-	(7.3) [†]	
2 days to 8 wk	15	-	-	(7.3) [†]	
Cattle					
Hereford × Friesian male*					(Webster and Gordon, 1977)
2 days to 8 wk	5	-	-	(7.3) [†]	
2 days to 8 wk	10	-	-	(6.5) [†]	
2 days to 8 wk	15	-	-	(6.5) [†]	

Table 1 (continued) – Moisture production (MP), sensible heat loss (SHL) and total heat loss (THL) of livestock based on calorimetric and housing systems studies

Livestock	Building Temperature °C	MP g H ₂ O/ kg·h	SHL W/kg	THL W/kg	Reference
British Friesian male*					(Webster and Gordon, 1976)
90-180 kg	5	(2.2) [†]	(6.8) [‡]	(8.2) [‡]	
100 kg	5	0.75	2.1	2.6	
90-180 kg	10	(4.4) [†]	(6.3) [‡]	(9.3) [‡]	
100 kg	10	1.4	2.0	2.9	
90-180 kg	15	(6.2) [†]	(4.6) [‡]	(8.7) [‡]	
100 kg	15	2.0	1.4	2.8	
90-180 kg	20	(7.1) [†]	(4.4) [‡]	(9.1) [‡]	
100 kg	20	2.3	1.4	2.9	
Brown Swiss Holstein					(Yeck and Stewart, 1960)
16 wk	10	2.0	2.3	3.7	
32 wk	10	1.2	1.5	2.4	
48 wk	10	1.0	1.5	2.2	
16 wk	27	3.0	1.5	3.5	
32 wk	27	2.2	1.1	2.6	
48 wk	27	1.9	1.0	2.2	
Jersey					(Yeck and Stewart, 1960)
16 wk	10	2.4	2.5	4.1	
32 wk	10	1.5	1.8	2.8	
48 wk	10	1.3	1.6	2.5	
16 wk	27	3.8	1.4	3.9	
32 wk	27	2.5	1.0	2.7	
48 wk	27	2.3	0.8	2.3	
Shorthorn, Brahman					(Yeck and Stewart, 1959)
Santa Gertrudis					
25 wk	10	1.6	1.4	2.5	
40 wk	10	1.1	1.0	1.8	
55 wk	10	1.0	1.0	1.6	
25 wk	27	2.8	0.7	2.6	
40 wk	27	2.1	0.5	1.9	
55 wk	27	1.8	0.5	1.7	

Table 1 (continued) – Moisture production (MP), sensible heat loss (SHL) and total heat loss (THL) of livestock based on calorimetric and housing systems studies

Livestock	Building Temperature °C	MP g H ₂ O/ kg·h	SHL W/kg	THL W/kg	Reference
Swine					
Sow and litter (solid floor)					(Bond et al., 1959)
177 kg (0 wk)	16-27	1.8	1.3	2.6	
181 kg (2 wk)	16-27	2.4	1.7	3.3	
186 kg (4 wk)	16-27	2.6	1.7	3.5	
200 kg (6 wk)	16-27	2.7	1.7	3.5	
227 kg (8 wk)	16-27	2.6	2.1	3.9	
Nursery pigs*					(Ota et al., 1975)
4-6 kg	29	1.7	2.2	3.3	
6-11 kg	24	2.2	3.1	4.5	
11-17 kg	18	2.2	3.5	5.0	
4 kg	15	-	-	6.4	(Cairnie and Pullar, 1957)
(single)	20	-	-	5.2	
	25	-	-	4.5	
	30	-	-	4.0	
6-8 kg	15	-	-	6.0	(Cairnie and Pullar, 1957)
(single)	20	-	-	5.6	
	25	-	-	5.2	
	30	-	-	5.1	
10-12 kg	15	-	-	5.8	
(single)	20	-	-	5.6	
	25	-	-	5.6	
	30	-	-	5.6	
Growing-finishing pigs (solid floor)					(Bond et al., 1959)
20 kg	5	2.5	4.2	5.9	
	10	2.7	4.0	5.4	
	15	3.1	3.0	5.0	
	20	3.7	2.3	4.8	
	25	4.7	1.6	4.8	
	30	6.3	0.6	4.8	
40 kg	5	1.5	3.0	4.0	
	10	1.6	2.5	3.6	
	15	1.9	2.0	3.3	
	20	2.2	1.6	3.1	
	25	2.8	1.2	3.0	
	30	3.6	0.6	3.0	

Table 1 (continued) – Moisture production (MP), sensible heat loss (SHL) and total heat loss (THL) of livestock based on calorimetric and housing systems studies

Livestock	Building Temperature °C	MP g H ₂ O/ kg·h	SHL W/kg	THL W/kg	Reference
60 kg	5	1.2	2.5	3.3	
	10	1.3	2.0	2.9	
	15	1.4	1.7	2.6	
	20	1.7	1.3	2.4	
	25	2.0	1.0	2.3	
	30	2.7	0.5	2.3	
80 kg	5	1.1	2.2	2.9	
	10	1.1	1.8	2.5	
	15	1.2	1.5	2.3	
	20	1.4	1.2	2.1	
	25	1.7	0.85	2.0	
	30	2.2	0.49	1.9	
100 kg	5	0.94	2.0	2.6	
	10	1.0	1.6	2.3	
	15	1.1	1.3	2.0	
	20	1.2	1.1	1.9	
	25	1.4	0.80	1.8	
	30	1.8	0.49	1.7	
Gilts, sows, and boars (solid floor)					
140 kg	5	0.79	1.8	2.3	
	10	0.79	1.5	2.0	
	15	0.84	1.2	1.8	
	20	0.93	1.0	1.6	
	25	1.1	0.77	1.5	
	30	1.3	0.54	1.4	
180 kg	5	0.64	1.7	2.1	
	10	0.63	1.4	1.8	
	15	0.65	1.2	1.6	
	20	0.70	0.97	1.4	
	25	0.80	0.80	1.3	
	30	0.96	0.63	1.3	

Table 1 (continued) – Moisture production (MP), sensible heat loss (SHL) and total heat loss (THL) of livestock based on calorimetric and housing systems studies

Livestock	Building Temperature °C	MP g H ₂ O/ kg·h	SHL W/kg	THL W/kg	Reference
Sheep					
Mature* 60 kg (maintenance diet)					(Armstrong et al., 1960)
Fleece length					
Shorn	8	0.33	2.4	2.6	
	20	0.40	1.5	1.7	
	32	0.79	0.81	1.3	
3 cm	8	0.34	1.2	1.4	
	20	0.52	0.94	1.3	
	32	1.3	0.45	1.3	
6 cm	8	0.40	1.0	1.3	
	20	0.76	0.68	1.2	
	32	1.4	0.29	1.2	
(1.3 × maintenance diet)					(Alexander, 1974)
Fleece length 12 cm	13	1.0	0.85	1.5	
	23	1.5	0.54	1.5	
Lambs					
1-14 days	10	-	-	6.7	(Alexander, 1961)
(dry—no wind)	23-27	-	-	5.2	
* Figures are obtained from calorimetric studies. Therefore the moisture production in livestock housing systems will be increased with a corresponding decrease in sensible heat loss.					
† Figures in () are g H ₂ O/h·kg ^{0.75} .					
‡ Figures in () are W/kg ^{0.75} .					

3.3.1.1 Relative humidities. Moisture ventilation rates are proportional to the humidity ratio difference between the inside and outside air ($W_i - W_o$, equation 3.3.1-4). The magnitude of W_i depends both upon temperature and relative humidity. Design relative humidities for most confinement housing systems should be in the desired range for the animal species, but higher humidities can be allowed for short periods (6 to 12 h) when maintaining lower humidities would result in large supplemental heating requirements.

3.3.2 Types of ventilation systems. Ventilation occurs in a building because of a difference in static pressure between the inside and outside of the building. If the ventilation fan forces air into the building through the air inlets, the static pressure in the building is greater than outside and is commonly referred to as a positive pressure system. If the fan removes air from the structure, the static pressure in the building will be less than that outside, and air will flow in through the inlets. This system is referred to as a negative pressure system. Each system has characteristics that should be considered when deciding which system to use.

3.3.2.1 Positive pressure systems. The pressure in the building forces the humid air out through planned outlets, if any, and through leaks in the walls and ceiling. If the air is humid, moisture may condense within the walls and ceiling in winter. This may cause deterioration of building materials and reduce effectiveness of insulation. Since the air is forced from the building, the positive pressure system is well suited to applications where ventilation air must be filtered to prevent contaminants and pathogens from entering the building. The 20 to 30% of the energy used by fan motors that is rejected as heat is added to the building; an advantage in winter but a disadvantage in summer.

Table 2 – Moisture production (MP), sensible heat loss (SHL) and total heat loss (THL) of poultry based on calorimetric and housing systems studies

Poultry	Building Temperature °C	MP g H ₂ O/ kg·h	SHL W/kg	THL W/kg	Reference
Laying hen					
Leghorn*	8	2.1	4.5	5.8	(Ota and McNally, 1961)
	12	2.8	4.0	5.9	
	18	2.9	3.9	5.8	
	28	3.8	3.2	5.8	
Broilers*					
0.1 kg	29	4	12	14	(Longhouse, et al., 1968)
0.7 kg	25	3	7	9	
1.1 kg	19	2	7	9	
1.6 kg	19	2	6	7	
2.0 kg	19	1.5	5	6	
Broilers					
0.1 kg	29	22.0	4.5	19.5	(Reece and Lott, 1982)
0.4 kg	24	12.5	6.5	15.0	
0.7 kg	16	10.5	6.0	13.0	
	27	10.5	3.0	10.0	
1.0 kg	16	8.0	5.0	10.5	
	27	9.5	3.0	9.5	
1.5 kg	16	7.5	4.5	9.5	
	27	9.0	3.0	9.0	
2.0 kg	16	6.5	4.0	8.5	
Turkeys					
Large white* toms					
0.1 kg	35	15.6	6.1	16.8	(DeShazer et al., 1974)
0.2 kg	32	9.8	6.3	12.9	
0.4 kg	29	7.2	5.4	10.2	
0.6 kg	27	4.1	5.9	8.7	
1.0 kg	24	2.4	6.3	7.9	
15 kg	25	1.7	1.1	2.2	(Shanklin et al., 1977)
hens					
8.2 kg	25	1.4	1.4	2.4	(Shanklin et al., 1977)
Worstad white* toms					(Buffington et al., 1974)
2.2 kg	21 light	-	-	9.1	
	21 dark	-	-	6.6	
3.0 kg	21 light	-	-	8.1	
	21 dark	-	-	6.1	