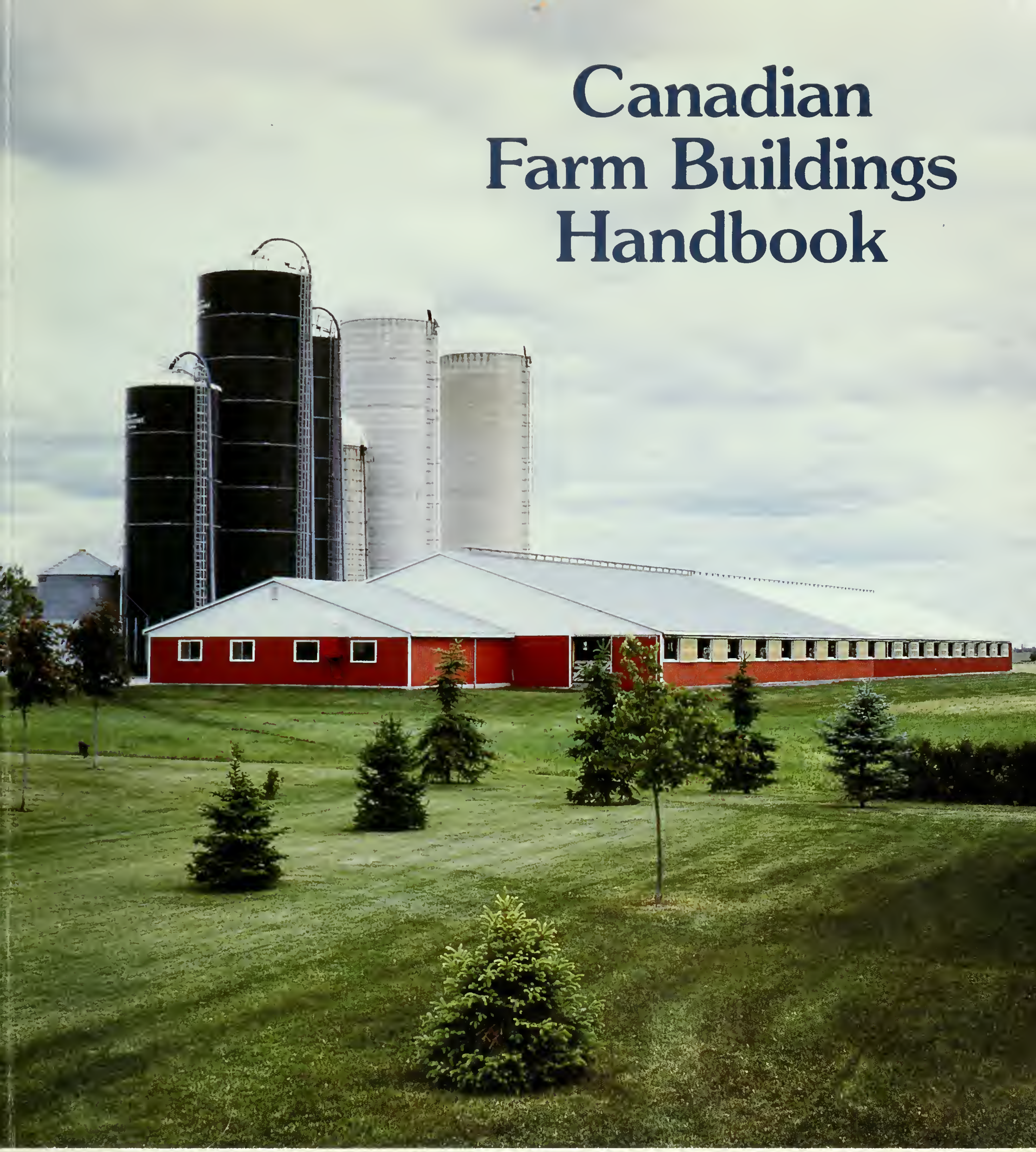
Canadian Farm Buildings Handbook



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Canadian Farm Buildings Handbook

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FOREWORD

This book sets out practical guidelines for the design and evaluation of a wide variety of farm buildings. Some of the material in this book was originally published in the *Canadian Farm Building Code.*

The book presents design data, engineering guidelines, and building management information that may be useful in planning the layout of farm buildings and services, service requirements, and design limitations. It is divided into six parts:

1 General principles
2 Enterprise planning
3 Facilities for the storage and processing of crops
4 Storage for supplies and equipment
5 Design, construction, and building materials
6 Building services.

The information is based on research world wide and on Canadian experience. The recommendations will help obtain the maximum productivity while providing suitable shelter for animals and products. The book also discusses the integration of material flows between buildings and work areas. The provisions discussed below are consistent with good practice, but they are not mandatory requirements, now or in the future.

This book is not a building code; you must still refer to the *National Building Code of Canada*, the *Canadian Farm Building Code*, and local or provincial authorities for regulations governing structural adequacy, human health, or fire safety. Nor does it deal with human living quarters, which are covered by national and provincial building codes. The standards set by the National Standards Council of Canada provide specific information on materials and building systems. A list of some of these standards is found at the end of this book. Address any comments or questions concerning this book to:

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PART 1
General principles

1.1 DEFINITION OF A FARM BUILDING

The *Canadian Farm Building Code* uses the following definition:

> *Farm building means a building which does not contain a residential occupancy and which is (a) associated with and located on land devoted to the practice of farming, and (b) used essentially for the housing of equipment or livestock, or the production, storage, or processing of agricultural and horticultural produce or feeds.*

Farm buildings include, but are not limited to, facilities for the storage and packing of produce, housing for livestock and poultry, milking centers, manure storage, grain bins, silos, feed-preparation centers, farm workshops, greenhouses, farm retail centers, and facilities for horse riding, exercise, and training.

Farm buildings may be classed on the basis of low or high human occupancy. Where so regulated, farmhouses or other structures with high human occupancy (for example, livestock sales arenas and public riding arenas) must conform to the applicable regulations of the *National Building Code of Canada*. Some relaxation of these rules is permitted for farm buildings with low human occupancy (not more than one person per 40 m^2 during normal use).

1.2 GOOD PRACTICE

Practices for the production of animals and plants change rapidly as new technology and management evolve, and so the structure and layout of farm buildings must also change. But certain basic animal and plant needs such as those for space, feed, water, and air remain relatively constant. This book should help in planning for these needs.

Good design ensures the physiological well-being of animals. Providing for their health and comfort helps to maintain – even to improve – productivity, and therefore the farm's economic viability. Distressed animals are not productive. To date, Agriculture Canada has published four codes of practice for animal care and handling (Agriculture Canada publications 1757, 1771, 1819, and 1821) and others are in preparation. In addition, good design must consider the health and safety of workers and the protection of the rural environment.

1.3 FARMSTEAD PLANNING

Before beginning any farm building project, consider the following.

1.4 ESTABLISHING USE ZONES

Dividing the farm into use zones allows you to plan for traffic patterns, fire separation, and the control of odor, dust, noise, and flies. It also permits you to consider the aesthetics of the whole farmstead. Zones should be large enough to permit later expansion without encroaching on other areas.

One method of zoning (described in *Farmstead Planning*) is to divide the farmstead into concentric rings (Fig. 1).

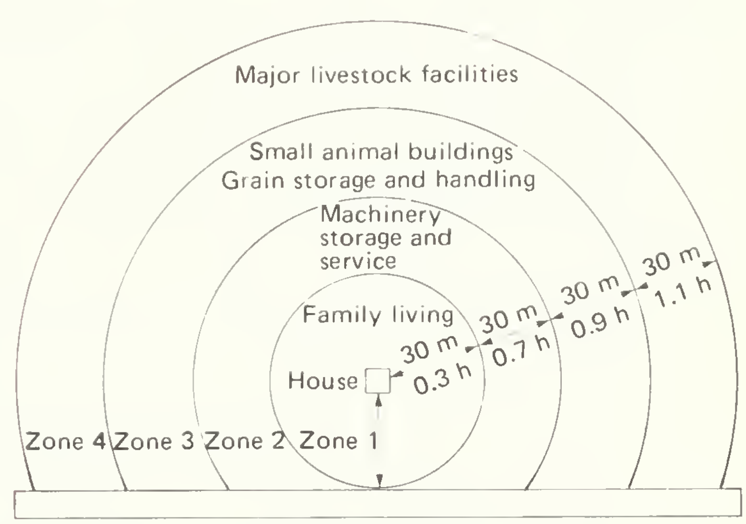


Fig. 1 Four planning zones
Source: Farmstead planning (Agriculture Canada, publication 1674)

Zone 1 is the inner circle, with a radius of 30 m and an area of 0.3 ha. It contains the farmhouse and farm office, and provides space for family living, driveways, and parking.

Zone 2 (30–60 m in radius) can include machinery storage and service areas.

Zone 3 (60–90 m in radius) holds small buildings for animals and facilities for storing, handling, and processing grain and crops.

Zone 4 (90–120 m in radius) has the major animal facilities. It is here that most ongoing nuisances are created and major expansion is most likely to occur.

The position of buildings in each zone depends on the location of public roadways, on the topography for site drainage, and on keeping nuisances away from the farmhouse.

1.5 LOCATING FARM BUILDINGS AND FEEDLOTS

Before deciding on the location of new housing for animals, check with appropriate authorities to determine local land-use planning regulations and any provincial requirements for keeping the facilities at a distance from neighboring properties. (See *Canada Animal Manure Management Guide*.)

Whenever possible, site any equipment or buildings that produce odors, noise, or dust downwind from the farm residence.

1.6 DRAINAGE

The shape of the land strongly influences drainage, access, and the view and often determines how farm buildings are designed and built.

Set buildings on high ground. Ditching and grading can correct some problems, but earthwork is expensive and should be kept to a minimum. Use existing slopes to direct surface runoff away from buildings and other parts of the farmstead. Animal operations in Zones 3 or 4 should drain away from the overall site, but not in such a way that the runoff contaminates nearby watercourses. Provincial or local authorities may have specific requirements for drainage.

Slopes of 2–6% for surface water and 4–8% for unpaved feedlots are enough to drain runoff without eroding most soils. To provide good drainage, operators normally have to do some grading and filling in preparing the site. Provide diversion channels for surface runoff and ensure that all floors are above grade.

Basements, elevator dump pits, well pits, and other below-grade structures should be provided with subsurface drainage including drains around the perimeter of the footings. If no subsurface drainage outlet is available, install a sump pump.

1.7 ACCESS

The farmstead should have one or more all-weather driveways at least 5 m wide with 2 m of additional clearance on each side. Drains can be set inside this 2-m clearance. A second driveway for trucks and machinery leading into Zones 2 to 4 helps to minimize dust, noise, and the risk of injury to children.

For security, plan to have a good view from the residence of all entrances to the farm.

1.8 SERVICES

Potable water is essential. Before you start developing a farmstead, make absolutely sure that an adequate supply is available. Water should also be available for firefighting; it can be surface water collected by a dam or in a pond.

The preferred sources of farmstead energy are electricity and natural gas, although bottled propane and fuel oil are common alternatives when natural gas is unavailable. Ensure that adequate supplies are available and plan early to prevent conflicts with building locations. Consider underground electrical lines to avoid accidents and possible injury when you move machinery or equipment around the farmstead. Farms need telephone service as well. Mark all underground lines and cables clearly and draw these on a farmstead map for future reference. For further details on services, see Part 6 of this book.

1.9 WASTE DISPOSAL

Dead animals and toilet waste must be disposed of in a way that meets both provincial and local health regulations. Milkroom wastes can be drained to sediment tanks or (preferably) collected in liquid manure tanks; the sewer pipe must have a gas trap.

Animal manure is a valuable resource, providing plant nutrients when properly handled, stored, and applied to the land. *Canada Animal Manure Management Guide* gives guidelines to follow to avoid pollution. For a detailed discussion, see Sections 2.99–2.104.

When designing waste disposal systems, check provincial and local codes for location, size, safety covers, and other details.

1.10 SEPARATION TO PREVENT THE SPREAD OF FIRE

Because many farm buildings and their contents are highly combustible, separate them whenever practical to minimize losses.

The risk is compounded by the fact that many farms are far from municipal fire stations and may lack an adequate water supply. All farm buildings and related structures such as fuel storage tanks should be designed or located to meet the requirements of Part 3, "Fire Safety," of the *Canadian Farm Building Code*.

Check with your fire insurance company and the local fire department for special requirements. Separating other buildings from high-risk structures may result in lower risk ratings and reduced insurance premiums.

Unless there are stricter regulations, use the following open-space separations as a guide to prevent the spread of fire by radiation. The distances given do not protect against wind-carried embers if nearby buildings have exposed wall or roof openings or low-sloped combustible roofs that can be ignited by prolonged contact with the embers.

For preventing the spread of fire by radiation, buildings are divided into three construction types.

- Type 1 construction has a fire-resistance rating of less than 30 min for either the walls or the ceiling and roof of the fire compartment.
- Type 2 has a fire-resistance rating of at least 30 min and has unprotected openings not exceeding 5% of the exposed compartment wall area *or* a fire-resistance rating of at least 45 min and unprotected openings not exceeding 12% of the exposed compartment wall area.
- Type 3 has a fire-resistance rating of at least 45 min and has unprotected openings not exceeding 5% of the exposed compartment wall area.

Tables 1–4 give suggested minimum separation distances for different sizes of fire compartments and exterior claddings. Consult the *Canadian Farm Building Code* and the *Supplement to the National Building Code of Canada* for fire resistance ratings for various constructions.

Table 1 Minimum space separation to prevent spread of fire by radiation to adjacent buildings having asphalt base siding or manufactured hardboard siding

Dimensions of fire compartment facing adjacent building (length × ridge height, m)	Construction type of burning building (space separation, m)		
	1	2	3
6 × 3.6	12	11	8
15 × 3.6	20	15	11
30 × 3.6	24	18	12
24 × 9.0	40	30	20

Table 2 Minimum space separation to prevent spread of fire by radiation to adjacent buildings having wood or plywood siding

Dimensions of fire compartment facing adjacent building (length × ridge height, m)	Construction type of burning building (space separation, m)		
	1	2	3
6 × 3.6	11	9	6
15 × 3.6	17	14	9
30 × 3.6	20	17	11
24 × 9.0	32	27	18

Table 3 Minimum space separation to prevent spread of fire by radiation to adjacent buildings having siding of noncombustible, nonreflective material,[1] and having no windows or other openings in the exposed sides

Dimensions of fire compartment facing adjacent building (length × ridge height, m)	Construction type of burning building (space separation, m)		
	1	2	3
6 × 3.6	9	9	6
15 × 3.6	15	12	8
30 × 3.6	17	14	9
24 × 9.0	26	21	15

[1] Materials such as asbestos-cement, painted metal, soiled metal, or stucco, which will absorb most of the radiation received.

Table 4 Minimum space separation to prevent spread of fire by radiation to adjacent buildings having siding of noncombustible, reflective material,[1] and having no windows or other openings in the exposed sides

Dimensions of fire compartment facing adjacent building (length × ridge height, m)	Construction type of burning building (space separation, m)		
	1	2	3
6 × 3.6	8	6	6
15 × 3.6	9	8	6
30 × 3.6	11	9	6
24 × 9.0	17	12	8

[1] Materials such as unpainted galvanized steel or aluminum, which will reflect most of the radiation received.

1.11 DESIGN AND CONSTRUCTION

Structural loads and design procedures for human safety are covered in Part 2 of the *Canadian Farm Building Code*.

Farm buildings are often exposed to harsh treatment from animals, manure, silage, water, cleansing, disinfectants, machinery, and stored products. Designers should be familiar with modern farming practices and be able to predict the effects these have on the strength and durability of building materials and components.

The following suggestions are based on research and field experience, and represent good practice. Good practice ensures sound, safe construction; structures should have reasonable lifespans that suit the intended use.

1.12 MATERIALS AND BUILDING COMPONENTS

The selection of materials and building components may be based on tests that simulate the expected conditions, or on other recognized engineering principles. The sturdiness and availability of materials will influence your choice, as may your experience of local contractors.

The component's function (to withstand structural loading, stop the flow of heat or water vapor, protect other components from mechanical damage, or provide for easy sanitizing) should be the primary criterion. Also consider your experience with the material and its relative cost.

1.13 DESIGN CONSIDERATIONS

Many farm buildings are long clear-span structures that must withstand high wind loads, pressures from stored material, or both. Others cover little ground area (silos, for example) but require special footings to carry high vertical and overturning loads.

1.14 Wall construction

Walls not only carry stationary and moving loads but must also transfer uplift, overturning, and lateral (sideways) loads to the foundation. In addition, they provide weather protection and may have to reduce the transmission of heat or water vapor.

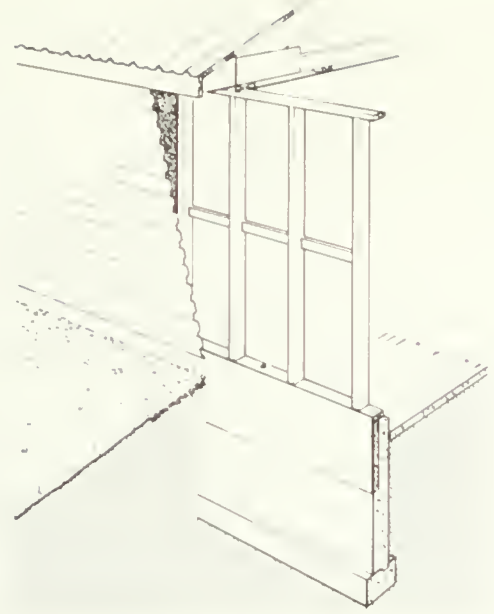
The choice of wall, and hence of the overall building shape, usually depends on the building's intended use. The most common wall types are stud frame and pole frame (Fig. 2). Masonry, including concrete blocks and cast-in-place (CIP) concrete, is fairly common, and metal, wooden-arch, or rigid-frame buildings are also used.

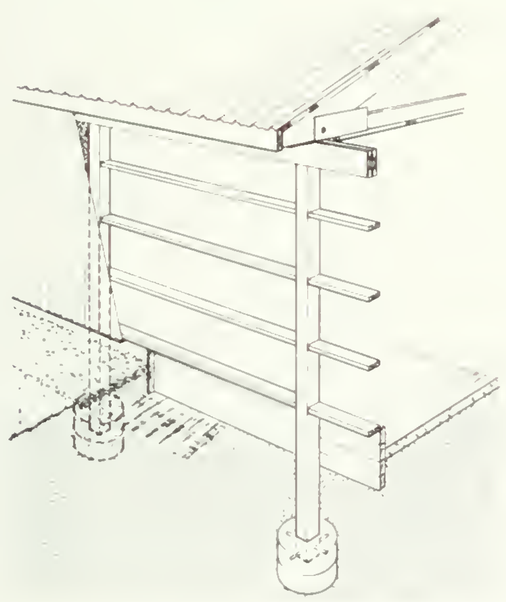
1.15 Building width and truss spacing

Many farm buildings need clear-span construction for an undivided interior. This allows flexibility in locating partitions and equipment and permits equipment to move freely inside the building. More importantly, clear-span construction also makes future renovations easier.

Buildings can be designed for a minimum perimeter; this lowers the cost per unit of floor area, but often seriously restricts the use of the building. In practice, the width is often limited by the truss design, the location of interior posts, pen layout, and ventilation systems. Conventional wood trusses limit clear-span widths to about 18 m, while pen layout and ventilation system requirements tend to keep many buildings in the 12-m range.

Some specialized housing units (such as those containing laying cages) tend to be about 12 m wide but very long. This stems from the high cost of the drive units for materials-handling equipment such as feeders and egg conveyors. Adding to the length decreases the cost per unit of floor areas for such systems.


A. STUD FRAME


B. POLE FRAME

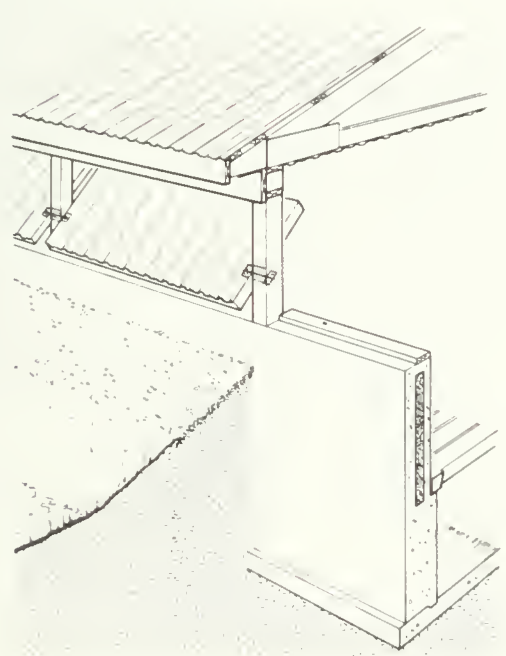

C. CAST–IN–PLACE CONCRETE

Fig. 2 Common wall constructions

Typical truss spacings are 0.6, 0.8, 1.2, and 2.4 m; of these 1.2 m is the most common in Canada. Increasing the spacing reduces the number of trusses but the purlins must be stronger, set closer together, or placed on edge. The spacing of trusses may also affect the size of the plate beams supporting the roof.

For buildings that need an insulated ceiling, using trusses spaced not more than 1.2 m apart makes it easier to insulate and sheath the ceiling.

The truss spacing should follow standard framing and sheathing dimensions to eliminate the need to cut and waste purlins, strapping (if used), and ceiling sheathing.

1.16 Snow loads

Estimate the probable snow load from local ground snow records. The load also depends on building orientation, nearby buildings, and natural or manmade windbreaks. Adjoining or nearby structures, particularly if these are higher, create special design problems due to sliding and drifting snow.

Designs for snow loads must satisfy the *National Building Code of Canada*, but the *Canadian Farm Building Code* allows some specific adjustments. Design ground snow loads for many cities and towns are listed in the *Supplement to the National Building Code of Canada*.

1.17 Wind loads

Most farm buildings are long; some are also quite high. Few have many cross walls or partitions. The structure must transfer the wind forces exerted on large wall and roof areas down to the side sills or end walls. This prevents the building from buckling or overturning or both. Remember that wind will push on the windward side of an enclosed structure and pull on the leeward side. These two overturning forces are additive. The typical wind forces on a roof are uplift.

A common method to resist side-sway is to use a wide panel-clad ceiling or roof to transfer the forces to the end walls. For this method to be effective, each panel must be connected on all four edges to adjacent framing or cladding, and the end walls must be rigid enough or braced to take the force. Diagonal bracing between end trusses and adjacent to corner studs helps to keep the building's corners plumb and the trusses from buckling. Well-fastened sheathing prevents side-sway more effectively than diagonal bracing.

Large roller doors should be securely fastened when closed and should have post or roller stops to control the movement caused by wind when they are open. Otherwise they can be torn free or blown up onto the roof. Doors opening inward and sliding doors hung inside the walls are particularly vulnerable to being blown in, exposing the inside of the whole building to wind pressures.

1.18 Internal lateral loads

All bulk materials or liquids that are stored against walls exert horizontal and often vertical loads. Design the walls, footings, connections, and tie rods (if required) of storage structures to take the resulting lateral pressure.

Some materials commonly stored in bulk are grains, silage, ground feeds, potatoes and other vegetable crops, and fertilizers. The most common stored liquid is manure.

Liquids and wet materials such as silage are commonly stored in circular structures. Their high lateral pressure can be resisted by sheet steel or concrete reinforced in hoops. Cylindrical tower silos, horizontal silos, and manure storage tanks should be designed in accordance with the *Canadian Farm Building Code*. (See Part 3 for specific information on silos.)

Stores for dry grains, ground feeds, fruits, and vegetables must also be designed to take the horizontal and vertical loads imposed on them. Again, see the *Canadian Farm Building Code*. Dry grains and ground feeds are commonly stored in circular storages but may also be put into square or rectangular storages. Fertilizers can be held in temporary circular plywood structures. See Parts 3 and 4 for more information.

Stacked pallet boxes are used to hold some products, primarily fruits and vegetables. Their lateral load on the storage structure is negligible.

Any moisture absorbed by grain during storage causes swelling and can increase the grain's lateral pressure by three or four times. (See the *Canadian Farm Building Code*.) The lateral pressure of grain on the storage bin also increases during emptying and when the building vibrates – if, for example, it is near a railway track.

1.19 PLANS AND SPECIFICATIONS

A plan for a building or system shows the horizontal layout; sections and elevations (side views) give the vertical dimensions. Specifications, on the other hand, provide written directions for materials, components, and techniques; these are not included in the plan, but are considered part of the building contract.

Preliminary floor plans must be revised to meet production requirements, the personal wishes of the owner, and site limitations. Final plans, including elevation drawings and specifications, are the basis for cost estimates from building contractors and subcontractors. These plans may also be required for building permits or loans.

In the case of a large building project using a general contractor for turnkey construction, plans and specifications protect the owner both when the contracts are signed and later, if deficiencies, extras, or completion dates are at issue.

1.20 Required content

Plans should include:

- the dimensions, location, and size of all structural members and connections in enough detail to enable the design to be checked structurally
- enough detail to enable all loads to be determined, including those due to materials, and to show ventilation and other materials-handling and service systems
- a complete site plan, showing positions and elevations of existing and proposed buildings, drainage, and services

Specifications should include:

- the grade or quality of materials expected
- the function and required performance of systems such as ventilation and materials handling, and any other services
- preparatory work planned by owner before construction
- condition of site during and after construction
- any additional site requirements (e.g. grading or supplying and compacting fill) which are not shown on plans
- lists of materials, labor, equipment, services, or subtrades to be supplied by owner
- completion date and penalties, if any, for failure to comply
- provision for payment for additional work
- method and timing of payment(s)
- warranties for equipment and structure
- details of any applicable construction insurance

- remedies for unforeseen problems, e.g. poor footing conditions, liability for structural failure or injury during construction
- correction of deficiencies to satisfy regulatory authorities.

1.21 **Available plans**

The Canada Plan Service (CPS) makes available a wide range of farm building plans through provincial extension agricultural engineers. These plans can often be altered to fit specific sites or permit attachment of new structures to existing buildings. An agricultural engineer or other professional engineer should confirm that the plan suits local conditions.

If you need plans for a new or renovated building system, speak to your provincial engineer or a private consultant; he or she might be able to advise you.

1.22 CONSTRUCTION SAFETY

Safety should be of utmost concern to designers, owners, and contractors. The site supervisor must ensure that all safety measures of the *Canadian Construction Safety Code*, as well as provincial or local safety requirements, are met during construction.

1.23 PLANNING BUILDING SYSTEMS

Planning must often go beyond the traditional one-building unit. The system must consider the storage of feed and manure, for example, and the siting of structures with related or interdependent functions. Before you start building a single unit, prepare a composite site plan of the total building layout. Keep your day-to-day operations in mind. Moving components on paper is faster and cheaper than moving buildings later.

In some instances, the production system might be built in phases; even so, you should have at least a tentative plan to prevent later conflicts. Some components, such as those used for feed processing or manure storage, may be oversized at first in order to reduce the expense and inconvenience of later expansion.

1.24 SPACE AND THE FLOW OF WORK, MATERIALS, AND ANIMALS

Production goals will determine the overall building size, but the layout can vary a good deal. Plan for good flow patterns while allowing for orderly expansion — usually at one or both ends of the building.

Will the building have free stalls or tie stalls? Will cows face in or out? Will animals be fed mechanically or manually from a feed cart? Will the old barn be tied into the new system? How will you handle manure?

The designer should be able to provide alternatives but should respect the wishes of the owner. After all, the owner will have to provide the investment, management, and in many cases much of the labor.

1.25 FEED

How you provide feed will affect a number of decisions. Purchased feed will probably come processed; this reduces storage and processing and eliminates the need for space and equipment for processing. If the feed is grown on the farm, your decisions will depend on past experience, personal preferences, available labor, and custom services. Either way, the provision of feed will affect your plans and costs.

1.26 MANURE STORAGE AND HANDLING

Manure may be solid, semisolid, or liquid, or a combination of these in the case of solids separation. Handling systems depend on personal preference, regulations, and the proximity of manure stores to water supplies and neighboring properties.

Liquid manure is the easiest to handle, but it also produces the most odor and gas. The principal manure gases range from irritants through asphyxiants to poisons (see Section 2.103). Decisions on the location and design of systems to store and handle manure are important for all operations involving large numbers of confined animals.

1.27 DISPOSAL OF DEAD ANIMALS

Any livestock operation must allow for the disposal of dead animals at the normal mortality rate, both to control disease and to meet local and provincial health requirements. Before making any final decision on disposal, check with local authorities to make certain the proposed method satisfies all regulations.

Large animals can either be buried with lime or picked up at the farm by rendering services. Smaller animals present greater problems. Swine may be picked up or delivered to a rendering plant if the volume is high enough or the plant is nearby. In many cases, burial or incineration may be the best alternatives.

If you plan on incineration, consult local authorities to ensure that the proposed equipment and installation meet all legal requirements.

In Canada, large poultry operations should have the facilities to handle dead birds at normal rates (about 1% per month). A number of methods may be used: refrigerated storage and periodic delivery to a rendering plant, incineration, storage in long-term holding tanks for future land disposal, and burial pits. To decide among these methods, you must consider a number of factors.

1.28 Burial and disposal pits

These must not pollute water supplies or be a hazard to people in the area; for this reason burial pits are less desirable for continual use than watertight disposal tanks. Although local water tables and soil conditions must be considered, tanks should generally be at least 45 m from any well or spring used as a water supply. Disposal tanks can be made of metal, concrete, or other approved waterproof material and should exclude insects, birds, and rodents. The addition of lime helps control odors. For safety, cover tanks with tight-fitting lids secured with a lock.

1.29 Refrigerated storage

Some poultry operators temporarily store dead birds in a refrigerator or domestic freezer. These are large enough for flocks up to 10 000 birds, assuming 1% death loss per month.

1.30 Incineration

Incinerators should be designed for complete combustion and should meet National Fire Protection Association standards for Type-4 wastes. In addition, they must meet local requirements. Some provinces require licensing; in these cases, the incinerator must be of an approved design, and each installation must be approved individually. Incinerators must be operated and maintained correctly. They should be fire-safe and located so that prevailing winds carry exhaust fumes away from neighbors.

1.31 Long-term storage and land disposal

This method uses two precast concrete cisterns, each large enough to handle dead birds for a period of 3–5 years. When one tank is full, the birds are put into the second tank, allowing an additional 3–5 years before the first tank is pumped out. Water is added to aid decomposition. A good lid, tight-fitting and childproof, can be made by cementing a milk can (with the bottom removed) into the top of the cistern.

For a 5-year filling time, a holding tank should provide 550 L of tank capacity per 1000 broilers or 2850 L per 1000 layers (the same size as disposal tanks). Add water equal to one-half of the tank capacity.

PART 2
Enterprise planning

2.1 DAIRY CATTLE

Dairy cattle (mostly Holsteins) provide fluid milk and milk for processing. While milk is their primary source of income, many producers raise heifers as a secondary enterprise. This is often reflected in the choice and design of housing facilities.

2.2 PRODUCTION CYCLES AND HERD MAKEUP

Cows are usually bred to calve at 12-month intervals, after a 283-day gestation period. Each cow is milked for 305–325 days, and is then allowed a dry period of 40–60 days before calving. The estrus (heat) cycle is 21 days. Heifers are normally bred to calve at about 24 months of age. Few producers maintain a bull, as most dairy cattle are bred by artificial insemination (AI).

With the exception of breeding stock replacement, bull calves are sold or raised for veal production as a secondary enterprise. They represent 50% of the annual calf crop. Producers normally raise heifer calves as herd replacements or for sale, or calves may be raised by others specializing in heifer production.

When the milk producer raises replacement heifers, the total number of animals to be housed will be about twice the number of mature cows. A typical herd of 100 mature cows would be made up as follows:

Mature cows	
Milking cows	85
Dry cows	15
Total	100
Replacements	
Heifers (0–3 months)	10
Heifers (3–10 months)	30
Heifers (10–15 months)	20
Heifers (15–24 months)	40
Total replacements	100

This assumes uniform calving throughout the year, 12-month calving intervals, no death losses or culling, 50% male and 50% female calves, and all males sold at birth.

The herd will need: housing for calves, heifers, and dry and milking cows; maternity and cow treatment areas; and milking facilities. In addition, it will require complete feed and manure handling systems for all the animals.

2.3 HOUSING SYSTEMS

Cows should be protected from wind, moisture, and extreme temperature fluctuations. The type of housing selected – warm, cold, tie-stall, free-stall, or loose-housing – depends on factors such as the size of the operation, availability of bedding, climate, existing facilities, degree of mechanization desired, and personal preferences.

"Warm housing" refers to barns kept warm enough to be comfortable for the operator in winter. The barns are designed so that the inside environment can be kept within the optimal range for milk production; they must therefore be well-insulated. Usually, fans remove the excess moisture in the winter and heat in the summer, although warm, naturally ventilated barns are now regaining some popularity.

In cold-housing facilities, natural air movement removes moisture and keeps the inside temperature only 5–10°C above outside temperatures in winter. These barns should have some insulation under the roof to reduce winter condensation and summer heat buildup. Cold barns are somewhat less expensive to construct than warm barns. Watering systems in cold barns must be protected against freezing.

The three basic housing systems are tie stall, free-stall loose housing, and open-pen loose housing. The tie-stall system is the most common in Canada and consists of a separate stall and tether for each cow. This allows individual feeding, grooming, and milking. Additional pens are designed to accommodate calves, young stock, and freshening cows. Tie-stall barns with two rows of stalls are generally 9.6–11.4 m wide. The minimum recommended ceiling height is 2.4 m, but a height of 2.7–3.0 m is preferable. The barn width can be reduced when mechanical conveyor feeding systems are used.

Open-pen loose housing systems use a deep-bedded resting area plus separate areas for feeding, holding, and milking. This system requires a great deal of bedding and is therefore seldom used now except where bedding is cheap and abundant. Loose-housing barns should provide 6 m^2 per head for milking cows and 4 m^2 per head for dry cows and heifers. The minimum ceiling height should be 3 m to allow for manure pack buildup and cleaning. Hard-surfaced exercise yards should provide a minimum of 6 m^2 per head for milking cows, dry cows, and heifers. If the yard is unpaved, provide 30 m^2 per head for milking cows and 20 m^2 per head for dry cows and heifers. Unpaved yards are unsuitable for heavy traffic or where annual precipitation exceeds 500 mm.

Free stalls are more popular for dairy herds, particularly in new facilities for 50 head or more. The system differs from open-pen loose housing in that the bedded area is divided into individual stalls but the cows are not tied. The alleyways between stalls are paved or slotted over a manure trench. Free stalls greatly reduce the need for bedding. Free-stall barns are frequently built with a feeder down the center and a row of stalls along each side; such barns should be 12–13.2 m wide. Wider barns with four rows of free stalls can be used for larger herds. The ceiling should be at least 2.7 m high, preferably more.

2.4 SPACE REQUIREMENTS

2.5 Tie-stall barns

The floor-to-ceiling clearance should be a minimum of 2.4 m with overhead services such as water, milk, and vacuum lines at least 2 m from the floor.

Litter alleys should be at least 2.1 m wide between gutters for face-out stalls, and 1.8 m wide between gutter and wall for face-in stalls, with open gutters at least 400 mm wide × 150 mm deep. If the gutters are covered by grates, the combined litter alley and grate width should be at least 2.7 m for face-out and 2.1 m for face-in stalls.

In face-in layouts, feed alleys for cart feeding should be at least 1.2 m wide for sweep-in mangers or 1.5 m for high-front mangers; for floor feeding provide a total width (stall front to stall front) of 2.1 m. These dimensions are also suitable for face-out arrangements, except that for floor feeding, the combined width of the alley from stall front to wall can be reduced to 1.8 m.

Sweep-in mangers for milk cows should be 500–600 mm wide, whereas high-front mangers should be 700 mm wide.

If you use mechanical conveyor feeding without a feed alley, you can reduce the combined feeding space to 1.5 m (stall front to stall front) for face-in stalls or 1 m (stall front to wall) for face-out installations.

All cross alleys through or at the end of tie-stall rows should be at least 1.2 m wide. Wider cross alleys may be needed for powered feed carts.

Stall widths and cow platform lengths can and should be varied to accommodate various sizes of cows. Table 5 shows the recommended dimensions. One common technique is to vary the stall width and length along the stall rows, providing wider and longer stalls for large, mature cows and smaller stalls for heifers and smaller cows. The barn width is constant, but the width of the litter or feed alley tapers. Some change in the effective stall length can be made by using an adjustable single headrail.

Platforms are often raised 50–100 mm above the height of the litter alley to show the cattle more effectively. An optional bedding keeper such as 38-mm galvanized pipe can be set along the rear of the platform; provide a drainage space of 12–25 mm between the bedding keeper and the rear edge of the stall platform.

The curb at the stall front can be concrete or wood plank, 75–200 mm high. The electric cow trainer should be 450 mm behind the curb at the stall front; it should be vertically adjustable.

2.6 Free-stall barns

Free stalls can be used for animals from 3 months of age to maturity if the stalls are sized accordingly. Free-stall dimensions are provided in Table 6.

Table 5 Dimensions for tie stalls for dairy cattle

Animal size (kg)	Stall width (mm)	Stall platform length with trainer (mm)[1]
400	1000	1450
500	1100	1500
600	1200	1600
700	1300	1700
800	1400	1800

[1] Make stalls 100 mm shorter if used without trainers.

Table 6 Dimensions for free stalls for dairy cattle

Animal size (kg)	Stall width (mm)	Stall length including curb (mm)
100	700	1200
200	800	1400
300	900	1650
400	1000	2100
500	1100	2250
600 and over	1200	2250

Table 7 Litter alley widths between free-stall curbs

Stalls per row	Minimum alley width (m)	
	Solid floors/ tractor scrape	Slotted floors or automatic alley scraper
1–5	2.1	2.1
6–16	2.4	2.1
17–36	3.0	2.4

An adjustable neckrail should span the top of the free-stall dividers. For cows of 550 kg average weight, the neckrail should be approximately 1.7 m in front of the back edge of the heel curb. The neckrail forces the animal to move back as she gets up, reducing soiling of the bedding.

The width of litter alleys between free-stall curbs should be as in Table 7.

Alleys between rows of free stalls for calves can be reduced to 1.2 m, or to 2.1 m between free stalls and manger. These widths must not be less than the width of a tractor and blade, if that is the method of cleaning the alleys.

If larger heifers or mature cows are fed from bunks or mangers, the feeding area should be at least 2.5 m^2 per head and not less than 3.3 m wide.

2.7 Maternity and cow treatment area

Most operators prefer to have this area in an enclosed, insulated building, or in an insulated part of a building, where they have reasonable control over the environment. Part of the stable section of an existing barn can often be converted for this purpose. The area must be dry, free of drafts, well lit, insulated, and ventilated.

Provide one 3 m × 4 m maternity pen, or one maternity tie stall without gutter, for every 15–20 cows. For loose housing, provide a treatment tie stall for every 20–25 cows. For every 40 cows, also provide one isolation pen at least 3 m × 3 m, separated from the main livestock area and equipped with a stanchion or tie stall for restraint.

2.8 Calf pen areas

For calves 0–3 months old, provide individual stalls at least 600 mm × 1.5 m or individual pens 1.2 × 1.8 m. This provides for individual attention, reduces sucking, and minimizes disease transmission.

Calves 3–10 months old are often penned in groups in the same facility as the younger calves. Provide 2.2 m^2 of pen area per head with bedding, or 1.5 m^2 per head with slotted floors. Alternatively, calves 3–10 months old can be housed in small free stalls. See Table 6 for suggested stall sizes.

2.9 Replacement heifers and dry cows

These animals should be housed apart from the milking herd. Use loose housing or free stalls to conserve labor. Separating heifers by size into smaller groups of 8–12 helps to reduce competition and crowding during feeding. For heifers 10–24 months old, provide 3.5 m^2 of bedded pen area per head or 2.0 m^2 per head on slotted floors.

2.10 Bull pens

If a bull pen is required, it should be at least 3 m × 3 m and should be provided with safety areas to protect workers and allow them safe exit. Provide vertical openings 350 mm wide at the corners or a roll-under escape passage with a vertical clearance of 450–500 from the ground.

2.11 Holding areas

When cows are milked in a milking parlor, they will need a holding area; provide 1.1–1.7 m^2 per cow. The holding area may be part of the regular animal traffic area or a separate space used only for this purpose. Design the holding area so that cows can enter the parlor easily without making sharp turns. The area requires adequate gates to keep groups of cows separate and to maintain good traffic flow.

2.12 ENVIRONMENTAL REQUIREMENTS

The effect of air temperature on milk production in Holstein and Jersey cows is shown in Fig. 3. Excessive heat affects production more than cold, particularly in the larger Holsteins.

Table 8 gives the removal rates for total, sensible, and latent heat for several free-stall dairy barns in Alberta. (For definitions of these terms, see Section 6.2.) The latent heat removed by ventilation includes that produced directly by the animals and the building latent heat, which results from the evaporation of water from floors and other surfaces.

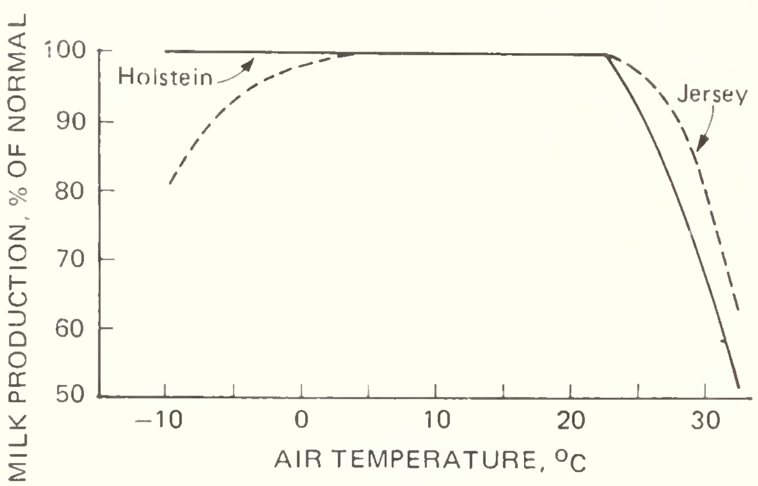


Fig. 3 Milk production versus temperature
***Source*: Yeck and Stewart (1959)**

Fig. 4 gives information on heat and moisture production for a range of cattle weights in winter conditions, but excludes the moisture evaporated from wet floors. Fig. 5 presents the total stable and latent heat produced by dairy calves.

Use data on the production of heat and moisture to calculate the necessary ventilation rates (see Part 6).

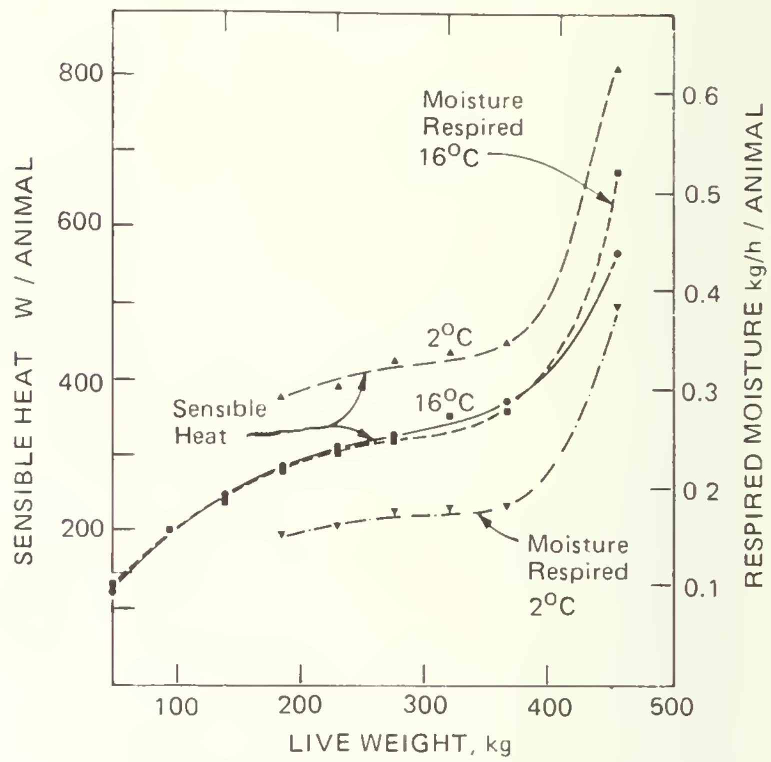


Fig. 4 Heat and moisture production from growing cattle under winter conditions

Table 8 Total, sensible, and latent heat removed by ventilation from free-stall dairy barns

Parameter	Solid passageways			Slotted passageways		
	SO-1	SO-2	SO-3	SL-1	SL-2	SL-3
Average temp, °C	4.3	7.4	13.6	12.9	7.2	15.5
Total heat[1]	4090	4458	4530	4244	4175	3341
Sensible heat[1]	2709	2686	2409	2444	2574	1943
Latent heat[1]	1381	1772	2121	1800	1601	1398
Latent heat/ total heat (%)	34	40	47	42	38	42
Animal latent heat[2]	614	664	851	807	656	955
Sensible heat converted to latent (%)	22	29	35	29	27	19
Building latent heat/total latent	0.56	0.63	0.60	0.55	0.59	0.32

[1] kJ/(h·cow) produced, based on 500-kg live weight.
[2] source: Yeck and Stewart (1959).

Source: Quille, McQuitty, and Clark (1986)

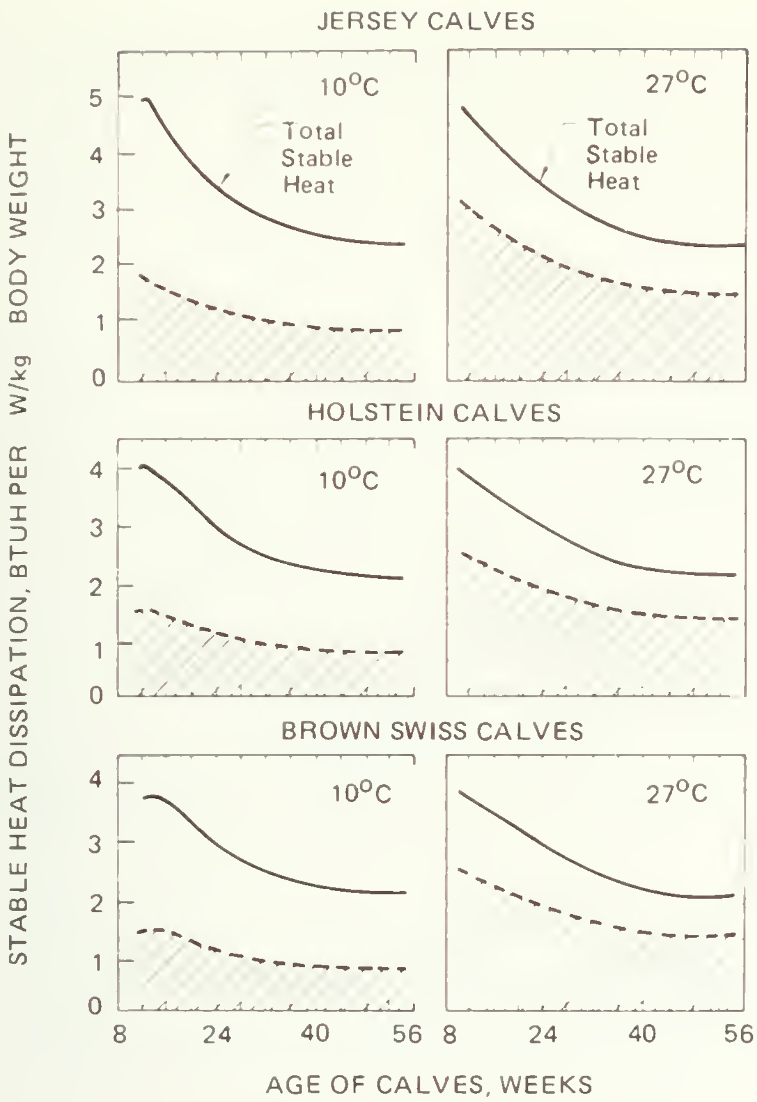


Fig. 5 Stable heat (total heat) and latent heat produced by dairy calves. Relative humidities were approximately 70% and 50% at 80°F. Calves were housed in pens cleaned daily.
***Source*: Yeek and Stewart (1960)**

2.13 FLOORS: MATERIALS, SLOPES, AND FINISHES

Concrete is relatively cheap, durable, and easy to sanitize and is by far the most popular flooring material. Solid concrete floors used by animals or exposed to wash water should be crowned or sloped to drain away from resting areas, feed bunks, milking areas, and milking equipment. Use a slope of 1:25 for cow platforms, feed bunk aprons, and holding areas. Slopes of 1:50 or even 1:100 will drain water, but surface irregularities and manure can impede drainage; hence the need for steeper slopes. One exception: in the case of cattle walk alleys that are regularly cleaned by a tractor scraper or mechanical cleaner, sloping the floor offers no advantages.

Floors in milking parlor operator pits should slope to drain in the direction that the operator normally faces during milking. An upward slope of at least 1:50 in holding areas helps to keep the cows facing in the desired direction – toward the milking parlor.

The floors of new tie-stall barns should slope toward the milkhouse end of the barn, at the same gradient as that recommended for a milk pipeline. This is usually a minimum of 1:80. Sloping the entire floor puts the pipeline at a uniform low height (but at least 2 m), making it more accessible. It also reduces the height to which milk has to be lifted in the line. This helps stabilize the vacuum level in the teat cups, reducing the chances of mastitis. If the milk room is at one end of an extremely long barn, it may be better to slope the entire barn including the floor, framing structure, and pipeline.

Cows do not like to walk on steeply sloped concrete, particularly when the floor is wet, for example in holding areas, in milking parlors, or around feed bunks. Ramp slopes should not exceed 1:3 and must have roughened, cleated, or grooved surfaces. Steps may be better than steep ramps for dairy cows. The rise of steps should not be more than 200 mm and the run should be 500–600 mm.

A concrete curb 300–400 mm wide × 150–200 mm high next to the feed bunks helps to prevent the animals from defecating in the bunks. Slotted floors for calves up to 3 months of age should have slat and slot widths of 80 mm and 20 mm, respectively. An alternative is 25 × 50-mm flattened expanded metal mesh. Slotted floors for animals over 3 months should have slat and slot widths of 130 mm and 40 mm, respectively; the slot width is more critical than the slat width.

Concrete floor finishes are critical for the safety and wellbeing of the animals. Never use a steel trowel to finish any animal traffic areas, but only for feed mangers, gutters, and floors that require sanitizing but are dry when in use. Floors with even occasional animal traffic must be rough enough to ensure traction. Finish the concrete in these areas with a rough wood float, a broom, or even a rake.

All concrete floors in cow traffic areas should be grooved to provide proper traction. This is especially critical in areas where cows mount to show heat. Grooving helps to keep floors in free-stall barns from being worn smooth by the tractor scraper blade. Any technique that forms grooves 10–20 mm deep and spaced not more than 150 mm apart will work. Use a herringbone or diagonal pattern so that scraper blades can pass without catching. If the scraper has a wood or rubber blade edge, it will cause less wear on the concrete. Existing concrete can be grooved or scabbled with special equipment, but grooving the concrete during construction is a better and cheaper alternative.

2.14 FEEDING AND BEDDING REQUIREMENTS

The storage space provided for feed depends on management practices. Allow for 14 kg of hay per milking cow per day with no silage, or 41 kg of silage per milking cow per day with no hay. If you feed silage and hay in combination, the ratio should be 3 kg of silage to 1 kg of hay. For concentrate storage, allow 3–7 kg of concentrate per cow per day, or 1 kg of concentrate per 3 kg of milk produced. Allow approximately 50% additional storage for the rest of the herd.

If the cows have free access to feed, the feeder space needed also depends on management practices. When adult cows are fed at intervals and all move to the bunk at once, allow 700 mm of feed bunk per animal. If feed is available at all times, feeder space can be reduced to as little as 300 mm per milking cow and 200 mm per dry cow or heifer. Feed bunks should be 750 mm wide if animals feed from one side and 1500 mm wide if animals feed from both sides. The maximum height at the throat should be 550 mm, and the maximum reach measured diagonally from the top of the throat board should be 850 mm. The minimum feeding area widths for cows and heifers should be 3.3 m from feed bunk to wall or fence, 3.6 m from feed bunk to the heel curb of the free stall, and 4.8 m from feed bunk to parallel feed bunk.

Storage for bedding should be based on the figures in Table 9.

2.15 WATER REQUIREMENTS

A plentiful, dependable supply of good-quality water is essential to a dairy operation. Lactating dairy cows require 135 L of water per day, while dry cows and heifers need up to half that amount. Have water available at all times at a temperature of about 10°C (ground temperature). Provide 0.1 m^2 of water surface per head for herds of 50 head or more, or one water bowl per pen for smaller groups. When cows are tied in stalls, use one water bowl between every two animals. Use frost-free waterers in cold animal housing.

Sanitizing milk equipment requires hot water (74°C minimum). You will need warm water for rinsing equipment and washing udders and possibly for feeding calves or cleaning the parlor. The total daily requirement for warm and hot water depends on the milking system installed and individual management practices; it can range from 5 to 13 L per cow per day. When average daily milk production exceeds 1000 L, or when hot and warm water uses are high, consider using equipment to transfer heat from the milk to the water. Fig. 6 estimates the potential energy savings from such a system, given the known daily milk production and warm water consumption.

Install enough hot water storage for washing and sanitizing the milking equipment and the bulk milk tank within 2 h, allowing for the recovery rate of the water-heating system.

2.16 ELECTRICAL REQUIREMENTS

A dependable electrical supply is important, especially for larger mechanized dairy operations. A standby power generator can be extremely useful.

Dairy operations require electricity for water supply, milking, milk cooling, lighting, ventilation, and some materials handling. It might also be needed for water and space heaters. For general information on service sizing and lighting requirements, see Part 6; for specific needs in dairy operations, see Section 6.44.

Table 9 Bedding requirements for dairy cattle

Class of animals	Manure-pack loose housing	Free-stall loose housing[1] (kg per head per day)	Tie-stall housing
Milk cows	4	1	4
Dry cows and heifers	2	1	2
Calves (3–10 months)	1	0.5	1

[1] Some operators use sand instead of conventional bedding materials, but not with liquid manure.

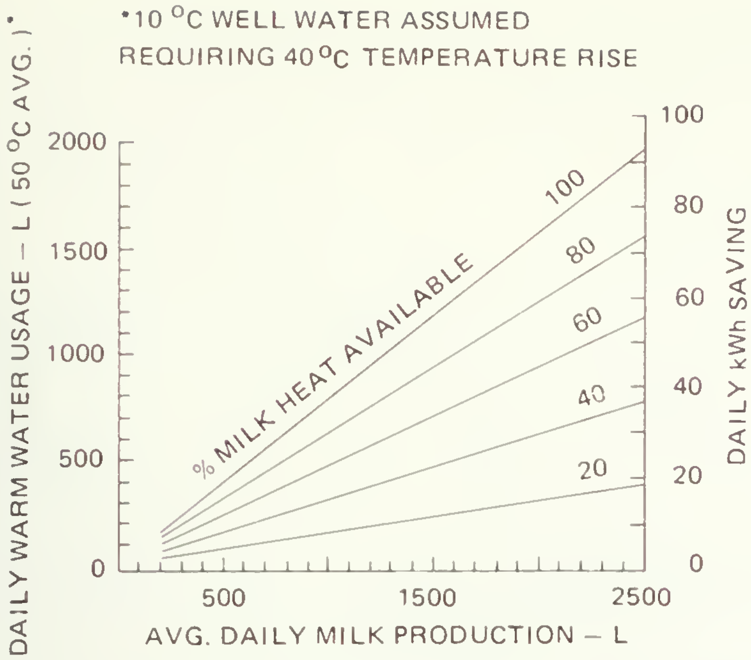


Fig. 6 Potential energy saved by transferring milk heat to water, based on milk heat available
Source: Winfield and Gee (1983)

Dairy barns, and other areas where livestock are watered, milked, or handled, have a special electrical requirement – the control of stray voltage. Stray voltage results from the neutral-to-earth (N-E) voltages that occur in all grounded neutral electrical distribution systems. For example, there may be a perceptible AC voltage between a cow tie or waterer and the concrete floor on which the animal stands. An animal may receive a shock when it touches a metallic part of a building or a piece of equipment. Shocks of less than 0.5 V are often tolerable, whereas 0.5 V or more may cause problems such as lowered intake of water or feed or a reluctance to enter milking parlors. The electrical resistance of animals to current flow is much lower than that of humans.

Electrical wiring must meet the requirements of Part 1 of the *Canadian Electrical Code* or the provincial or local amended forms of that code. In addition, the following nonmandatory requirements are good practice in dairy barns.

- All metal parts of the building and equipment, either inside the building or outside but connected to the electrical service, should be bonded to the ground bus of the electrical service. The bus is connected in turn to a ground electrode at that service location.
- Service neutral current should be minimized by balancing 120-V loading and by the use of 240-V motors and heaters whenever possible.
- Ground fault circuit interrupters (GFCI) should be installed in electrical circuits serving frost-free waterers and water pumps.
- All new milking parlor and milking tie-stall installations should be provided with equipotential grids in the cow stand and operator pit floors as shown in Fig. 7.
- An isolation device can be installed at the barn or farm electrical service to suppress outside N-E voltage, if necessary.

2.17 PRODUCTION, HANDLING, AND STORAGE OF MANURE AND WASTE

Estimate the size of manure storage on the basis of the production and required storage as given in Table 10. With liquid systems, allow for the wastes from the milk center if they are to be added. They increase the storage volume by about 35%.

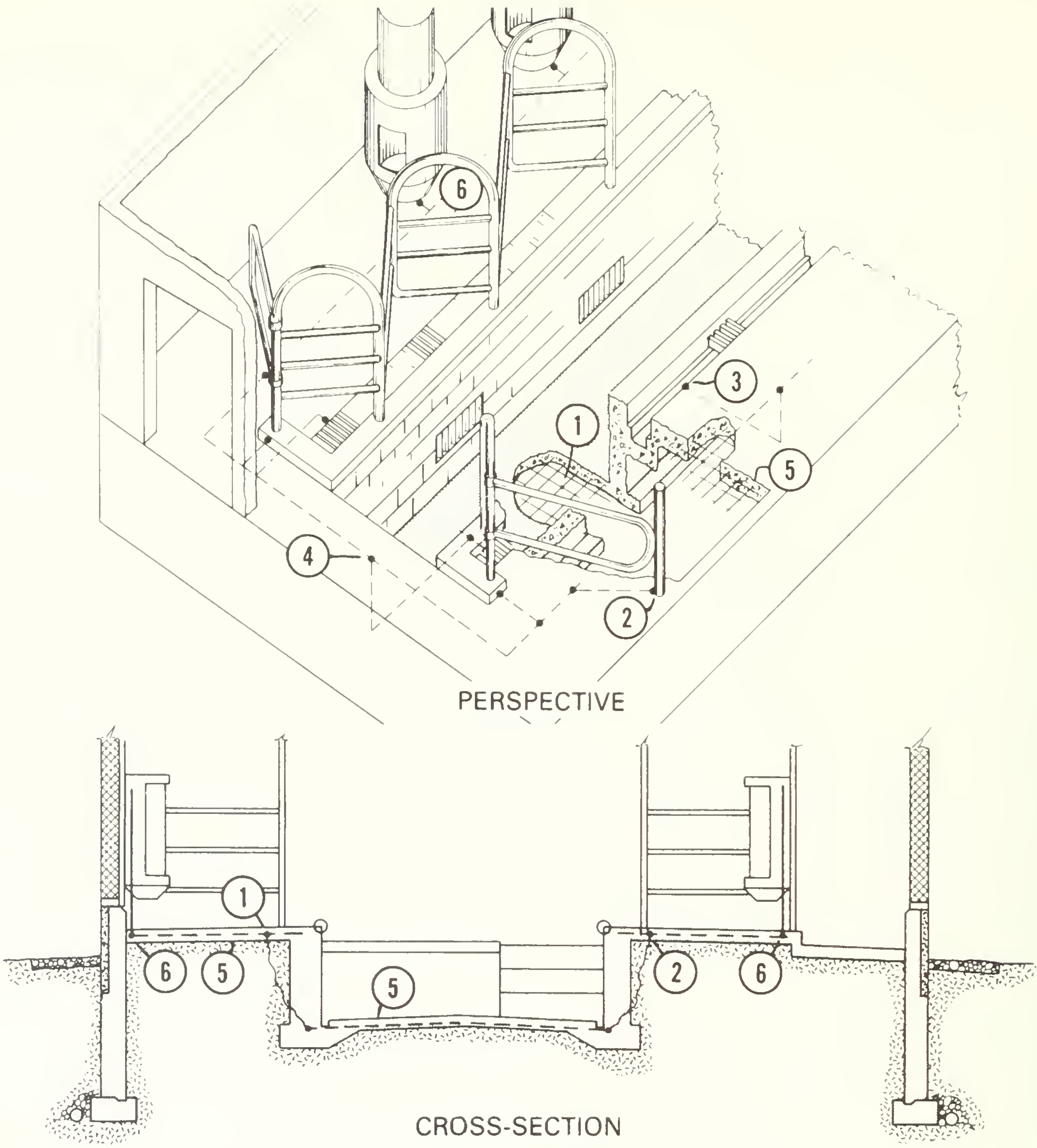
Manure storage areas should be located so that prevailing winds carry odors away from the farmhouse. Provide enough storage to avoid spreading the manure on snow, frozen ground, or sensitive crops. In most locations, this means storage for at least 6 months and preferably 12. The storage period may be dictated by provincial or local requirements.

If you do not use liquid manure storage, a sediment tank (see Table 11) and underground disposal field can be used for milk center wastes. The tank contents must still be periodically pumped out and spread on the land or otherwise disposed of in a manner acceptable to local authorities. When solid manure from the milking parlor is allowed to enter the sediment tank, the tank should be twice the size shown in the table. For more information on manure and its disposal, see Sections 2.99–2.104.

2.18 MILK PRODUCTION AND STORAGE

2.19 Milking center

The main function of the milking center is to supply a sanitary and efficient arrangement for milking cows and for handling, cooling, and holding milk. This area demands the largest investment in buildings and equipment, the greatest use of time and labor, and the most rigorous sanitation. Because sanitary requirements vary regionally, contact local health or dairy officials before construction begins.



— — — min. #6 AWG stranded copper bonding (grounding) conductor

●— — bonding point

152 x 152 MW18.7 x MW18.7 reinforcing mesh with overlap joints welded

1. Bond copper ground wire to wire mesh in concrete floor at 3 m intervals maximum.
2. Bond all steel posts, gate posts, support posts, feeder brackets, etc. to copper ground conductor (weld a 100 mm length of rod to posts at least 50 mm below concrete surface to facilitate connection).
3. Bond steel-angle grate supports for floor drains at both ends of parlor and at both sides of grate.
4. Connect copper ground loop in pit floor and return alley (if adjacent) to ground loop in cow platform floor at no less than six locations or at 3 m intervals.
5. Make concrete cover and underlay for wire mesh both 50 mm thick, to minimize corrosion.
6. Weld one end of steel rod to feeder, and either weld or clamp other end to mesh and bonding connector; install two rods per side of parlor if all feeders are interconnected by metal components.
7. Install gradient ramps where cows enter or exit; drive 2.4-3 m rods 300 mm apart, and angled 45° toward holding area. Weld rods to mesh.

Fig. 7 Equipotential grid system in a milking parlor *Source*: Canada Plan Service, CPS Plan M-9611

Table 10 Manure storage requirements for dairy cattle

Class of animals	Manure production	Required storage (L per animal per day)	
		Liquid manure	Solid manure including bedding
Dairy calves (0–3 months)	5.4	5.4	
Dairy calves (3–6 months)	7.1	9.9	
Dairy heifers (6–15 months)	14.2	19.8	17.0
Dairy heifers (15–24 months)	21.2	31.1	22.6
Dairy cows (550 kg)	45.3	62.3	
Open pen housing			56.6
Free-stall housing		67.9	48.1
Tie-stall housing			50.9

Table 11 Sizes of settling compartment in sediment tank and underground disposal field for milk center wastes

Number of cows	Settling compartment volume (L)	Length of tile trench (m)		
		Good subsoil drainage (sand and gravel)	Medium subsoil drainage (sandy loam)	Poor subsoil drainage (silt, clay)
1–25	2500	30	30	45
26–45	3000	30	55	80
46–65	3500	40	80	120
66–100	4500	60	120	180

2.20 Milking parlor

In free-stall and open-pen loose-housing systems, cattle are milked in a special room where the floor of the milking stalls is 750–900 mm above the workers' floor. This allows workers to move about and operate milking machines without kneeling. In modern milking parlors, workers walk down steps about 600 mm into an operators' pit. Cows walk up one step (about 150–200 mm) into the parlor. In some larger, double-return milking parlors, where cows returning from milking do not have to cross human traffic, the entire operator floor area (including milk room and passage) can be set about 800 mm below the cow stalls. This arrangement gives the added advantage of a higher ceiling in the milk room and mechanical equipment room. The minimum clearance should be 2.1 m above the milking-stall floor.

Stalls in the milking parlor must fit the cow closely enough to keep her from dislodging the milking machine. Stalls may be arranged in tandem (head to tail) or in a herringbone (head by belly). In the herringbone arrangement, cows enter in groups and are confined diagonally so that the worker sees only the rear quarters of each cow. This places the cows' udders only about 1.0 m apart, whereas with tandem stalls the operator must walk almost 2.4 m from udder to udder. A disadvantage of the herringbone is that cows must enter and leave a stall row in groups, and a slow milker delays the whole group.

The design of the milking parlor depends on the usual number of workers available for milking, the number of cows to be milked, and the degree of automation used. One worker is most effective in a double-four herringbone parlor, or possibly a double-five if there is a mechanical crowding gate in the holding area. To speed up the process, use a double-eight or double-ten arrangement with two operators milking together.

A polygonal milking parlor can be practical for herds of 250 cows and more. A typical 24-stall polygonal herringbone parlor requires two or three operators and (with suitable automation) handles 110–130 cows per hour. The triagonal parlor is a more recent adaptation; it has many of the advantages of the polygonal parlor and is easier to fit into rectangular building plans.

Various rotary parlor arrangements are available, but their equipment costs are higher than those for herringbone or polygonal parlors of equal milking capacity.

2.21 Milkhouse

The milkhouse is attached to but partitioned off from the barn and the milking room. Here milk is cooled and held for pickup, and milking equipment is cleaned and stored between milkings. This building must meet strict sanitary requirements. If milk is to be carried by hand or cart, site the milkhouse to minimize the walking distance. Include double doors or removable wall panels extending to floor level to allow changing the bulk tank.

Table 12 gives minimum recommended milkhouse dimensions based on herd size. When possible, use a separate utility room next to the milkhouse for the vacuum pump, the refrigeration unit for the bulk tank, the water heater, and the barn electrical service panel. The utility room should have at least one outside wall for ventilation to help remove heat from the refrigeration unit in summer.

The milkhouse must include a two-basin wash sink. Each compartment should be large enough to hold the largest piece of milking equipment.

Good lighting is needed over the wash sink as well as near the bulk tank, but *not* over the tank opening, since broken glass could fall into the tank.

The bulk tank should normally be large enough to hold at least two days' milk production. Unless precooling or other equipment is used, the minimum cooling capacity of the condensing unit should be as in Table 13 to ensure that the blended milk temperature is lowered to 3°C within 2 h of milking.

The interior walls of the milkhouse should be light-colored, easily washed, and stain-resistant. Use insulation of RSI 2.5 or better in the walls and RSI 3.5 in the ceiling. Insulation around the foundation of at least RSI 1.4 is also recommended. The use of proper insulation reduces heating requirements and condensation.

If the milkroom is ventilated separately it should be slightly pressurized to make sure that no air enters from nearby animal housing.

Table 12 Minimum recommended outside dimensions for new milkhouse construction

No. of cows	Size (m)
20–40	4.2 × 5.4
40–60	4.8 × 6.0
60–80	4.8 × 6.6
80–100	5.4 × 7.2

Table 13 Recommended cooling capacity for condensing units

Number of milking machines	Milk production (kg/h)	Cooling capacity (kJ/h)[1]
2	150	10 500
2	200	14 000
3	250	17 500
4	300	21 000
4	400	28 000
5	500	35 000
6	600	42 000
8	800	56 000
10	1000	70 000

[1] Conversion kJ/h × 0.2778 = watts (W)

Have milkhouse plans, including layouts, materials, and components, checked by local health or dairy officials before construction starts.

2.22 BEEF CATTLE

A variety of pure and crossbred animals are produced for beef. Some producers specialize in such enterprises as producing breeding stock or calves, backgrounding, and finishing. Regardless of the type of operation, you will need to provide housing for at least one of the following phases: cow-calf, growing calf, or finishing.

2.23 PRODUCTION CYCLE AND ANIMAL PERFORMANCE

The beef cow is bred naturally or by AI to produce a calf about once every 12 months after a gestation of 282 days. Factors to consider when selecting a complete beef cattle system include: environment, climate, number of days on feed during each season of the year, and labor. The season of calving has a significant effect on building requirements. Calving in January requires more elaborate housing than calving in March or calving on pasture in May. On the other hand, calves born in January can be weaned in early October, reducing feed requirements for maintenance of the brood cows and permitting the weaned calves to enter backgrounding facilities or separate facilities for replacement heifers before winter begins.

First-calf heifers should be penned separately from mature cows. This allows you to adjust the feed ration for different growth requirements. Depending on the feeding program, animal frame size, and market requirements, beef animals are normally finished to 390–450 kg (heifers) or 450–500 kg (steers).

Tables 14 and 15 provide guidelines for rates of gain and feeding periods for growing calves and finishing cattle. Figs. 8–9 compare the weight of crossbred steers with their age or days on feed.

2.24 HOUSING SYSTEMS

Housing systems range from open lots with only wind protection to slotted-floor confinement buildings. The local climate, existing facilities, feeding season, weight of cattle, feed materials, availability of bedding material, capital, and labor are all determining factors.

Cattle suffer more from mud, wet weather, and cold winter winds than from low temperatures alone. Windbreaks and simple open-front sheds, when properly laid out, can provide adequate protection.

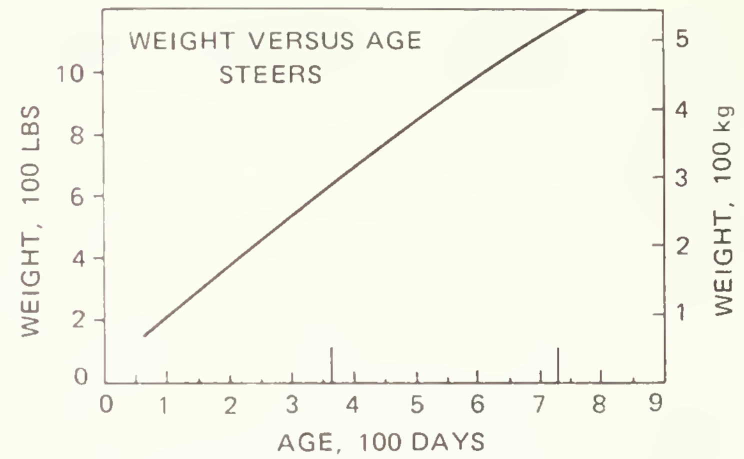


Fig. 8 Weight versus age for steers of European breeds
Source: Agricultural Engineers Yearbook of Standards (1986)

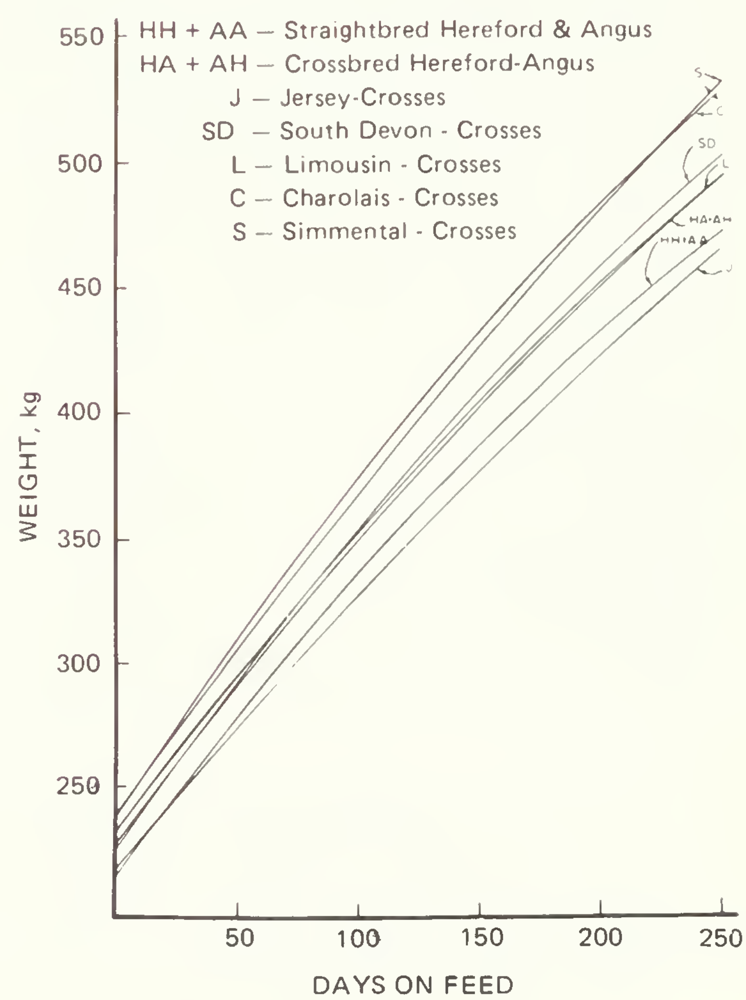


Fig. 9 Weight of crossbred steers on feed, beginning at 225 days of age
Source: Agricultural Engineers Yearbook of Standards (1986)

Table 14 Guidelines for growing calves

	Backgrounding for pasture			Backgrounding for feedlot		
	Small frame	Medium frame	Large frame	Small frame	Medium frame	Large frame
Rate of gain, kg/day	0.3–0.6	0.3–0.6	n/a[1]	0.6–0.7	–0.7–0.8	0.8–1.1
Starting weight, kg						
Heifers	160	180	n/a	160	180	200
Steers	180	200	n/a	180	200	225
Final weight, kg						
Heifers	225	250	n/a	300	320	300
Steers	275	300	n/a	340	360	340
Length of time in lot or pasture, days						
Heifers	120–200	120–200	n/a	200–240	175–200	80–120
Steers	160–260	160–260	n/a	230–280	200–230	100–140

[1] Not advised.

Note: Assume that cattle gain 68 kg over a 100-day grazing season on good pasture.

Table 15 Guidelines for finishing cattle

	Small frame	Medium frame	Large frame
Rate of gain, kg/day	1.1–1.4	1.1–1.4	1.4–1.6
Starting weight, kg			
Heifers	300	320	300
Steers	340	360	340
Final weight, kg			
Heifers	under 390	390–450	over 450
Steers	under 450	450–550	over 500
Length of time in lot, days			
Heifers	65–80	50–120	120+
Steers	85–100	65–160	140+

For winter and early spring calving, provide a dry draft-free area with controlled access. This gives you more of a chance to help at calving and to use radiant heating to help dry the newborn.

An open feedlot with wind protection is usually satisfactory for locations with annual precipitation less than 500 mm. But even a shed or a structure open to the south improves weight gain and feed conversion by approximately 10%.

The location of open lots or lots with minimal shelter is of the utmost importance. The site should slope predominantly southward at 1:15–1:25 away from feeding and bedded resting areas. Individual lots should have the greatest slope running southerly or diagonally, with mounds parallel to the slope to help keep water from pooling.

Feed bunks along the fence line should run face-to-face along a feed alley, preferrably along the highest side of each lot. The feed alleys should run nearly north and south to prevent any part of the bunk from being shaded in winter.

If the alleys between open lots are used only for handling cattle, they should be 3.6 m wide. If trucks or tractors use them for feeding, the alleys should be 7 m wide for a feed bunk on one side, or 12 m for feed bunks on both sides. The extra width is necessary for snow removal and to allow for a shallow V-shaped drainage channel down the center of the alley.

Pole-type sheds should be at the north edge of individual lots, with the front or end completely open to the south.

Rainwater from roofs and higher land should be diverted around the lots. Lot runoff containing manure should be held in a holding pond acceptable to local or provincial authorities.

When artificial windbreaks are required, they should be porous (20% open) and at least 2.4 m high. In regions of heavy snowfall, add a single or double snow fence 45 m upwind from the windbreak fence. Double snow fences should be spaced at least 8 m apart to create a snow trap.

2.25 FEEDING SYSTEMS

Many systems are possible for feedlots and cow–calf overwintering facilities. Analyze the expected cost per kilogram of gain to determine which system is the most feasible. Some of these systems are as follows:

- *System 1* Feeding hay or chaff in large round bales or loose stacks with the cattle restrained by electric wire, plus rolled grain rations fed from a double-sided trough in a separate pen
- *System 2* Perimeter bunks filled with a complete ration, using a horizontal mixing truck or trailer (simultaneous feeding)
- *System 3* Self-feeders with a complete ration, filled from a tractor-powered grinder–mixer
- *System 4* Double-sided feed bunks filled with a complete ration, using a mechanical feed distributor (e.g., auger or chain conveyor)
- *System 5* Self-feeders filled with grain processed by a mix mill, and forage fed in separate feeders

System 1 costs little and is an excellent choice for cow–calf overwintering. It is also feasible for feeder cattle. System 2 works well with bunker silos and rolled grain mixed with concentrates, but it requires using the tractor daily. System 3 uses baled straw and hay hammered with grain and concentrates to make a complete ration. Cattle have free access to feed. The ration must be carefully selected to match the cattle's expected intake. System 4 provides fast and accurate feeding of a mixed ration of silage, processed grain, and concentrates. It and system 5 require little labor; one operator can feed many cattle. System 5 requires cattle to be full-fed on grain. Forage, chaff, or straw is fed separately and can be fed free-choice.

Systems 2 and 4 can use horizontal silos, vertical concrete silos unloaded from the top, and vertical oxygen-limiting bottom-unloading steel or cement silos lined with glass. The horizontal silo could have concrete floor and walls. The oxygen-limiting silo could contain haycrop silage or high-moisture grain. (See Part 3 for details on silos and silage.)

The feedlot may be dirt or paved. The capital cost is higher for paved lots, but they take up much less space. Paved lots are preferable in locations with high precipitation (over 0.5 m annually) or where yards slope too little to provide adequate drainage. A compromise in less wet locations is to strip-pave the areas of high animal traffic along feed bunks and around waterers.

Confinement buildings with slotted floors offer the greatest opportunity to control runoff and therefore surface water contamination. The manure is held in deep gutters or tanks under the slats until it can be spread on the land.

Slotted floors of reinforced concrete for calves to 3 months of age should have slat and slot widths of 80 mm and 20 mm, respectively. An alternative is 25 × 50 mm flattened expanded metal mesh. For beef cattle over 3 months (140 kg), the slat and slot widths should be 200 mm and 40 mm, respectively; the slot width is more important.

2.26 SPACE REQUIREMENTS

Table 16 provides guidelines for the minimum space for housing beef cattle. Space requirements for heavy feeders are the same as for cows, except that no maternity pens are needed. The feed storage requirements are also different.

Table 16 Minimum recommendations for housing beef cattle

Requirements for feeders	Cows and bred heifers	Calves (225 kg)	Yearlings (to 350 kg)	Heavy (to 500 kg)
Feedlot without shed (m²/head)				
Hard-surfaced[1]	8	4	4.5	8
Soil[2]	30	15	25	30
Bedded mound[3]	3.5	2.5	3	3.5
Feedlot with shed (m²/head)				
Hard-surfaced[4]	5	2.5	2.5	5
Soil	30	15	25	30
Shed area				
Floor area (m²/head)	3	1.5	2	3
Clear height (m)	3	3	3	3
Slotted floors (m²/head) (0.4–0.5 m²/100 kg live wt)	–	1.1	1.9	2.8
Maternity pens (m) (1 pen/20 cows, not slotted)	3 × 3 min.	–	–	–
Water[5]				
Surface area (m²/head)	0.1	0.1	0.1	0.1
Daily demand (L/500 kg live wt)				
Average temperatures	40	40	40	40
Hot weather	80	80	80	80
Feed bunk, length per head (mm)[6]				
Simultaneous or limited feeding	650–750	450–550	550–650	650–750
Full or self-feeding				
Roughage	200	150	200	200
Complete ration	150	125	150	150
Grain	75	50	75	75
Feedbunk				
Height at throat (mm)	550	450	450	550
Max. reach (top of throat board to bottom outside corner) (mm)	850	600	750	850
Feed storage (kg/day·head)				
Hay (10% m.c.[8]) *or*	11.0	5.5	6.8	9.0
Silage (60% m.c.)[9]	25.0	12.3	15.5	20.5
Grain and concentrate (10% m.c.)	2.37	2.3	2.3	3.6
Hay (10% m.c.) *or*	1.4	1.8		
Silage (60% m.c.)[10]	3.2	4.1		

continued

Table 16 *(concluded)*

Requirements for feeders	Cows and bred heifers	Calves (225 kg)	Yearlings (to 350 kg)	Heavy (to 500 kg)
Grain and concentrate (10% m.c.)	6.8	10.0		
Bedding storage (except for slotted floors) (kg/day per animal)	2.3	1.4	1.8	2.3
Manure storage (m^3/day·animal)				
With bedding	0.034	0.017	0.023	0.034
Without bedding	0.028	0.014	0.021	0.028

1 Slope: 1:50 to 1:25 on concrete.
2 Slope: 1:25 to 1:12 on soil.
3 Slope mounds 1:4. Sawmill chips and shavings preferred to straw for bedding mounds.
4 200 head is the maximum capacity of one pen.
5 Maintenance ration only.
6 Bunk width: 1200 mm if fed from both sides, 1350–1500 mm if divided, 450 mm bottom width if fed from one side.
7 Bred heifer ration; also cow ration for approximately 30 days prior to calving, and after calving until cows go to pasture.
8 m.c., moisture content.
9 High forage ration.
10 High grain ration.

2.27 ENVIRONMENTAL REQUIREMENTS

Beef animals, when acclimatized, can tolerate a wide range of environmental conditions without distress. Table 17 shows the range of recommended temperature and relative humidity, as well as the estimated lower critical temperatures (LCT). The LCT is the effective still-air temperature at which an animal starts to suffer from hypothermia. The actual LCT varies with such factors as energy level in feed, dryness of hair coat, and exposure to wind.

Fed for maintenance at temperatures below 15–20°C, cattle need 1% more feed energy for each 1°C reduction in the effective environmental temperature. To demonstrate this effect, Table 18 shows the effects of winter and summer conditions on steers weighing 350–500 kg in similar feedlots in Saskatchewan and Alberta. Low temperatures decreased the average daily gain (ADG) by 21–22% and increased the feed-to-gain ratio by 27–41%.

Some other results of the Saskatchewan study were as follows:

- Straw-bedded manure packs in the cattle pens improved feed utilization and ADG.
- The most important and economical form of shelter was a manure pack with a high-porosity windbreak fence 2.4–3 m high.
- Windbreaks improved feedlot cattle production in cold, dry environments, but in areas with milder winters, windbreaks may not improve the feed efficiency.
- Open-front sheds provided better rates of gain and feed-to-gain ratios than no shelter. An exception is where the sheds trapped too much snow in the pens; this had a negative effect.
- A controlled environment improved the feed-to-gain ratio but did not improve the rate of weight gain.
- The lowest feed-to-gain ratio was recorded during mild, dry weather.
- The lowest rates of gain were recorded in wet, muddy pens. Muddy pens can be more stressful than wind and rain.

Feed cost, the major expense in beef production, should be a major factor in assessing the benefits of any buildings for beef cattle.

For the design of closed confinement buildings, Figs. 10–11 show total and sensible heat production values for raising beef cattle with no bedding. Note that below 0°C, the total heat loss increases substantially as the animal adjusts its metabolic rate to maintain its body temperature.

Table 17 Recommended air temperature, relative humidity range and estimated lower critical temperature (LCT) for beef animals

Beef cattle	Recommended temperature (°C)	Relative humidity (%)	Estimated LCT (°C)
Finish feedlot	–20 to 25	40–75	–40 to –30
Background and growing	–10 to 25	40–75	–20 to –30
Dry and pregnant cows	–18 to 25	40–75	–10 to –20
Growing calves (50–200 kg)	10–25	40–75	0 to –10
Newborn calves	15–25	40–75	10[1]

[1] Lower as the calf grows.

Table 18 Effect of seasonal climate on average daily gain (ADG) and feed-to-gain ratio of beef steers in research station feedlots

Location and number of animals	Dates	Average temp (°C)	ADG (kg)	Feed-to-gain ratio
Saskatoon	Mar–Nov	12.5	1.54	6.1
1970 head	Dec–Feb	–9.8	1.20	8.6
Edmonton	May–Sept	14.6	1.46	6.7
179 head	Nov–Mar	–13.6	1.15	8.5

Many beef barns are naturally ventilated with open sides and ridge. In winter, they are in effect cold buildings, operating at about 5°C above ambient temperature.

For the principles of ventilation, including applications for beef cattle, see Section 6.1–6.7.

2.28 CATTLE-HANDLING FACILITIES

Facilities for cattle handling are essential to beef production and contribute much to the easy, safe, and rapid handling of cattle for treatment, breeding, or sorting. Table 19 provides recommended dimensions for the design of beef cattle corrals and handling facilities.

All pens should connect to handling facilities. Choose a well-drained area; a slope of 1:12–1:25 away from the headgate and squeeze area provides a dry area where most of the work on the cattle can be done. A rough concrete pavement in the chute and around the headgate gives good footing and eliminates puddles.

The loading chute should have access by truck to an all-weather road. The farmer can then buy and sell livestock according to the market.

Take animal psychology into account when planning the design and layout of handling facilities.

- Cattle have panoramic vision; they can see all around without turning their heads. They are motivated by fear and are sensitive to harsh contrasts of light and dark.
- All species of livestock instinctively follow the leader; therefore single-file chutes should be long enough to take advantage of this tendency. The single-file chute length should be at least 6 m, but 9–15 m is better.

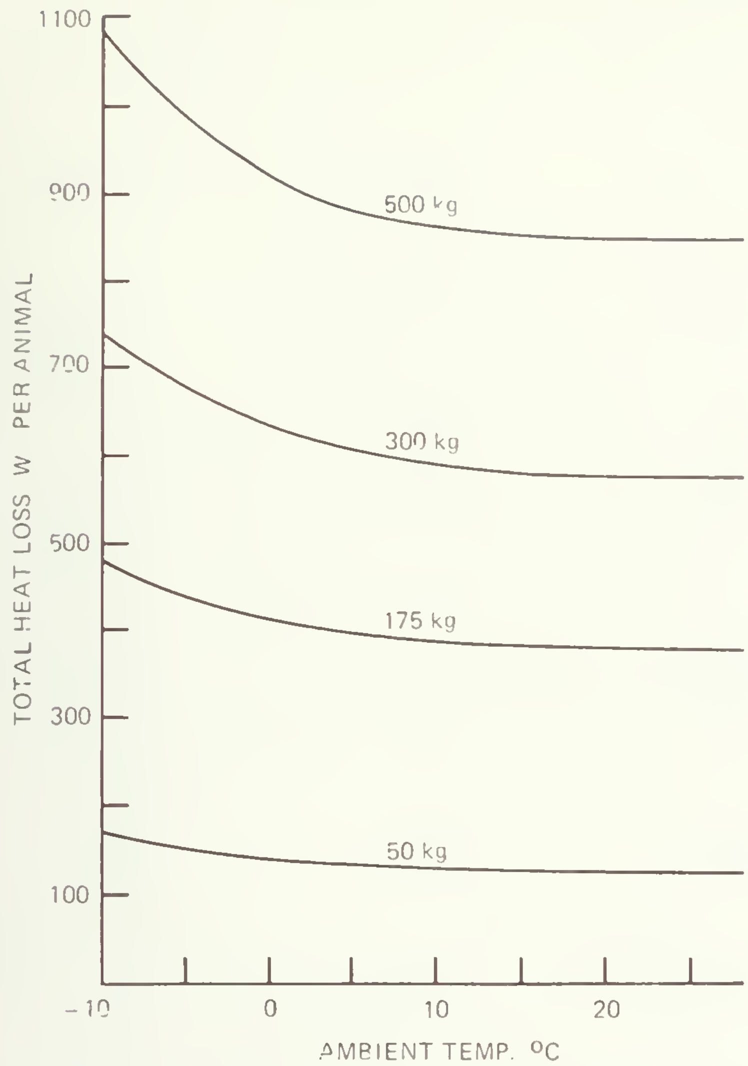


Fig. 10 Total heat loss from growing cattle

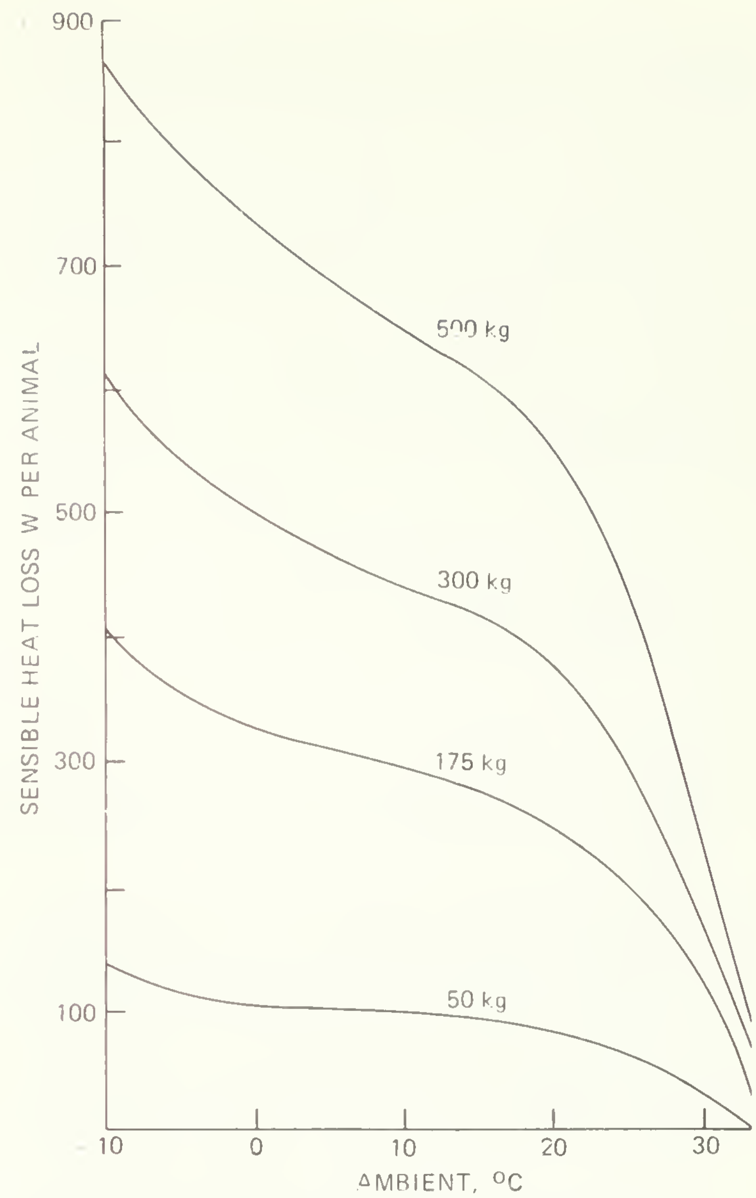


Fig. 11 Sensible heat loss from growing cattle

- Cattle tend to move toward the light and prefer not to enter a darkened area. Therefore single-file chutes should extend 3–5 m outside enclosed (darkened) buildings. At night, a diffused light helps to attract cattle.
- Cattle often balk if they see moving or flapping objects. The sides of crowding pens, single-file chutes, and loading chutes should be solid to prevent animals from seeing distracting objects – including their handlers.
- The funnel entrance from the crowding pen to the chute should have one straight wall, not two angled ones, to prevent the animals from being wedged at the narrow end.
- A curved chute works better than a straight chute. Animals are prevented from seeing the squeeze, the truck, or people. A curved chute also takes advantage of their natural tendency to circle around the handler. An inside radius of curvature of 3.6–5.2 m is practical; the larger radius is better.
- A raised catwalk for handlers on one side of the handling facility is highly desirable. It should never be above the chute.

Loading ramps for cattle should take the form of steps with risers of 90–100 mm and treads of 300 mm. The treads should be rough to provide good footing. For adjustable and wooden ramps, cleats 38–50 mm high should be spaced 200 mm apart (measured edge to edge). Provide a landing 1.5 m long at the top of loading chutes. The height of loading chutes should adjust from 800 mm to 1 m. Telescoping side panels and a self-aligning dock bumper help to prevent foot and leg injuries and minimize escape attempts.

2.29 FEEDING REQUIREMENTS

Most storage volumes and dimensional data are given in Table 16. Feed storage depends on the nature of the ration (high-forage or high-grain).

Table 19 **Recommended dimensions for beef cattle corrals and handling facilities**

	Less than 270 kg	270–540 kg	Over 540 kg
Holding area (m^2 per animal)			
Worked immediately	1.4	1.7	2.0
Held overnight	4.5	5.0	6.0
Working chute (vertical sides)			
Width (mm)	450	550	700
Minimum desirable length (m)	7.2	7.2	7.2
Working chute (sloping sides)			
Width at bottom (mm)	500	500	550
Width at top (mm)	760	760	800
Minimum desirable length (m)	7.2	7.2	7.2
Working chute with feedlot line fences			
Minimum height (mm)	1200	1350	1500
Depth of posts in ground (mm)	1000	1000	1000
Corrals and bull pen fences			
Height (mm)	1500	1500	1800
Depth of posts in ground (mm)	1200	1200	1200
Loading chute			
Width (mm)	700	760	810
Length, minimum (m)	3.6	3.6	3.6
Slope	1:4	1:4	1:4
Ramp height			
Gooseneck trailer (mm)	375		
Pickup truck (mm)	700		
Van-type truck (mm)	1000		
Tractor trailer (mm)	1200		
Double deck (mm)	2500		
Access or collecting alley width (m)	3.6	3.6	3.6

Note: For cow–calf operations, use the dimensions for cattle over 540 kg.

Beef animals are often fed from bunk feeders. Bunks may give the cattle access to the feed from both sides, if filled by conveyor, or from one side (fenceline type) if filled by wagon or truck.

Beef animals can also be self-fed from horizontal silos or large hay bales in a storage area, if their access to the feed is controlled by a moveable feed gate or shock fence. Portable hay feeders may also be used, but they need regular filling.

2.30 WATER SUPPLY

Water should be supplied by frost-free waterers during the winter. Most of these require an electrical supply, although some use ground heat. Larger or double units can be located in pen partitions to reduce installation costs. All units should be surrounded by a 150 mm × 400 mm step up for calves, with a concrete apron 1.8–3 m wide. This step also keeps larger cattle from defecating in the waterer.

2.31 ELECTRICAL REQUIREMENTS

Electricity is normally required for lighting for service, security, and some tasks and for frost-free waterers. It may also be needed for feed-handling equipment, for heating facilities for early calves, and for removing ice or frozen manure from concrete aprons around water bowls. For this last, use a watt density of 250 W/m^2 and allow a 12-h preheat period.

As in dairy operations, bonding of metallic hardware and equipment to minimize stray voltage is essential, especially around electric frost-free waterers. GFCIs, equipotential grids with step potential control, or both, are also recommended around waterers.

The size of the radiant, infrared heating units for early calving can vary from 250 to 1750 W, depending on calving season, the amount of shelter provided, and climate. Suspend the heating units by chains over a boarded-off corner of the maternity pen. Units of 1000 W or larger should be operated from 240-V circuits.

For lighting needs, see Section 6.45.

2.32 MANURE HANDLING AND STORAGE

Storage requirements for manure and bedding are given in Table 16.

Open dirt feedlots require careful management to control runoff and odors. Good drainage and regular mounding of manure are essential to maintain high levels of sanitation and minimize odors. Contain runoff from the feedlot and manure storage in leakproof storage to avoid contaminating surface water and groundwater. To minimize the pollution of groundwater by infiltration and deep percolation of nitrates beneath feedlot surfaces in active use, leave the surface of the soil undisturbed when you mound manure on the lot or remove it during cleanout. Snow control around the feedlot is important; so is the provision of diversion ditches to prevent outside water from entering the lot.

In areas with heavy rainfall, operators using open feedlots and covered shelters must consider the runoff from the feedlot. Paving the feedlot reduces the area required and aids in cleaning. Lot scrapings can normally be stockpiled on a curbed slab. Catch the runoff from the slab and feedlot in an earth basin or concrete storage. You will require equipment for handling solid manure from the covered bedded area and the slab, as well as for liquid manure from the runoff storage area.

Covered feedlots generate only solid manure if enough bedding is available to retain scrapings from the feeding–watering area. Alternatively these scrapings could be held on a curbed slab with adequate provision for runoff detention. Provide enough headroom (3–3.6 m) in the bedded area to allow the manure pack to build up.

In housing systems with completely slotted floors, liquid manure is normally stored directly beneath the slats. When agitating liquid manure, choose a windy day, remove the animals, and open all doors to reduce the risk of gas poisoning.

All storages should be large enough to hold at least 6 months' capacity. For more information on manure storage and handling, see Sections 2.99–2.104.

2.33 SHEEP AND GOATS

Rearing sheep or goats is often a specialized part-time enterprise on small farms. Unregulated production is increasing the interest in the production of wool, milk, meat, and hides. Producers can get started with a relatively small capital investment. Building costs can be kept low, since both sheep and goats tolerate low temperatures.

Controlling predators near flocks of sheep is important, and the serious breeder often makes a major investment in confinement housing.

2.34 PRODUCTION CYCLES

Both sheep and goats tend to be seasonally polyestrous. Sheep go into heat every 14–19 days, and goats every 19–21 days, but only during the normal breeding season of August to February. By adjusting lighting periods and temperature in controlled environments, breeders are trying to extend the breeding season to increase the production of lambs and to make the supply of goat milk more continuous.

Both sheep and goats have a gestation period of 145–150 days. Multiple births are common and highly desirable, particularly in sheep.

Goats produce milk for approximately 10 months following kidding and are held dry for 2 months before freshening.

A mature ram can serve 40–50 ewes, but a more common practice is to have 3 rams per 100 ewes. A similar ratio is required with goats.

2.35 HOUSING SYSTEMS

Sheep and goats are both grazers and can be pastured during the summer with excellent fencing and good control of predators (especially for sheep). Both are often confined to open feedlots or buildings because of the fencing and predator problems. Otherwise, housing facilities can be simple. Both types of animal tolerate low temperatures, but need clean, dry, draft-free housing in winter and shade in summer.

Dixon (1984) has shown the desirability of providing shelter from the wind and of keeping young animals dry. For example, a fine-coat newborn lamb of 5 kg, born in the open on a windy day, loses heat faster than it can metabolize unless the temperature is greater than 10°C. For a newborn lamb with a hairy coat the minimum temperature would be about -11°C. If the lamb is dry and there is no wind, the limiting temperature is much lower. A roofed shelter would keep the lamb out of the wind and dry, except for the moisture on the coat at birth. Once dry, even a small lamb could maintain its body temperature with ambient temperatures as low as -10°C.

To summarize:

- More lambs survive when lambing operations are sheltered.
- Small lambs need higher temperatures for survival than heavier lambs.
- Keeping the lambs dry and out of the wind increases their chances of survival.
- The lamb needs to suckle successfully immediately after birth to survive.

This information can be helpful in the selection and design of appropriate shelters for lambing.

Some flocks of sheep, allowed to range on pasture and lambing late in the spring, require few if any buildings, as long as the feeding area has a water source and gives natural protection against wind and snow.

Partial confinement is useful for lambing in early spring or for housing a dairy goat herd. It is relatively inexpensive and flexible. Sheds or pole-frame buildings are the most common. They are often open on the south side or end to pens sloping away at least 1:25 from the housing. If the yard slopes to the north as well, shaded summer pens can be built on the north side for feeder lambs.

Providing moveable panels or doors on the north side or end can help to keep the animals cool in summer. With a gabled roof, leave the ridge open or use commercial ventilators for good air flow. Make sure that the internal design of a commercial ventilator does not restrict air flow – a common problem.

For early lambing, use claiming pens in the housing facility (one per ten ewes). In colder climates this area should be partially insulated, with provision for radiant, infrared heating. Similar kidding pens should be provided for goats.

Hold rams and bucks apart from the ewes and does, except during the breeding season.

Board fences 1.2–1.8 m high with not more than 100 mm between the boards are preferred for goats. Do not use barbed wire.

2.36 SPACE REQUIREMENTS

Table 20 provides guidelines for housing sheep; except for the information on feed rack height at throat and feed storage, these can be used for goats as well. Individual grain boxes and keyhole hay feeders for goats minimize competition and reduce the waste of feed.

2.37 ENVIRONMENTAL REQUIREMENTS

Most operators use cold housing units with natural ventilation. Confinement housing can be kept warmer and mechanically ventilated if desired, but it must be insulated to make the most of animal heat and to prevent condensation. It may also need supplemental heat in extremely cold weather.

For mature sheep and goats, the comfort range is 7–24°C; 13°C is optimum. Feeder lambs on high feeding levels can be comfortable at 3°C. Newborn lambs and kids should be kept at 24–27°C until they are dry. This temperature is best provided by localized radiant heating.

The relative humidity should be in the 50–75% range. Some fogging is likely to occur at relative humidities above 90%.

The heat and moisture produced by sheep are given in Figs. 12–13.

2.38 FLOORS, SLOPES, AND SHEEP HANDLING

Dirt lots and floors are common, but paved lots are preferable if annual precipitation exceeds 500 mm. The lot should slope at least 1:25 away from the housing facility, waterers, and feeders. A paved strip with a 1:25 slope should extend 1.8 m from each feed bunk or waterer.

Table 20 gives the recommended dimensions for slotted flooring in confinement buildings.

Finish concrete floors and slats in dairy goat buildings with a broom to provide good footing.

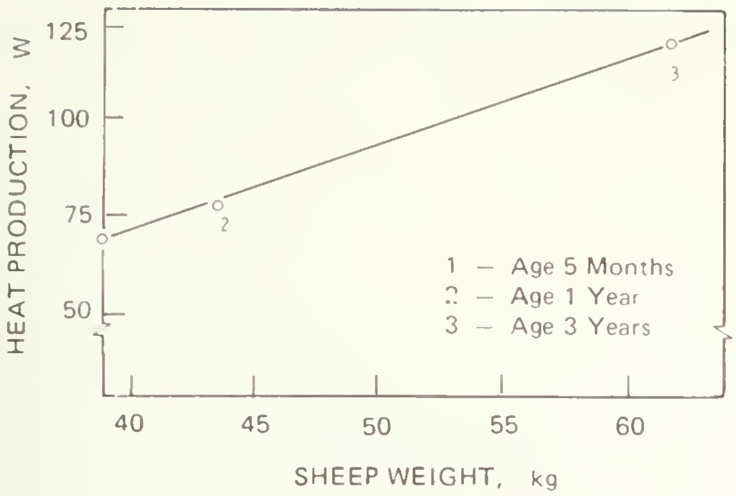


Fig. 12 Effect of sheep weight upon heat production
Source: **Reitzman and Benedict (1930)**

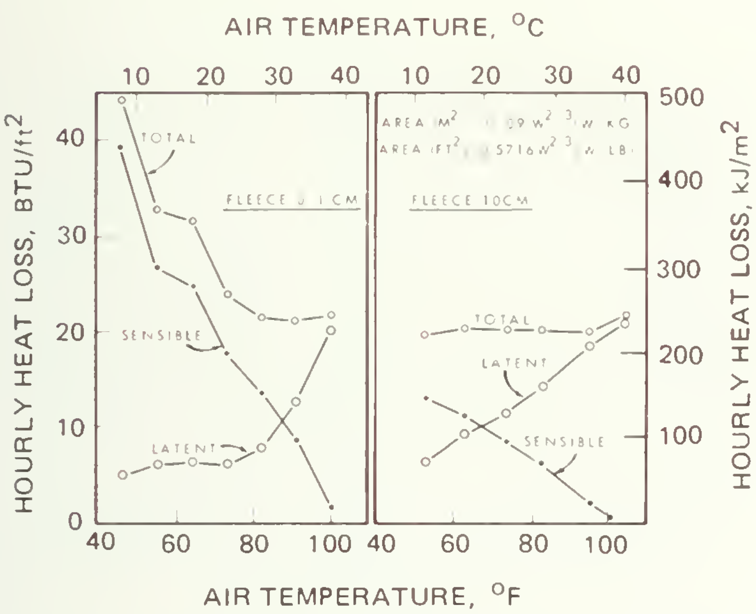


Fig. 13 Effect of environment and fleece length on heat losses from sheep (halfbred × Dover-Cross wethers). Relative humidity, 45–54%; airflow 1.9 L/s
Source: **Blaxter, Graham, and Wainman (1959)**

Handling facilities are essential for treating, shearing, and shipping sheep. These facilities should be on a well-drained site near the housing (if any). They should have access to an all-season road and should be provided with electricity and water. Include areas for gathering, crowding, and holding the animals, as well as a working area. The gathering area should provide 0.4–0.5 m^2 per sheep or 0.65 m^2 per ewe and lamb. The crowding area (preferably circular) should hold six to eight sheep or more. The working chute should have sliding blocking gates at the entrance and exit to control movement. Make the chute width adjustable, 275–375 mm for single-file flow, and 4.8 m long to handle six to eight sheep.

The single-file chute can have sloping sides, if preferred, with a bottom width of 200–300 mm and a top width of 450–700 mm. A 1-m-wide chute may be better for larger flocks. In any case, the chute height should be about 800 mm. In the working chute, provide a fixed or portable footbath with vertical sides 180–200 mm high for the treatment of foot disorders.

One set of handling facilities is enough if the shearing room is nearby. Portable claiming pens may be removed to allow the building area to be used for shearing.

2.39 FEED STORAGE REQUIREMENTS

The feed storage requirements for sheep are given in Table 20.

A milking doe requires 1.0 kg concentrate, 2.5 kg hay (less when silage is available), and 1.5 kg silage per day. Various designs for sheep feeders are available through the Canada Plan Service.

2.40 WATER REQUIREMENTS

With free access to water, the surface areas given in Table 20 should be adequate. Otherwise, provide at least one waterer per pen. Double or large units may be located in pen partitions. Except in warm confinement housing, all waterers should be of the frost-free type.

Ewes and does normally need 7–11 L per head per day. Greater volumes are required when the animals are lactating and in warm weather. Water at about 10°C (ground temperature) is desirable.

2.41 ELECTRICAL REQUIREMENTS

Most operations need electricity to pump water and operate shears and frost-free waterers, and to provide lighting, ventilation, and heat in claiming or kidding pens. Dairy goat operations may also require electricity for milking, milk cooling, and heating the water for washing and sanitizing.

2.42 MANURE AND MILKROOM WASTES

A ewe produces 2.8 L of manure per day. The required storage per head is 6.8 L/day for liquid manure or 4.3 L/day for solid manure including bedding. Provide storage for a minimum of 180 days with no overflow of effluent. Milkroom wastes should be handled in the same manner as for dairy cows; see Section 2.16.

Table 20 Guidelines for housing sheep

	Ewes and rams	Feeder lambs
Feed lot (m^2/head)		
Hard surfaced	1.4	0.6
Soil[1]	6.5	2.8
Open-front shed floor area (m^2)		
Pregnant ewe	1.4	0.6
Dry ewe	0.93	
Ceiling height minimum (m)	2.7	2.7
Slotted floors (m^2/head)[2]	0.65	0.4
% floor area slotted	100	100
Slot width (mm)	19	16
Slat width (mm)	50–75	50–75
Lambing pens, not slotted (m, minimum)		
Claiming pen only	1.2 × 1.2	
Lambing and claiming pen	1.2 × 1.5	
Feed rack, length per head (mm)		
Group feeding	400	300
Self feeding	150	100
Height at throat (mm)		
Small breeds	300	250
Large breeds	375	300
Feed storage		
Hay (kg/day per head)		
Small breeds	1.4	0.9
Large breeds	2.3	
Grain (kg/day per head)	0.15	0.23 (maintenance) 0.45–1.13 (finishing)
Bedding storage (kg/day per head)	0.34	0.11
Water surface area (m^2/40 head)	0.1	0.1

[1] Soil-surfaced feed lots should be used only where annual precipitation is less than 500 mm. Provide a paved feeding strip next to each feed bunk. This paved strip should be at least 1.8 m wide or as wide as the tractor used for cleaning. The strip should slope 1:25 away from the feed bunk.

[2] An alternative to slotted floors for ewes, rams, or lambs is 25 × 50 mm, 4-mm gauge expanded and flattened mesh. Expanded metal mesh floors may be covered with a solid panel to retain bedding for lambing.

2.43 DAIRY GOAT MILK PRODUCTION CENTERS

Dairy goats can be grouped in community pens or tied in individual stalls. Stalls should be 600 mm wide with a raised platform 1050 mm long. The raised platform permits washing and disinfecting and should be removable. A semicircular gutter behind the stall can be scraped and washed out. A grate-covered gutter may be useful in larger operations.

Milking stands can be used for small herds, or milking parlors for large herds. Of course the milking machine needs only two teat cups. Considerations for vacuum pumps and lines, milk cooling, and sanitation are the same as for dairy cows.

2.44 SWINE

Because of Canada's relatively cold climate, most pigs are raised in insulated, temperature-controlled buildings. Pigs have little hair, and their rate of gain (kilograms per day) and feed-to-gain conversion ratio are both affected by cold.

Since feed is the major production cost with pigs, high capital costs in buildings and equipment can sometimes be justified if they reduce feed costs.

2.45 PRODUCTION CYCLES, NORMS, AND HERD MAKEUP

Swine housing is the most complex of all livestock facilities because of the number of distinct areas – farrowing, weanling, breeding, gestation, growing, and finishing. To make the system work efficiently, each area must be the correct size or some areas will be overcrowded while others are underfilled.

To determine the size of each area, one must know the duration and production norms for each stage of the pig's development.

2.46 Farrowing

Sows usually farrow 10–12 live pigs, except in the first litter, which is often one or two pigs smaller. The nursing period varies from 3 to 6 weeks; the majority of operations aim to wean at 4 weeks. Losses of nursing piglets should be less than 15% of those born alive. Most of this loss occurs in the first week of life. Nine pigs weaned per sow per farrowing and 20 pigs weaned per sow per year are realistic goals.

The farrowing stall must be cleaned after the piglets are weaned, and the next sow should be acclimatized to the crate. Allow 1 week for these items. The cycle time for the farrowing stall is therefore the number of weeks for nursing plus 1 week for clean and fill.

Many larger swine farms have several farrowing rooms for an all-in, all-out farrowing cycle. This means that the farrowing rooms can be cleaned more easily and thoroughly for better disease control. In such a system, the number of farrowing rooms would equal the number of weeks in the stall cycle.

2.47 Breeding and gestation

The remainder of the swine herd, including boars (one for every 20 females in the breeding herd) and replacement gilts, is normally housed nearby for the breeding and gestation period.

Sows normally come into heat 5–7 days after weaning. During this period, they are housed in groups in pens next to the boar pens. Seeing, smelling, hearing, and touching the boar at this stage all help to induce strong heats in sows and gilts. After breeding, the sows are moved to the gestation area. Some producers leave the bred sows and gilts in the breeding area for four more weeks. This allows the operator to watch for a return to heat after 21 days (the normal estrus cycle) and to check for pregnancy with an electronic pregnancy tester 28 days after breeding.

The gestation period lasts 114–116 days, approximately 16 weeks. The sows are housed either in small groups of five or six sows or in individual pen stalls. Pen stalls prevent fighting and eliminate competition for feed.

Expect the normal problems in the sows during this dry period; some may lead to culling. Problems may include failure to conceive as a result of infertility or disease, abortion, or physical deterioration. Or sows may not be in pig (NIP sows), even though they do not return to heat and do pass their pregnancy checks.

This expected failure rate (5–20% of those bred) can lead to a reduction in farrowings. To maximize returns, the farrowing room must be kept at full production. To achieve this, breed and house extra sows (about 10%) to replace the failures.

2.48 Weanlings

Being separated from its mother and changing to dry feed, the new pen, and possibly new pen mates can all stress the newly weaned pig. Weanlings should be specially penned under precise environmental control. Some producers use hot nurseries (27°C) where small pens, often double or triple decked, house individual litters of pigs. After 3 weeks (7 weeks of age, 12 kg), the pigs are moved to a cooler weanling room (24°C) for another 3–5 weeks (10–12 weeks of age, 24–34 kg).

Other producers may keep pigs in the same room for the whole 6–8 weeks. If only 1–2 weeks' production of weanlings are kept in each room, so that all are about the same age, the room temperature can be adjusted downwards as the young pigs grow. This latter scheme fits into all-in, all-out scheduling; again, this method permits easier and more thorough cleaning.

2.49 Growing and finishing

Feeding pigs from 25 to 100 kg can be tied to the farrowing operation or a separate enterprise. Some operators break finishing into the growing phase (up to 50–60 kg) and the finishing phase (to market weight). The grower pigs can then be given a free-choice high-protein diet and warmer temperatures, and the finishers can have a more restricted diet and cooler temperatures.

The objective is to maximize the rate of gain (kilograms per day) with minimum feed input or feed conversion ratio (kilograms feed per kilogram weight gain). Feed per pig, days to market, and hog index at slaughter are also useful guides.

Growth rates for finishing pigs vary a good deal and depend on genetics, feeding rate, feed quality, health, environment, and general management. The average commercial producer should be able to meet the following goals, and many producers exceed them:

Age (weeks)	*Weight (kg)*
1–4	7
5	8
6	10
7	12
8	16
9	20
10	24
11	30
12	34
13	39
14	44
15	49
16	54
17	59
18	64
19	69
20	74
21	79
22	84
23	89
24	94
25	100

In large feeder pig operations, disease control justify dividing the growing and finishing barns into several sections, with each section operated "all-in, all-out" and cleaned at the end of each cycle. Smaller operations are more likely to practice continuous housing.

Regardless of the size of the operation, the acquisition of healthy pigs of known origin and the control of potential carriers of disease should be a part of designing both the enterprise and the management program.

2.50 SIZING SWINE FACILITIES

Swine farmers usually organize their work on a weekly schedule. For example, they may move nursery pigs on Wednesday, wean sows on Thursday to avoid weekend breedings, and ship finishing pigs on the same day every week. The objective is to maintain an even flow of pigs for each of these tasks from week to week.

To determine the sizes for the various areas for the herd, start with the desired number of farrowings or litters per week. Table 21 was developed using this weekly routine approach. It calculates the number of pigs in each area, based on the number of weeks' stay there.

Column 1: Determine the number of animals needed to produce one litter per week.

Column 2: Enter the desired number of litters per week.

Column 3: (Column 1) × (Column 2) = required number for each area for the desired litters per week.

The assumptions upon which this table are based follow each item and reflect present common swine management. For variations in these practices, modify Column 1 to suit your needs. As an example, for 5-week weaning, the number of pens in each farrowing room would increase from five to six.

2.51 HOUSING SYSTEMS

Because of the need to maintain relatively high building temperatures for the herd's health and for efficient feed use, all swine buildings should be well insulated. The minimum insulation values should be RSI 3.5 in walls, 5.3 in the ceiling, and 1.4 around the perimeter to at least 300 mm below grade.

Pigs' specific temperature and space requirements depend on age. For these reasons, swine housing is usually partitioned into rooms or sections so each phase of production can be provided with the proper environment.

Every room or section of the building requires ventilation to remove moisture. The housing system must be laid out to ensure appropriate inlets for fresh air and a means of exhaust, using either fans or natural ventilation.

The layout of swine housing systems must also take into account the flow of pigs, feed, and manure, as well as operator traffic patterns and truck access.

Buildings and manure storages must be located to minimize odor and dust at the farmhouse and in neighboring areas. Consult provincial and local authorities.

You may want to use existing facilities as part of the planned housing system. Carefully assess their proposed use and suitability, since reusing existing facilities often limits layout options and future expansion.

Table 21 Sizing swine facilities

	1	2		3
	For one litter per week	Desired litters per week		Col. 1 × Col. 2
Breeding herd				
Sows in farrowing crates (4 weeks nursing, 1 week clean/fill)	5	x	=	$5x$
Open sows (1 week after weaning)	1	x	=	x
Gilts (40% replacement/year)	3	x	=	$3x$
Gestating sows (for 15 weeks after breeding)	15	x	=	$15x$
Boars (add 1 to any herd size for replacement)	1			
Total breeding herd size	25	x	=	$25x + 1$
Suckling piglets on sow 0–4 weeks of age (9 piglets/litter weaned)	36	x	=	$36x$
Weanlings				
Newly weaned 4–7 weeks (to 12 kg)	27	x	=	$27x$
Older weanlings 7–10 weeks (to 25 kg)	27	x	=	$27x$
Total weanlings	54	x	=	$54x$
Finishing				
Growers 10–18 weeks (to 60 kg)	72	x	=	$72x$
Finishers 18–26 weeks (to 100 kg)	72	x	=	$72x$
Total finishing	144	x	=	$144x$
Total herd	259	x	=	$259x + 1$

The choice and use of construction materials varies with their availability, the contractor's experience, and cost. Swine buildings must be insulated. They should have durable, washable inner surfaces and be impervious to birds and rodents.

You must also consider the movement and handling of boars and sows in the breeding, gestation, and farrowing sections. Adult pigs can become very aggressive when moved individually. Provide for continuous forward movement of the animals. An enclosed truck-loading ramp should be included in the weanling or finishing sections of the housing systems, or both, to prevent balking.

The Canada Plan Service provides a wide range of swine-housing plans showing layout and service alternatives.

2.52 SPACE REQUIREMENTS

All group pens should have a length 2.5–4 times their width. The minimum width of group pens should be 1.5 m for sows up to 180 kg, 0.9 m for weaners, and 1.2 m for growers and finishers up to 100 kg. With self-feeders, increase the width of grower and finisher pens to at least 1.8 m in order to prevent traffic jams.

Table 22 provides space requirements for accommodating common classes of swine.

2.53 ENVIRONMENTAL REQUIREMENTS

In pigpens, air temperature, air movement, air speed, radiant temperature, and flooring (including the use of bedding), as well as stocking density and the opportunity to huddle, all influence the effective air temperature.

The efficiency of pork production depends on whether nutrients are used for maintenance or growth. Any factor that influences an animal's heat production has a direct effect on how much energy intake is used for growth and how much is dissipated as heat.

2.54 Temperature

Feeding levels, age, condition, and social environment, as well as the health of the animals, all have a significant effect in determining the lower critical temperature (LCT). This is the temperature below which an animal must increase its rate of metabolic heat production to maintain its body temperature (homeothermy). The LCT decreases as body weight and body fat increase. Individual newborn piglets have an LCT in the region of 34°C. Table 23 gives lower critical temperatures for pigs of various body weights depending on the rate of feed intake.

When the environmental temperature falls below the LCT, animal heat production increases 2–4% per degree Celsius. The impact of environmental temperature on growth rate and the effect on growth rate of a 1°C decrease below LCT are given in Tables 24–25.

Air speeds of less than 0.1 m/s near the pigs will not create drafts in cold weather. Air movement above 0.1 m/s, the use of individual pig stalls, or the presence of slotted or wet floors all increase the pig LCT. On the other hand, the LCT is reduced if you provide bedding and keep pigs in groups to permit them to huddle. As the temperature increases above the LCT, the rate of animal heat production decreases to a minimum. This range is called the thermoneutral range. The upper end of the range is the upper critical temperature (UCT). Animals should be kept in the thermoneutral range. Above the UCT the animal's body temperature increases. If the animal is kept at this temperature without cooling, it will die.

The thermoneutral range for various sizes of pigs is approximately as follows:

Breeders	7–21°C
Finishers	15–21°C
Piglets	15–34°C

2.55 Cooling

Pigs do not have sweat glands. At temperatures near or above the UCT, they must dissipate body heat either through the respiratory system or by evaporation from wetted skin.

The intermittent spraying of coarse water droplets on larger penned animals has proved to relieve heat stress. The spray is controlled by a thermostat and interval timer, connected in series to control a solenoid valve in the spray line. For example, Sojak (1977) reported a reduction of 0.1 in the feed-to-gain ratio when grouped finishing pigs were sprayed with water at temperatures over 24°C. The spray was supplied for 2 min every half hour, for a total of 0.45 L/h per pig.

In dry climates, the animals may also be cooled by using evaporation pads on the inlet air stream. The relative humidity outside must, of course, be low enough to allow sufficient evaporation for cooling.

Zone or snout air cooling, or drip cooling, can also relieve heat stress of restrained animals such as sows in farrowing stalls.

Table 22 Guidelines for swine housing

Accommodation	Sows	Weaners (under 25 kg)	Feeders (25–100 kg)
Feedlot			
Hard-surfaced	2.3 m^2/sow	0.75 m^2/sow	1.9 m^2/pig
Pasture area	0.4 ha/sows and litters	0.4 ha/25 pigs	0.4 ha/10 pigs
Confinement housing			
Solid floor pen (m^2/animal)	1.8 (under 180 kg) 2.0 (over 180 kg)	0.3	0.5 (under 45 kg) 1.0 (over 45 kg)
Slotted floor pens, total floor area (m^2/animal)	1.5 (under 180 kg) 1.9 (over 180 kg)	0.2–0.3	0.35 (under 45 kg) 0.5 (45–67 kg) 0.7 (over 67 kg)
Slotted floor/ total floor ratio (%)	35–100 (100% preferred)	30–100	30–100
Slot width (mm)	25–32	9 or 25	25–32
Slat width (mm)	38–230	38–130	38–230
Partition height (mm)	1070	700	900
Self-feeder length (mm/pig)	not recommended	50	75
Feed trough length (mm/animal)	450	250	330
Individual feeding stall dimensions (mm)	450 × 600–1800	330 × 1500	
Gestation tie stall (mm)			
Width	600–700		
Length of feed trough			
To gutter	1450–1650		
To slotted floor	1200		
Gestation pen stall (mm)			
Width	660		
Length	1800		
Height	1060		
Farrowing pen dimensions (mm)			
With side creeps, early weaning	1500 × 2100		
With side creeps, late weaning	1800 × 2100		
With front creep	1500 × 2700		
Clearance under creep partition	200–250		
Feed	1 t per sow per year	295–325 kg (birth–90 kg)	

Note: Breeding boar pens should be 7.5 m^2 in area.

Table 23 Relation between body weight, feed intake, and lower critical temperature in groups of growing pigs at normal levels of feeding

Body weight (kg)	Feed intake (kg/day)						
	0.5	1.0	1.5	2.0	2.5	3.0	3.5
	Lower critical temperature (°C)						
20	21	14					
40		20	14	8			
60			18	13	8		
80				16	11	7	
100				18	13	9	
120					15	11	8

Source: Close (1983)

Table 24 Effect of environmental temperature on growth rate, feed conversion efficiency, and carcass composition of 35-kg pigs with a feed intake of 1.58 kg/day

	Environmental temperature (°C)				
	10	15	20	25	30
Growth rate (kg/day)	0.524	0.583	0.612	0.613	0.585
Food conversion efficiency (kg feed/kg gain)	3.02	2.72	2.58	2.58	2.71
Lean gain (kg/day)	0.334	0.336	0.338	0.341	0.344
Fat gain (kg/day)	0.103	0.135	0.149	0.148	0.129

Source: Close (1983)

2.56 Relative humidity

Relative humidity has not been shown to significantly affect pig performance. It is generally agreed, however, that 50% is the lowest desirable level to maintain a supply of mucus in the respiratory tract, and 80% is the highest level allowable to control condensation or fogging in well-insulated buildings.

2.57 Heat and moisture production

Heat and moisture production vary widely and seem to depend on pig activity, floor type, dunging habits, and individual management practices.

Tables 26–27 present field evaluations by Clark, McQuitty, and Feddes (1984) for pigs of 55 kg average weight, housed during the

Table 25 Reduction in growth rate and additional feed requirements per 1°C decrease below the lower critical temperature

	Body weight (kg)		
	20	60	100
Reduction in growth rate			
kg/day	0.014	0.012	0.008
g/kg body weight per day (%)	0.7	0.2	0.08
Additional feed required			
g/day	14	2	2
g/kg body weight per day	0.7	0.33	0.2

Source: Close (1983)

winter in facilities with solid floors or with 35% slotted floors. Average relative humidities were kept low (49–64%) by ventilation and the addition of heat. The ratio of floor latent heat to total heat remained about the same in all barns, but both latent and total heat production were lower in barns with slotted flooring (Table 27). The ratio of latent heat to total heat was higher in barns with solid floors than in barns with 35% slotted floors, suggesting that more moisture evaporates from solid floors than from 35% slotted floors. Fig. 14 gives the required rate of moisture removal versus room temperature for several concrete floor systems. Figs. 15 and 16 give rates for removing moisture and sensible heat from pig rooms, given various pig weights and room air temperatures. Fig. 17 provides data on sensible and latent heat for sows and litters.

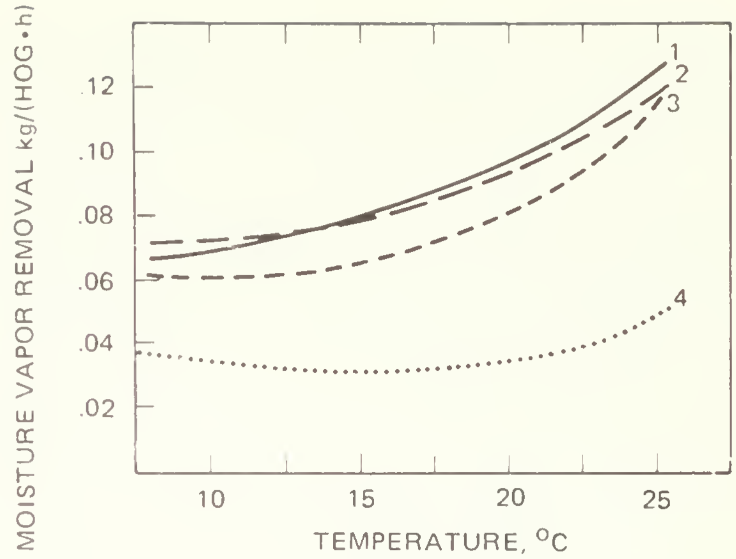


Fig. 14 Moisture removal rate versus temperature for swine
Sources: (1) Bond, Kelly, and Heitman (1959) (concrete floor; average 84 g/h per hog); (2) Harman, Dale, and Jones (1968) (concrete floor, average 86 g/h per hog; (3) Harman, Dale, and Jones (1968) (35% slotted floor, average 73 g/h per hog); (4) Harman, Dale and Jones (1968) (slotted floor, average 36 g/h per hog)

Table 26 Average heat production by pigs in commercial barns

	Barn			
	1	2	3	4
	Solid floors		35% slotted floors	
Total heat[1]	739	843	533	417
Range	432–975	574–1557	378–826	5–770
Sensible heat[1]	515	586	370	281
Range	305–713	345–1005	277–558	–61 to 543
Latent heat	224	257	163	136
Range	126–308	116–720	95–305	66–233
Latent/total	0.30	0.30	0.30	0.33

[1] kJ/(h·pig).

Source: Clark, McQuitty, and Feddes (1984)

Table 27 Comparisons of partitioned latent heat and total heat loads in commercial swine barns (KJ/h·pig)

	Barn			
	1	2	3	4
	Solid floors		35% slotted floors	
Total latent heat	224	257	163	136
Pig latent heat	74	77	85	69
Floor latent heat	150	180	78	67
Floor latent heat/total heat	0.20	0.21	0.15	0.16

Source: Clark, McQuitty, and Feddes (1984)

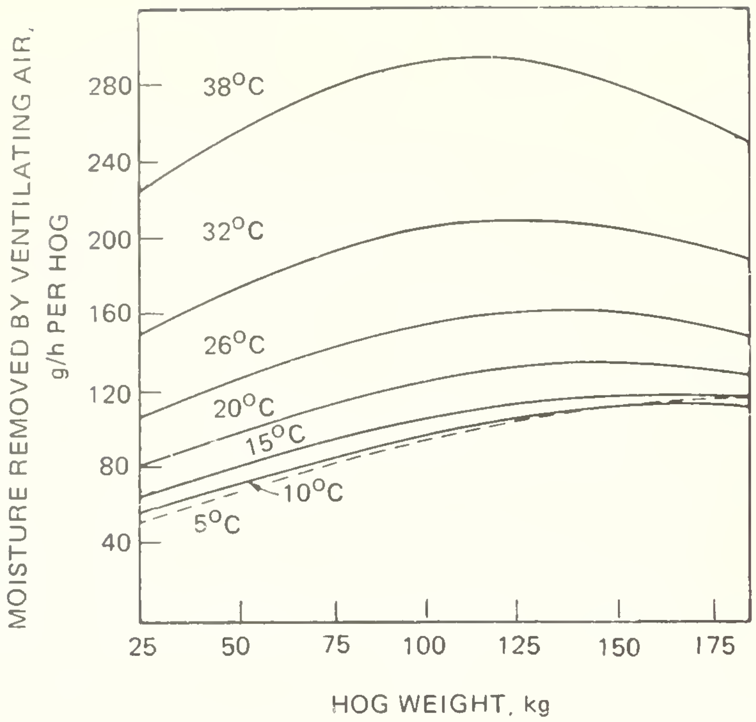


Fig. 15 Total moisture removed by ventilation of test room housing swine for various room temperatures

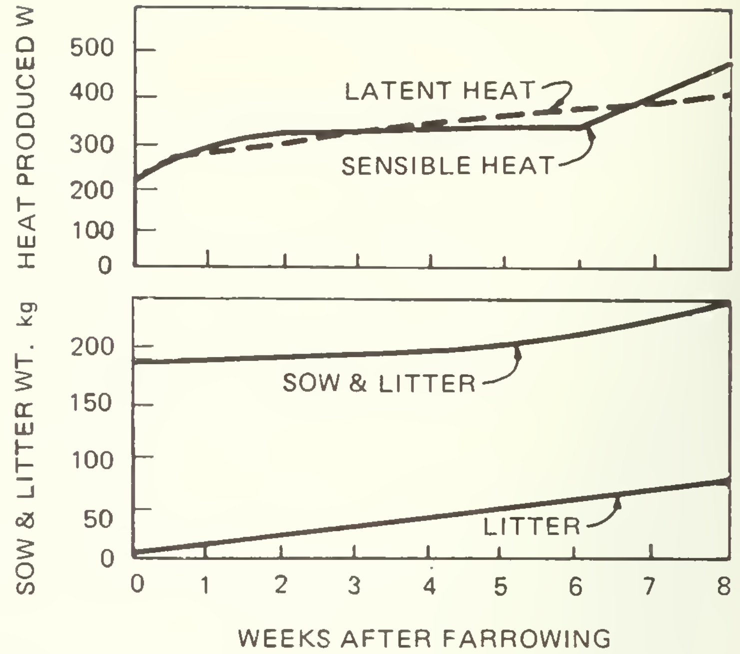


Fig. 17 Building sensible and latent heat and animal weight for sows and litters. Heat and moisture production were measured at environmental temperatures of 10, 16, and 21°C, and then averaged
Source: Bond, Kelly, and Heitman (1959).

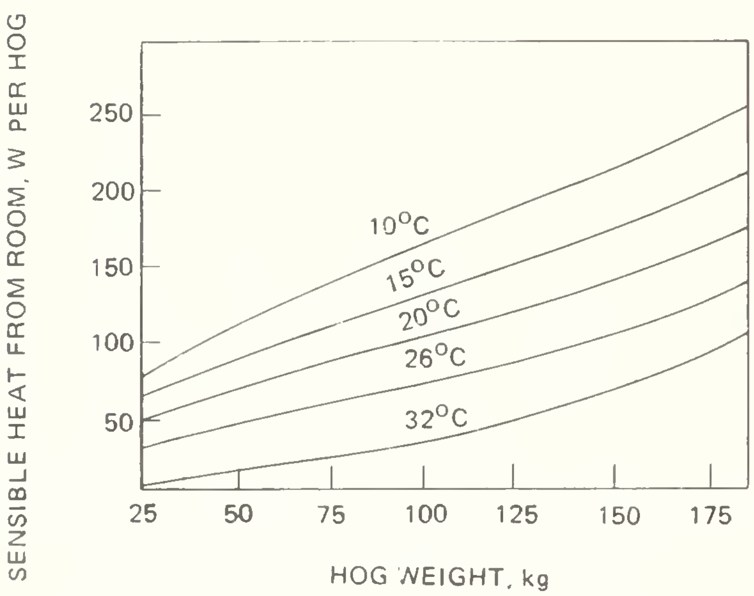


Fig. 16 Curves for estimating room sensible heat in a hog house on the basis of animal size and room temperature
Source: Bond, Kelly, and Heitman (1959).

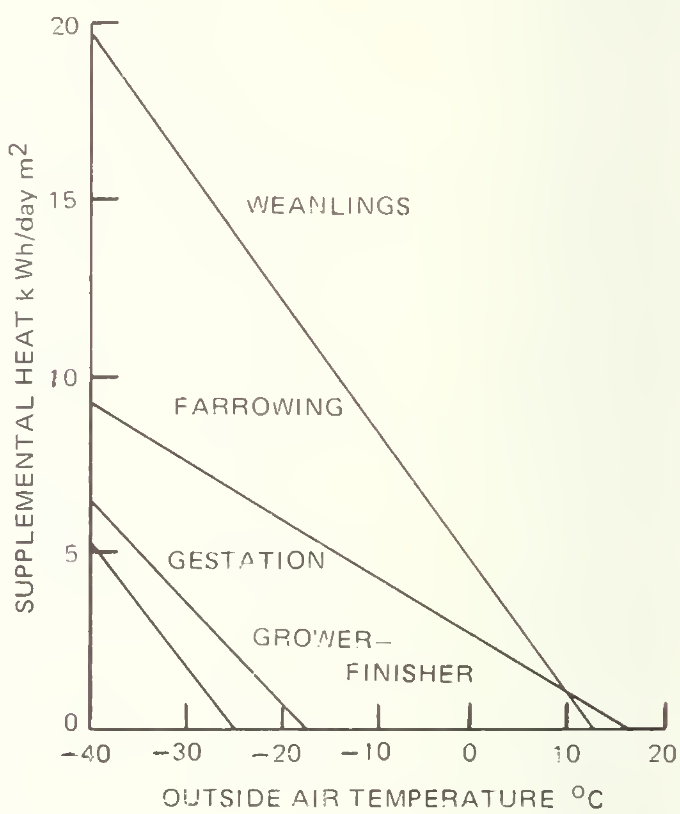


Fig. 18 Estimated supplemental heat requirements of swine buildings as a function of outside air temperature
Source: Sokhansanj and Barber (1982).

2.58 Supplemental heat

Fig. 18 provides a means for estimating supplemental heating requirements for insulated swine buildings at various outside air temperatures.

2.59 FLOORS, MATERIALS, SLOPES, AND FINISHES

Concrete is the most common flooring material because it is relatively cheap, durable, and easily sanitized. Totally or partially slotted floors help remove manure quickly, providing a drier, cleaner resting place. Pigs may require less floor area when part or all of the floor is slotted.

2.60 Slotted floors

Slot and slat width (see Table 22) are important both for keeping pens clean and for preventing injuries to the pigs' feet, legs, and teats. For pigs in stalls, the slats should be at right angles to the stall length for proper footing.

Concrete slats, when properly sized, cast, and placed, are satisfactory, especially for larger animals. Expanded metal, plastic-coated metal, premolded structural plastic, fiberglass, and other smooth materials with low heat conductivity are better for small pigs; these reduce abrasion and body heat loss.

To reduce the accumulation of manure, space the edge slats at least the specified slot width from vertical structures such as center pen dividers or walls.

2.61 Slopes

The solid portions of all pen floors should slope at 1:16–1:25 toward the manure gutter or trenches. Service alleys should be raised at least 50 mm above pen floors and be crowned or sloped toward pen areas.

2.62 Finishes

Very smooth floors and slats can be hazardous to the animals. Do not use power or steel trowels on concrete floors; instead, give the concrete a rough-textured finish.

The pigs' age and development determine the roughness required. Weaner pen floors should be the smoothest and floors in breeding pens and pig traffic alleys should be the roughest. A number of tools provide a roughened finish: magnesium float, wood float, wire brush or broom, or corn broom.

A magnesium float finish is best for the floors in farrowing crates and weaner pens. The floor of the farrowing area must provide adequate footing for the sow without being too rough for the baby pigs. The magnesium float can also be used to finish floors in gestation stalls and pens, finishing pens, and general traffic areas.

Use a rough wood float to finish high-activity passageways such as loading areas, breeding and gestation pens, and pens housing boars.

A normal wood float (in between a magnesium float finish and a rough wood float finish) gives enough traction in growing and finishing pens.

Finish floors with high animal traffic, such as sow wash and weighing areas, with a new corn broom. This is not rough enough for areas such as breeding pens that require good traction.

Use a wire brush or wire broom finish at the rear of individual gestation stalls to improve traction. The grooves should be parallel to the sow to aid in urine drainage.

2.63 FEED STORAGE AND HANDLING

The storage capacity required depends on the delivery schedule for prepared feed, or on the operator's work schedule if rations are prepared on site. Moist feed such as high-moisture corn or barley is susceptible to spoilage and must be prepared and eaten daily.

One common system uses hopper-bottom bins, placed near the housing system, with mechanical conveyors to the feed room or service alley.

The pigs may be fed manually from a cart or the feeding system can be completely mechanized and automated. If you use self-feeders or feed troughs, their lengths should equal or exceed the values given in Table 22.

2.64 WATER REQUIREMENTS AND SYSTEMS

Both the quality and quantity of water are important. Some impurities can affect pigs' growth rate.

Water should be provided at least twice daily, but a constant supply is preferable. In warm barns, nipple-type drinkers on water supply lines are common and minimize fecal contamination. Free-access drinkers should be located in the dunging area. Restrained animals (sows) require a drinker at the front of the stall.

Provide one drinker for each 10 pigs in a pen, but in no case should the number exceed 20 pigs per drinker in warm weather.

Nipple-type drinkers should be set at a convenient height:

Weaners	200 mm from floor
Growers	250–400 mm
Finishers	400–600 mm
Sows and boars	500–600 mm

Table 28 shows daily water consumption.

Table 28 Daily water consumption for swine

Weight or condition	Daily water consumption (L)
22-kg weaner	2.3–3.2
27- to 36-kg grower	3.2–4.5
34- to 90-kg finisher	4.5–7.3
90- to 172-kg sow	5.4–3.6
Pregnant sow	13.6–17.2
Lactating sow	18.1–22.7

2.65 ELECTRICAL REQUIREMENTS

The electrical requirements for controlled-environment housing are high. Pig facilities need electricity for water supply and lighting, and often for ventilation, feed processing, handling materials (including manure), and heating air or water.

Providing standby power and a warning system is an excellent way to ensure emergency ventilation and water supply.

2.66 MANURE HANDLING AND STORAGE

Handling and storage systems depend on the type of manure to be handled (solid, liquid, or semisolid). Table 29 provides guidelines for manure production and storage volumes. The storage should hold at least 6 months' production, but preferably 1 year's production, to make good use of the manure on cropland.

Keep the quantity of manure stored in the barn to a minimum (7–14 days' production) to reduce anaerobic decomposition and gas production. If you install a liquid gutter system, provide for flushing under the slats with fresh water or clear effluent. (Flushing with cold liquid can, however, cause chilling or fogging in the building.) Continuous gravity flow over a weir has also been used successfully. The best way of removing solids from the gutter or trenches may depend on feed ingredients and other management factors.

If you use pipes or channels between the building and the manure storage, install an effective gas trap to stop the back-flow of contaminated air from the storage.

The best system, when the site permits, uses underground gravity flow from all sections of the swine housing to one or two storages behind and downwind from the housing complex.

If it is necessary to agitate liquid manure under the slats, move the pigs out and ventilate the building or take other action to dilute the manure gases. See Sections 2.99–2.104 for further discussion of manure handling and storage.

Table 29 Manure storage volumes for swine

Class of swine		L/(pig·day)		
		Manure production	Required storage for liquid manure[1]	Required storage for solid manure
18–91 kg	(8–22 wk)	5.1	7.1	7.1
4–11 kg	(3–6 wk)	1.1	1.6	
11–23 kg	(6–9 wk)	2.3	3.1	
23–34 kg	(9–12 wk)	3.4	4.8	
34–57 kg	(16–20 wk)	5.1	7.1	
57–80 kg	(16–20 wk)	7.4	10.2	
80–91 kg	(20–22 wk)	9.1	12.7	
Dry sow		11.3	15.9	13.6
Nursing sow and litter				
Wean at 3 wk		15.6	21.8	
Wean at 6 wk		19.5[2]	27.5	

[1] This column is calculated by multiplying manure production by a factor of 1.4 to allow for spillage from waterers, floor washing, and dilution water where required.
[2] Estimated.

2.67 POULTRY

Poultry production in Canada is highly specialized. Poultry equipment manufacturers design their equipment to fit a specific size and shape of building. In offering their equipment to producers, they are in fact promoting a specific building system.

Nonetheless, siting, ventilation, manure disposal, and the adaption of new technology all require an awareness of poultry production cycles and other basic information.

2.68 PRODUCTION CYCLES

Producers usually aim for one of two specific functions – egg production or meat production. Breeder flocks provide fertilized hatching eggs.

All day-old chicks and turkey poults are brooded at decreasing temperatures for a minimum of 4 weeks. The length of the growing phase is determined by the end use of the birds.

Table 30 provides approximate production times and live weight ranges for various classes of commercial poultry.

2.69 HOUSING SYSTEMS

Most Canadian producers rear poultry in confinement. Turkey flocks can be raised free-range in the summer as long as predators are controlled and some shade is available. Most producers tend to specialize in one type of production, so that poultry housing must be planned accordingly.

The site for poultry buildings should be well drained with adequate provision for access, services, and future expansion. Brooding buildings using fuel-fired heaters have the highest fire risk; buildings should be set at least 45 m apart and the furnace room should be isolated from the poultry buildings by a fire separation.

All poultry buildings in Canada (except for barns in seasonal use) should be well insulated. This is especially true for brooding buildings. Use at least RSI 3.5 for walls, 5.3 for ceilings, and 1.4 for foundations to at least 300 mm below grade.

All poultry buildings must be adequately ventilated, either naturally or by fans. The ventilation system often determines the maximum building width – usually about 12 m. Widths up to 18 m or more require special provisions for ventilation inlets.

Poultry buildings are usually one-story, but chicken brooder buildings can have two or more stories to reduce building and brooding costs.

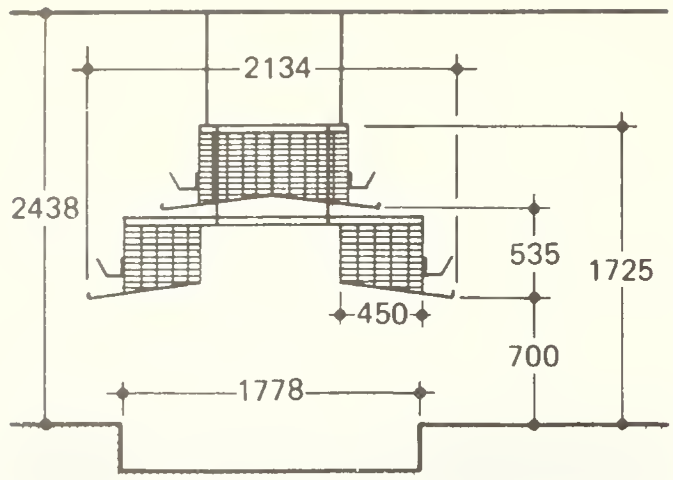
The conveyor drive unit is usually the most expensive component in mechanical systems for distributing feed, gathering eggs, and cleaning out manure. Therefore the lowest cost per bird housed results from extending the conveying equipment and making the building as long as possible. Most poultry buildings have few or no fixed partitions, although moveable cross partitions may help prevent floor-housed birds from crowding if a sudden outside noise frightens them. For these reasons, the structure must be structurally designed to resist overturning and sidesway caused by wind pressure.

Poultry may be caged separately or in groups or held in indoor pens (floor housing). Floor housing is common for breeder flocks, broilers, roasters, and turkeys. The caging of commercial laying hens increases the number of birds per unit area and facilitates the handling of eggs and droppings. To reduce the stress of adjusting to cages, replacement pullets can be brooded and grown in cages. They are usually transferred to laying cages at 18–20 weeks. Typical cage arrangements are shown in Fig. 19.

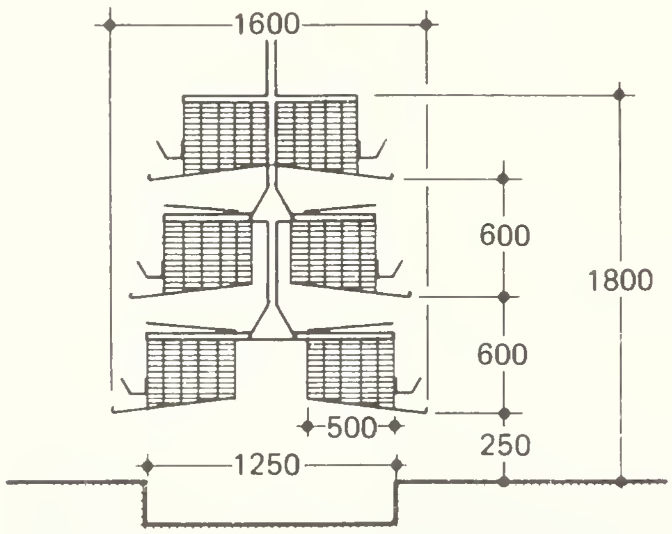
Chicken cages are normally made from 25 × 50 mm galvanized welded wire mesh. Cages may hold from 2 to 16 or more birds, but usually three or four are caged together. Cages for starting and growing replacement pullets usually have level wire bottoms. Baby chicks are brooded for 3–4 weeks on a fine plastic mesh or with newspaper laid on the wire floor. Cages for laying hens have bottoms sloped about 7 degrees toward the cage front. This slope rolls the freshly laid eggs gently forward into an egg trough for gathering.

Table 30 Poultry production times and weights

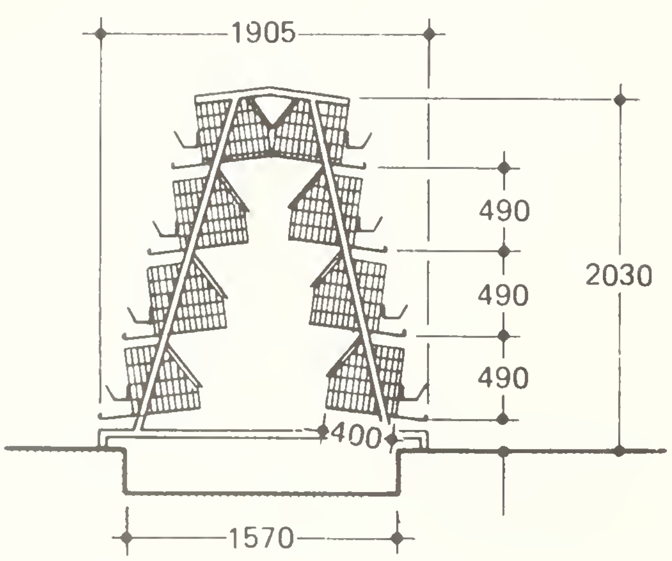
Class	Housing period (weeks)	Weight range (kg) live at end of housing period
Broiler chickens	6–8	1.7–2.0
Roasters	9–12	2.3–2.7
Pullets to lay	18–20	–
Hens (laying period)	13–15	–
Broiler turkeys	11–14	4.5–6.8
Large hen turkeys	15–17	7.2–8
Large tom turkeys	19–22	12.5–15



deep cages, full stairstep, ceiling suspended, 2 levels



deep cages, modified stairstep (with dropping boards), ceiling suspended, 3 levels



modified stairstep, curtain-back, floor suspended 4 levels

Fig. 19 Typical laying cage arrangements

Cages can be floor-supported or suspended from the ceiling depending primarily on the system used to remove droppings. Allow for the weight of suspended cages, if these are to be used, in the structural design of the roof.

Flocks of breeder chickens are housed on the floor in large pens. Part or all of the floor area can be covered in deep litter (loose bedding and accumulating droppings). The remainder of the floor can be made of slats or wire mesh over a shallow manure pit. Suspend feed and water troughs over the slatted floor part to minimize damp in the deep litter part. Nest boxes that are dark inside will encourage hens to lay eggs in nests rather than on the floor.

Excluding the sunlight permits systematic adjustment of the photoperiod (the period of light). Light regulation is essential in all buildings housing pullets intended for laying. Make the building windowless and use light traps on ventilation inlets and outlets.

The choice of system for removing manure from buildings housing caged birds can have a considerable effect on the building design. Droppings can be regularly removed from shallow gutters under cage rows by a cable or motorized scraper, or held in a deep pit under the cages for the laying period and then removed by a tractor with loader.

2.70 SPACE REQUIREMENTS

Tables 31–33 give space requirements for various types and ages of birds housed in floor systems. Turkeys up to 8 weeks of age require 0.1 m^2 per bird floor space and 0.17 m^2 per bird floor space to 14 weeks of age. Turkeys that are to be raised beyond 14 weeks and marketed at heavier weights need at least 1 m^2 per 36 kg of live weight. The length of feeder trough per turkey and the watering equipment per 100 turkeys can be the same as those for chickens and hens, given in Table 33.

The automatic pan-feeder lines in common use serve up to 6 m of pen width, with pans spaced at 750–1000 mm along the feed conveyor. Automatic water lines or rows of automatic fountains are placed so that feeder lines alternate with water lines. Use one more water line than feeder lines.

One pan serves 0.75 m $\times$ 6 m or 4.5 m^2 of pen area, or (4.5 m^2/0.07 m^2 per broiler) = 64 broilers. Therefore 15.6 pans serve 1000 broilers. One circular pan is about equal to 2 m of linear feeding space, giving (2000/64) or 31 mm/bird.

The following guidelines should be used for designing poultry housing:

Table 31 Floor systems for broiler chickens, roasting chickens, and pullets

	Age (weeks)			
	0–2	3–6	7–10	1–20
Floor area per bird (m^2)	0.05	0.07	0.07	0.14 (light breeds) 0.19 (meat breeds)
Length of feeding trough per bird (mm)	25	50	75	75
Watering equipment per 100 birds	2 fountains of 4.5 L each	automatic trough 1.5 m long *or* 2 fountains of 13.6 L each	automatic trough 1.5 m long *or* 2 fountains of 13.6 L each	automatic trough 2.5 m long

Table 32 Requirements for floor systems for laying chickens and chicken-breeding flocks

Accommodation	Deep litter; dropping pits under roosts	Combined wire or slats (1/2–2/3) and deep litter (1/2–1/3)	All wire or slats (minimum)
Floor area per hen (m^2)			
Egg-strain breeds	0.19	0.09	0.05
Heavy breeds (over 2.3 kg)	0.28	0.14	0.09
Feeding space per 100 hens	If hand fed, 6 m of double-sided troughs *or* four round hanging feeders (pan diameter 9.4 m); for automatic feeding reduce feeding space by 50%		
Watering equipment per 100 hens	Two watering cups; two 19-L fountains *or* 1.5 m of linear drinking troughs		
Nesting space per 100 hens	20 nests 250 × 300 × 325 mm high for both light and heavy breeds *or* 1 community nest 0.6 × 2.4 m, not more than 500 mm above the floor		

Table 33 Housing for turkey breeding flocks

Item	Requirements
Floor area per bird, all breeds (m^2)	0.5
Feed space per bird (mm)	75
Watering space per bird (mm)	38
Nest space per five hens (mm)	One nest, 350 × 600 × 600
Daily feed consumption per bird (kg)	
Broiler strain	
Toms	0.34
Hens	0.23
Heavy strain	
Toms	0.90
Hens	0.34
Broody space[1]	0.05 m^2 of wire floor, no bedding, well lighted

[1] Area separate from breeding pen used to isolate broody breeder.

- The floor area for multiple laying cages should be about 0.04 m^2 per 1.6 kg bird (for example, two birds in a cage 200 × 400 mm, three birds in a cage 300 × 400 mm, or three birds in a 400 × 300-mm "reverse" cage). For 2-kg birds, the cage floor area should be increased to 0.045 m^2 per bird (two birds in a cage 200 × 450 mm).
- Multiple bird breeder cages should allow 0.06 m^2 per bird – for example, 20 hens and two cockerels in a cage 550 mm × 2400 m and 575 mm high.
- Feeder trough space should be 100 mm per bird for two or more birds per cage.
- Cage height should be at least 400 mm so that hens can stand erect.
- If you use carts for feeding and egg gathering, provide a clear passage of 800 mm between cage rows and to longitudinal walls, and a clear passage of 2.4 m at end walls for turning.

Table 34 shows typical cage sizes and bird densities for commercial laying flocks.

2.71 ENVIRONMENTAL REQUIREMENTS

Temperature Most adult birds can tolerate a considerable range of temperature and relative humidity. Chickens can be housed at 10–29°C. Heavy turkeys are more vulnerable to heat stress and should not be subjected to temperatures above 21°C if possible. For maximum efficiency, the housing temperature should be above the lower limit. Newly hatched chicks and poults suffer from cold; see Table 35 for a temperature guide for the brooding period.

Relative humidity The relative humidity in poultry buildings should be 50–75%, high enough to minimize airborne dust from litter and feed, and low enough to prevent condensation or fogging.

Heat and moisture production The rate of removal of heat and moisture depends on the housing system. Table 36 presents information on three cage-laying units; the data are for white leghorns in Alberta during winter months. Dark and light periods indicate the effect of bird activity.

Fig. 20 shows the total heat production of growing turkeys, based on age and time of day. Fig. 21 shows the total heat production and moisture removal from barns for broiler chickens in Alberta over the complete production cycle, based on bird age. The barns studied were one-story wood-frame buildings with earth floors and short-cut straw for litter; they were heated by wall-mounted hot-water systems. The room temperature was lowered from 33 to 21°C over the 7-week cycle.

Table 37 shows the total production of latent and sensible heat by caged and floor-reared replacements in Alberta over the complete production cycle. The birds were white leghorn pullets. The higher total heat production from broilers (compared to pullet replacements) is primarily latent heat.

Heating or brooding A heating or brooding system is necessary for certain types of poultry production. Heating may be needed to provide brooding temperatures with little or no ventilation, or to warm incoming air for ventilation in cold weather. The system must

Table 34 Recommended bird densities for commercial laying flocks confined in cages

Cage floor dimensions, length along feeder × cage depth (mm)	Floor area (m^2)	No. of birds/cage
305 × 457	0.14	3[1]
305 × 508	0.15	3
381 × 508	0.19	4
457 × 356	0.16	4
500 × 480	0.24	6
508 × 457	0.23	6
610 × 356	0.22	5
610 × 508	0.31	7

[1] The above densities are generally one or two birds per cage less than manufacturers' recommendations.

Table 35 Temperature guide for brooding chicks and turkey pullets[1]

Age of birds (weeks)	Suggested temperature under brooders, 50 mm above floor near edge of hood (°C)	Temperature of building (°C)
Up to 1	35	24–27
1–2	32	21–24
2–3	29	23–24
3–4	27	22–23
4–5	21–24	21–22
Over 5	reduce by 1 degree per week to 18	

[1] These temperatures are guides only. The temperature should be adjustable according to behavior of chicks or poults. If it is too hot, birds cluster along the cardboard enclosures; if too cold, they stay under the brooders and stop eating and drinking.

Table 36 Partitioned latent heat and total heat loads in each of three commercial cage-laying barns for three periods

	Barn								
	A Triple deck			B Deep pit			C Shallow gutter		
	Light	Dark	Daily avg.	Light	Dark	Daily avg.	Light	Dark	Daily avg.
Measured total heat, kJ/(h·bird)	33.2	24.9	29.5	34.3	28.7	32.2	34.6	31.0	33.2
Measured latent heat, kJ/(h·bird)	9.8	6.8	8.4	8.8	6.5	7.9	8.3	6.8	7.9
Latent heat removed/total heat	0.30	0.27	0.28	0.26	0.23	0.25	0.24	0.22	0.24
Bird latent heat, kJ/(h·bird)[1]	6.6	5.0	5.9	6.9	5.7	6.4	6.9	6.2	6.6
Building latent heat, kJ/(h·bird)[1]	3.2	1.8	2.5	1.9	0.8	1.5	1.4	0.6	1.3
Building latent heat/total heat	0.10	0.07	0.08	0.06	0.03	0.05	0.04	0.02	0.04

[1] Total heat × 0.2 = bird latent heat.

Source: Feddes and McQuitty (1983)

Table 37 Total latent and sensible heat production from floor-reared (barn A) and caged (barn B) white leghorn pullet replacements

Bird age, days	KJ/(h·bird)					Total latent/ total heat converted	% sensible heat
	Total heat	Sensible heat	Total latent	Bird[1] latent	Building latent		
Barn A							
10	2.4	1.0	1.4	0.4	1.1	0.58	50
36	6.7	4.5	2.2	1.6	0.6	0.33	12
61	14.3	9.9	4.4	3.0	1.4	0.31	12
90	19.6	14.1	5.6	5.1	0.5	0.29	3
Barn B							
6	2.3	1.2	1.1	0.5	0.6	0.48	33
35	13.3	7.9	5.4	2.0	3.4	0.41	30
63	19.2	12.3	6.9	3.3	6.6	0.36	35
93	27.2	19.0	8.2	4.5	3.7	0.30	16
113	27.7	19.5	8.2	5.5	2.7	0.30	12
134	30.5	20.5	10.0	6.4	3.6	0.33	15

[1] Estimated from calorimetric data (Scott et al. 1983).

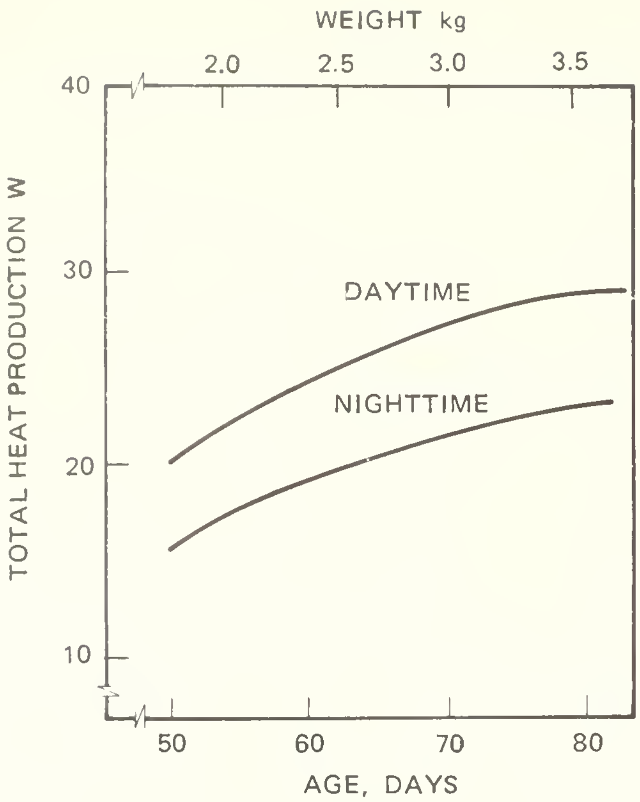


Fig. 20 Total heat production of growing turkeys
Source: Buffington, Jordan, and Boyd (1982)

be flexible enough to allow brooding in cold or warm weather; it should be easy to regulate and safe to operate in a dusty environment.

Types of heating systems and design guidelines can be found in Part 6.

2.72 FLOOR MATERIALS

All floor materials, especially those for cages, must not injure or deform the birds' toes during any period of the production cycle.

In floor production, clean wood shavings, cut straw, and shredded paper may be used for litter. All materials should be dry, free from disease-carrying organisms, and highly absorbent. Arrange ventilation and heat to maintain litter moisture below 35% moisture content on a wet weight basis.

All litter materials should be removed between bird production cycles to allow the building to be thoroughly cleaned and disinfected.

Heated concrete floors without litter have been used for poultry brooding in Atlantic Canada, but the system is not widely used.

2.73 FEED REQUIREMENTS, HANDLING, AND STORAGE

Prepared feed is stored in bulk storage bins for delivery to feed carts or automatic feeding system. Tables 31–33 provide minimum feeder space requirements. For laying hens, feed storage requirements should be based on average consumption of 0.11 kg/hen per day for light breeds and 0.16 for heavy breeds.

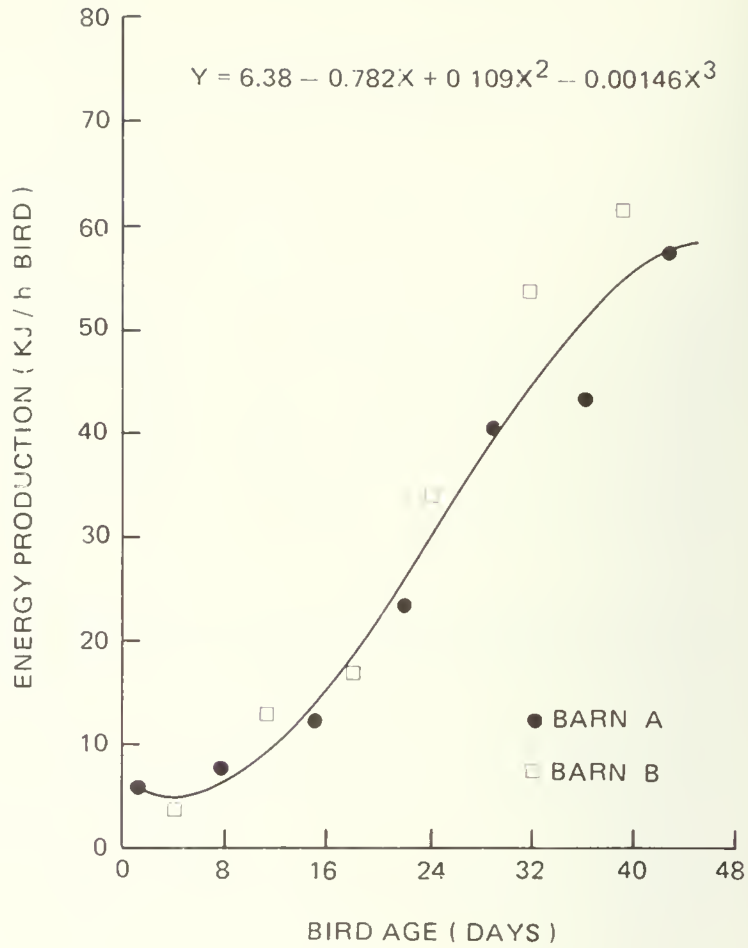


Fig. 21 Total heat production and building latent heat for broiler chickens in two barns during complete production cycle
Source: Feddes, Leonard, and McQuitty (1982)

2.74 WATER REQUIREMENTS AND SYSTEMS

For good production and growth, poultry need a continuous supply of fresh water. Birds drink 0.9–1.4 L of water for each kg of feed consumed. Tables 31–33 give minimum watering space per bird, or equipment per 100 birds, for all floor systems. Drinkers should not be more than 1.2–1.5 m from feeders.

Water must be continuously supplied to each caged bird. This can be done by small V-troughs or by individual drip drinkers or cups for each cage or pair of cages.

The following guidelines should help in designing watering systems. For each 100 birds, provide the following number of litres per day:

Chicken broilers	11–16
Roasters and pullets	14–18
Laying hens	18–32
Turkey broilers	230–360
Heavy turkeys	up to 450

The larger quantities are for heavy birds or in hot weather.

Install a water meter in the distribution system to monitor consumption, and provide for a medication dispenser.

When eggs are washed on the farm, supply hot water as specified by the washer manufacturer.

2.75 ELECTRICAL REQUIREMENTS

All poultry buildings with mechanical ventilation require warning systems for high or low temperature, power interruption, and low water pressure. Make provision for standby power.

Since natural light does not provide the desired daily light periods for poultry, artificial lighting is used almost exclusively. All lighting outlets should be controlled by wall switches and time clocks. When a variable lighting level is required, install dimming controls.

Electricity is usually needed for water supply, lighting, ventilation, and handling materials; it may also be used for brooding or feed processing. See Section 6.49 for lighting requirements.

2.76 MANURE HANDLING AND STORAGE

Table 38 gives guidelines for the volume of manure (droppings), including litter materials; plan manure storage accordingly.

Poultry manure can be handled in various ways depending on the housing system. Floor systems using litter normally produce manure that is dry enough to be handled by box spreaders. The manure must be stockpiled if poultry units are cleaned at times when manure cannot be applied to the land. Use at least a curbed slab with adequate provision for collecting runoff; in areas with heavy precipitation, the slab may have to be roofed.

When birds are caged or on slats, poultry manure is normally semisolid. If the manure is collected in deep pits under the birds and partially dried by exhausting the ventilation air over the manure, it may be loaded by a tractor onto a box spreader with an end gate.

Droppings from caged birds may be collected by various methods and must be held in a walled storage. This can be earth or concrete, depending on soil conditions and local requirements; try to protect the manure from dilution by seepage or rainwater. A roof or cover minimizes odors and keeps out rainwater. If the manure is to be pumped out and spread by a tanker or irrigation equipment, it should be diluted during agitation. See Sections 2.99–2.104 for details on manure handling.

Table 38 Poultry manure storage volumes

Bird	Volume of manure/bird (L/day)	Volume of manure and bedding/bird (L/day)
Chickens		
Broiler (0–1.8 kg)	0.08	0.14
Laying hen (1.8 kg)	0.14	
Turkeys		
Broiler (0–14 wk)	0.13	
Growing hen (0–22 wk)	0.18	
Growing tom (0–24 wk)	0.28	
Breeder	0.34	

2.77 GATHERING, GRADING, AND HOLDING EGGS

Eggs can be gathered by hand from nest boxes or cage systems, or by mechanized conveyors from specially designed cage systems. Eggs should be gathered at least twice a day into baskets or containers that allow rapid cooling. Eggs should be immediately cooled to between 7–13°C. The humidity in the cooler should be as close as possible to 70% to minimize moisture loss.

Egg conveyor belts must carry the eggs smoothly in single file to prevent bumping and cracking. Where carts are used for egg gathering or transport, straight passages should be at least 850 mm wide and turning areas should be at least 2.4 m wide.

All rooms used for holding and grading eggs should be well lighted, heated, and ventilated. Floors should slope to drains; floors, walls, and ceilings should be smooth for easy cleaning and disinfection.

Table 39 provides guidelines for sizing egg rooms, based on caged laying hens producing 1.67 cases/100 hens per week. Refrigeration equipment should be powerful enough to cool the eggs quickly and to deal with heat gains from other sources, including conducted room heat and infiltration gains. If the walls or ceilings of egg rooms are exposed to the outdoors, they may need to be heated to keep the eggs from freezing in cold weather.

Table 39 Sizes for egg cooling rooms[1]

	Flock (thousands of birds)			
	3.0–3.6	3.6–4.2	4.2–6.0	6.0–9.0
Minimum inside size (m^2)	6	8.4	10	13
Cases (30 doz)	60	70	100	160

[1] Based on 1.67 cases/(100 hens·week).

Table 40 Accommodations and feed storage for horses

Accommodation	Two years old or more		Yearling
	Small breeds	Large breeds	
Tie stall dimensions (m)			
Width	1.5	1.5	
Length	3[1]	3[1]	
Box stall	3 × 3	3.6 × 4.3	2.4 × 3
Hay manger (mm)			
Width	690	690	600
Height at throat	960	1070	840
Grain box dimensions (mm)	300 × 600	300 × 600	460 × 250
Feed storage (kg/year·horse)			
Hay	1800	1800	900
Grain	620	1240	460

[1] Including manger.

2.78 HORSES

Horses are kept for various purposes, but the most popular reason is for riding, either individually or in commercial riding establishments. This section deals specifically with housing for riding horses.

2.79 PRODUCTION CYCLE AND HERD MAKEUP

The gestation period for a mare is about 330 days. Few commercial riding establishments maintain stallions. Mares to be bred are usually serviced elsewhere and returned for foaling.

Housing is usually required for mares and geldings in the 400–650 kg weight range and for some foals as small as 45 kg and up to 160 kg at weaning.

2.80 HOUSING SYSTEMS

In the summer, horses can be pastured with some protection from sun and wind provided by sheds or open-front structures. For winter (and often year-round) they may need more substantial housing. Stables can be single-storied or may have overhead lofts for hay and bedding. Riding horses are usually kept in individual box stalls or tie stalls. This allows individual attention and prevents them from kicking each other.

Provide an indoor or outside arena for winter riding or exercising. Indoor riding arenas should provide wide, clear-spanned areas.

2.81 SPACE REQUIREMENTS

Table 40 presents basic dimensions for housing horses.

Many barns have only box stalls. Tie-stall barns should include one or more box stalls for sick animals, mares at foaling, and colts. If possible, box stalls for foaling mares should be 4.8 × 6.0 m. A large temporary box stall can be made by installing a removable partition between two regular box stalls; this can be removed when necessary.

The partitions between box stalls should be 2.1 m high to prevent contact between the animals. The bottom 1.4–1.5 m should be solid 38-mm hardwood planking, both to prevent drafts and to protect the animals.

The minimum alley width between rows of face-out stalls or pens should be 3 m, or 1.8 m between the rear of stalls and the wall. Feed alleys and cross alleys should be at least 1.2 m wide.

The ceiling height over stalls and passages should be at least 2.7 m for larger breeds; 3 m is better. Riding arenas should have a vertical clearance of 4.2–4.8 m.

Stables should include a tack room and short-term feed room, both at least 11 m^2. Their size depends on the number of horses stabled.

All fragile equipment such as light fixtures, ventilation fans, water lines, and windows should have guards or be set out of the horses' reach.

2.82 ENVIRONMENTAL REQUIREMENTS

Horses should be kept in a dry, draft-free environment with temperatures between –7 and 29°C. The relative humidity should be between 25 and 75%.

Usually stables are ventilated by fans in winter and naturally by windows and doors in summer. Because of the relatively low number of animals housed in a stable, condensation or fogging can create problems in cold weather. Air should be exhausted to reduce the moisture content, and incoming air should be heated. For natural ventilation in warm weather, each box stall should have a guarded window that can be opened.

A warm ventilated area should be provided for washing or cooling down the animals after strenuous exercise.

2.83 FLOORS, SLOPES, MATERIALS, AND FINISHES

Packed stone-free clay on a well-drained base makes a good resilient flooring for horse stalls. Concrete floors are the least desirable for tie stalls and box stalls but are good for wash areas, feed rooms, feed alleys, and tack rooms. Concrete should be sloped for drainage in wash areas; it should have a texture equivalent to a broomed finish to prevent slipping in traffic areas.

Provide straw bedding, changed daily, to keep the stalls dry and odor-free. To minimize floor maintenance, especially in tie stalls, use wood plank floors spaced over sloped concrete.

2.84 FEED AND BEDDING REQUIREMENTS

Feed storage and feeding unit sizes are given in Table 40.

- Grain can be stored temporarily in bags in the feed room, but rodent-proof bins with tight lids are better.
- Hay and straw can be held in a loft or in separate on-grade storage.
- The amount of bedding needed varies with the type of housing but is about equal to the annual hay storage.

2.85 WATER REQUIREMENTS AND SYSTEMS

Horses require from 30 to 50 L of water per day. Most horses are watered by hand from a frost-free hydrant in winter and are given free access to water troughs in summer. One frost-free waterer can serve two stalls or 8–10 horses in a lot.

2.86 ELECTRICAL REQUIREMENTS

Electricity is usually needed for water pumps, lighting, and grooming aids. It may also be required for frost-free hydrants and waterers, space and water heating, feed processing, and other domestic uses in the tack room, and for keeping foals warm.

See Section 6.46 for specific information on lighting layout and equipment.

2.87 MANURE HANDLING AND STORAGE

Each adult horse produces about 26 L/day of manure; with bedding, this amounts to 55 L/day. Plan manure storage accordingly.

Manure is usually removed as a solid each day by hand, using a wheelbarrow or other conveyance. If you provide a work alley at least 3.0 m wide with sliding doors at each end, the manure can be loaded directly into a trailer, truck, or box spreader.

Stored manure should be piled on a well-drained site away from water sources and natural drainage channels. Empty the storage at least weekly during warm weather to control flies.

Manure can be field-spread with a box spreader but is often supplied to local mushroom producers.

2.88 SMALL FUR AND MEAT ANIMALS

Mink, foxes, and chinchilla are raised commercially for fur. Rabbit production is primarily for meat. Since most of these operations are specialized and husbandry practices are still evolving rapidly, this section deals only with common design factors affecting animal wellbeing and productivity.

Since rabbits benefit most from intensive enclosed housing, most of the following discussion considers their housing needs.

2.89 PRODUCTION CYCLE NORMS FOR RABBITS

Female rabbits (does) are usually first mated at 4.5–6 months. The gestation period is approximately 31 days and the doe returns to the estrus cycle immediately after birth. The breed-back period varies from 14 to 35 days, depending on weaning time, available cage facilities, and breeding program. Five litters per year are common with up to eight possible.

The normal goal is to produce 1.8-kg fryers at 8 weeks of age, although heavier rabbits (11–12 weeks) are also produced. Weaning can occur as early as 3 weeks after kindling.

Rabbit breeding is sensitive to day length (photoperiod) and therefore requires light control. Windowless housing is preferable.

2.90 HOUSING SYSTEMS

- Rabbits can be raised in outdoor hutches, but commercial producers usually raise them in cages in closed housing units.
- The rabbitry should be well insulated and ventilated to provide a dry, draft-free environment, kept above freezing temperature.
- Plan on housing one male rabbit (buck) separately for each 10 does.
- Cages can be at one level or in several tiers to make more efficient use of building space.
- Maternity cages with removable nest boxes can also be used for replacement stock, bucks, and pregnant does. If you produce heavier rabbits requiring 10–12 weeks of housing, use a separate feeder area for them.
- Depending on the breeding program, the rabbitry needs 40–90% more cages than the number of breeding does in the herd.
- A separate quarantine area should be available for sick rabbits and incoming breeding stock.
- If cages are suspended, the roof system must be designed to support the additional load.

2.91 SPACE REQUIREMENTS

Rabbits Maternity cages should have at least 0.38 m^2 of floor area for smaller breeds when the nest is recessed, or 0.56 m^2 when the nest is not recessed. For medium-sized breeds, the cage floor area should be 0.70 m^2. The cage height should be at least 375 mm for smaller breeds and 450 mm for medium breeds.

Cages should be made from 14-gauge welded galvanized wire, or its equivalent, to permit good air flow. The bottom and sides to 100 mm above the bottoms should be 25 mm × 12.5 mm "baby-saver" mesh. The remainder of the sides can be 25 mm × 25 mm mesh. The top can be 25 mm × 25 mm or 25 mm × 50 mm mesh.

Nest boxes should have solid sides and bottoms for privacy, and should provide at least 0.12 m^2 of floor area for small breeds and up to 0.15 m^2 for medium breeds. The nest box should be 300 mm deep with an opening at least 150 mm and not more than 175 mm above the cage floor. If necessary, the nest box can be temporarily covered to settle a fretful doe.

With back-to-back cages arranged in rows, the walking space between pairs of cage rows should be 1 m. Walkways should be slightly narrower to avoid treading on the droppings. Cross alleys at the end of cage rows should be at least 1.2 m wide; 3 m is better if feeding or manure-removal equipment must turn.

Mink The breeder pen for confinement of bred females should be at least 460 × 760 mm and 460 mm high. Space should be provided to attach a nest box of 250 × 250 × 460 mm.

Side-by-side mink pens arranged in rows should be spaced 38 mm apart, or separated by sheet metal or closely spaced wire mesh, with a clear alleyway at least 1 m wide between rows of pens. Pens should be elevated at least 460 mm above ground.

Pen areas should be surrounded by a 1.2-m guard fence extending at least 150 mm underground and designed to exclude other animals such as dogs.

Foxes Individual fox pens should be 1.2 × 2.1 × 1 m high, with the pen bottom set 600 mm above grade.

2.92 FLOORING IN RABBITRIES

The use of concrete floors with raised walkways between cage rows allows manure to be scraped or flushed into an outside storage tank. Alternately, the use of earth or gravel-bottom manure pits with tile drainage reduces the amount of urine exposed to the air, and thus the production of ammonia. Floor gutters for droppings under cage rows should extend at least 100 mm beyond cage fronts. For liquid flushing, gutters should be 250 mm deep, with sides sloping from the feed passage to a 600-mm-wide flat bottom in the gutter. Gutters should be sloped slightly to the outlet end.

2.93 ENVIRONMENTAL REQUIREMENTS FOR RABBITRIES

The recommended temperature limits for rabbit housing are -7 to 29°C; ideally it should be in the range of 10–18°C. The temperature should be kept above freezing to prevent the water distribution system from icing. Relative humidity should be kept at 50–75%.

For design purposes, assume that one 2.3-kg rabbit produces 32–42 kJ of sensible heat and 6.5–9.7 g of moisture per hour in the 10–16°C range. The rabbitry temperature and manure system affects these values.

2.94 FEED REQUIREMENTS FOR RABBITRIES

Provide storage for 45 kg of pelleted feed (plus hay, if used) per doe and litter. Keep feed dry, protected from rodents, and out of the rabbit housing area. Provide a self-feeding hopper with a 1-day capacity of 450 g of pelleted feed for each cage. The hopper lip should be 75–100 mm above the cage floor to prevent contamination. A creep feeder with a number of small round openings can be located under the doe hopper.

2.95 WATER REQUIREMENTS AND SYSTEMS FOR RABBITS

Rabbits must have access to fresh, clean water at all times. Provide one watering device per cage. Individual waterers are acceptable, but the use of automatic low-pressure watering systems with hose and "dew-drop" valves in each cage helps to reduce labor.

2.96 ELECTRICAL REQUIREMENTS FOR RABBITRIES

Electricity is required for water supply, lighting, and ventilation and may be required for space or water heating.

2.97 AUXILIARY FACILITIES

Before building an abattoir, thoroughly investigate local, provincial, and federal meat inspection requirements. These regulations determine what facilities you need. For fur-production operations, allow for a pelting room.

2.98 MANURE HANDLING

For details on manure management, see the following sections. Use the following figures as a guideline:

Rabbits:	doe and litter	0.7 L/day
	fryer	0.3 L/day
Mink:	female and kits	0.2 L/day

2.99 MANURE MANAGEMENT

Manure is a useful byproduct of all animal production, but for maximum benefit, it must be stored and applied to land within a limited period of time. Table 41 provides guidelines for determining equivalent fertilizer values for manure.

Spreading manure on frozen ground or applying too much at one time not only wastes nutrients, but also greatly increases the risk of polluting surface or ground water and air. Most provinces have specific legislation or guidelines, and these should be followed to minimize the effects of animal manure on the environment and the inconvience to neighboring property owners.

Further details can be found in *Canada Animal Manure Management Guide*.

2.100 MANURE HANDLING AND STORAGE

2.101 Calculating storage requirements

Manure storages should be large enough to hold at least 6 months' and preferably 1 year's manure production, plus any dilution or wash water added, or rain or snow that enters. Flushing gutters significantly increases the volume required.

Table 41 Nitrogen, phosphorus, and potassium excreted by animals over a 365-day period

	kg		
	Nitrogen (N)	Phosphorus (P_2O_2)	Potash (K_2O)
1 dairy cow (545 kg)	64	30	80
2 beef cows (182–500 kg)	64	30	80
6 pigs (14–90 kg)	64	36	22
120 hens (2.3 kg)	64	51	28
180 broilers (0–1.8 kg)	64	29	25

Note: Figures refer to freshly voided manure and include feces and urine. The kind of manure management system has a very large influence on actual nutrient content at time of land application.

Source: (From Jones et al. 1968)

Use the average number of animals confined during the storage period, *not* the total number of animals produced, to calculate storage size.

To minimize the space required for liquid manure storage, add only enough dilution water to bring the moisture content to about 90% for easy agitation and pumping, unless you plan to apply the manure through an irrigation system.

Use the following formula to determine the size of manure storage:

$$V_s = (N_a \times V_m \times T)/1000 + V_w$$

where

V_s = volume of storage, in cubic metres

N_a = number of animals confined during storage period

V_m = volume of manure produced in litres per animal per day

T = storage time in days

V_w = volume of dilution water in cubic metres

See Fig. 22 for the amount of dilution water needed to change the moisture content.

To calculate the volume of detention basins to store runoff from open feedlot and manure storage areas, use the following formulas:

For paved feedlots:

$$V = A \times (0.48\,P_m + 0.65\,P_s)$$

For unpaved feedlots:

$$V = A \times (0.22\,P_m + 0.45\,P_s)$$

For solid manure storages:

$$V = A \times (0.25\,P_m + 0.65\,P_s)$$

where

V = volume of detention basin in cubic metres

A = area contributing to runoff in square metres

P_m = sum of the November–April (6 months) mean monthly total precipitation (rainfall plus equivalent water depth of snowfall) in metres

P_s = the maximum 24-h precipitation from a storm expected once each 25 years, in metres

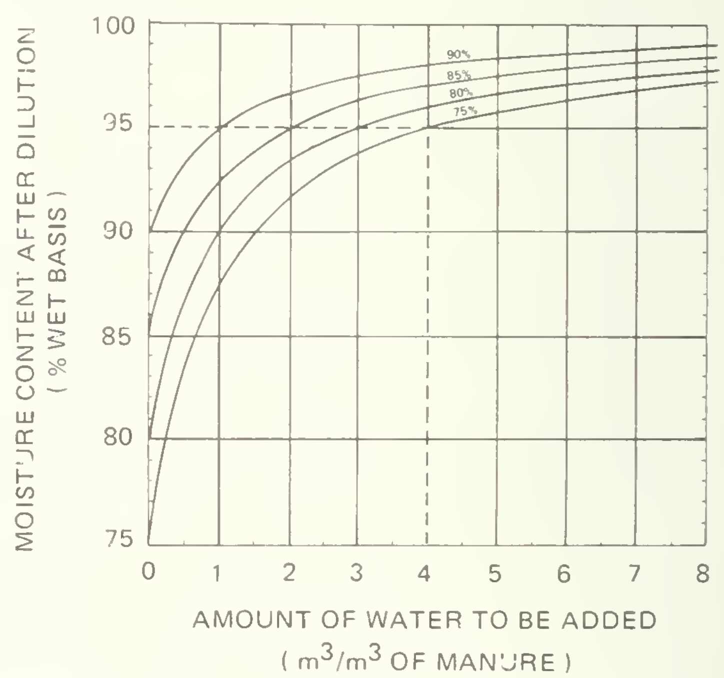


Fig. 22 Volume of dilution water required to change the moisture content of manure

In commonsense terms, the design storage capacity should be based on winter runoff plus the worst storm runoff that could occur before emptying the storage in the spring. From May to October, the runoff can be applied to cropland.

A settling basin between feedlot and detention basin to remove some solids from the runoff, although not always built, is useful. As a guide to design, the surface area of the settling basin should be about 2.5% of the feedlot area that contributes runoff, and the depth should be 0.6–1.2 m. The ramp and bottom of an earthen settling basin should be paved if solids are to be removed with a tractor scraper or bucket.

2.102 Constructing manure storages

The details of the design of manure systems are critical; they can depend on animal feeding and management systems as well as the site and climate. Ask your local extension engineering for advice before designing such systems.

Storage facilities for manure or runoff should be watertight to avoid polluting the ground water. Although most storages are constructed as single units, multiple units may be necessary when it would be uneconomical to build beyond a particular capacity, or when agitation equipment has limited capacity.

Solid manure storages must have a paved slab to provide a footing for the operation of loading equipment, and a perimeter curb to contain liquid runoff. In areas of heavy precipitation, it may prove economical either to add a roof or to drain the runoff to a nearby holding pond. The floor of the storage should slope to a low corner, preferably that diagonally opposite to the paved entrance ramp. The crown of the ramp and the top of the perimeter curb should both be at the same level to maximize the storage capacity.

Semisolid manure storages require a slab surrounded either by a concrete wall or by a low curb combined with an earth bank to contain both liquid runoff and sloppy manure. Provide a ramp entrance for manure removal equipment. Outside the storage, slope the ramp to exclude drainage water from the yard. If the floor slab slopes to a low point at the corner opposite the entrance ramp, it is easier to completely remove the liquid by a vacuum tanker or irrigation system. An optional drain or porous wall and drain may be installed at the low corner, or along one side and adjacent to the loading ramp, to allow liquids to separate and drain into a separate storage basin.

In areas of heavy precipitation, a roof or cover over a rectangular walled storage may prove economical. Where odors from storages create a nuisance, rectangular storages can be covered at less cost than circular storages.

Liquid manure storages can be either below or above the level of collecting gutters or sumps.

Below-ground storages Storages below gutters or alleys can be filled by gravity flow. The manure must be agitated before it is removed, an operation commonly done with a manure pump powered either electrically or by a tractor power takeoff (PTO). The effective agitation radius of a typical tractor-powered vertical-shaft manure pump is only 7–9 m; circular storages should therefore be no more than 15 m in diameter with pump access at two opposite sides. Rectangular storages work best if they are divided into compartments no larger than 7 × 9 m with the pump access midway along one long side.

Earthen manure storages are inexpensive, but they need either a suitable dock for a tractor and a vertical-shaft pump agitator near the deepest part of the storage, or a ramp access for an inclined-shaft propellor agitator or pump. Install a paved slab under the pump to prevent erosion while pumping. Unless the manure is pumped under pressure, the inlet pipe should be above the liquid level in the storage, since submerged inlets using gravity flow may block up where the pipe flow witches from partial to full flow. (An exception: a large-diameter gravity transfer pipe has been successfully used for gravity flow of manure from the barn to the bottom of the storage.)

Above-ground storages Above-ground storages are usually circular concrete structures resembling silos. They can overcome construction problems in areas with high water tables and provide a degree of safety due to the height of access. One disadvantage is that a malfunctioning pump or valve can allow manure to run backwards from the storage, possibly flooding the barn. Liquid manure forms a crust more readily in silo-type storage, so that odors are reduced as long as the crust remains undisturbed.

Typically, circular storages for liquid manure are 9 m in diameter and up to 9 m high. As agitator pumps improve, silos with diameters up to 18 or even 24 m have begun to appear. For cast-in-place concrete structures, this increase in size requires good-quality concrete, reinforced to resist liquid pressures. Concrete stave structures must be coated on the inside with waterproof plaster.

The plumbing and sump pump system is important; it must be able to transfer manure into storage at convenient intervals, agitate the manure, and remove it to a tanker.

Earthen storages should be used only when soil conditions would keep manure from seeping (otherwise install a waterproof lining) and in locations where odors do not create a nuisance.

Liquid manure storage tanks, manure hopper openings, and slotted floors over tanks must all meet the strength and access requirements of the *Canadian Farm Building Code*.

2.103 MANURE GASES

Manure undergoes microbial decomposition in which organic matter is broken down to simpler compounds, with the production of a number of gases. If decomposition takes place with a continuous supply oxygen, it is called aerobic; when it occurs in the absence of oxygen, it is called anaerobic. In practice, most manure storages are anaerobic. Anaerobic decomposition occurs in liquid manure-handling systems, collection gutters, holding tanks, and storages.

Aerobic decomposition is essentially odorless, but anaerobic decomposition is characterized by unpleasant odors and by the production of considerable quantities of gases, some of which are potentially hazardous to people and animals. These include carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and hydrogen sulfide (H_2S). The last of these is particularly dangerous. For more information on the properties and characteristics of these gases, see *Canada Animal Manure Management Guide*.

Manure gases have caused property damage and deaths or near-deaths in both humans and animals. Such accidents are usually the result of high concentrations of gas accumulating below floor level or in poorly-ventilated areas, especially when manure is agitated.

To minimize the possibility of manure gas poisoning, use the following good practices in designing animal housing units:

- Minimize the volume of manure stored in the barn.
- Provide effective gas traps in all liquid manure lines between building sections or to outside storage.
- If animals are housed directly above the manure storage, remove them while agitating and pumping the manure.
- If possible, install the continuously running exhaust fans of the ventilation system so that they draw air out of any manure sumps or short-term holding tanks in the building.

2.104 MANURE TREATMENT

Considerable research, past and present, has tried to find means to minimize odors from animal manure and to reduce its potential for polluting surface water. At present, no single, inexpensive system can be recommended for general use.

One promising route, anaerobic digestion, could provide single-cell protein and biogas with no loss of manure nutrients, but the technique is expensive to set up and requires excellent management skills.

2.105 GREENHOUSES

Plants can be grown without natural sunlight, but high levels of artificial light are required for photosynthesis. There is little commercial demand for plant growth chambers in Canada. This section deals only with structures that use natural light.

In selecting glazing materials for greenhouses, the most important factor to consider is their ability to transmit sunlight. Table 42 gives values for common glazing materials.

Table 42 Transmission of shortwave and longwave radiation by several glazing materials

	Transmission (%)	
	Shortwave[1] radiation (direct sunlight)	Longwave[2] radiation
Glass, single	88	4
Polyethylene, single	89	71
Double acrylic (SDP)	85	0
Double polycarbonate (SDP)	78	3
Polyester	90	16
PVC film	91	12
Glass, double	75	2
Fiber glass	78	1

[1] 0.4–0.8 μm.
[2] 0.8–18 μm.

Unfortunately, materials that transmit sunlight are poor insulators. Other materials, designs, and equipment may help to retain solar energy at night to reduce the need for heating.

Greenhouses can be symmetrical or asymmetrical. They may be free-standing, lean-to, or connected by gutters to another structure.

For winter use, free-standing greenhouses should be set east–west to obtain the maximum amount of sunlight when the sun's angle is low. When the greenhouse is primarily used at other times of the year, it should be set north–south to minimize overheating.

In single free-standing greenhouses for winter use, an insulated north wall sloping inwards can reduce heat loss and increase solar gain. This design is called the Brace Research Institute greenhouse.

Most commercial greenhouse complexes consist of a number of units connected by gutters, or parallel free-standing houses connected at one end by a header house. These layouts maximize the floor area while they reduce the outside wall area and provide for good patterns in traffic and work flow.

Lean-to greenhouses attached to the south side of other structures are primarily used for research or display or by hobbyists.

2.106 SNOW LOADS

Snow loads are a major concern in greenhouse design. Designs for greenhouses of low human occupancy must meet requirements of the *Canadian Farm Building Code*.

When greenhouses are unheated or use thermal curtains, they must be provided with systems to prevent structural damage from accumulated snow. An alarm and monitor system can activate mechanisms to open thermal curtains, turn on additional heat lines in the gutters, or sound an alarm, or some combination of these.

2.107 GREENHOUSE HEATING

Estimates for heating and cooling greenhouses must consider the usual factors of conduction, infiltration, ventilation, and energy exchange (see Part 6), as well as solar energy gains and heat from electrical loads such as lights. In the past, several methods have been used to calculate heat requirements. A popular method now used considers conduction and infiltration as described below:

$$Q_t = Q_c + Q_i$$
$$Q_c = U \cdot A(t_i - t_o)$$
$$Q_i = 0.5 V \cdot N(t_i - t_o)$$

where

Q_t = total heat loss (W)
Q_c = conducting heat loss (W)
Q_i = infiltration heat loss (W)
U = overall heat loss coefficient, $W/(m^2 \cdot °C)$
A = exposed surface area, m^2
t_i = inside temperature, °C
t_o = outside temperature, °C
V = greenhouse internal volume, m^3
N = number of air exchanges per hour (Table 43)

See Table 43 for values for the coefficient of heat loss U for several greenhouse coverings. Coefficients for more common construction materials such as concrete can be found in Part 6. For safety's sake, allow 10–20% more heat than the amount calculated by this formula.

Consider a larger system if you contemplate expanding the operation.

2.108 Temperature, humidity, and control

Many plants benefit from diurnal temperature cycles. Table 44 gives some guidelines for common greenhouse crops. Individual types of flowering plants have specific temperature requirements; consult experts in the field.

Circulating water through pipes set in the soil below the growing crop heats the soil and allows you to use lower night temperatures. Usually the resulting fuel savings more than compensate for any productivity loss. Plastic pipes 25 mm in diameter are normally set about 0.5 m deep and 0.7 m on centers. The water temperature is set to maintain a soil surface temperature of 20°C.

Most plants can regulate their water loss through respiration as a cooling mechanism. A relative humidity of 50–80% usually permits leaves to cool without wilting.

Greenhouse air temperature is usually regulated by heating at night and ventilating during sunny days. Ventilation systems should be able to provide 15 air changes per hour under fall and spring conditions. For summer conditions, provide a minimum of 50 L/s per square meter of greenhouse floor area, plus evaporative cooling of intake air, or at least one air change per minute.

Table 43 **Approximate heat loss coefficients (*U*) and suggested design rates for air exchange for greenhouse heat loss calculations**

Greenhouse covering	W/(m^2·°C)	Air exchanges per hour[1]
Single glass	6.3	1.5
Single plastic[2]	6.8	0.8
Single fiber glass (FRP)	6.8	1.0
Double plastic[3]	4.5	0.7
Rigid double-wall plastic[4]	3.0	0.8
Double glass	3.0	1.0
Single or double plastic over glass[5]	3.0	0.6
Single glass and thermal blanket[6]	3.0	0.5
Double plastic and thermal blanket	2.5	0.3

[1] Low wind or protection from wind reduces the air exchange rate. In glass houses, values should be 0.5 or less for outside temperatures below zero, since freezing condensate usually seals small cracks.
[2] Plastic films, polyethylene, vinyl, etc.
[3] Inflated plastic films, enclosing an airspace.
[4] Twin-wall rigid panels of acrylic, polycarbonate, or polypropylene.
[5] On the outside, with one airspace enclosed.
[6] Solid blanket.

Table 44 **Night and day temperatures for common greenhouse crops (°C)**

	Night temperature	Day temperature
Tomato	16–19	21–27
Lettuce		
Cloudy days	13	17–18
Sunny days		21–26
Cucumber		
Cloudy days	18	24
Sunny days		27

Ventilation and relative humidity can be controlled by natural convection or by mechanical systems. For natural convection ventilation, set controlled openings in both side walls and at the ridge. Both systems can be automated with controls sensing the relative humidity and temperature, or both.

Shading may be necessary to protect all of the crop or certain types of plants from direct summer sun. This can be done by covering the glazing or the crop with a translucent (not transparent) material.

2.109 Energy conservation

A number of energy-saving measures (for example thermal curtains, double glazing, and perimeter insulation) have been used to retrofit existing greenhouses or have been used in new construction.

Film covers in the form of one or two layers of plastic over the whole greenhouse can cut heat losses. With two layers, the space between is pressurized. Radiant heat loss is reduced by 10–15% per layer of plastic film.

Double-glazing with glass or rigid plastic helps to conserve heat, but it is expensive and reduces the transmission of light by about 10% compared with single glazing. Any moisture accumulation between the glazing layers further reduces the light.

The methods described above reduce heat loss by reducing infiltration. They also result in lower condensation, higher relative humidity, lower carbon dioxide levels, and an increase in ethylene and other pollutants. Combined with reduced light levels, these factors can result in delayed crop production, elongated plants, soft plants, and various deformities and diseases, all of which reduce crop value.

A thermal blanket is any flexible material that is pulled from gutter to gutter and end to end of a greenhouse or over each bench at night. Several materials and systems have been tried with varying degrees of success. Heat losses can be cut 25–35%, but the effectiveness of the blanket depends very much on a tight fit around the edges. Two problems with blankets are: problems in installing the system in a greenhouse with interior columns, and loss of usable growing space due to shading by the rolled-up blanket system during the day.

2.110 CARBON DIOXIDE ENRICHMENT

Some greenhouse operators add carbon dioxide (CO_2) to increase growth and enhance yields. It can, however, be used only during periods when the greenhouse needs little or no ventilation for temperature control. The gas can be generated by burning fossil fuels, by thawing dry ice, by using bottled CO_2, or by misting with carbonated water. If you use gas from burning fossil fuels, ensure that complete combustion has taken place and provide enough makeup air to prevent the depletion of oxygen as combustion proceeds. Bulk or bottled CO_2 is usually distributed through perforated tubing placed near or beneath the plant canopy. CO_2 from dry ice is distributed by passing the greenhouse air through an enclosure containing the ice. Regardless of the method of generating CO_2, circulating the air around the plant leaf increases the efficiency with which the plant absorbs whatever CO_2 is available.

2.111 SPACE ALLOWANCES

Table 45 offers guidelines on the bed area required per hectare of crop to be transplanted as seedlings. Crop variety, different management systems, and weather at planting may require adjustment of these figures.

Table 45 Guidelines for greenhouse bed areas for crops to be transplanted

Crop	Greenhouse bed area (m^2/ha transplanted crop)
Tobacco, flue-cured or burley	23
Tomatoes	
Early	15–20
Stake	23–38
Late	1.8–3.2
Cabbage	11–16
Cantaloupe	9–15
Cauliflower	7–11
Celery	20–23
Cucumber	25–34
Eggplant	21–28
Lettuce	14–16
Onions, Spanish	11–12
Pepper	11–14
Watermelon	6–11

2.112 LIGHTING REQUIREMENTS

Plants respond to both the amount and duration of light. While light regulates the development and form of plants, the main concern in greenhouses is to extend the duration of light (day length), so that photoperiodic responses occur.

Regulation of photoperiod responses can occur with radiation of only 0.9 W/m^2. For maximum growth during winter months, however, plants need up to 24 W/m^2 for 8–16 h/day.

Install timing devices on lighting circuits in greenhouses.

2.113 ELECTRICAL REQUIREMENTS

Electrical service capacity should be available for lighting (both for tasks and plant growth), as well as for inflating double polyethylene houses, water supply and distribution, ventilation, equipment for handling materials, and heating.

PART 3

Facilities for the storage and processing of crops

3.1 GRAIN AND FEED

3.2 VOLUME AND HANDLING

3.3 Volume requirements

Storage volume can include grain that fills the storage up to the eaves, as well as the surcharge of grain that can be piled in the roof headspace. An angle of repose of 28° is suggested as a standard for rating the volume capacity of storage bins. To find the tonne capacity of a grain storage, measure the container in metres (m), calculate the volume in cubic metres (m^3), and then determine the capacity as follows:

Bin capacity (t) = volume (m^3) × apparent density (kg/m^3)/1000

Some formulas for calculating rated volume V are as follows.

For a rectangular pile, ends and sides sloped 28°

$$V = 0.133\, w^2(s - w) + 0.08867\, w^3$$

where

s = length (m)

w = width (m)

For a cylinder

$$V = \pi r^2 d$$

where

π = 3.1416

r = radius = 1/2 diameter (m)

d = depth (m)

For a circular cone

$$V = 1/3\, \pi r^2 h$$

where

π = 3.1416

r = radius = 1/2 diameter (m)

h = cone height (m)

Where the cone sides slope 28°, then

$h = 0.532r$ (m) and

$V = 0.557r^3$

Bin volume Fig. 23 shows how to rate bin volume for various typical roof configurations of both round and rectangular storages. Apparent densities of stored foodstuffs, including many grains, seeds, and milled feeds, can be found in Table 46. Do not use these values for determining lateral pressures for structural design; instead refer to the table of bulk densities given in the *Canadian Farm Building Code*. The values given in the code may be slightly higher since the code provides maximum values in the interests of safe design, whereas the values listed here represent average values that can be used to estimate volume requirements.

All grain and feed storage containers and supporting structures should be designed to meet the requirements of the *Canadian Farm Building Code*.

3.4 Flow, handling, and planning

Use the following checklist to plan facilities for handling feed and grain.

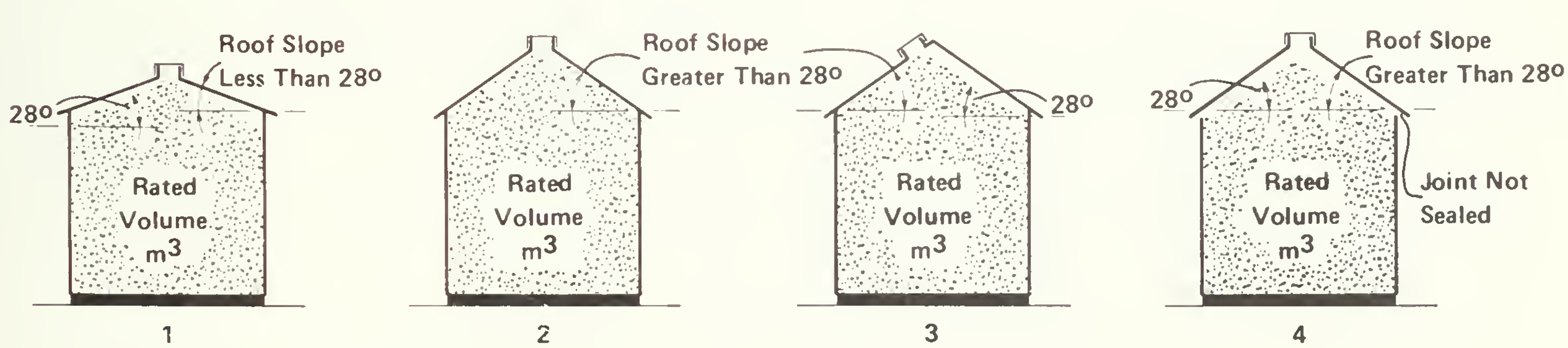


Fig. 23 Illustrations of bins and volume shapes

First, assess the present situation:

- existing facilities and equipment
- harvesting rates
- types and volumes of crops
- labor situation
- site
- grain bins in other locations
- available electrical capacity
- expansion plans.

Determine what you would like to have:

- single-point delivery to all storages
- single-point unloading of storages
- bucket elevator overhead surge bins
- two-stage drying (combination drying)
- natural air drying
- aeration
- weigh scale
- bin monitoring
- automatic controls
- type and capacity of heated air dryer
- ability to custom dry
- ability to expand
- any specific types or brands of equipment
- ability to accommodate semi-trailer trucks
- grain use (feed, seed, commercial)
- ability to clean grain.

Several basic points to keep in mind while planning are as follows.

- Plan all systems to permit two-stage drying now or in the future, to improve capacity and fuel economy.
- Overhead surge bins require a grain elevator, usually a bucket-type leg elevator. Locate the bins where they can serve two or more functions.
- Custom drying or the removal of dried grain to remote storage requires one or more surge bins for dry grain.
- If possible, plan systems to allow for a future change in dryer type.
- Set bins so that the bucket elevator reaches a maximum storage volume or number of bins with a minimum height of elevator.
- Equip all storages for aeration or natural air drying. Large bins should all have fully perforated floors.

Table 46 Apparent densities of agricultural materials in storage

Material	Apparent density (kg/m^3)
Grains and seeds	
Barley	620
Buckwheat	610–670
Corn	
Shelled, 15.5% moisture	720
Shelled, 28% moisture	750
Ground shelled	840
Husked ear	450
Ground ear corn	580
Flax seed	720
Lentils	770
Mustard seed	740–770
Oats	
Whole	400–560
Ground or rolled	300–400
Peas	820
Rapeseed	
Argentine	770
Polish	640
Rye	720
Soybeans	770
Sunflower seed	310–410
Wheat	770
Concentrated feeds	
Alfalfa meal, dehydrated	260–350
Alfalfa pellets	660–680
Beet pulp, dried	180–260
Brewers' grains	
Dried	220–240
Wet	880–960
Bone meal	800–850
Fish meal	480–540
Meat meal	590
Linseed oil meal	510
Soybean oil meal	540–670
Wheat	
Bran	180–260
Middlings	290–400
Pelleted ration	590–620
Crumbled ration	540
Salt	990–1120
Roughage feeds and bedding	
Hay (air-dried)	
Long	60–80
Chopped	130–160
Baled	100–130
Wafered	320
Straw	
Long	50–60
Chopped	100–130
Field-baled	110–130
Wood shavings, baled	320

- Allow sufficient turnaround space so that trucks do not have to back up.
- Make sure that foundation heights of bins are adequate for mechanical unloading and return conveyors.
- If possible, keep the grain handling system a safe distance from other buildings to minimize chances of fire spread, dust and noise pollution.

The *Canada Farm Building Code* gives friction coefficients for grains at various moisture contents on a number of surfaces. These coefficients are useful in designing grain handling systems. Use Fig. 24 for determining the length of grain auger required for a given situation, and Table 47 to determine hourly capacities and power requirements. For gravity spouting of grain or feed, the downspout angle must be at least 45° (for grain) or 60° (for feed). Given the horizontal distance from the elevator leg to the discharge spout, use Fig. 25 to determine the height the elevator discharge must be above the spout discharge.

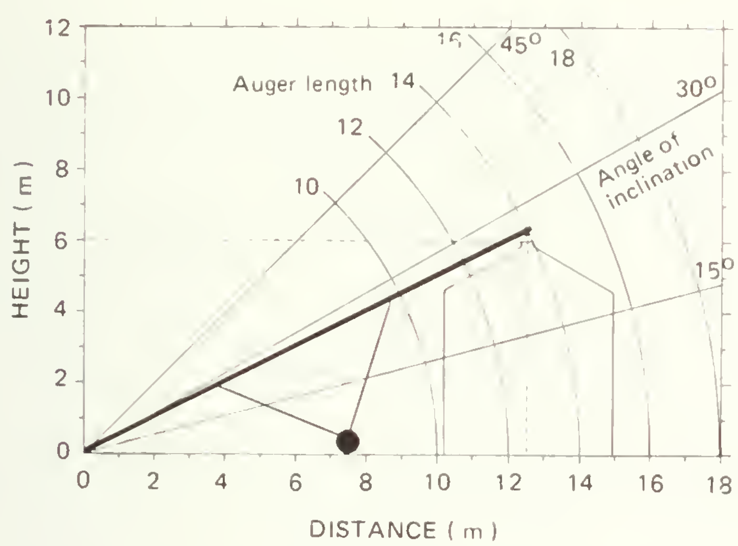


Fig. 24 Grain augers – height, distance, length, and angle

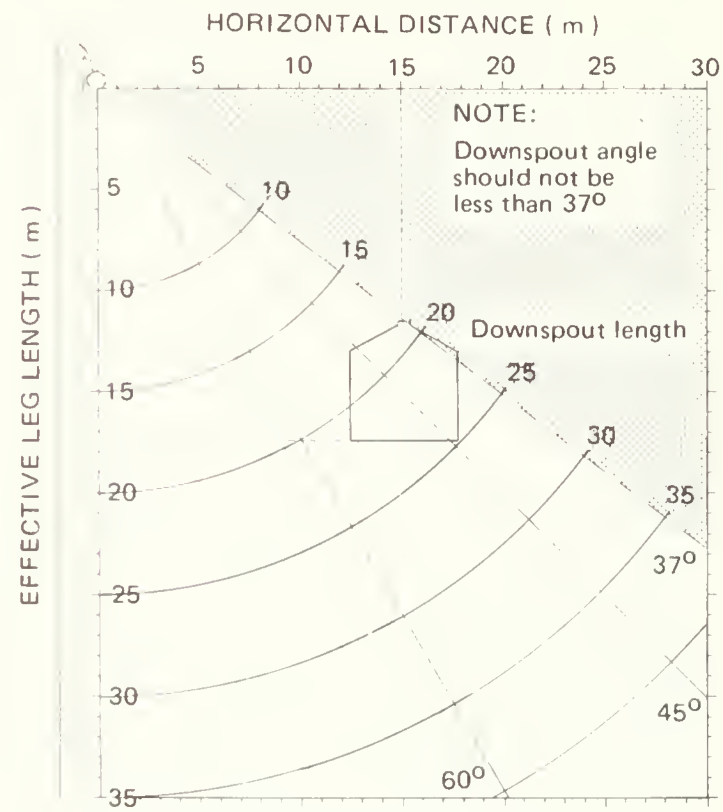


Fig. 25 Effective leg length and downspout angle

Table 47 Power requirements (W/m) and maximum capacities (m3/h) for grain augers

Diameter (mm)	rpm	Auger angle of inclination									
		0°		30°		45°		60°		90°	
		cap.	power	cap.	power	cap.	power	cap.	power	cap.	power
150	300	30	170	30	220	25	220	20	200	10	125
	400	40	220	35	300	30	300	30	250	15	170
	600	55	330	50	450	40	450	40	400	20	250
	800	60	490	60	575	45	575	45	520	25	330
200	300	80	420	65	515	55	515	45	490	30	350
	400	100	540	80	685	70	685	55	635	40	400
	500	120	660	100	860	80	860	65	800	50	600
	600	130	800	120	1030	90	1030	75	1000	55	650
250	300	170	760	130	1000	110	1000	80	950	60	650
	400	200	1000	150	1300	130	1300	110	1200	75	800
300	200	235	855	195	1200	160	1200	125	1075	80	660
	300	305	1275	255	1750	220	1750	170	1665	110	980

Source: Grain handling on the farm

Table 48 **Summary of conveyors**

Type of conveyor	Type of material	Capacity	Power req't	Cost	Advantages	Disadvantages
Screw (auger)	Ground, granular, chopped	Medium	Low to medium	Medium	Can be used as mixer or for uniform flow feeder, good for unloading bulk storage, wide range available	Size of material limited, single sections limited in length, medium to heavy wear
Chain	Most feed grains and farm products	Medium	Medium	Low to medium	Inexpensive, multiple use, wide range	Noisy, heavy wear
Bucket	Ground, granular, lumpy	Medium to high	Low	Medium to high	Efficient, low maintenance, high capacity for vertical lift, low power requirement	Limited speed range difficult to erect, expensive, should be equipped with automatic brake
Belt	Grain, packaged units	High	Low	High	Can be used for long distances, low power requirement	Limited in angle of elevation, expensive
Pneumatic	Grain, ground feed, chopped forage	Variable	High	Low to medium	Low first cost, low maintenance, flexibility of installation, excessive manpower may be needed to clean plugged pipes	High power requirement, creates dust, usually requires separation equipment, conditions of operation vary with type of material
Vibrator	Grain, ground feed	Low	Low	High	Can be used as meter, reliable, easy control	Limited capacity, cost
Oscillator	Grain, feed roughage	High	Low	Medium to High	Efficient, can handle large volumes of several materials	Cost, must be solidly mounted, limited to lengths of about 30 m
Pump and pipe	Liquids, slurries	High	Low	Low to medium	Efficient, easy control, low maintenance	Materials limited, subject to freezing

Source: Agriculture Canada Publication 1572.

A wide variety of grain and feed conveying equipment is commercially available. Table 48 offers some comparative guidelines. All grain conveying equipment should be operated near full capacity to minimize handling damage.

A handling system must be sized or controlled to prevent any of the components from being overloaded. Each piece of equipment in the flow path should have a capacity up to 10% larger than the preceding piece, to avoid bottlenecks (Fig. 26).

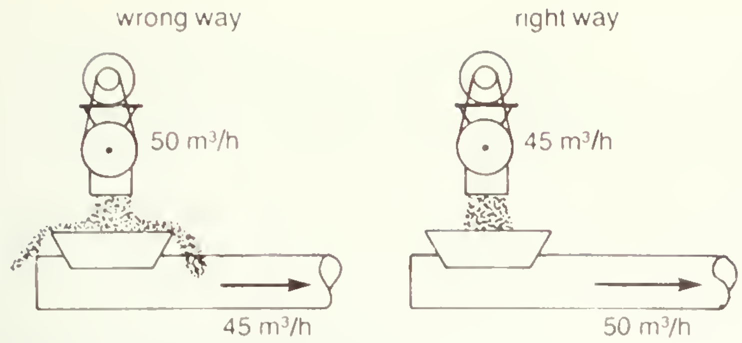


Fig. 26 Conveyor selection

3.5 DRY GRAINS – STORAGE AND CONDITIONING

3.6 Circular bins on grade

Circular grain bins can be made of corrugated or flat galvanized steel, reinforced concrete, plywood, or other materials strong enough to meet design criteria. The structure should have a weathertight roof, and be rodent-proof and fire-resistant.

Unload large cylindrical bins from the center to avoid putting an uneven load on the bin walls. Use a distribution system for even loading during filling.

3.7 Hopper-bottom bins

Hopper-bottom bins can be set on grade or supported overhead. They are most useful as surge bins or loadout bins in grain handling systems and are frequently used as feed bins. The bottom of the hopper should slope enough to ensure complete gravity emptying. It can be center- or side-draw and can be circular, square, or rectangular. Side-draw hoppers help to avoid bridging in feed bins.

The volume of hopper-bottom bins can be determined from the formulas given in Section 3.3 or from manufacturers' specifications.

3.8 Flat storage

Flat or horizontal storage facilities are often considered for large volumes of grain, for buildings that may be needed for other purposes (such as machinery storage), or for temporary storage of surplus.

Wood-arch or frameless steel buildings with inward-sloping side walls are often used for this purpose. The lateral load of a given depth of grain is less on inward-sloping walls than on vertical walls.

Removing grain from flat storage usually involves a portable auger or conveyor or a tractor with front-end loader. Be careful when filling not to submerge the frame of the portable auger or conveyor.

Depending on the shape of the facility, its storage volume can be calculated by the formulas given in Section 3.3.

3.9 Temporary storage

Temporary on-grade storage can consist of a concrete pad, portable or stationary walls or rings, or temporary storage bins bought for the purpose. Such structures should be covered. Use portable waterproof covering material or put the grain storage in an existing building if the building is strong enough to have grain piled against its walls.

3.10 CONDITIONING OF GRAIN CROPS IN STORAGE

Equip all grain storages larger than 50 m^3 with equipment to circulate air through the grain for fall cooling, moisture equalization, and spring warming.

Aeration slows deterioration by cooling the grain and reduces moisture migration by decreasing the temperature gradients throughout the bulk. It should not be confused with unheated air drying, which uses larger flows of air at near-ambient temperature to dry the grain. The purposes of aeration and unheated air drying are different, and so the design and operation of the two systems are not alike. Aeration sytems may, however, help to dry the grain slightly and unheated air drying systems may cool it.

Bin ventilation systems may also be designed and operated for dryeration or to cool the grain in bins after high-temperature drying. In dryeration, the grain is held unventilated (tempered) for a few hours after leaving the high-temperature drier. Air at near-ambient temperature then circulates through the hot grain to remove 1–3 percentage points of moisture and to cool the grain. In-bin cooling is used to cool the grain immediately after high-temperature drying with little or no tempering time or drying in the bin.

3.11 Equilibrium conditions

When grain is exposed to air, the grain tends to come to a temperature and moisture in equilibrium with the air. For example, when wheat is exposed for a long enough time to air at 20°C and 70% relative humidity, its moisture content equilibrates at about 14.5–15%. In technical terms the vapor pressure of the grain equals that of the air. If the wheat comes into equilibrium with more humid air, its moisture content at equilibrium is higher and microorganisms may cause it to spoil. If the grain is dried to a lower moisture content and the relative humidity is kept low, the grain is less likely to deteriorate rapidly. But under the present grading system, the market value of the grain is less because it is sold by weight.

3.12 Cooling and drying fronts

Normally, when air is passed through a bin of grain or oilseeds, the material does not cool or dry uniformly. Instead, a cooling (or warming) front passes through the grain mass; in this front the grain comes into temperature equilibrium with the incoming air passing through the grain. For aeration systems with an airflow of about 1 L/s·m^3, the cooling front takes about 150–200 h to pass through the bin. The drying front moves through the grain more slowly than the cooling front and its progress depends on the rate of airflow. The grain upstream from the drying front comes into equilibrium with the entering air and the grain downstream from the drying front remains near the initial moisture content of the grain. Because all the grain in a bin does not dry or cool at the same time, the airflow through the grain must be sufficient to dry or cool the last remaining layer of the grain before it deteriorates.

3.13 Changing ambient air conditions

Although we might expect warm daytime air to dry the grain and cold night air to increase its moisture content, this does not necessarily happen. The effect of diurnal air fluctuations on grain drying can be complex. For example, when warm air passes through cold grain the air cools and its relative humidity increases, and the effect may be an increase in the moisture content of the grain. Conversely, passing cold air through warm grain can result in drying, with a continued movement of the drying front through the grain as well as a reduction in grain temperature and rate of deterioration.

3.14 Operating aeration systems

Use the following procedure.

- Start the fan as soon as grain enters the bin.
- Run the fan until all grain is down to the average ambient temperature.
- When the average ambient temperature drops to 10°C, cool the grain again.
- Cool the grain down to near 0°C for winter storage.
- Check the grain every week or two during the winter.
- If grain is to be stored over the following summer, warm the grain up to 10°C whenever the relative humidity is below 70%.

To operate systems that are based on natural air drying, follow these steps.

- Start the fan as soon as the grain enters the bin.
- Operate the fan continuously until the grain is at a safe storage moisture content or until it has cooled to 0°C.
- Check the grain every day or two, to ensure that no problems are developing.
- If the grain is not dry when the temperature reaches 0°C, stop the fan and check the grain every week to make sure it is not heating.
- Start the fan again when the average daily temperature exceeds 0°C (early April) to complete the drying.

Natural air drying offers these advantages.

- You can harvest earlier and remove up to 6% moisture in storage.
- It does not require a heated air dryer or fossil fuels.
- It needs no extra handling.
- There is no danger of heat damage.

Natural air drying also occasionally presents these problems.

- It requires fans and air distribution systems.
- Available power may be limited.
- The crop may not be dried when you want.
- The bottom layers may be overdried, resulting in loss in value.

3.15 Airflow patterns

Air moves through grain along the path of least resistance – usually the shortest path. Therefore when air is introduced into a grain bulk by ducts, the grain midway between or furthest from the ducts is poorly ventilated. The only system that provides uniform airflow, and therefore uniform cooling or drying, is a completely perforated floor covered by an even depth of grain.

3.16 Pressure losses

Obtaining the desired rate of airflow through grain requires appropriate design. Take into consideration the pressure losses through fan transitions and perforated floors, and the airflow resistance of various grains. Use Figs. 27–29 (from Friesen 1984) to help design systems using fully perforated floors.

For design purposes, pressure losses through perforated flooring can be ignored for velocities up to 225 L/(s·m^2) for cereal flooring and up to 75 L/(s·m^2) for rapeseed flooring. For rapeseed flooring with air velocity B between 75 and 225 L/(s·m^2), add an additional pressure loss (in pascals) equal to

$$50[(B/50 - 1.5)1.6 + 1]$$

When the bin floor area is not totally perforated, air velocity through the grain near the perforated area is greater than the average flow through the grain mass. For bin floors with a perforated area of 50% or less, all resistance values in Figs. 27–29 must be multiplied by a factor K since these values are based on fully perforated floors.

$$K = 0.00065(B - 100) + (6.31 - \ln A)/2.38$$

where

A = % of floor covered by perforated flooring

B = total bin air flow/area of perforated flooring (L·m^2/s)

ln = natural logarithm

Note that K should only be used for floors with 50% or less perforated area. When B is less than 100, it should be set equal to 100.

3.17 Transitions

Transitions are used to deliver air from fans to ducts or perforated floors in grain bins. Besides preventing leakage losses, a transition should both keep air turbulence to a minimum (to avoid energy losses and reduced airflow) and reduce the air speed so that the air is distributed uniformly through the perforations. Usually the shape of the fan outlet is different from the shape of the air inlet at the bin; the transition must also accommodate this difference.

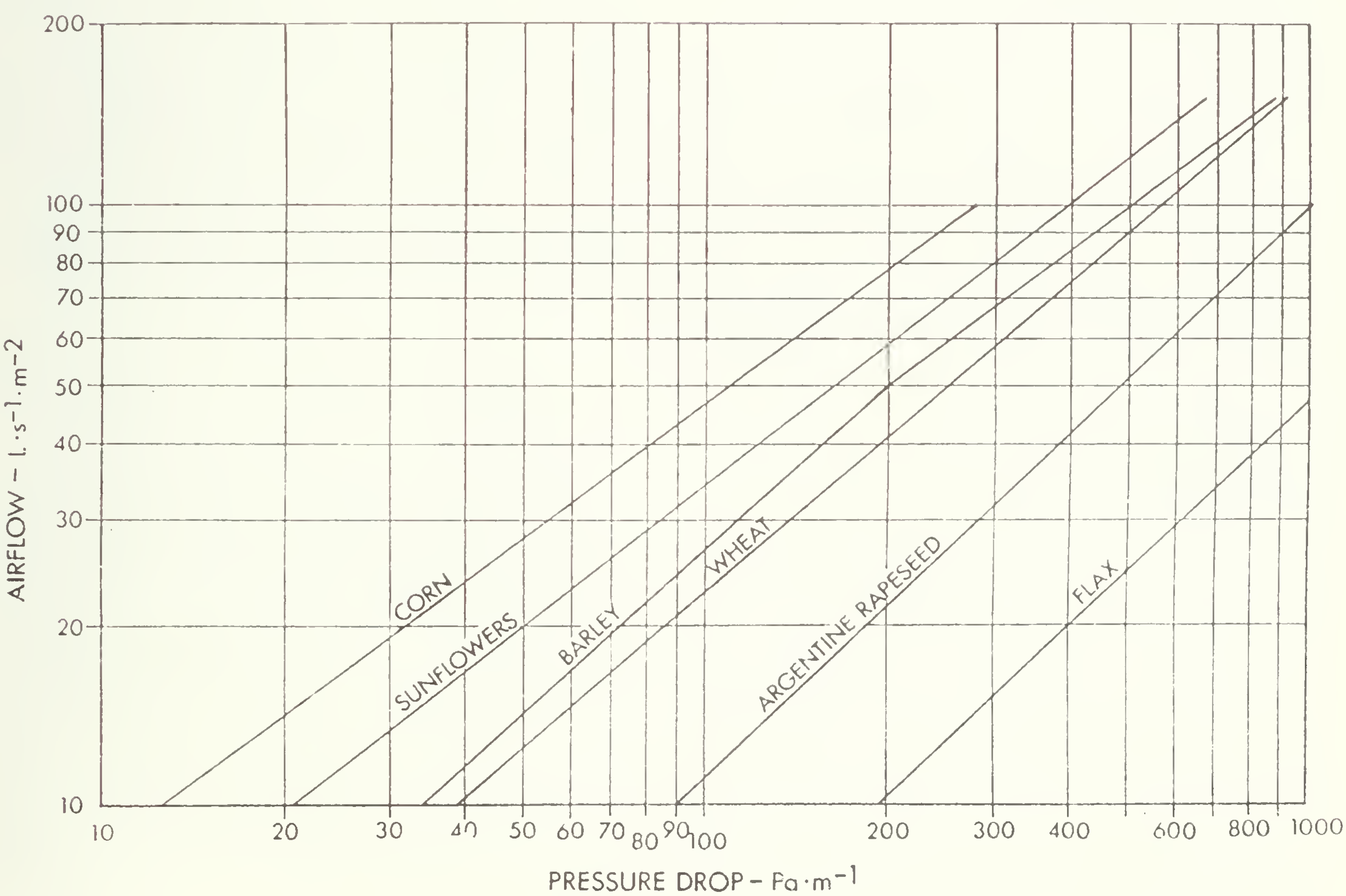


Fig. 27 Resistance of grains and oilseeds to airflow

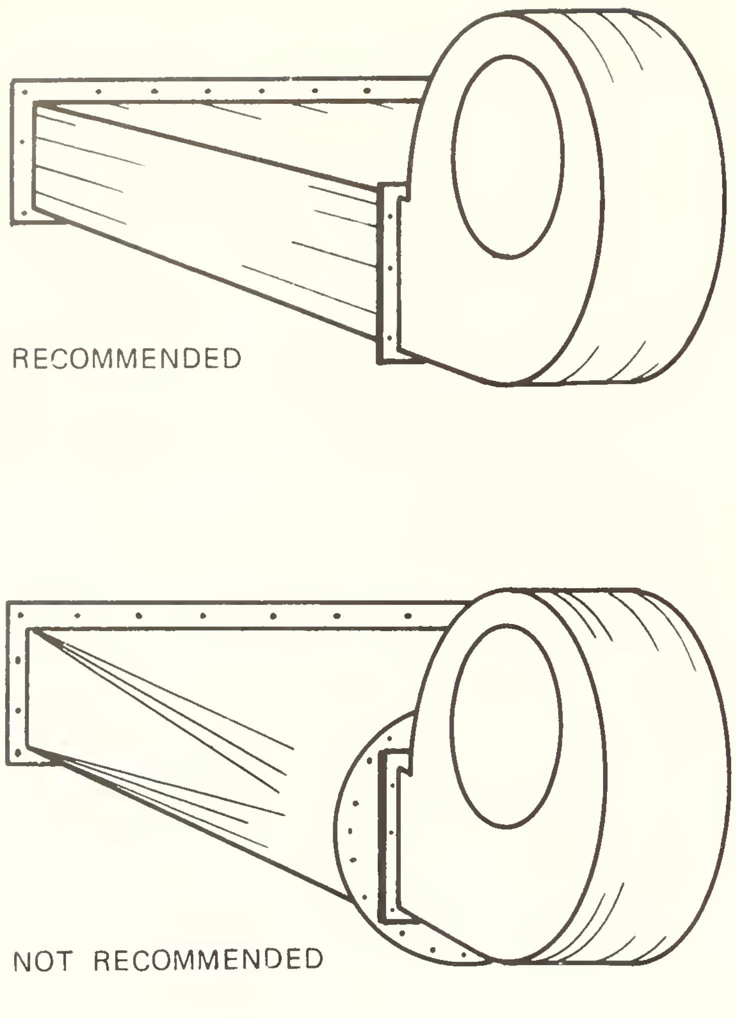


Fig. 28 Transition design

Ready-made transitions are available for many fans, but some of these are poorly designed or very expensive, or both. It may be cheaper and more efficient to have a properly designed transition built at a local sheet-metal shop.

The entrance of the transition should match the size and shape of the fan outlet as closely as possible. Do not try to fit a rectangular fan outlet to a circular transition inlet with an adapter plate.

For natural air-drying of stored cob corn, the effective storage width at the base of a rectangular crib should not normally exceed 1.5 m. Circular cribs greater than 1.5 m in diameter require a vertical center duct of 600 mm. The maximum space between the center of the duct and the outside of the bin should not exceed 1.5 m. The open area of slatted crib walls should be at least 30% of the total wall. If the openings are horizontal slots, the slots should not be more than 40 mm high. If the openings are vertical slots, the slots should not be more than 50 mm wide. For husked ear corn, use a bulk density of 450 kg/m^3.

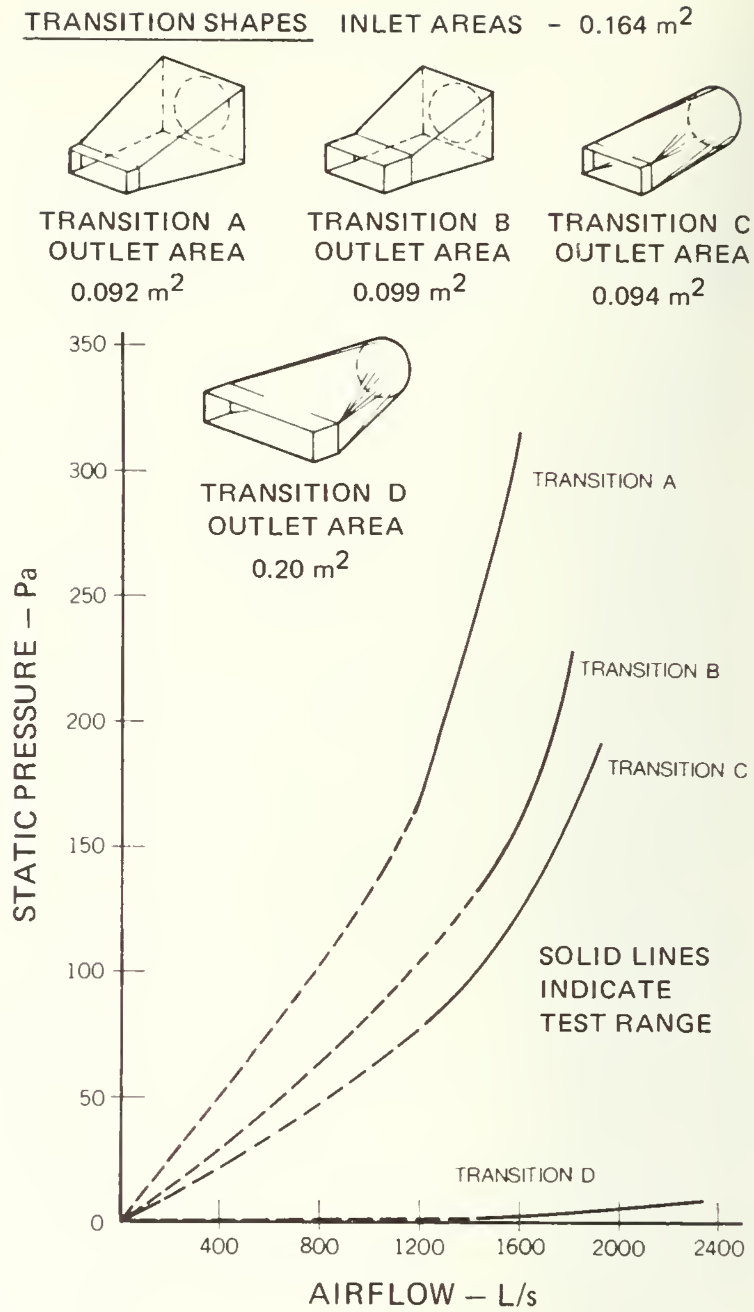


Fig. 29 Pressure losses through four different fan transitions

3.18 WET OR ENSILED GRAIN AND FEED

Ensiling is basically a method of crop preservation. Silos are commonly used to store most of the types of crops usually fed to livestock – whole-plant corn, haycrop, or whole-plant cereals, as well as moist grains such as corn and barley. If crops are harvested at the right stage of maturity and stored at the correct range in moisture content, using proper management practices, the chances are very good that losses of dry matter and nutrients will be at least as low as (and probably lower than) those resulting from any other means of crop handling.

Ensiling occurs in two stages:

Aerobic (with oxygen) stage When fresh plant material is first put into storage, the living cells continue to respire. These cells, together with microorganisms present on the plant material, use up the oxygen in the trapped air, digest plant carbohydrates and produce carbon dioxide, water, and heat. The temperature of the material may rise to about 40°C. At the same time spoilage organisms such as molds and yeasts thrive and multiply. This initial phase normally takes 24–36 h.

Anaerobic (without oxygen) stage When all available oxygen has been consumed, respiration stops and the plant cells die. At the same time, anaerobic bacteria begin to predominate. If sufficient soluble carbohydrates are available in the plant material, bacteria that produce organic acids grow rapidly. Initially bacteria that produce acetic acid predominate, but after several days lactic acid bacteria predominate. Under normal conditions, this activity is well under way after 3–4 days of storage. The moisture content of the stored material and the temperature developed in the mass determine the balance of bacterial species, and hence the types and levels of acid produced. As the pH decreases, spoilage organisms cease to function. During this period the temperature of the ensiling mass slowly begins to fall. Finally, after a period of 2–3 weeks the level of acidity reaches a point (pH 3.8–4.2) where even the acid-producing bacteria cannot grow and reproduce, and the ensiling process comes to a standstill. At this point the silage is preserved and, unless too much air is allowed into the mass, no further activity takes place.

3.19 SILAGE MATERIALS

The materials most commonly ensiled are whole-plant forage crops (corn, haycrop) and cereals (barley, oats, wheat). Corn contains relatively high amounts of simple sugars and starches and therefore ensiles well. Legumes are somewhat more difficult since their energy content is lower. Grasses and cereals are somewhere in between.

Storing corn and cereals as whole-plant silage results in a higher dry-matter yield per acre (up to 50% or more) than harvesting the grain alone, although the energy level per unit weight is somewhat lower. Harvesting and storing haycrop as silage (normal moisture range 50–65%) can result in lower losses in dry matter and feed value than in field-cured hay. Fig. 30 shows the total dry-matter loss at

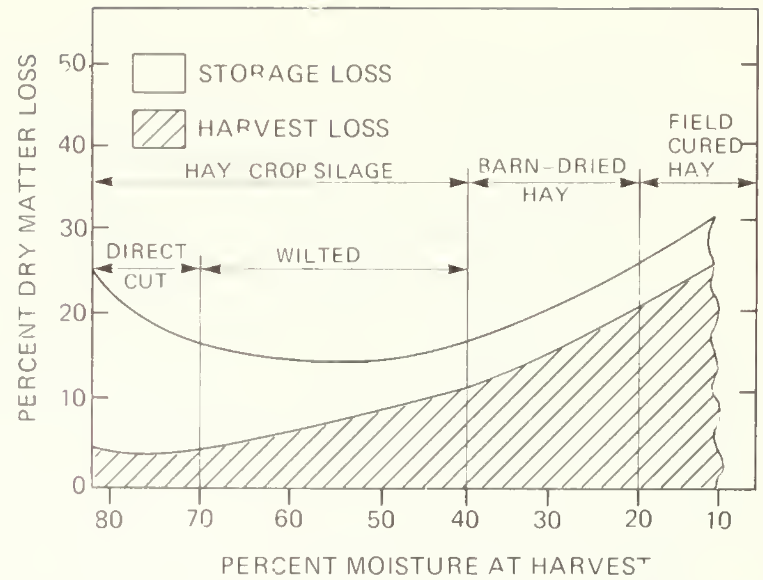


Fig. 30 Average range in harvest, storage, and total losses of dry matter associated with forage handling systems

harvest for different moisture levels and related harvesting methods. In addition to reduced dry-matter loss, lab reports on feed tests usually show that haycrop silage has at least 2 percentage points more protein than dry hay.

The time needed to wilt the hay crop, and thus to reduce the moisture content to acceptable levels for ensiling, is less than that required for barn-dried hay and considerably less than that for field-cured hay. This reduces the chance of exposure to rain and the related losses. Moreover, the crop can be harvested earlier when it is at an optimum stage of maturity.

Corn and cereal grains for livestock can be harvested, ensiled, and handled at a moisture level in the 25–35% range. This type of material, if air is excluded from the mass, undergoes the fermentation described above. Because of their high carbohydrate content, high-moisture grains ensile well. The resulting feed has a characteristic fermented odor, a soft texture, and in some cases a slightly darker color. Corn, either shelled or ground with the ear, is the most common grain for silage, but barley, wheat, and oats can also be stored in this fashion.

The advantages of ensiling high-moisture grains include

- elimination of drying costs
- slightly earlier harvest
- complete mechanization of feed handling from field to feedbunk
- reduced harvesting and storage losses.

In general, livestock make as efficient use of the grain crop in the high-moisture form as in the dry form on a dry-matter basis.

Ensiling high-moisture grains has several disadvantages.

- The grain can only be used as livestock feed.
- Feed can spoil rapidly after removal from storage, particularly in warm weather, and silage must be completely fed daily.
- Horsepower requirements for mechanical conveying equipment are higher.
- Silage is considerably more difficult to feed through self-feeders than dry grain.
- The market for sale off the farm is limited.

High-moisture grains may be successfully stored in all types of silos, given proper management. Because of the value of high-moisture grain it is important to prevent spoilage – that is, to keep air away from the silage. To do this the silo must be virtually airtight.

High-moisture grains going into an open-top silo (tower or horizontal) should be ground or rolled to provide a dense mass that is effectively airtight at the exposed surface. Although high-moisture grains have been successfully stored in open-top tower silos without grinding, the risk is still high.

3.20 TOWER SILOS

Tower silos can be constructed of various materials; cast-in-place concrete, precast concrete stave, and glazed sheet steel are the most common. Concrete structures make use of steel rods (rebars for cast-in-place silos, hoops for stave construction) to resist the lateral forces imposed on them. Most steel silos have a bonded glass coating on both sides of the component sheets or are made from special alloys, to resist corrosion from the silage acids.

There are two main types of tower silos, open-top and oxygen-limiting, categorized according to their ability to control the internal atmosphere.

In the construction of tower silos, the following points should be considered.

3.21 Silo footing

A proper footing is one of the most basic considerations in silo construction. A tower silo concentrates a large load onto a relatively small area. It is therefore essential to match the area of the footing to the support capacity of the underlying soil. The footing must be designed for a particular size of silo (diameter and height) and the type of soil on which it bears.

The footing distributes two loads to the supporting soil: the weight of the silo itself, and the weight of a considerable amount of stored silage. More than one-half of the weight of the stored material in open-top silos is transferred to the ground via the silo wall, and in oxygen-limiting bottom-unloading silos the weight of nearly all the silage can be transferred in this way. This transfer occurs through the outward pressure of the silage on the walls and the frictional resistance on the walls causing downward forces.

3.22 Wall reinforcing

In concrete silos, the outward pressure of the stored material must be resisted by the horizontal steel placed in or around the silo walls. The maximum pressure exerted by different materials varies, as does the pressure distribution, so silo walls should be designed to safely contain any feed that might be stored. In addition, both the pressures encountered and their distribution differ greatly between open-top silos unloaded from the top and oxygen-limiting silos unloaded from the bottom. The section area of steel per foot of wall height should meet the expected lateral pressures as calculated using a recognized standard (for example, the *Canadian Farm Building Code*).

3.23 Silo location

Tower silos, especially in multiples, can alter snow and wind patterns – a fact that should be considered in the design of nearby buildings and in the layout of yards, laneways, and so forth.

3.24 Silo capacity

The capacity of a silo depends on a number of factors: the type and maturity of the crop, its moisture content, chopping fineness, and method of distribution, as well as the smoothness of the silo wall (friction coefficient) and the silo size, including the ratio of silage depth to silo diameter. Tables 49–51 show the capacities for different types of silage of tower silos of various heights and diameters. These can be used as a guide in size selection.

Table 49 Estimated concrete silo capacities for forages, in tonnes[1]

Silo diameter × settled depth (m)	% moisture, wet basis							
	Alfalfa silage				Corn silage			
	40	50	60	70	55	60	65	70
3.7 × 9.1	32	40	52	75	43	49	56	67
3.7 × 12.2	45	56	73	105	60	68	79	93
3.7 × 15.2	57	71	94	136	77	88	101	120
4.3 × 12.2	63	78	103	148	84	96	110	130
4.3 × 15.2	81	101	134	193	110	124	143	168
4.3 × 16.8	90	113	149	215	122	139	159	187
4.9 × 15.2	109	137	181	261	148	167	191	224
4.9 × 18.3	135	169	224	323	182	206	235	275
4.9 × 19.8	147	185	245	354	200	225	258	300
5.5 × 15.2	142	178	236	339	191	216	247	288
5.5 × 18.3	176	221	293	421	237	266	304	353
5.5 × 21.3	211	264	351	504	283	317	361	419
6.1 × 18.3	224	281	372	533	298	335	381	442
6.1 × 21.3	268	337	446	639	357	399	453	524
6.1 × 24.4	314	394	522	746	415	464	526	607
7.3 × 18.3	338	423	559	796	442	494	560	647
7.3 × 21.3	407	511	674	956	529	590	667	767
7.3 × 24.4	479	600	790	1180	616	685	773	888
7.3 × 27.4	551	690	908	1281	704	782	880	1009
9.1 × 24.4	796	993	1297	1813	989	1164	1343	1480
9.1 × 27.4	920	1146	1494	2079	1129	1341	1547	1480
9.1 × 30.5	1046	1301	1692	2346	1270	1540	1754	1934
9.1 × 33.5	1173	1457	1891	2614	1411	1701	1962	2165

[1] 1 tonne = 1000 kg; the capacity in tons (2000 lb) can be obtained by multiplying the capacities in the table by 1.1.

Source: Jofriet (1982)

3.25 Advantages and limitations

The operation of a tower silo as part of a feed storage and handling system can be mechanized to the point of complete automation, if desired. Under normal circumstances, weather conditions have very little effect on the operation of this type of silo. The major limitation is the moisture content of the material to be stored. Tower silos are unsuitable for wet materials since the weight of the silage squeezes out free liquid, especially in the bottom third. Seepage creates three problems.

- It can create excessive liquid pressures far greater than normal silage pressures, especially near the bottom of the structure.
- Seepage contains organic acids (mainly lactic and acetic), which quickly attack unprotected concrete and steel, reducing their strength and durability.
- Wet silage freezes, increasing the possibility of unloading problems during winter.

3.26 Open-top silos

In open-top tower silos, the top of the silage is not sealed off from the outside. The silo roof keeps out rain and snow but does not control the composition of the air in the headspace above the silage.

Table 50 **Estimated steel silo capacities for forages, in tonnes**[1]

Silo diameter × settled depth (m)	% moisture, wet basis							
	Alfalfa silage				Corn silage			
	40	50	60	70	55	60	65	70
3.7 × 9.1	34	43	56	81	46	52	60	70
3.7 × 12.2	49	61	80	115	65	74	84	99
3.7 × 15.2	63	79	105	151	85	96	110	128
4.3 × 12.2	68	85	112	161	91	102	117	137
4.3 × 15.2	89	112	148	212	119	134	152	177
4.3 × 16.8	100	125	166	238	133	149	170	197
4.9 × 15.2	120	150	198	283	158	177	202	234
4.9 × 18.3	150	188	248	354	196	220	249	287
4.9 × 19.8	166	207	274	389	216	241	273	314
5.5 × 15.2	155	195	256	365	203	227	258	299
5.5 × 18.3	195	245	322	456	252	281	318	367
5.5 × 21.3	236	296	389	549	302	336	379	435
6.1 × 18.3	247	308	405	572	315	351	396	456
6.1 × 21.3	300	374	490	688	377	419	471	540
6.1 × 24.4	354	441	576	806	439	487	547	625
7.3 × 18.3	368	459	600	842	461	512	577	662
7.3 × 21.3	449	558	727	1013	551	611	686	784
7.3 × 24.4	532	660	857	1187	642	710	795	907
7.3 × 27.4	616	764	988	1361	734	809	905	1031
9.1 × 24.4	867	1070	1379	1892	1033	1269	1459	1606
9.1 × 27.4	1007	1240	1590	2169	1202	1472	1690	860
9.1 × 30.5	1150	1411	1803	2447	1374	1678	1923	2116
9.1 × 33.5	1294	1584	2017	2726	1549	1886	2159	2374

[1] 1 tonne = 1000 kg; the capacity in tons (2000 lb) can be obtained by multiplying the capacities in the table by 1.1.

Source: Jofriet (1982)

Nearly all modern open-top silos are made of concrete, either cast-in-place or precast stave. Some silos using pressure-treated wooden staves and galvanized steel have been built.

The following points should be considered in the construction of open-top tower silos.

Wall protection As noted above, silage acids react with the hardened cement in concrete, gradually causing the inside surface of the silo wall to deteriorate. Because of the greater compaction pressures, the acid action is more pronounced in the bottom of larger silos. To prevent this deterioration, at the time of construction apply a protective coating to the interior surface of all concrete tower silos (including cast-in-place silos), at least to the bottom third where the acid action is most severe. A number of coatings are available at a fairly wide range in cost, which is usually directly related to durability and effectiveness. Since labor makes up a large part of the expense of a protective coating, using a cheaper but less durable material is poor economics. Some of contractors erecting concrete stave silos incorporate a protective material into the plaster mix used to coat the interior of the silo wall.

Silo roof A roof reduces the loss of feed through weathering and by birds; it cuts down on top spoilage and helps to reduce total dry-matter loss. Equally important, it reduces surface freezing and keeps rain and snow off the silage and unloading equipment. A mixture of snow and silage has lower feed

Table 51 Estimated concrete silo capacities for high-moisture corn, in tonnes[1]

Silo diameter × settled depth (m)	% moisture, wet basis								
	Whole shelled corn			Ground shelled corn			Ground ear corn		
	25	30	35	25	30	35	30	35	40
3.7 × 9.1	74	81	89	77	86	96	66	75	86
3.7 × 12.2	99	109	120	104	116	131	89	102	118
3.7 × 15.2	125	137	152	131	146	165	113	129	150
4.3 × 12.2	137	150	165	143	160	180	123	141	161
4.3 × 15.2	172	189	209	180	202	228	155	179	208
4.3 × 16.8	190	209	231	199	223	252	172	198	230
4.9 × 15.2	227	249	275	238	267	301	205	237	276
4.9 × 18.3	274	301	333	288	232	365	249	287	335
4.9 × 19.8	298	327	362	313	351	397	271	313	365
5.5 × 15.2	289	318	351	303	340	384	263	303	353
5.5 × 18.3	350	384	425	367	412	466	318	368	429
5.5 × 21.3	410	451	499	431	484	547	374	434	506
6.1 × 18.3	434	477	528	456	512	579	396	459	535
6.1 × 21.3	510	561	620	536	602	680	466	541	631
6.1 × 24.4	585	644	713	616	692	782	536	622	727
7.3 × 18.3	632	694	768	663	745	841	578	670	781
7.3 × 21.3	742	816	902	780	876	989	681	770	992
7.3 × 24.4	852	938	1037	896	1007	1132	784	910	1063
7.3 × 27.4	963	1059	1172	1012	1138	1285	887	1030	1204
9.1 × 24.4	1346	1480	1637	1413	1587	1791	1242	1442	1681
9.1 × 27.4	1521	1673	1851	1597	1794	2025	1405	1633	1905
9.1 × 30.5	1697	1867	2064	1781	2001	2258	1569	1824	2128
9.1 × 33.5	1872	2060	2278	1965	2208	2592	1734	2016	2352

[1] 1 tonne = 1000 kg; the capacity in tons (2000 lb) can be obtained by multiplying the capacities in the table by 1.1.
[2] Percent moisture (wet basis).

Source: Jofriet (1982)

value and may create handling problems in the feedroom. Silo unloaders operate more freely with fewer breakdowns under cover.

3.27 Silo drainage

Unless the moisture content of material put into a silo is kept below a certain level, free liquid will be squeezed out. The liquid should be allowed to escape in order to protect the silo from hydrostatic overpressure, particularly at the bottom. In addition, any seepage must be prevented from entering the supporting soil. This requires two things:

- an impermeable membrane-type floor under the silage to seal off the soil below
- a drainage system that allows any free liquid to drain off and away from the silo site.

3.28 Silo size

In choosing the right size of open-top tower silo for a particular operation, consider two major points:

- the larger the diameter of the silo, the lower its initial cost per tonne of capacity

- the greater the diameter of the silo, the thinner the slice of silage removed each day for a given quantity of feed.

To prevent spoilage in warm weather and freezing in cold weather, base the silo diameter on the requirement to remove at least 5–10 mm of silage each day (the greater depth during hot weather).

The silo height primarily depends on the amount to be removed each day times the number of days in the feeding period. In addition, allow for silage settlement—about 15% of the initial height of the material if the silo is filled once. Often up to 2 m should be allowed to accommodate a silo unloader during filling. These allowances may be reduced if the silo is refilled once or more and if the silo unloader can be completely lifted into the roof dome of the silo during filling.

Note that height must be kept in proportion with the diameter for the sake of structural stability. This relationship depends on silo type, but generally the height of settled silage should not exceed 3–3.5 times the silo diameter, nor should the total silo height exceed 4 times the silo diameter. Tables 49–52 may be used as a guide in choosing the correct silo size.

Distributors for open-top tower silos The way in which chopped or ground material is loaded into a tower silo is important. For best results, the silage should be spread evenly and uniformly in circles concentric with the silo wall.

Unloaders for open-top tower silos Open-top tower silos are normally unloaded from the top. The unloader either sits on the surface of the silage or is suspended in the headspace at silage level. As the gathering arm rotates around the silo, it moves a thin slice of silage to the opening of the chute door.

Advantages and limitations of open-top tower silos Open-top silos cost considerably less to build than oxygen-limiting silos (often about one-half). With good management, the dry-matter loss can be kept to 10% or less, depending on silo size. Since the silage surface is open to the atmosphere, it is necessary to size the silo diameter so that at least a minimum amount is removed each day. For best results, this requires a relatively constant demand for feed.

Since this type of silo uses a top unloader, you must climb the silo to start up the unloader and for periodic maintenance and adjustment; some operators may object to this. The top unloader must be raised and lowered every time the silo is refilled. Also, the last feed in is the first out, and this may cause a change in ration that might affect, for example, milking cows.

3.29 OXYGEN-LIMITING SILOS

An oxygen-limiting silo has gastight walls, floor, and roof. Gastight hatchways in the sidewall and top allow access from the outside for filling, unloading, and servicing. Equipped with a breathing system (see below), the structure provides a controlled atmosphere in which ensiled materials can be stored with a minimum loss of both quantity and quality. It can be adapted to store many different livestock feeds.

Operation of oxygen-limiting silos When chopped whole-plant forage with more than 40% moisture and grains with more than 25% moisture are put into an oxygen-limiting silo, they go through the fermentation described above. As the material ferments, it consumes oxygen and produces carbon dioxide. Carbon dioxide is heavier than air and normally saturates the silage mass and the space immediately above it. Because the structure is gastight, the atmosphere inside quickly changes from natural air containing about 20% oxygen to mostly carbon dioxide with little oxygen. The success of this type of storage depends primarily on the structure's ability to keep the oxygen content in and above the ensiled mass low enough to prevent spoilage.

Sealing the silo is not enough. Airtight silos need some type of pressure-equalizing system because gas pressures change daily. When silage is removed from the bottom of the silo, it creates a vacuum above the silage mass. Heat during the day causes the gases to expand, increasing the internal pressure, while cooling at night decreases the pressure by reducing the gas volume. Any appreciable vacuum can buckle thin sidewalls. Furthermore, if any leaks develop in the structure, a vacuum will pull air into the silo and promote deterioration of its contents.

One system of pressure equalization uses large plastic breather bags, either suspended in a doughnut-shaped ring inside the roof cavity and vented to the outside, or set in the foundation cavity below the elevated silo floor and connected by pipe to the inside of the silo at the top. In both cases, the breather bags compensate for gas pressure changes inside the silo by expanding or contracting. This equalizes the pressure without allowing outside air to come into contact with the silage.

Table 52 Dry matter capacities[1] of horizontal silos at various widths and depths (whole-plant silage)

Silage depth[2] (m)	Thickness of vertical slice[3] (mm)	Silo width[4] (m)														
		4.8	6.0	7.2	8.4	9.6	10.8	12.0	13.2	14.4	15.6	16.8	18.0	19.2	20.4	21.6
2.4	75	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60
	100	0.18	0.22	0.27	0.31	0.36	0.40	0.44	0.49	0.53	0.58	0.62	0.67	0.71	0.75	0.80
3.0	75	0.18	0.22	0.27	0.31	0.35	0.40	0.44	0.49	0.53	0.57	0.62	0.66	0.71	0.75	0.80
	100	0.24	0.29	0.35	0.41	0.47	0.53	0.59	0.65	0.71	0.77	0.83	0.88	0.94	1.00	1.06
3.6	75	0.22	0.28	0.34	0.39	0.45	0.51	0.56	0.62	0.67	0.73	0.79	0.84	0.90	0.95	1.01
	100	0.30	0.37	0.45	0.52	0.60	0.67	0.75	0.82	0.90	0.97	1.05	1.12	1.20	1.27	1.35
4.2	75	0.28	0.35	0.42	0.48	0.55	0.62	0.69	0.76	0.83	0.90	0.97	1.04	1.11	1.18	1.25
	100	0.37	0.46	0.55	0.65	0.74	0.83	0.92	1.01	1.11	1.20	1.29	1.38	1.48	1.57	1.66
4.8	75	0.33	0.42	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.16	1.25	1.33	1.41	1.50
	100	0.44	0.55	0.67	0.78	0.89	1.00	1.11	1.22	1.33	1.44	1.55	1.66	1.78	1.89	2.00

[1] Silo capacities were calculated based on the following:

- an allowance for a crowned top to the silage mass with a 1 in 5 slope to each side.
- dry matter densities of 154, 164, 173, 183, and 193 kg/m^3 for depths of 2.4, 3.0, 3.6, 4.2, and 4.8 m.
- to calculate actual capacities at various moisture contents multiply the figures shown by the following factors: for 65% × 2.857; for 70% × 3.333; for 75% × 4.0.

[2] Vertical depth of settled silage from silo floor to upper edge of silage at silo wall.

[3] Total silo capacity equals capacity for 100-mm slice times silo length in metres times 10.

[4] Silo width is measured at half the depth of settled silage along the silo walls.

Another system uses a series of air chambers below the floor in the silo foundation; these are connected by pipe to the top of the silo. The gases above the silage can move into or return from these chambers as the pressure changes.

3.30 Types

Steel Almost all oxygen-limiting silos of this type are made of glass-coated steel; a few use stainless steel, aluminized steel, or galvanized steel with some type of inner coating. The silo wall and roof are made from prefabricated panels or sections that are shipped to the site and erected on a specially prepared base. The sections are bolted together, usually with some type of sealing compound between the joints to make the silo airtight. Airtight hatches are installed in the roof and sidewall.

Concrete These silos look much like open-top concrete tower silos, but additional construction details ensure that they are gastight and especially reinforced for bottom-unloading. The usual chute and doors are replaced with airtight steel hatches embedded in the wall at the bottom of the silo. Flat or slightly conical roofs of reinforced concrete are fitted with airtight hatches for filling. Nearly all oxygen-limited concrete tower silos have cast-in-place walls. Several companies have, however, used precast concrete stave walls with some type of interior gastight coating or liner. Double-thick wall construction is usual at the bottom to take care of the high horizontal and vertical pressures of bottom unloading, particularly of forage.

Since concrete in itself is not a complete gas barrier, oxygen and carbon dioxide slowly diffuse through the silo wall unless some type of seal, usually an epoxy coating, is applied to the inside.

Unloaders for oxygen-limiting silos Most oxygen-limiting silos are equipped with a bottom unloader. For whole-plant silage, the three most common types are chain-saw sweep-arm, auger sweep-arm, and chain flail. Another unit is essentially a top unloader with bottom delivery. For free-flowing ensiled grain, a relatively simple auger unloader is commonly used.

Advantages and limitations of oxygen-limiting silos The high degree of control over the internal atmosphere helps to promote proper fermentation. This control can, with proper management, result in storage loss of about 3–5% dry matter, the lowest of all silo types.

Because of the controlled atmosphere, feed can be taken out at any rate without causing appreciable deterioration of the remaining feed. There is no need, from a feed quality standpoint, to select a silo diameter to match the daily feeding rate, so necessary with open-top silos to prevent feed deterioration. This is a particular advantage to operators with smaller herds or when "all-in, all-out" feeding operations result in fluctuating feed requirements.

Because oxygen-limiting silos are unloaded from the bottom, they offer the following advantages.

- It is not necessary to climb the silo to open the chute doors for unloading. As well as being a convenience, this reduces the risk of silo gas poisoning.
- There is no need to climb the silo to service the unloader. The motor and drive unit are at ground level outside the silo and are readily accessible for adjustment, servicing, and repair.
- The first silage in is also the first out. Fermented silage can be taken from the bottom while new material is piled on top, with no sudden change in the acidity of the ration.
- The silo can be filled or refilled without moving the unloader, although this is sometimes recommended when filling an empty silo.

3.31 HORIZONTAL SILOS

All silage storage structures that are broader or longer than they are high are called horizontal silos. For purposes of definition, the following types of storage are called horizontal silos, although combinations may also be found.

Trench silo This consists of a hole or trench dug below ground. Trench silos are often built wholly or partly into the side of a knoll or hill and are sometimes called pit silos.

Bunker silo This is built above the natural grade; the walls may or may not be banked with fill.

Stack This is essentially a pile of silage without permanent walls and as such is not a true silo at all.

3.32 Wall construction

The most popular types of walls are either wood (posts plus lumber or plywood) or concrete (cast-in-place or tilt-up). The choice of wall types and materials depends on their capital and annual cost, the availability and durability of materials, the type of silo, and personal preference.

Wood Wood walls are usually used for bunker silos. The structural strength of the wall comes from the use of closely spaced posts dug into the ground. The structure is supported either by using a diagonal brace from the ground to the upper part of each post, or by setting each post firmly in backfill, to act as a cantilever.

Although chemically treated posts and lumber would make the structure more durable, the preservative creates a potential health hazard if it comes into contact with animal feed. Currently there is no preservative registered in Canada for direct feed contact. One possible solution is to line the structural planking with a full covering of at least 100 µm polyethylene film, and to protect this in turn with a layer of plywood (untreated Douglas fir exterior sheathing). This has the added advantage of making the walls essentially airtight.

Concrete Concrete's durability and low maintenance make it an excellent material for permanent silos. It can be used equally well in trench and bunker silos.

Cast-in-place concrete is probably most practical for walls up to 2.4–3.0 m high; at greater heights, the problems of placing the concrete and steel increase considerably during construction. If the wall is self-supporting with a constant profile (not using buttresses) a great deal of steel reinforcing is required, especially with higher walls.

Precast tilt-up construction has a number of advantages. The costs for material and labor can be lower than for cast-in-place, especially when the contractor has experience in the technique. Precast tilt-up concrete is equally suited to both trench and bunker silos.

The method is as follows: for a trench silo, the excavation is made slightly larger than the finished width. The floor is constructed first. Then wall panels 100 or 150 mm thick, suitably reinforced, are cast on top of the floor. After curing, these are hoisted up into place against supports anchored into the earthen banks. The joints between the panels are caulked or grouted to make the wall airtight. For a bunker silo, reinforced concrete buttresses, either precast or cast-in-place, are erected along the sides of the silo to support the wall at intervals corresponding to the width of the tilt-up panels.

3.33 General construction details

Silo location Good surface and subsurface drainage is of prime importance. The site should also provide plenty of room and easy access for filling and unloading equipment. In deciding the location and orientation of the silo, consider normal snow and wind conditions. A horizontal silo should face south or southerly to reduce freezing problems in winter.

Silo design Regardless of the kind of wall, it must be made airtight, and strong enough to withstand the silage pressure and the weight of the filling and packing equipment, which combined could overturn the structure. The amount of reinforcing steel needed for concrete walls, or the size and spacing of support posts in a wood wall, depend on the maximum height of silage likely to be stored, as well as the equipment and method used to fill and pack.

Silo walls At no time should air reach the silage along the outside walls. To pack the silage against the walls as the material settles, the inner surface, particularly of the lower walls, should be slightly sloped. This slope also makes it easier for packing equipment to work right up to the wall. Moreover, tilt-up concrete walls supported only by earthen banks need to be sloped outward to keep them from being tipped inward by the pressure of the earth when the silo is empty. Similarly, the bottom edge of the walls must be restrained in some way to keep the slabs from sliding inward when the silo is empty.

Try to keep surface water (rain and melting snow) from entering the silage where it meets the walls. Runoff water contains dissolved oxygen that can cause serious spoilage if it penetrates into the silage.

Floor Some type of paved floor is required for permanent silos. Earth alone is seldom satisfactory for either mechanical or self-feeding operations. The floor should slope away from the silage feeding face (approximately 1:100) and should also be crowned diagonally or sloped to one corner for good drainage.

Roof A roof has only minor effects on storage losses if the silage is properly sealed. But it does eliminate weather problems and should be considered for the snow-belt regions of the country, particularly for smaller silos. It will, however, increase the capital cost of the silo to more than that for a tower silo of the same capacity.

Selection of silo size In determining the proper size for a horizontal silo, consider the following points.

- To reduce the cost of storage, as well as storage losses, the depth should be at least 2.4 m; a depth of 3.6–4.8 m is better. If, however, silage is to be self-fed from a silo, the depth should not be over 2 m, to keep labor to a minimum; deeper silos need constant attention to prevent a dangerous overhang from developing. For mechanical unloading, the depth need only be limited by the vertical reach of the unloading equipment.
- Width is related to the rate of removal of the silage. In warm weather, remove an average of 100 mm or more lengthwise each day to prevent spoilage. In cold weather, at least 75 mm should be taken out to stay ahead of freezing. The maximum silo width therefore depends on the volume and weight of silage to be fed out each day during the critical period. This amount dictates the number of cattle that can feed from the face of the silage if the cattle are self-fed. For group feeding, allow 450–700 mm per head depending on the size of animal; for full feeding allow a minimum of 75 mm per head.
- The optimum length equals the average length removed per day times the number of days in the feeding period. Allow additional length for the sloping end of the silage pile.
- Table 52 shows the capacity of horizontal silos of various lengths, depths, and widths; use it as a guide in size selection.

3.34 Other forms

In recent years, operators have shown increasing interest in the use of plastic for sealing silage. There are several types of storage.

Stacks Plant material is deposited in an elongated pyramid and then, without packing, totally wrapped in plastic to exclude air. Fermentation takes place inside the plastic. When the process is complete the plastic can be opened and silage fed out using a tractor and front-end loader, as with other stacks and horizontal silos. Such factors as moisture content and fineness of chop are highly important in keeping air out of the mass once the plastic is opened for feeding.

Large cylindrical bags Equipment has recently come on the market that mechanically stuffs the feed material into a large, sausage-like bag or tube 2.4–2.7 m in diameter and up to 45 m long. The bag can hold approximately 1 tonne of silage per 300 mm length. The bag is opened at one end for unloading.

Big bale silage In order to make use of existing round balers, many farmers are baling hay-crop material at the normal silage-making moisture, and then wrapping the bales in plastic by one of three ways:

- single bales each put into a separate plastic bag and tied off
- a number of bales put end-to-end into a long plastic bag
- a number of bales piled three tiers high in a pyramidal cross-section and then completely sealed in plastic.

In each case, the haycrop is only fed out after fermentation has taken place. The number of bales wrapped together should be balanced against the feeding rate so that the silage is exposed to the air for only a short time before feeding.

3.35 Advantages and limitations

The main advantage of the horizontal silo is its low initial cost, particularly for large volumes. This is not true, however, if the silo is roofed. Horizontal silos work extremely well with large-volume feeding (several thousand tonnes) since they can be filled and unloaded at a high rate. They are best suited to materials with a high moisture content, since there is less compaction and therefore less seepage loss. Horizontal silos may be more suitable for areas in which the support capacity of the subsoil is too low for tower silos.

The principal drawback is potentially high dry-matter losses; these can be kept to 15% or less (depending on silo size) with good management. Management is highly important with horizontal silos. At present, it is not possible, practically speaking, to fully mechanize the unloading of horizontal silos; this still needs manual labor. Unroofed horizontal silos are open to rain, snow, or ice, a fact that often leads to increased management problems.

3.36 SILO GAS

During fermentation, silage produces what is loosely called "silo gas," often in sufficient concentration to be harmful or even fatal to humans and animals. Silo gas is actually a mixture of several gases – carbon dioxide (CO_2) and oxides of nitrogen, principally nitrogen dioxide (NO_2). CO_2 at high concentrations is an asphyxiant; NO_2, even at quite low levels, is a deadly poison. The production of oxides of nitrogen is rather unpredictable. It varies from season to seaon and farm to farm.

CO_2 is one of the normal products of the ensiling process, but NO_2 may or may not be produced at toxic levels – a fact that makes the substance even more dangerous in that it may not be expected. The production of NO_2 seems to depend directly on the conditions under which the plant material grew before harvest. Adverse growth conditions, coupled with abundant nitrogen in the soil, can cause an excess of nitrates to be deposited in the stalks of the plants. Fermentation of this material can result in the production of NO_2.

Most accidents involving silo gas have occurred with open-top tower silos, although covered, enclosed horizontal silos could create risks as well, as could any silage storage where ventilation is poor. Both CO_2 and NO_2 are considerably heavier than air and will sink and collect in the lowest area in any confined space.

In dealing with silo gas there are two major points to consider: detection and elimination. The presence of both CO_2 and NO_2 can be determined through the use of a hand-held gas detector fitted with the proper reagent vial. In practical terms, however, this means going into a possibly dangerous environment in order to use the detector; use a proper type of self-contained breathing apparatus.

The most practical way to eliminate silo gas from an open-top tower silo is to use the forage blower to ventilate the headspace above the silage level. Research has shown that the blower is most effective if the chute doors are all in place, and the blower is much more efficient if a drop tube is used to conduct the incoming air down to within 6 m of the silage surface.

Details on silo gas – its nature, production, detection, and elimination – are discussed in the Canada Plan Service publication *Silo Gas*.

3.37 HAY AND STRAW

Hay normally consists of grasses or legumes or a combination, and is air-dried to about 15% moisture content (wet basis) for winter storage. It is commonly baled or chopped but can be wafered, depending on the handling system preferred. Hay can also be stored as haylage or haycrop silage. For haylage, a material of high legume content, usually alfalfa, is field-dried to about 50% moisture by weight and ensiled. Straw is usually chopped in the field or baled and used as bedding for animals.

Storage requirements for hay and straw can be determined using the formulas and apparent densities in Section 3.3.

On-grade storage structures for hay or straw can be used with single-story animal housing. They should be separated from the animal housing for fire safety, with convenient access provided.

A typical hay or straw storage is a clear-span pole-frame construction with a trussed roof. It might be the back part of an open-front beef barn or a separate structure. Covered on-grade storage can be used for both large round bales and conventional rectangular bales.

For centuries hay and straw have been stored above animal housing, primarily for ease of access in cold or wet weather. But this practice increases both the fire risks to the animals and the initial cost of construction.

3.38 BARN HAY DRYING

The barn hay dryer is making a comeback as an alternative to the silo. It permits the harvest to be properly timed, prevents heavy losses from bad weather, preserves feed value, and helps to prevent spontaneous combustion. The following points must be considered when investigating the feasibility of a hay drying system.

- Hay to be barn dried weighs 25–30% more than field-dried hay.
- The mow floor must be airtight so that air is forced through the hay and not through the floor. Use doubled flooring with 0.15 mm (6 mil) polyethylene plastic between the two layers to seal a relatively solid floor.
- The air flow required is determined by using the *greater* of these formulas:

  [1] 75–100 L/s per square metre of mow area

  or

  [2] 156–200 L/s per tonne of dry hay.

Note: One tonne of dry baled hay occupies about 8 m^3. One tonne of chopped hay occupies about 11 m^3.

In general, choose a fan that moves the required amount of air at a static pressure of 250 Pa.

3.39 Types of systems

There are four main types of hay-drying systems, although many variations do exist.

The triangular center main (Fig. 31) is used only in narrow mows. The depth of the hay above the duct must be about equal to the distance from the edge of the duct to the mow wall on either side. The duct is lined on the inside and has control doors allowing the air to move out of the duct into a plenum or open space, separated from the hay by a layer of slats, evenly spaced. This provides more even air distribution.

The center rectangular main is used in similar applications, but the rectangular duct allows more combinations of duct width and height. This system allows you to maintain equal depths of hay on the top and sides of the duct. It is also slatted.

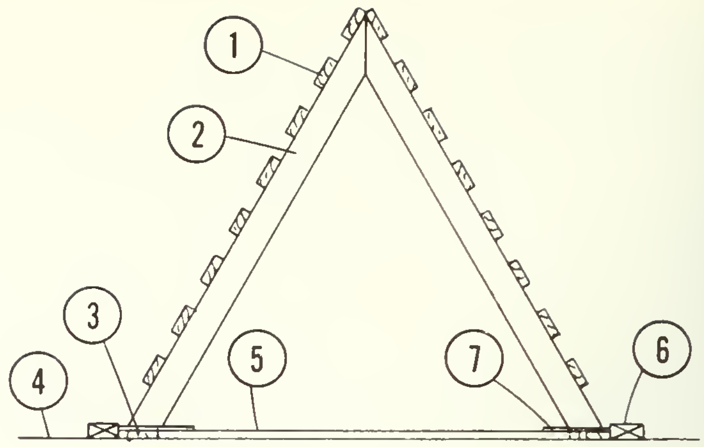
The side main and center main ducts (Fig. 31) with slatted floors are similar in design. The rectangular main has air control doors that open into a slatted floor distribution system. These systems may be used to dry hay in a mow with a large floor area. The ducts may be unlined, but then the main duct must be adequately covered with hay to prevent the air from short circuiting when the fan is started. This system lacks flexibility to dry a mow only partly filled.

Some considerations for design are as follows.

- The main duct should be large enough to provide 0.2 m^2 of cross-sectional area for every 1000 L/s of fan capacity.
- In a slatted-floor system, the air control doors should create an air velocity of about 2.5 m/s through the opening. Making the air control door the same size as the joists supporting the slatted floor usually provides a large enough opening.
- In a slatted-floor system, the slats should end 2–2.5 m from all walls.
- The first 1.8–2.4 m of the duct next to the fan should be sealed tight.
- For air discharge, provide 0.4 m^2 of air outlet from the mow space for every 1000 L/s of fan capacity. Openings can be in the form of roof vents, louvers, or similar devices.

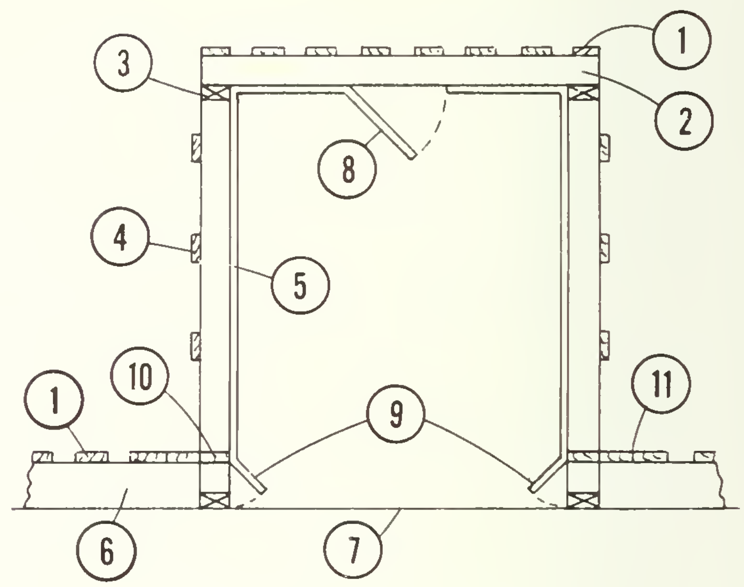
3.40 Installing the fan

Locate the fan where it can be easily reached for maintenance and repair. Protect it from the weather by a small roof and door.



1 19 x 89 mm slats spaced 75 mm apart
2 38 x 89 mm spaced 600 mm
3 19 mm plate
4 Mow floor
5 19 x 89 mm tie, every 1200 mm
6 38 x 89 mm spiked to floor to prevent duct from spreading
7 7.5 mm plywood gusset

A Unlined triangular duct



1 19 x 89 mm slats 75 mm apart
2 38 x 89 mm spaced 600 mm
3 38 x 89 mm plate
4 19 x 89 mm slats
5 Duct lining
6 38 x 140 mm joists, spaced 600 mm
7 Mow floor
8 300 mm air control door
9 150 mm air control door
10 19 x 89 mm blocking
11 No spacing first 300 mm

B. Lined rectangular duct with slatted floor

Fig. 31 Ducts for barn hay driers
***Source*: Atlantic Provinces Agricultural Services**

Remember when you choose the fan location that it will be running continuously and making considerable noise; install it on the side of the barn farthest from the farmhouse and neighbors, if possible.

3.41 Harvesting and filling

Field-dry hay to about 35% moisture content before baling. Hay with a high grass content may be baled with a slightly higher moisture content, whereas hay with a high legume content should be slightly drier.

Bale the hay as loosely as possible.

Pack the mow tightly with bales laid on edge, putting alternate layers at right angles to each other. Although this arrangement is ideal, satisfactory results can be obtained with bales laid flat.

The whole system, including the duct, should be uniformly covered with 1.2 m of hay before the fan is started.

Add no more than 1 m of wet hay per day and no more than the maximum depth given in Table 53 in a 2-week period.

Overloading the dryer seriously impairs drying efficiency and results in moldy and musty hay.

3.42 Operating the dryer

Once the fan is started, run it continuously until the hay is dry. When the hay at the top seems fully dry, turn the fan off overnight. Start it again and walk over the mow to check for warm or musty air.

If you sense any heat in the hay, run the fan for a day or two and recheck.

If no heat is evident after three checks, the hay may be considered dry.

3.43 FRUITS AND VEGETABLES

The long-term storage of fruits and vegetables under controlled environmental conditions allows for orderly marketing over much of the year. The design of fruit and vegetable storage facilities must take into account the number and variety of crops stored, handling requirements, grading and packaging, and the prospects for future expansion. It must also deal with specific requirements. For example, many fruit and vegetable crops require cooling before they are marketed, whereas controlled atmosphere (CA) storages, in which oxygen and carbon dioxide are regulated, need specialized gas seals and monitoring equipment.

Table 53 Comparison of hay-drying systems[1]

Type of duct system	Form of hay	Recommended mow width (m)	Maximum mow width (m)	Maximum duct length	Depth above duct	Depth above floor	Weight of hay-dried (tonnes)
Triangular center main	Chopped	6–11	11	12	4	6.5	50
	Baled		7.5	15	3	5	50
Rectangular center main	Chopped	9–11	11	23	4	6.5	50
	Baled		8.5	27	3.5	6	50
Side main with slatted floor	Chopped	6–12	12	18	4	4	50
	Baled		12	18	3.5	4	50
Center main with slatted floor	Chopped	10–13	13.5	17	4	4	50
	Baled		13.5	17	3.5	4	50

[1] Based on a fan capacity of 7750 L/s at 0.25 kPa static pressure.

All storage structures for fruits and vegetables should be designed to meet all the applicable requirements of the *Canadian Farm Building Code*.

3.44 STORAGE SPACE, STORAGE TYPES, AND SPECIAL REQUIREMENTS

3.45 Storage space

Storages vary from one large room to multiple bins or rooms. Multiple bins or rooms offer better control of small batches, reduced risks of storage losses, and more flexibility in the use of bins or rooms for different crops.

The actual storage space provided in bins can be calculated using bulk density data from Table 54. Do *not* use these values for determining lateral pressures for structural design; instead refer to the table of bulk densities in the *Canadian Farm Building Code*. The values in the code may be slightly higher since they represent maximum values in the interests of safe design, whereas the values listed here represent average values for estimating volume requirements.

3.46 Storage types and special requirements

Storages are of two general types, bulk and pallet. Storages can be further classified by the produce stored and by the cooling system (refrigerated or air cooled).

For bulk storage, the produce is piled in the whole storage or in room-sized bins. The pressure exerted by the pile must be held by the bin walls. Ventilation of bulk storage is accomplished by blowing conditioned air up through the pile of produce from a duct system set on or in the floor.

Bulk storage is best for crops that can be handled in quantity and piled fairly deep—turnips, beets, potatoes, carrots, and onions, for example. When sizing bulk storages, leave at least 600 mm of headspace for loading equipment and air circulation.

In pallet storage, the crop is put in large boxes (pallet bins), which in turn are stacked in storage rooms. Ventilation air at the proper temperature and humidity is circulated between rows of bins. The bins are moved and stacked by forklifts and unloaded by pallet-dumping equipment. Since the crop does not exert pressure on the building walls, the building need be designed only for climatic requirements.

Table 54 Bulk density, specific gravity, and specific heat of various fruits and vegetables

Product	Bulk density (kg/m^3)	Approximate specific gravity	Specific heat (kJ/kg·°C)
Fruit			
Apples	600	0.77	3.64
Apricots	610		3.68
Berries			
Blackberries	610		3.68
Cranberries	480		3.77
Gooseberries	–		3.81
Raspberries	610		3.56
Strawberries	610		3.85
Cherries			
With stem	720		–
Without stem	810	1.08	3.58
Grapes			
Vinifera	370		3.56
American			3.60
Melons			
Watermelon			3.94
Cantaloupe			3.94
Honeydew			3.94
Peaches	610	1.00	3.81
Pears	640	0.99	3.60
Plums	720	1.04	3.73
Vegetables			
Asparagus	570		3.94
Beans			
Snap green	770		3.81
Lima	770		3.06
Beets			
Red topped	700		3.77
Red bunched	550		–
Sugar	700		–
Broccoli			3.85
Brussels sprouts			3.68
Cabbage	450		3.94
Carrots			
Topped	550	1.03	3.81
Bunched	480		–
Cauliflower	320		3.89
Celery	530		3.98
Corn			
Cob	440		
Shelled	710		1.11
Cucumbers	610	0.94	4.06
Eggplant	420		3.94
Garlic			2.89
Lettuce	300–350		4.02
Onions	650–700		3.77
Onions, green bunched	270–300		3.81

continued

Table 54 *(concluded)*

Product	Bulk density (kg/m^3)	Approximate specific gravity	Specific heat (kJ/kg·°C)
Parsnips	550		3.48
Peas (in pod)	390		–
Peppers	320		3.94
Potatoes	650–680	1.07	3.50
Pumpkins			3.85
Radishes	650		4.02
Rutabaga	650		3.81
Spinach	260		3.94
Squash			3.84
Tomatoes			
Ripe	680		3.98
Green		0.98	3.94
Turnips	650	0.95	3.89

Pallet storage is generally used for crops that bruise easily or cannot be piled – most fruits, cabbage, parsnips, carrots, and greenhouse crops. Pallet storage also allows different varieties or types of crops, or crops from several growers, to be stored together. Bins can be selectively marketed, and problem bins can be removed with less danger of widespread spoilage. Pallet storage is essential for warehouses and plants in which produce turnover is high.

The capacity of a pallet storage is determined by laying out the required number of bins in tiers and rows. Stacking height is often determined by the limitations of the stacking equipment; stacks are usually four to six tiers high. The most efficient room size provides for precise rows of bins, with about 150 mm space between bins and along walls for air flow.

Some special considerations for design follow.

- Don't forget to allow for wind and snow loads.
- Consider whether a pallet-storage building might be used for bulk storage in the future.
- Remember that the highest concentrated floor loads are caused by forklift wheels.

In designing bulk storage structures, pay particular attention to the strength of wall members, the connections at the top and bottom walls, the lateral forces on the foundation, and the extra forces on the roof or ceiling system exerted by wall pressure.

Good design information is available on potato bin pressure, but not for most other crops. It is best to design all bulk storage walls for potato storage; although other crops exert less pressure, the storage may some day be used for potatoes.

In engineering terms, wall systems for potato storage can be designed on the basis of a granular product with equivalent fluid density. Bending moments and wall forces are calculated accordingly. Refer to the *Canadian Farm Building Code.*

Most storages require high humidity. No matter what material is used for construction, the storage must have good insulation and moisture resistance. Vapor barriers must be thorough and effective.

Consider the following principles, regardless of the construction type.

- Insulate foundations, preferably on the exterior.
- Pay particular attention to thermal bridges or cold spots in wall or roof systems; these could cause serious condensation problems.
- Make inside surfaces durable and easy to disinfect.
- Do not use wood treated with preservatives in direct contact with produce, or exposed above it (dripping).

3.47 ENVIRONMENTAL CONTROL

This includes control of temperature, humidity, and airflow in the whole storage or in individual rooms.

3.48 Basic storage requirements and data

Table 55 gives recommended temperatures, relative humidities, and other conditions for fresh fruits and vegetables held in storage.

Table 56 gives the heat of respiration of fresh fruits and vegetables at various temperatures. Use data on the heat of respiration from this table, together with the specific heat from Table 54, to calculate the cooling load needed to remove heat and maintain storage temperature.

3.49 Environmental control systems

Storages may be air cooled, refrigerated, or both. In air-cooled storage, the temperature is controlled by blending cold outdoor air into the ventilation system. Outdoor temperatures must therefore be below storage temperature for all but short periods during most of the storage season. In general this restriction applies to storage for potatoes, onions, and squash, and to some short-term colder storages.

Table 55 Recommended temperature and relative humidity levels, approximate storage life, freezing point, and ventilation rate, for various fruits and vegetables in storage

Product	Temperature (°C)	Relative humidity (%)	Approx. storage period	Highest freezing point[1] (°C)	Ventilation rate (L/s·t)
Fruit					
Apples	–1 to 4	90	3–8 mo	–1.7	
Apricots	–1	90	1–2 wk	–1.1	
Berries					
Blackberries	–1 to 0	90–95	2–3 days	–0.8	
Cranberries	2.4	90–95	2–4 mo	–0.8	
Gooseberries	–1.0	90–95	2–4 wk		
Raspberries	–1.0	90–95	2–3 days	–1.1	
Strawberries	0	90–95	5–7 days	–0.8	
Cherries	–1	90–95	2–3 wk	–1.7	
Grapes					
Vinifera	–1	90–95	3–6 mo		
American	–1	85	2–8 wk	–1.3	
Melons					
Watermelon	4 –10	80–85	2–3 wk	–0.4	
Cantaloupe	0 –2	85–90	5–14 days	–0.8	
Honeydew	7–10	85–90	3–4 wk	–1.1	
Peaches	–1	90	2–4 wk	–0.9	
Pears	–2 to –1	90–95	2–7 mo	–1.6	
Plums	–1	90–95	2–4 wk	–3.1	
Vegetables					
Asparagus	0 –2	95	2–3 wk	–0.6	
Beans					
Snap-green	4 –7	90–95	7–10 wk	–0.7	
Lima	0.4	90	1–2 wk	–0.6	
Beets					
Red topped	0	95	3–5 mo	–0.9	20–30
Red bunched	0	95	10–14 days	–0.4	
Broccoli	0	90–95	10–14 days	–0.6	
Brussels sprouts	0	90–95	3–5 wk	–0.8	
Cabbage	0	90–95	1–4 mo	–0.2	20–30
Carrots, topped	0	90–95	4–5 mo	–1.4	20–30
Cauliflower	0	90–95	2–4 wk	–0.8	
Celery	0	90–95	2–3 mo	–0.6	
Corn cob	0	90–95	4–8 days		
Cucumbers	7 –10	90–95	10–14 days	–0.5	
Eggplant	7 –10	90	1 wk	–0.8	
Garlic	0	65–70	6–7 mo	–0.8	
Lettuce	0	95	2–3 wk		
Onions	0	65–70	1–8 mo	–0.3	10–20[2]
Onions, green bunched	0	90–95			
Parsnips	0	90–95	2–6 mo	–0.3	20–30
Peas, in pod	0	90–95	1–3 wk	–1.2	
Peppers, sweet	7 –10	90–95	2–3 wk	–0.7	
Potatoes		90		–0.8	6–10
Pumpkins	10 –13	70–75	2–3 mo	–0.8	15–20
Radishes	0	90–95	4–5 mo	–0.4	

continued

Table 55 *(concluded)*

Product	Temper-ature (°C)	Relative humidity (%)	Approx. storage period	Highest freezing point[1] (°C)	Ventil-ation rate (L/s·t)
Rutabaga	0	90–95	2–4 mo	–1.1	15–25
Spinach	0	90–95	10–14 days	–0.3	
Squash					
Winter	10–13	50–75		–0.8	15–25
Summer	0–10	90	5–14 days	–0.5	
Tomatoes					
Ripe	7–10	85–90	4–7 days	–0.5	
Mature	13–21	85–90	1–3 wk	–0.8	
Turnips	0	90–95	2–4 mo	–1.1	15–25

[1] Though this is the freezing point, some crops (e.g., potatoes, cucumbers, squash, tomatoes) are seriously damaged by temperatures above their freezing points but below their optimum storage temperatures.
[2] For curing, use 35–40.

Table 56 Heat of respiration of fresh fruit and vegetables at various temperatures

Commodity	Joules per kilogram per hour at indicated temperature, J/(kg·h)		
	0°C	15°C	25°C
Fruit			
Apples	24–44	145–329	–
Apricots	–	402–732	–
Blackberries	189–208	–	–
Blueberries	24–111	363–659	833–1320
Cranberries	29–34	–	–
Gooseberries	73–92	233–344	–
Raspberries	189–267	877–1080	–
Strawberries	131–189	756–984	1800–2240
Cherries			
Sour	63–141	291–533	567–756
Sweet	44–58	267–480	–
Grapes			
Vinifera	15–24	107–126	267–320
American	29	170	412
Melons			
Cantaloupe	53–63	359–412	664–761
Honeydew	–	126–170	281–368
Peaches	44–68	354–451	867–1300
Pears			
Bartlett	34–73	160–640	–
Kieffer	19–24	116–257	208–305
Plums	19–34	126–136	300–756

continued

Table 56 *(concluded)*

Commodity	Joules per kilogram per hour at indicated temperature, J/(kg·h)		
	0°C	15°C	25°C
Vegetables			
Asparagus	300–640	1240–2500	3960–5070
Beans			
Lima	111–320	1070–1330	–
Snap	267–436	1560–2140	–
Beets, red topped	131	349	–
Broccoli	199–228	1850–3620	5970–9380
Brussels sprouts	107–320	683–1450	–
Cabbage	48–68	199–276	518–678
Carrots, topped	102–218	276–572	–
Cauliflower, trimmed	174–204	455–523	896–1490
Celery	78	397	–
Corn, cob	320–548	1610–1860	3000–4640
Cucumbers	–	160–354	204–586
Garlic	44–150	150–310	–
Leek	102–179	882–1250	1140–1260
Lettuce			
Head	63–179	339–480	780–974
Leaf	204–291	548–790	1280–1840
Mushrooms	300–465	–	–
Onions			
Dry	29–34	111–121	291–310
Green	111–237	703–1040	1040–2230
Parsnips	126–165	344–455	–
Peas, in pod	325–499	1900–2160	3660–4020
Peppers, sweet	–	213–611	383–790
Potatoes			
Immature	–	141–329	–
Mature	–	63–126	–
Radishes			
With tops	155–184	746–829	1690–2050
Topped	34–102	237–451	644–945
Spinach	204–237	1430–2380	–
Squash			
Butternut	–	–	703–1300
Yellow	126–135	800–969	–
Sweet potatoes			
Cured	–	208–257	–
Uncured	305	577–780	–
Tomatoes			
Mature	–	174–300	368–543
Ripe	–	257–310	320–557
Turnips	92	228–257	–

Ventilation moves conditioned air around or through the produce to remove heat, maintain uniform relative humidity, and control condensation. This system involves known airflow rates and patterns, temperature controls, fans, and duct design. Airflow requirements vary significantly and, in most cases, should be dealt with only by experienced designers of storage systems.

The ventilation rates given in Table 55 are for sound, healthy, mature produce; they should be used only as a guide. Immature or diseased produce requires much more ventilation because of its higher-than-normal respiration rate and the resulting release of moisture and heat.

In bulk storage, air circulates through the pile by a fan and duct system. Temperature control is usually accomplished by a system of thermostatically controlled dampers that blend cold outside air into recirculated air. Controls should include

- a thermostat controlling the amount of cold air to be blended in
- a low-limit safety thermostat
- a differential temperature sensor (to prevent ventilation with too-warm outside air)
- a timer
- damper control motors.

Another system uses one set of timer-controlled fans for recirculation and another set of fans controlled by thermostat for bringing in fresh air or exhausting stale air.

Design of the system for air handling and distribution should adhere to sound engineering principles. Ducts should be smooth, designed to minimize abrupt changes in air velocity, and large enough both to minimize pressure drop and to ensure uniform distribution. Lateral ducts under piles of produce are normally spaced 2.4–3.6 m apart.

Storages requiring high humidity should include a high-capacity humidifier as an integral part of the system.

Refrigeration is required for storage extending past the winter months and for early fall storage of more sensitive crops such as carrots, celery, and lettuce. The refrigeration system should be designed to remove field heat, heat of respiration, and other increases in temperature. The system must operate effectively at high humidity and near-freezing conditions, yet minimize moisture loss from the produce. With conventional refrigeration, this requires a large evaporator coil area, adequate air flow, defrosting cycles, and humidification.

Most storages also require heating equipment to prevent freezing during sustained cold weather in case the storage is only partially full.

3.50 Controlled atmosphere storages

Controlled atmosphere (CA) storages allow regulation of the respiration rate of the stored product, thus extending its storage life. CA systems monitor and adjust the levels of carbon dioxide and oxygen, and refrigeration and humidifying equipment control temperature and relative humidity.

Normal atmosphere contains 20–21% oxygen and 0.03% carbon dioxide. CA storage of apples uses oxygen at 3–5% and carbon dioxide at 2–5%. This special atmosphere is usually produced by an external generator that burns a hydrocarbon fuel with a catalyst. The generator should be installed according to manufacturers' recommendations, and should meet all safety requirements to prevent raw fuel release or the buildup of pressure in the storage.

CA storages do not have enough oxygen for human breathing. If you must go into the storage, use a portable air supply such as scuba equipment or preferably a full face mask and air tank – the type used by firefighters, for example. At least one person should be outside the room for each person inside. When the room is opened, no one should enter without remote breathing apparatus until gas analysis shows 18–20% oxygen.

Special requirements are necessary to ensure a good gas seal in the room.

- All joints and fasteners should be sealed with silicone caulking.
- Polyethylene sheeting under the concrete floor should extend to a caulked joint between the floor and wall.
- Wall-to-wall and wall-to-ceiling joints should include an additional angle section, overlaid and caulked to seal any gaps in the butt joints.

Well-sealed CA storages must be equipped with a gastight bag system for adjusting to pressure changes (see Section 3.30), as well as a valve to regulate differential pressures, or a trap to relieve pressure, or both. They must quickly equalize the inside and outside pressures when the barometric pressure or temperature changes, to avoid damage to the storage seals. Storage seals should be tested at 250 Pa, and valves to limit differential pressure should be set at 125 Pa.

Additional structural details, including insulation, should meet or exceed requirements for normal refrigerated storage.

3.51 ELECTRICAL REQUIREMENTS

Electrical services should be available for lighting, ventilation, product handling, humidification, and water supply.

The use of refrigeration units greatly increases your power demand and probably requires three-phase service. See Section 6.52 for specific information and Part 6 for general recommendations on electrical service.

PART 4
Storage for supplies and equipment

4.1 CHEMICALS AND FERTILIZER

4.2 FERTILIZER STORAGE

Fertilizer may be liquid or granular. Liquid fertilizer requires large, heavy-duty steel storage tanks; most of these are lined to resist corrosion. The phosphate in commercial fertilizer solutions has been shown to have corrosion-inhibiting properties.

Granular fertilizer may be either bagged or in bulk and requires high-quality storage facilities. Most fertilizer is highly corrosive and hygroscopic (that is, it absorbs water from air). Storage structures must therefore be rain- and snow-tight, with corrosion-resistant linings, materials, and connections.

Table 57 shows some physical properties of typical granular fertilizers. Note that the properties of any type of fertilizer depend both on the manufacturer and on the material's physical condition (for example, the size of the particles and the moisture content).

Fertilizers may exert far more pressure on walls and floors than the same volume of grain. These pressures can be estimated from the bulk density and angle of repose, applying standard engineering formulas (Rankine, Janssen). Moisture can greatly influence the angle of repose.

The storage of bagged fertilizer depends on traffic, the stacking patterns for pallets, and the maximum depth recommended to avoid compacting the material. There is usually no practical weight limit for concrete floors on grade.

Table 57 Densities and angles of repose of several fertilizers

Fertilizer type	Approx. density (kg/m^3)	Angle of repose (degrees)
46-0-0	740–770	28
27-27-0	865	
14-14-7 23-23-0 26-13-0 27-14-0 34-0-0 10-30-10	910	26–30
11-55-0 11-48-0 11-51-0 16-20-0 17-34-0	930	28–30
16-16-16 13-16-10 8-24-24	950	
21-0-0 0-0-60	1120–1200	32–35

4.3 Nitrate fertilizers

Nitrate fertilizers can be explosive, particularly when combined with petroleum fuels. These and all fertilizers, fuels, and farm chemicals should be stored away from each other and from other buildings.

4.4 Security, access, and safety

Provide for convenient and safe locked storage of chemicals such as pesticides on the farmstead. The inadvertent addition of pesticides to animal feed has resulted in substantial losses. Storage rooms should be secured with a lock and equipped with door latches that open from inside. A clear well-drained gravel area around the building or storage makes it easier to deliver and remove the materials. The chemical storage area should be isolated in case of fire, spills, or similar accidents. To contain spills, floors should be curbed and watertight to a height of 100 mm, without a floor drain. All storage rooms should be ventilated, and an ABC chemical fire extinguisher should be readily accessible in each.

4.5 Service requirements

Electrical and water supplies may be needed, depending on specific applications and local requirements.

4.6 VEHICLE AND EQUIPMENT STORAGE

Farm machinery and equipment should be stored indoors whenever possible, both for security and to reduce weather damage.

4.7 SIZING

The total floor area needed to store farm vehicles and equipment should be calculated by adding up the areas occupied by all machines and vehicles, plus 20% for parking clearance. Door openings should be at least 300 mm wider and 100 mm higher than the largest machine to be stored in the building. If access is from only one side, the depth of the storage should not be over 10 m. Where doors are at the ends only, the span of the building can be 2.5 times the door width.

If the maintenance shop area can be used for vehicle storage, and if this area is suitable for a workshop (see Section 4.9), up to 50% of the maintenance shop floor area may be counted as storage area for self-propelled farm equipment and vehicles.

One common method of estimating the storage space for equipment is the stake-and-string method. This can be done in two different ways.

- Take all the farm machinery and park it in the area where the storage structure would be located. Drive stakes in at the corners of the area, and run a string between the stakes. This gives the minimum perimeter and hence the minimum size of structure needed. Remember to add 20% for parking clearance.
- To determine how much equipment you can store in a proposed building, drive stakes into the ground at the proposed location to outline the building's dimensions, including door openings. Then attach a string to the stakes to form the outside perimeter of the structure you plan. Both parking space and accessibility can be established by this method. Doors should be carefully located to make the best use of long-term storage space and for easy temporary storage.

4.8 LOCATION

The machinery shed should be readily accessible to all parts of the farm and convenient to the farmhouse, but far enough away from it for fire protection. It should be close to the farm workshop; alternatively, the shop could be in the shed, if the necessary safety precautions are observed (fire protection, ventilation, and so forth). The shed can be set upwind from other buildings since it generates little odor, noise, or dust. Gravel or hard surfaces in front of south-facing doorways dry quickly after rains or spring thaw. If prevailing winds are from the west, then east-facing doorways are the next best compromise between dry roadways, wind protection, and accessibility.

A level, well-drained site is best. Machinery storage buildings, floors, parking aprons, and access lanes should be slightly above grade to improve drainage away from the buildings and parking areas. Some space should be provided nearby for temporary parking of machinery in use. For further information, refer to the following booklets and publications:

- *Farmstead Planning*
- *Agricultural Materials Handling Manual*, Part 6
- *Canadian Farm Building Code.*

4.9 FARM WORKSHOP

4.10 SPACE REQUIREMENTS

The workshop floor area should be not less than 20% of the area needed for vehicle and equipment storage (minimum 40 m^2). It should be free of columns and be at least 5 m long or wide. It may be at the end of an equipment storage building, forming a single unit, or a completely separate building. Provide a paved strip 12–15 m wide in front of the workshop for servicing equipment. A clear area to one side of the shop is also useful for parking machinery.

4.11 FIRE SAFETY

Farm workshops should conform to the fire safety provisions of the *Canadian Farm Building Code.*

4.12 ELECTRICAL REQUIREMENTS

Farm workshops and machinery sheds generally need convenience outlets and lighting. Heavier wiring may be required for large power tools, welders, or space heating. For furthur details on electrical services and wiring in the farm workshop and machinery storage, see Section 6.54.

PART 5
Design, construction, and building materials

5.1 FOUNDATIONS

All farm buildings should have adequate foundations. Foundations can be footings, pilings, posts, piers, pilasters, rafts, slabs, grade beams, or other supporting members bearing on soil or rock for the purpose of supporting the building.

A foundation should be designed for existing soil according to recognized engineering principles. Have a review carried out by a qualified person to make sure that subsurface conditions are consistent with the design. If, during construction, you find that the soil, rock, groundwater, or climatic conditions have changed and are not of the type or in the condition of the design, then the design should be reconsidered.

An adequate foundation must resist the following forces and actions:

- the weight of the building and contents, including snow loads
- soil movement caused by changes in moisture content, settlement, or frost action
- horizontal soil pressure
- wind forces that tend to lift and overturn the building
- lateral forces from stored contents or from roof loads on rigid arch frames.

A good foundation distributes these forces so that movement of the building is both small and uniform.

Some foundation failures result from poor drainage, uneven settlement of inadequate footings, and too-shallow foundations. Shallow foundations can, however, be perfectly adequate if they are properly built.

Two other types of foundation failures can damage farm structures. First, tower silos put a great deal of weight on a comparatively small area. This can lead to soil consolidation, causing the structure to settle unevenly and eventually to overturn. Second, some soils (soft clays) have little shear strength and may roll or slide out of place when a load is put on them. This can be a problem both for silos and for pole-type structures built without an adequate footing.

In wet or potentially wet soils, lay drain tile, perforated drainpipe, or tubing around the outside of the foundation so that the top of the drain is below the bottom of the floor slab. Lay all drains at the same slope. They should carry water away from the foundation to an outlet that always remains open.

Drain tile with butt ends should be laid with open joints 6–10 mm wide. Put cover strips of durable material, such as asphalt felt, at least 75 mm wide over at least the top half of open joints. Perforated drainpipe should be laid with the perforations down, and can be connected with couplings. Cover the drain with at least 150 mm of coarse gravel or other porous, granular material.

Backfill carefully against foundation walls to avoid damaging the walls or any damp-proofing. Remember that the fill may settle; backfill to above grade so that the final grade does not slope toward the foundation. For further details refer to the *National Building Code of Canada* and the *Canadian Foundation Engineering Manual*.

5.2 FOOTINGS

Footings under foundation walls, columns, piers, and poles should cover a large enough bearing area to distribute loads according to the allowable bearing value of the supporting material. When designing footings for small buildings, consult Part 9 of the *National Building Code* for further information on the bearing capacity of soil and rock.

Footings may be omitted if the safe bearing capacity of soil or rock is not exceeded, and if the foundation is otherwise prevented from overturning. Proportion the wall and column footings to minimize uneven settlement.

If footings are to be supported on consolidated fill or unstable soil, they should be designed for these conditions, and the building should be constructed so that it will not be structurally damaged by uneven settlement.

5.3 Concrete

Proportion the footings for concrete or masonry walls according to load, to give uniform soil-bearing pressures, to minimize uneven settlement. The bottom of footings should extend below the frost line, unless they are set on rock or coarse-grained soil. If possible, the site should be well drained to at least the frost line. If the building is to be permanently heated in winter, consider providing enough perimeter insulation to prevent frost from penetrating under the footings instead of using very deep footings.

For further details on the minimum dimensions of plain or reinforced concrete strip or column footings, see *Design of Concrete Structures for Buildings* and Part 9 of the *National Building Code of Canada*.

5.4 Wood

Wood used for footings should be at least 38 mm thick. All wood footings carry no more than the allowable stresses for the grade and species of wood used, as specified in *Engineering Design in Wood (Limit States Design)* or *Engineering Design in Wood (Working Stress Design)*. (See Section 5.8 for information on pressure-treated wood.) For further information and details see: *Construction of Preserved Wood Foundations* and *Wood Preservation*.

5.5 CONCRETE FOUNDATION WALLS

Concrete foundation walls include poured and concrete-block construction. They should resist vertical and horizontal loads, taking into account their own unsupported length and height.

The design of concrete foundations should conform to *Design of Concrete Structures for Buildings*. The design of concrete block foundations should conform to *Masonry Design for Buildings*.

5.6 WOOD-FRAME FOUNDATIONS

Wood-frame foundation walls and wood post-and-plank foundations should be designed to resist vertical and horizontal loads, taking into account their unsupported length and height. The following members should be pressure-treated:

- all horizontal and vertical framing
- plywood or lumber sheathing, planks and posts, and wood sills
- lumber or plywood skirting below grade and to a minimum height of 200 mm above grade.

Wood sills should be at least 38 mm thick. Cedar poles for pole barns may be used without treatment, but will not last as long as pressure-treated poles. (See Section 5.8, below.)

For further details and information refer to the *National Building Code of Canada*, Canada Plan Service leaflets, and *Construction of Preserved Wood Foundations*.

5.7 OTHER FOUNDATIONS

Concrete beams A concrete beam foundation on grade consists of a series of concrete piers supporting a reinforced concrete beam around the perimeter of the building. The piers should be proportioned to carry all vertical loads and should be reinforced to resist lateral and uplift forces. The cross-sectional area of steel should be at least 0.01 times the cross-sectional area of the piers. The bottom of piers should have enough bearing area to safely distribute loads over the supporting soil or rock. Piers should extend below the frost line to a firm bearing surface, and should be at least 250 mm in diameter.

Grade beams should be designed to carry the live and dead loads of the building supported by the walls and should extend at least 200 mm above grade. If the soil is subject to frost heave or changes in volume with moisture content, there should be at least 150 mm of clearance between the soil and the lower face of the beam.

Concrete slabs On-grade concrete slabs with perimeter foundations should be at least 100 mm thick. The top of the slab should be at least 100 mm above the exterior finish grade. If used, reinforcement for slabs on grade should be uniformly distributed and should weigh at least 18 kg/10 m^2 (152 × 152, MW 18.7 × MW 18.7).

Slabs on grade may not have to be reinforced if grooves 25 mm deep (for shrinkage control) are scored or sawn into concrete at not over 6-m intervals. In areas requiring sanitation (milk rooms, for example) these grooves should be caulked.

Footings for load-bearing partitions should rest on undisturbed soil or well-compacted fill. These footings should be at least 125 mm thick, measured from the underside of slabs on grade, and at least 300 mm wide.

Slabs on grade without foundation walls (floating slab foundations) should meet or exceed the requirements for those with foundation walls. The top of a floating slab should be at least 100 mm above exterior finish grade. A tapered perimeter beam should be provided with a minimum bottom width of 200 mm and should extend at least 300 mm into undisturbed soil.

For further design and construction information refer to *Design of Concrete Structures for Buildings*, and the *National Building Code of Canada*.

5.8 WOOD

All structural members, assemblies, and fastenings made of wood should be of adequate size and quality to carry all loads and other forces that can be reasonably expected during construction and use, without exceeding the allowable limits of stress or deformations. All members should be framed, anchored, tied, and braced together so as to provide the strength and rigidity needed for the purpose for which they are designed. Unless otherwise specified in this section, farm buildings or structural elements made from wood or wood products should conform to the *National Building Code of Canada* and to *Engineering Design in Wood (Working Stress Design)* or *Engineering Design in Wood (Limit States Design)*.

Wood in contact with earth, manure packs, deep poultry litter, concrete, or masonry, or under other conditions favoring decay, must be pressure-treated with an effective preservative. All boring, grooving, sawing, and other shaping should, when possible, be completed before treatment. All cuts and holes made after treatment should be locally treated with a compatible wood preservative.

All glue-laminated members should be fabricated in accordance with *Qualification Code for Manufacturers of Structural Glue-Laminated Timber*.

For further information and details, refer to: the *Canadian Farm Building Code*, *Construction of Preserved Wood Foundations*, *Qualification Code for Manufacturers of Structural Glue-Laminated Timber*, *Wood Preservation*, and the *National Building Code of Canada*.

5.9 SAWN LUMBER

Sawn lumber includes plates, braces, studs, blocking, rafters, poles, lintels, purlins, trusses, strapping, and other similar material used in the structure or in relation to the structure.

5.10 PLYWOOD AND FLAKEBOARD

Plywood used in farm structures should be exterior type conforming to one of the following standards:

- *Douglas fir plywood*
- *Canadian softwood plywood*
- *Poplar plywood*

Waferboard used in farm structures should meet the requirements of *Waferboard*.

Further information on load versus span for various thicknesses of plywood can be obtained from the Council of Forest Industries of British Columbia, Vancouver, B.C.

5.11 MASONRY

Concrete block construction should conform to the requirements of *Masonry Design for Buildings*. Part 9 of the *National Building Code of Canada* provides further information about the required thickness and height of masonry walls.

To prevent lifting in high winds, roofs should be securely anchored to masonry walls by means of anchor bolts sized and spaced according to the estimated uplift forces and adequately embedded in concrete, or by other methods. All lintels should bear at least 200 mm on the wall on each side of the opening.

All masonry should be built true and plumb. Concrete blocks should be dry when laid, and each should be properly embedded in mortar. Joints should be tooled. Table 58 shows recommended mortar mixes.

5.12 CONCRETE

Farm buildings or structural elements made from concrete or concrete products should be designed in accordance with *Design of Concrete Structures for Buildings*, *Precast Concrete Materials and Construction*, and the *National Building Code of Canada*. See Tables 59 and 60 for some guidelines on concrete use. Ready-mix concrete should conform to *Concrete Materials and Methods of Concrete Construction* and *Methods of Test for Concrete*.

Air-entrained concrete should be used for all structures that will be exposed to freezing and thawing or to deicing salts. Other special products such as high-early-strength or sulfate-resistant cement are available for specific applications. All aggregates used in concrete must be sound and free from organic material. Water-washed aggregates are preferable for ready mix and on-site mixing.

The minimum thickness of floors other than slabs on grade should be 100 mm. Provide all flat floor surfaces with control joints in the form of a saw cut, a vertical strip of moisture-resistant material, or a join in the floor slab.

Table 58 Recommended mortar mixes

Use	Proportions by volume: Cement/lime	Proportions by volume: Mortar sand (damp and loose)
Ordinary construction	1 masonry cement	2.25–3
	OR	
	1 portland cement + 1 hydrated lime	4.5–6
Extreme loads Violent winds Severe frost	1 masonry cement + 1 portland cement	4.5–6
Isolated piers	1 portland cement + 1/4 hydrated lime	3–3.25

Table 59 Guide for ordering ready mixed concrete[1]

Specifications	Maximum size of aggregate (mm)	Slump (mm)[2]	Minimum 28-day compressive strength (MPa)[3]
Flat work			
Severe exposure (garbage, feeding floors, floors in dairy plants)	40	50–100	25
Normal exposure (paved barnyards, floors for farm buildings, sidewalls)	40	50–100	20
Mild exposure (building footings, concrete improvements in mild climates)	40	50–100	15
Formwork			
Severe exposure (mangers for silage feeding, manure pits)	20	75–125	25
Normal exposure (reinforced concrete walls, beams, tanks, foundations)	20	75–125	20
Mild exposure (concrete improvements in mild climates)	20	75–125	15

[1] Use air-entrained concrete for all concrete exposed to freezing, thawing, and salt. Aggregate with a maximum size of 40 mm should contain 3–6% air and aggregate with a 20-mm maximum size should have 4–7% air.

[2] When vibrators are available to consolidate the concrete, these slump values may be reduced by 25 mm.

[3] Concrete in contact with soils or groundwater with high sulfate levels should contain sulfate-resistant cement and entrained air, and should have a compressive strength of at least 25 MPa. The cement should meet the requirements of *Portland Cements*.

These joints should define an area of approximately 40 m². Use isolation joints to prevent floating floors from bonding to foundation walls, columns, or other rigid parts of buildings.

To waterproof a concrete floor, lay a moisture barrier of 0.15 mm polyethylene or the equivalent over the subgrade. If the vapor barrier is composed of strips, lap the strips at least 100 mm. In wet areas, underlay the vapor barrier with at least 100 mm of compacted gravel or sand. Provide adequate drainage of the subgrade by means of drain pipe or tubing.

Table 60 Recommended concrete mixes for on-the-job mixing

Use	Litres of water added to each 1-bag batch of sand			Suggested mixture for 1-bag trial batches[1] (1 bag = 40 kg)		
	Damp[2] sand	Wet[3] sand	Very wet[4] sand	Aggregates (m^3) Fine	Aggregates (m^3) Course	Approx. yield (m^3)
Severe wear, harsh weather or weak acid and alkali solutions (max. size of aggregate 20 mm)	16	14	12	0.04	0.06	0.09
Floors (basements, dairy barns), driveways, walks, septic tanks, storage tanks, structural beams, columns, and slabs						
Maximum size of aggregate 25 mm	20	17	15	0.06	0.07	0.10
Maximum size of aggregate 40 mm	20	17	15	0.07	0.09	0.12
Foundation walls, footings, mass concrete, etc. (maximum size of aggregate 40 mm)	22	20	17	0.07	0.10	0.13

[1] Mix proportions vary slightly depending on gradation of aggregates.
[2] Damp: sand falls apart after being squeezed in the palm of the hand.
[3] Wet: sand balls in the hand when squeezed, but leaves no moisture on the palm.
[4] Very wet: sand that has been subjected to a recent rain or been recently pumped.

Concrete pavements should be at least 100 mm thick. For surface drainage, provide a minimum slope of 1:50. Allow isolation and contraction joints (see above) to control cracking in floors.

The subgrade should be free of sod, large stones, organic matter, mud, and debris and should provide uniform support under the floor. Fill material should be laid in 150-mm layers and well compacted.

5.13 STEEL

The design of steel farm buildings, or of structural elements made from steel products should be in accordance with *Steel Structures for Buildings (Limit States Design)*; buildings or members made of cold formed steel should conform to *Cold Formed Steel Structural Members*. For further details, refer to the following Canadian Sheet Steel Building Institute (CSSBI) publications: *Snow Load Design Criteria for Low Human Occupancy – Steel Farm Buildings; Snow Load Design Criteria for Steel Building Systems*; and *Standard for Steel Farm Buildings*.

5.14 ALUMINUM

The design of farm buildings and structural elements made from aluminum products should be in accordance with *Strength Design in Aluminum*.

5.15 CLADDING

All cladding materials should possess the essential properties to perform their intended functions in the structures. Cladding should be designed, constructed, and attached to take the stresses and deformations caused by wind and temperature effects. Cladding should be weathertight and present a neat and workmanlike appearance.

5.16 METAL CLADDING

Store sheets in a dry place, or in such a way as to allow air circulation between the sheets to avoid condensation. To prevent staining, separate wet sheets immediately and allow them to dry.

Use the manufacturer's load-span tables for the various profiles, thickness, and grade of exterior metal claddings to determine roof and wall purlin spacing. Steel cladding for farm use varies from manufacturer to manufacturer, but may generally be classified into four types.

- Type 1 profiles have a major rib height up to 18 mm and a cover width of up to 1.0 m, with the major ribs spaced 150–300 mm on center.
- Type 2 profiles have a major rib height of 19–25 mm and a cover width of up to 900 mm, with the major ribs spaced 150–300 mm on center.
- Type 3 profiles have a corrugated (wave pattern) profile of at least 12 mm between top and bottom of wave, a pitch of 65–75 mm from crest to crest, and a cover width up to 750 mm.
- Type 4 profiles have a major rib height greater than 25 mm and a cover width of up to 900 mm, with the major ribs spaced 150–300 mm on center.

Fig. 32 shows typical steel cladding profiles for each of these types. Some manufacturers may produce other varieties. Table 61 provides guidelines for total sheet thickness.

Example Sheet steel, 28 gauge, galvanized, prefinished two sides:

- overall nominal thickness $= [0.38 + 0.04 + (0.02)2]$ $= 0.46$ mm
- permitted thickness range $= (0.46 \pm 0.08)$ $= 0.38\text{–}0.54$ mm

Manufacturers who are members of CSSBI use the following criteria to establish load-span tables.

- The structural properties of the profile are determined in accordance with *Cold Formed Steel Structural Members*.
- Design is based on strength considerations under a uniformly distributed load.
- Load-span tables usually assume that a cladding sheet spans four or more structural supports continuously (three-span continuous).

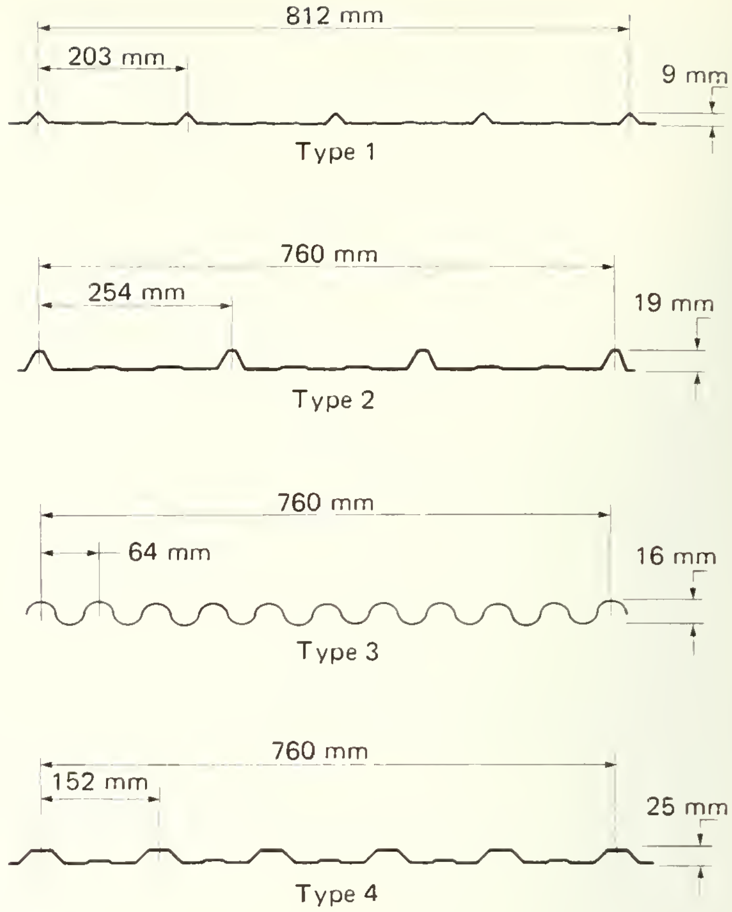


Fig. 32 Typical steel cladding profiles
Source: Standard for Steel Farm Cladding

- For two-span continuous or single-span coverage, the load-carrying capacity is reduced by 20%.
- The design does not consider deflection under load.
- The capacity of the fasteners to resist stress may be the most important criterion in certain loading cases (e.g. wind uplift of roof cladding).

5.17 Finishes for steel

Zinc coating for the protection of exterior steel cladding should be at least equal to the specifications in *Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process*. Steel in contact with high-moisture feeds that have been treated with acid preservatives such as propionic acid should be coated with chlorinated rubber paint over a primer in accordance with the paint manufacturer's recommendations. Silos and storages for fertilizers and other farm chemicals need additional protection; see Part 3.

For furthur information, see the following CSSBI publications:

- *Standard for Steel Farm Cladding*
- *Care and Maintenance of Prefinished Sheet Steel Building Products*

Table 61 Sheet thickness of prefinished steel cladding (mm)

Former gauge number	Base steel nominal thickness	Metal coating thickness allowance[1]	Prefinish coating allowance[2]	Thickness tolerance (plus or minus)
26	0.46	0.04	0.02	0.08
28	0.38	0.04	0.02	0.08
30	0.30	0.04	0.02	0.08

[1] Total of coating on both sides of sheet for Z275 (G90) galvanized and AZ150 Galvalume coatings.
[2] Per painted surface for Series 2000 and 5000 or equivalent.

- *Metric Standard for Sheet Steel Cladding*
- *Metric Zinc-Coated (Galvanized), Sheet Steel for Structural Building Products*
- *Prefinished and Post-Painted Galvanized Sheet Steel for Exterior Building Products.*

5.18 Some practical specifics

When cladding is side lapped, secure down all exposed edges of the laps; these edges should turn away from prevailing winds.

Do not use copper or bare steel accessories either in contact with aluminum or where water could drip from them onto aluminum.

When aluminum sheets are to be applied over hardwood or concrete, underlay the aluminum with felt impregnated with asphalt or with two coats of bituminous paint.

The holes for attaching the sheets should be at least 25 mm or more from the ends of the sheets.

Fasteners should be of aluminum or galvanized steel.

Do not use fasteners containing lead or copper with steel sheets coated with aluminum–zinc alloy (for example Galvalume).

The fasteners for siding should be located in the valley of the profile, next to the rib.

Use roof screw fasteners in roofing valleys if the fastener makes a permanent watertight connection and if the roofing manufacturer recommends the practice.

Translucent skylight material should be reinforced polyester; the profile of the material should match the adjacent siding or roofing metal to provide an effective weather seal.

Purlins at the eaves and ridge should be spaced not more than two-thirds the spacing specified for intermediate purlins.

5.19 Roofing

The roof slope should be a minimum of 1:3, except when special low-slope roofing materials are used according to manufacturers' recommendations. Sidelaps should also follow the manufacturer's recommendations. They are typically nailed or screwed at each purlin and consist of one rib or more. Endlaps should be made according to manufacturer's recommendations but should overlap at least 150 mm and should be supported by a purlin.

Fasteners should resist corrosion. Nails for roofing should have a spiral or ring shank. For metal purlins use self-tapping screws or bolts and nuts. Fasteners should be provided with washers to seal the hole when the fastener is tightened. Fasteners should be spaced across the sheet according to manufacturer's recommendations. In maritime areas such as the Atlantic Provinces and British Columbia salt spray can cause serious corrosion; check with roofing manufacturer for the best fastener and washer to use.

5.20 Reroofing

Metal roofing can be applied over old roofing if the deck is solid and the old roofing is clean, dry, and flat, with loose pieces fastened down. It is good practice to restrap over old roofing, using 19 mm × 89 mm wood strapping securely fastened. Metal roofing should not be applied directly over old metal, slate, or tile. Where new aluminum roofing laps other metals, apply a coat of bituminous paint between the sheets at the lap to prevent the different metals from coming into direct contact.

5.21 Siding

Install sidelaps according to the manufacturer's recommendations. Typically the siding units have one or more ribs and are nailed or screwed at each girt. Endlaps should be at least 100 mm and supported by a girt. Use corrosion-resistant fasteners with a spiral or ring shank.

5.22 STUCCO

Stucco should be mixed, applied, fastened, and finished to meet the requirements of the *National Building Code of Canada*, Part 9.

5.23 ASPHALT SHINGLES

The application, fastening, finishing, and other construction details of asphalt shingles should meet the requirements of the *National Building Code of Canada*, Part 9.

5.24 LUMBER SIDING

Lumber siding should be free from knotholes or loose knots larger than 12 mm in diameter and should have no checks or splits longer than one-half the width of the piece.

Drop, rustic, novelty, lapped-board, and vertical wood siding should be at least 14 mm thick and no more than 300 mm wide. Bevel siding should be not less than 5 mm thick at the top and 12 mm thick at the butt for sidings 180 mm or less in width, and 14 mm thick at the butt for sidings wider than 180 mm. Bevel siding should be not more than 300 mm wide.

Lap or match the joints or use vertical battens to prevent water from entering at the joints. Siding should overlap at least 1 mm per 15 mm width of lumber, but not less than 10 mm for matched siding, 25 mm for lapped bevel siding, or 12 mm for vertical battens. Butt the joints over studs, furring, blocking, or lumber sheathing.

Lumber siding should be fastened with corrosion-resistant nails spaced not more than 600 mm on center to framing, furring, or lumber sheathing, or to blocking nailed between framing members and spaced not more than 600 mm on center. Furring lumber should be at least 19 × 38 mm if the furring is applied horizontally over sheathing. If you apply furring without sheathing to studs not more than 1200 mm on center, use furring lumber at least 38 × 38 mm or 19 × 89 mm. Blocking lumber should be at least 38 × 38 mm. Note that the *Canadian Farm Building Code* requires fire and rodent stops between wall furring or purlins, spaced not more than 6 m horizontally and 3 m vertically.

5.25 WAFERBOARD ROOF AND WALL SHEATHING

Waferboard should conform to the specifications in *Waferboard*. Further details about support spacing, thickness, spacing at joints, and the like can be found in Part 9 of the *National Building Code of Canada*.

5.26 PLYWOOD

All plywood used in farm structures should be exterior type, conforming to one of the following CSA Standards:

- *Douglas fir plywood*
- *Canadian softwood plywood*
- *Poplar plywood*

See Part 9 of the *National Building Code of Canada* for details on the minimum thickness, support, laps, and joints for plywood roof or wall sheathing. The Council of Forest Industries of British Columbia, in Vancouver, can provide you with pertinent information for cases in which the plywood will be under a continuous, uniformly distributed load.

If wall panels are exposed to weather, use sheathing or select-sheathing grade plywood, finished with a heavy-bodied stain. Shingle or shake stains protect the wood and provide an attractive finish requiring little maintainence. The edges of plywood siding should be treated with a suitable paint or sealer.

5.27 Paint

If you plan to paint, consider using medium-density overlaid fir plywood. This material needs no presanding or sealer coat. All surfaces to be painted must be completely clean and dry, and new wood must dry for at least 48 h before it is painted. To prevent knotholes and other imperfections in the wood from bleeding through the finish coat, spot-prime them with shellac or lacquer before applying the primer. Follow the manufacturer's recommendations for applying any paint.

One cautionary note: make absolutely sure that the primer and finish paint are compatible. Water-based paints such as latex and alkyd do not bond to oil-based paints. No latex, alkyd, or oil paint bonds to varnish, polyurethane, or metallic paints such as aluminum unless the surface is thoroughly sanded. Check with a reliable supplier to make sure that the primer paint provides the proper surface for the final coat. Use the best quality paint you can afford.

For exterior finishes, especially in humid areas, latex paints outwear oil-based ones, since latex allows moisture to escape from the wood underneath. Oil finishes eventually check and peel and may have to be burned off. For inside finishes, oil or polyurethane paints are easier to clean and sanitize than even the best-quality latex or alkyd. A high-gloss finish resists scrubbing well and wears better than a matte finish, but it may create glare. Latex and alkyd paints are, of course, easier to use, but this advantage may be less important than the long-term wear, depending on the application.

5.28 INSULATION

Insulation helps to prevent condensation and reduce the loss of heat through walls, floors, and ceilings. Install insulation in all buildings that are to be heated, between heated and unheated spaces, and around the perimeter of foundations and concrete slabs on grade. Insulate the foundations of heated buildings and buildings where heat loss is critical, as well as concrete slabs on grade, to at least 300 mm below grade. Insulate concrete slabs to the same depth, but make sure that some heat can reach the ground beneath the perimeter unless the slab has a footing that extends below the frost line.

Install insulation so that it gives a reasonably uniform insulating value over the entire insulated area. It should fully occupy the space between furring or framing members.

Even in well-insulated buildings, thermal bridges can be serious problems. Thermal bridges are the points where insulation is compressed, missing, or replaced by a denser material such as steel or wood. Common examples are steel purlins or beams, the join between sill and foundation, and various pieces of hardware or fasteners that penetrate wall cavities. Although heat bridges lose little heat, they may cause unacceptable condensation, especially in structures that store produce or house livestock, where the humidity levels are high. Various construction techniques can help avoid or minimize this problem.

In new buildings, use loose-fill insulation only on horizontal surfaces. An exception is expanded mica or granular insulation made of pulverized polystyrene in concrete-block structures; in this case, seal the warm side of the walls with a vapor-sealing paint and protect the outside of the walls to keep out wind-driven rains. Protect rigid insulation from mechanical damage with a plaster coat or other suitable material.

If insulation is in contact with the ground, use a material that resists the action of soil and water. Do not use materials whose insulating properties are reduced by moisture in any potentially wet locations. Protect insulation from the weather, mechanical damage, and tunneling rodents.

Polystyrene foam dissolves in many organic solvents, including petroleum oils and fuels. Use it only where it will never be in contact with such products.

In the past, the *Canadian Farm Building Code* prohibited the use of exposed foam insulation in building interiors. The material had to be covered with plywood, galvanized steel, or special fire resistant coatings as specified in the code. Some new products include a fire retardant and may be approved in the near future for exposed locations.

The insulation values of common insulating materials and types of construction are given in Tables 62–64. For further information on insulation materials, see:

- *Thermal Insulating Mineral Fibres for Buildings, and Insulating Fibreboard*
- *Thermal Insulation: Expanded Polystyrene*
- *Thermal Insulation: Urethane Isocyanurate Unfaced*
- *Insulation in Farm Buildings*
- *National Building Code of Canada.*

5.29 VAPOR BARRIERS

All materials for vapor barriers should conform to *Vapor Barrier, Sheet, For Use In Building Construction.* Failure to install vapor barriers may increase air leakage, interfere with the intended operation of the air inlet, and interfere with the desired mixing and flow of air.

Use Type 1 vapor barriers where high resistance to vapor movement is required and Type 2 vapor barriers in all other locations. Type 2 vapor barriers are unsuitable for most farm buildings. Put vapor barriers on the warm side of all insulated structures, as close to the surface as possible. Install the material so that joints are over supporting members and lap by at least 100 mm. The entire surface, including the framing members, should be covered so that no gaps occur. Cut openings for electrical outlets or water pipes in such a way that the

Table 62 Insulation values of common insulation materials

Material	Thickness (mm)	RSI value[1] per thickness given
Mineral wool or fiber glass blanket insulation (including paper-faced and friction-fit), density 10–24 kg/m^3	100	2.6
Macerated paper, cellulose fiber (cotton, wood pulp, etc.)	100	2.5
Expanded vermiculite, density 64–96 kg/m^3	100	1.6
Dry wood shavings or sawdust, density 130–240 kg/m^3	100	1.5
Straw (cut, dry), density 100–130 kg/m^3	100	1.0
Corkboard	25	0.65
Polystyrene foam		
Expanded beadboard, density 16 kg/m^3	25	0.61
Extruded type, density 29–35 kg/m^3	25	0.69–0.87
Polyurethane foam (applied at site), density 24–40 kg/m^3	25	1.04[2]

[1] Values listed are for dry insulation materials at an average temperature of 25°C. When the average temperature is –5°C, values may be increased by a factor of 1.1 except for polyurethane foam applied at site.

[2] These are aged values for spray-on foam, and the values may continue to decline as urethane ages. Some manufacturers claim much higher RSI values due to the foaming gases (typically freon) that are trapped in the foam during manufacturing. Since air with a lower insulation value tends to replace the freon over time, the claimed values cannot be maintained unless the faces are sealed at the factory with a gastight material such as metal foil.

material fits snugly around the intrusion. If possible, mount plumbing and electrical services on the interior surface to avoid such cuts. Repair or replace a damaged vapor barrier.

Remember to caulk around doors, windows, and other openings in the structure. Failure to caulk properly may lead to serious wood rot.

5.30 SAFETY: CONSTRUCTION AND THE FARM WORKER

Part 2 (Structural Design), Part 3 (Fire Safety), and Part 4 (Health) of the *Canadian Farm Building Code* apply to all farm structures and systems. During construction, follow the sections of the *Canadian Construction Safety Code* and relevant provincial codes that apply to workers' safety.

The CPS leaflet *Silo Gas* reports incidents of death or injury caused by silo gases and summarizes recommendations to prevent similar tragedies. It also discusses the properties and detection of silo gas. *Manure Gas* discusses the precautions to be followed when designing livestock buildings or handling manure in and around buildings.

In addition to the requirements of the *Canadian Farm Building Code*, the following safety measures are good practice. Most are discussed in more detail in other sections of this book.

- Provide bull pens with safety areas and a protected exit (Section 2.10).
- Provide convenient, safe, locked storage for dangerous chemicals on the farmstead (Section 4.4).
- Store ammonium nitrate fertilizer away from liquid fuel (Section 4.3).
- Equip sealed rooms such as controlled atmosphere storages and walk-in coolers with door latches that open from inside the room and with warning lights to show when the room is occupied (Section 3.50).

Table 63 Insulation values of typical building materials, air spaces, windows, and concrete floors

Materials	Thickness (mm)	RSI value per thickness given
Building boards and papers		
Asbestos board	5	0.01
Aspen flakeboard (Aspenite, etc.)	6	0.08
Asphalt felt		0.01
Fiberboard (Ten-test, etc.)	12	0.23
Fir plywood	9	0.08
Polyethylene film vapor barrier	0.1	0.00
Frame construction		
Lap siding or wood shingles		0.14
Solid wood sheathing, pine or fir	25	0.22
Wood sheathing and building paper	19	0.20
Wood sheathing with lap siding		0.35
Roofing materials		
Asphalt shingles		0.08
Built-up bitumen and felt	9	0.06
Concrete and masonry		
Plain or reinforced concrete density 2240 kg/m^3	200	0.11
Lightweight concrete		
density 1900 kg/m^3	200	0.26
density 1280 kg/m^3	200	0.55
density 640 kg/m^3	200	0.19
density 480 kg/m^3	200	1.54
density 320 kg/m^3	200	1.98
Concrete block oval cores plus vermiculite fill	200	0.20
Concrete block oval cores	200	0.32
Lightweight block (expanded shale, clay, slate, slag, or pumice)	200	0.35
Lightweight blocks plus vermiculite fill	200	0.70
Surface resistances		
For outside wall (24 km/h wind)	0.03	
For inside surface (no wind)		
Ceiling (horizontal surface)	0.11	
Wall (vertical surface)	0.12	
Vertical air space in wall, 20 mm or larger	0.21	
Windows (including resistances of air space and surfaces)		
One vertical glass sheet	0.16	
Two vertical glass sheets		
With air space 12 mm	0.32	
With air space 25 mm or greater	0.33	
Air 150 mm above concrete floor to ground (temperature difference 11°C)	1.76	

Table 64 Typical factors for heat losses around floor perimeters

Description of floor perimeter	Perimeter heat loss factor (F)
Normal concrete, not insulated	1.42
Normal concrete, insulated near exterior face to 300 mm below exterior grade with rigid insulation having RSI = 0.7	0.85
Normal concrete, insulated near exterior face to 300 mm below exterior grade with rigid insulation having RSI = 1.4	0.43

- Equip maintenance shops and other enclosed spaces where internal combustion engines may be operated with exhaust systems independent of the building heating and ventilation systems.

5.31 RODENT CONTROL

Rodents damage insulation, structural components, and electrical wiring. In addition they consume and contaminate food and feed materials and can transmit disease. Take every possible precaution to exclude rodents from farm buildings during and after construction. Consider the following.

- Use rodent-proof building materials whenever possible, but particularly around grains and in livestock buildings where grains are fed.
- Raise grain bins 300 mm off the ground or use deep concrete foundations.
- Use steel flashings at joints between different exterior building materials.
- Use closure strips, resistant weather-stripping, strong wire mesh screens, or other suitable materials at the ends of corrugated cladding, around building openings, and at other possible entry points.
- Attach galvanized or corrosion-resistant wire mesh with openings smaller than 12 mm to splash planking on the exterior; extend this at least 180 mm horizontally underground to discourage tunneling under concrete floor slabs in pole-frame buildings.
- In insulated walls, use blocking at intervals of less than 3 m vertically and 6 m horizontally; the blocking can be continuous lumber members at least 38 mm thick, or continuous metal or concrete of any thickness.
- Eliminate rodents' access to any attic space.
- Mount electrical wiring on the interior surface; provide mechanical protection of the wiring in concealed spaces.
- Keep the building site clean and well organized during and after construction.
- Take care to eliminate refuges and sources of food for rodents.

If you plan to attach a new structure to an existing one, install continuous metal rodent blocking unless the existing building has ideal rodent control. Access doors should be self closing and fit tightly. All other access points should be sealed by metal flashing or its equivalent.

PART 6
Building services

6.1 VENTILATION

Proper ventilation provides a healthy and comfortable environment for livestock and poultry, or a good conditioning or storage environment for produce such as fruit and vegetables. Ventilation can be used to remove the heat and moisture produced by livestock or stored produce, or to dilute or remove gases, odors, dust, or disease organisms. Each purpose requires a different ventilation rate; you must therefore determine which factors are most important and plan accordingly.

Principles relating to air's carrying capacity for heat and moisture remain the same for heating or cooling, humidifying or dehumidifying, or livestock or crop storage. The following section describes some of the psychometric properties of air and how they apply to the ventilation of agricultural buildings. Much of the following text and many of the figures are adapted from the *Midwest Plan Service Structures and Environment Handbook* (1983) and from the *Ventilation Handbook, Livestock and Poultry* published by the British Columbia Ministry of Agriculture and Food.

The ventilation requirements for preventing gas or odor buildup or for removing dust or disease organisms are discussed in other sections of this handbook relating to the specific type of livestock or product (Parts 2 and 3).

6.2 PSYCHROMETRICS

A psychrometric chart represents the physical and thermal properties of moist air. It provides a convenient graphic method for solving air-conditioning problems. Figs. 33–34 are psychrometric charts for normal and low temperatures.

The coordinates on the psychrometric chart axes are dry-bulb temperature (horizontal axis) and humidity ratio (vertical axis). The other properties given are wet-bulb and dew-point temperatures, enthalpy, relative humidity, and specific volume, all based on a kilogram of dry air. The intersection of any two property lines pinpoints a given state, and all other properties can be read from this point. Fig. 35 shows the properties that can be obtained from the psychrometric chart.

It may be helpful to define or describe some of the terms used in ventilation and psychrometrics.

Specific heat capacity (c_p) The quantity of heat required to raise a one-kilogram mass of a material by one degree (kJ/(kg·°C)).

Sensible heat (q_s) The quantity of heat energy associated with a change in temperature (kJ); also expressed as:

[1] $q_s = m \cdot c_p \, (t_1 - t_2)$

where

q_s = total sensible heat, kJ

m = mass of material, kg

c_p = specific heat of the material, kJ/(kg·°C)

t_1 = temperature of material at condition 1, °C

t_2 = temperature of material at condition 2, °C

Latent heat (q_l) The energy absorbed or released when a material changes phase (from liquid to vapor, for example) without a change in temperature. The latent heat of vaporization of water varies with temperature, but for designing animal ventilation systems it is usually taken as 2428 kJ/kg.

When water vapor cools, it returns to the liquid phase or condenses. The heat of condensation is equal to but of opposite magnitude to the heat of vaporization; it yields heat instead of absorbing it.

The difference between sensible and latent heat is important; sensible heat is the energy required to raise the temperature, whereas latent heat is the energy required to change water from one phase to another – for our purposes, usually from liquid to gas. Livestock, grain, and produce generate both kinds of heat. Latent heat is released into the air in the form of respired water vapor, and sensible heat is transferred to the environment by conduction, radiation, and convection.

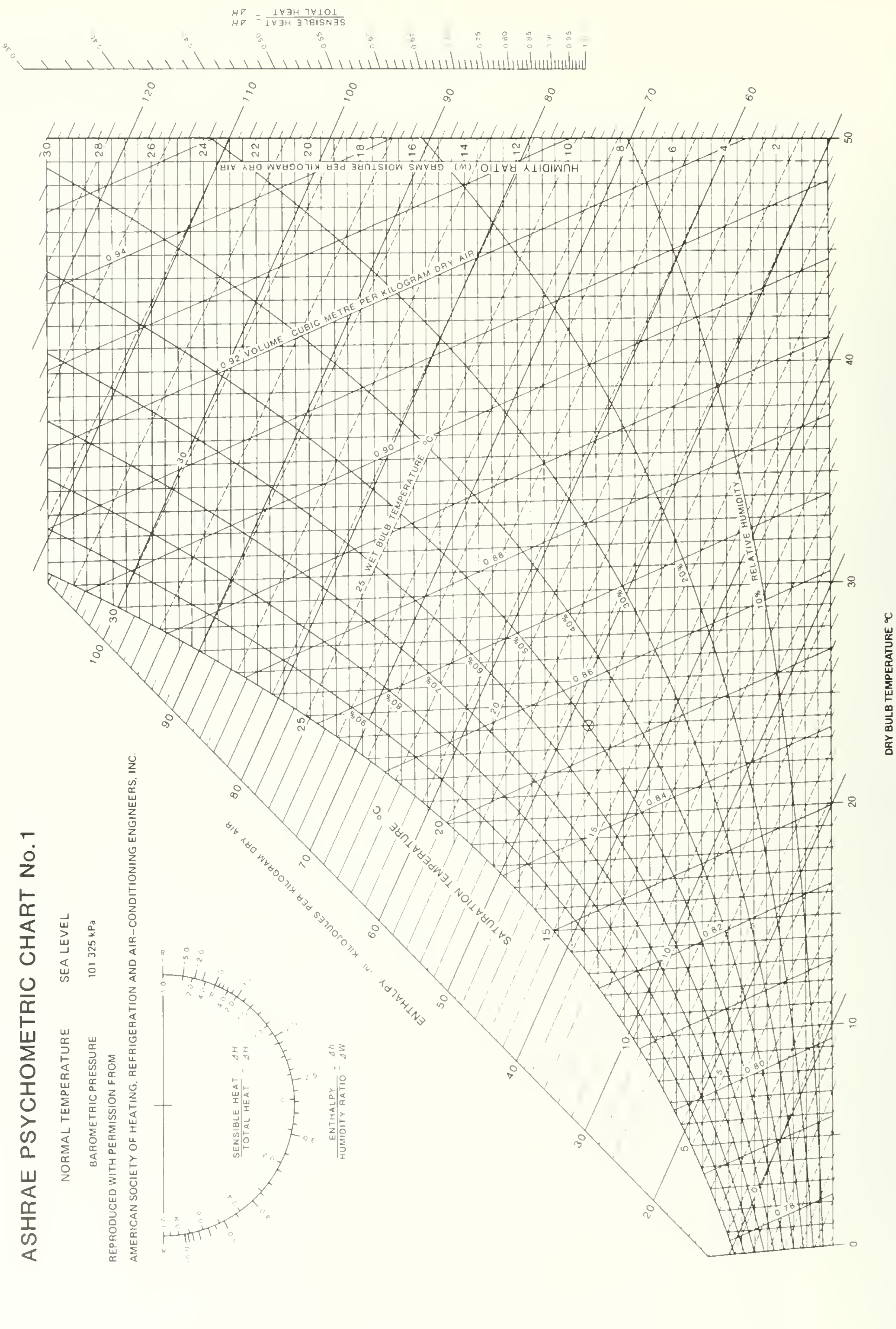


Fig. 33 Psychrometric chart for normal temperatures

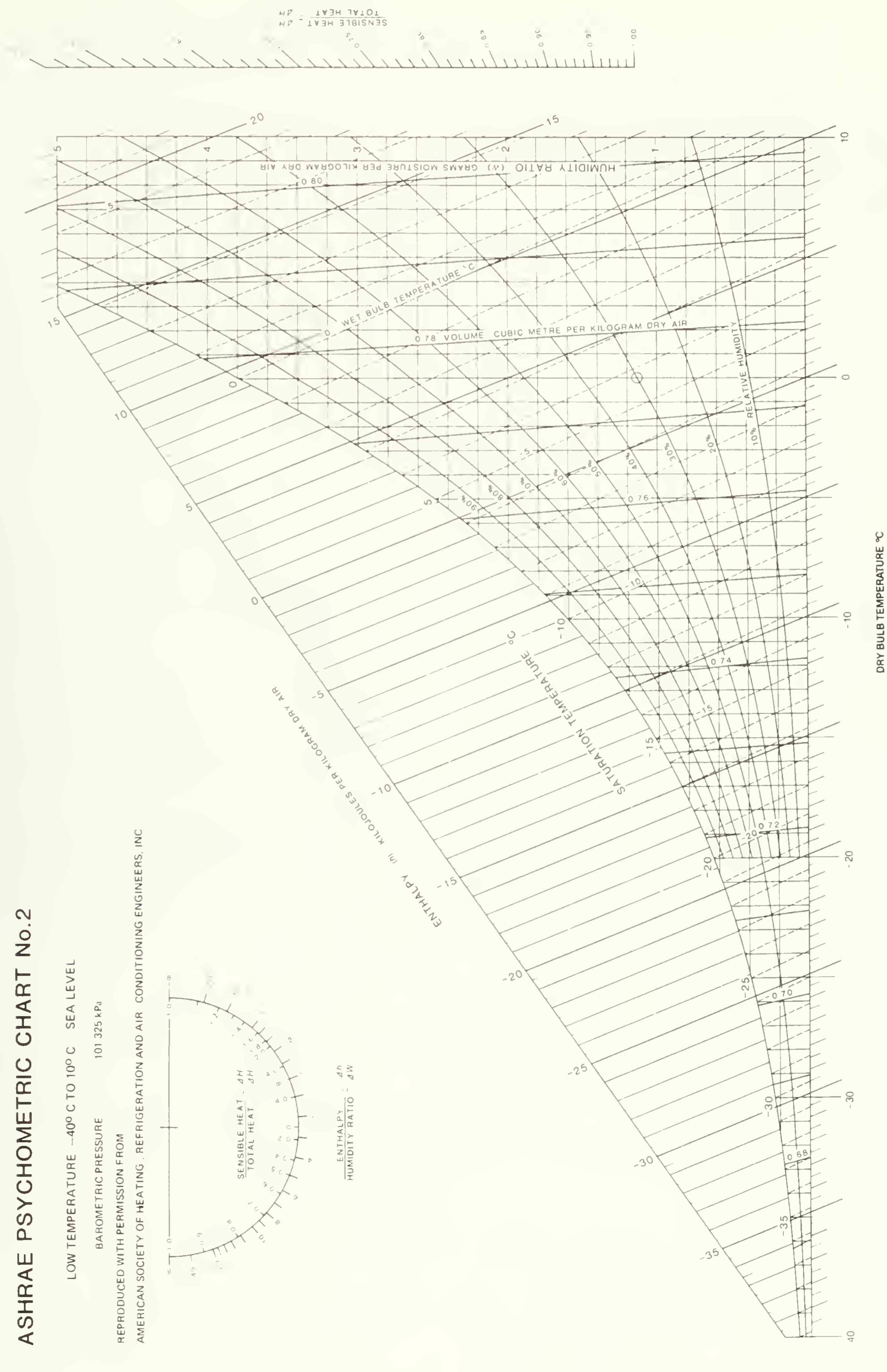


Fig. 34 Psychrometric chart for low temperatures

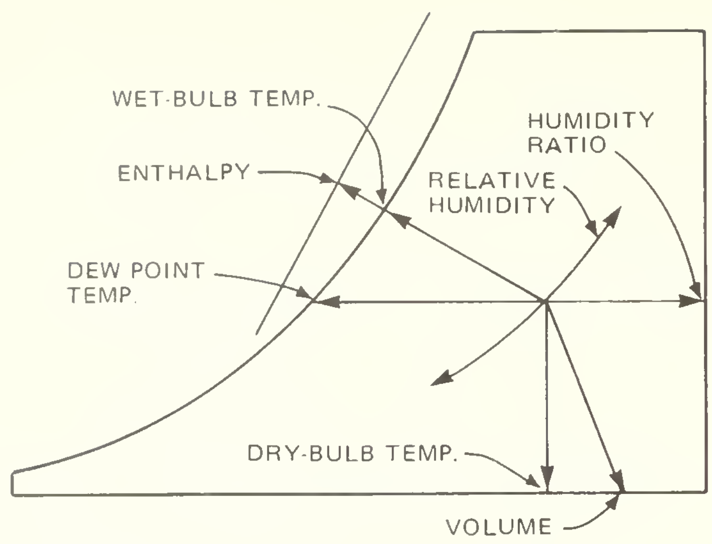


Fig. 35 Properties of moist air on a psychrometric chart

Humidity ratio The ratio by weight of water in air (kg/kg).

Relative humidity The degree of saturation of air at a particular temperature; technically, it is the ratio (percent) of partial water vapor pressure to the vapor pressure of saturated air at the same temperature. For ventilation purposes, relative humidity can be considered to be the weight of water vapor in a kilogram of dry air divided by weight of water vapor in the same amount of completely saturated air at the same temperature.

Dry-bulb temperature The temperature measured with an ordinary thermometer, kept dry and shielded from radiation.

Wet-bulb temperature The temperature measured with the same thermometer, except that the bulb or sensor is wrapped in a water-moistened wick and held in a moving stream of air until the temperature stabilizes. The wet bulb is cooled by the evaporation of water from the wick; therefore, unless the air is saturated, the wet-bulb temperature is lower than the dry-bulb temperature. The lower the relative humidity, the more the moisture evaporates, and the greater the temperature difference. Relative humidity is determined by observing the difference between wet and dry bulb temperatures.

Dew-point temperature The temperature at which moisture starts to condense when air cools at constant pressure and humidity ratio.

Enthalpy (h) The heat energy content of a mixture of air and water vapor. This includes both sensible heat (indicated by dry-bulb temperature) and latent heat of vaporization (energy content of the water vapor). The values of enthalpy are relative and are based, for convenience, on the difference in internal energy between a fixed condition (that for dry air at 0°C) and the condition being considered. The units are kilojoules (kJ) per kilogram dry air.

The enthalpy of a mixture of air and water vapor is defined by the relation:

[2] $$h = h_a + W \cdot h_g$$

where

$h_a = c_p \cdot t_{db}$
= enthalpy of dry air

h_g = enthalpy of water vapor, kJ/kg water

c_p = specific heat of dry air, approximately 1.007 kJ/(kg·°C)

t_{db} = dry-bulb temperature, °C

W = humidity ratio of air, kg/kg dry air

6.3 AIR-CONDITIONING PROCESSES

The ventilation of livestock housing or product storages usually involves modifications of environmental conditions such as heating, cooling, humidifying, dehumidifying, or mixing volumes of air.

Sensible heating is the addition of heat to air without a change in the humidity ratio. On the psychrometric chart, the process takes place along a horizontal line moving left to right (Fig. 36). Sensible heating may be calculated from the mass and the enthalpy change of the air. The sensible heat (in kilojoules) added in going from state 1 to state 2 can be calculated as follows:

[3] $$q_{s(1-2)} = m(h_2 - h_1)$$

where

m = mass of dry air (kg)

$h_2 - h_1$ = enthalpy difference of air in state 1 and state 2 (kJ/kg dry air)

If the process is continual, express the sensible heat loss or gain per unit of time:

[4] $$q_s = V(h_2 - h_1)/v_a$$

where

q_s = sensible heat added (kW)

V = air flow volume (m^3/s)

v_a = specific volume (m^3/kg dry air)

Sensible cooling is the cooling of air at a constant humidity ratio and is represented on a psychrometric chart by a horizontal line moving from right to left (Fig. 37). Sensible cooling is often accomplished by passing an air stream over a refrigerator coil with a surface

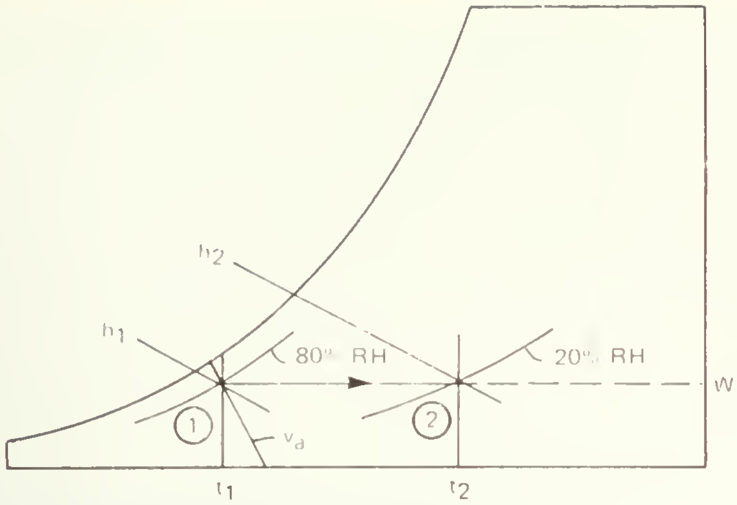


Fig. 36 Sensible heating process

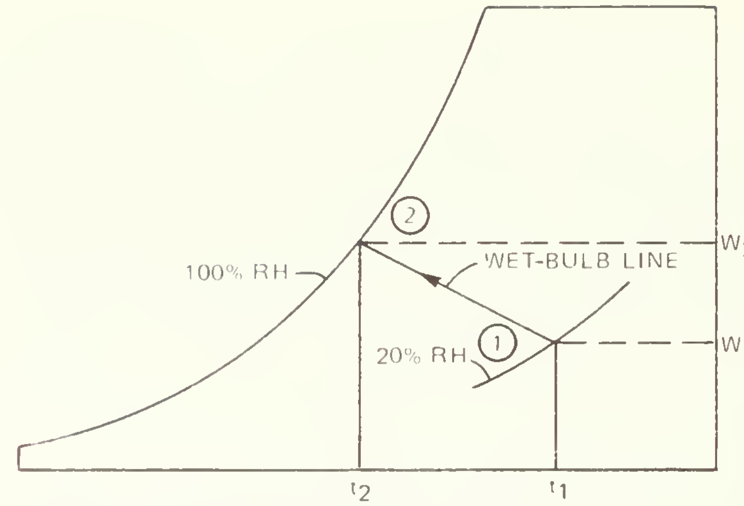


Fig. 38 Evaporative cooling process

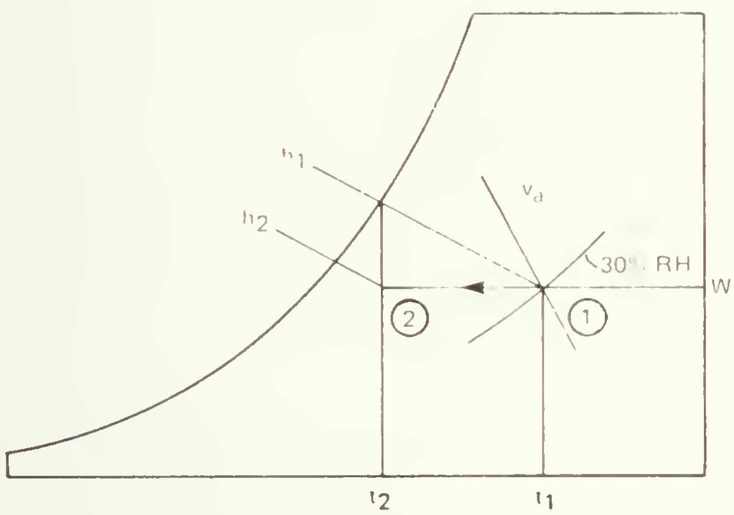


Fig. 37 Sensible cooling process

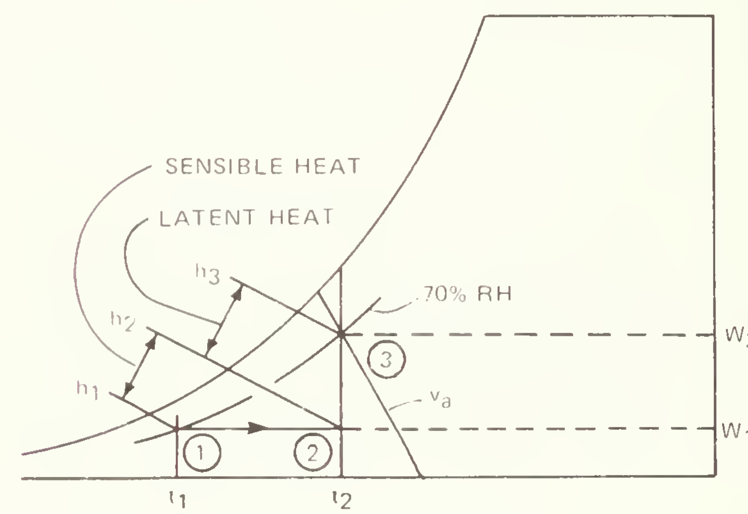


Fig. 39 Heating and humidifying process

temperature above the dew-point temperature of the air (otherwise condensation and removal of latent heat will occur). Eqs. 3 and 4 apply to both sensible heating or cooling; the sign of the result indicates heat gain or loss.

Evaporative cooling is an adiabatic saturation process, that is, a process of increasing the humidity ratio with no heat loss or gain. On a psychrometric chart, the line follows upward along a constant wet-bulb temperature line (Fig. 38). In technical terms, the sensible heat contained in an air stream that passes over a wetted surface converts water to vapor, and the dry-bulb temperature drops. More simply, if you pass a stream of warm air over a wet surface, the air temperature drops as the air picks up moisture. Evaporative cooling is best suited to hot, dry climates in which the water-vapor content of the air can rise substantially without raising the relative humidity to uncomfortable levels.

Heating and humidifying (Fig. 39) occur as animals or products respire. The heat and water vapor produced are added as sensible and latent heat to the ventilating air as it moves through the building. How do we make allowances for this factor? We need to make two calculations, one for the sensible heat added, and one for the latent heat.

1. The addition of sensible heat by livestock and by a heating system (if any) proceeds horizontally along the constant humidity ratio line.

   $q_{s(1-2)} = m(h_2 - h_1)$

2. The addition of latent heat proceeds vertically along a constant dry-bulb temperature line.

[2] $q_{l(2-3)} = m(h_3 - h_2)$

6.4 HEAT BALANCES

In a livestock building, the balance of heat gains and losses can be defined by the following equation:

[5] $Q_a + Q_s = Q_b + Q_v$

where

Q_a = animal total heat production (kJ/h)

Q_s = supplementary heat added (kJ/h)

Q_b = building heat loss (kJ/h)

Q_v = ventilation total heat loss (kJ/h)

Under constant conditions, the total heat gained must equal the total heat lost. The balance must be maintained by naturally or mechanically adjusting one or more of the components.

Animal total heat (Q_a) varies directly with the number and size of the animals and with their activity level (night or day), nutritional state, and other factors. Total heat is made up of two components, sensible and latent. The animal gives up sensible heat to its surroundings by radiation, conduction, and convection. Latent heat comes from evaporated moisture, primarily from respiration.

Moisture evaporated from floors, water bowls, and other wet surfaces requires heat of vaporization. In contrast, cold surfaces can condense liquid, freeing its heat of vaporization. Some authorities combine this gain or loss of latent heat with the production of latent heat by animals and call the total the "building latent heat production."

The proportions of sensible and latent heat vary in the total heat production by animals. The common method of presentation is latent-to-total ratio. This ratio increases as the ambient temperature increases and animals attempt to maintain a constant body temperature (homeothermy). (See Part 2 for data for specific types of livestock.)

Supplemental heat (Q_s) includes all heat added to the building from sources other than animals, including lights, motors, heat lamps, and warm floors, as well as heaters. Heaters usually supply sensible heat, although an exception is moisture added by an unflued propane heater.

Building heat loss (Q_b) is the loss of sensible heat through ceilings, walls, and foundations to earth and the surrounding air. These losses increase with the surface area exposed and the inside-to-outside temperature difference, but decrease with the insulation value of the building components (RSI).

Ventilation heat loss (Q_v) results from the exchange of outside for inside air. Winter air is cold with a low humidity ratio, but the air inside a livestock building (for example) is warm and humid. Ventilation heat loss is proportional to the ventilation rate and the difference between inside and outside air total heat content (enthalpy). Q_v involves the loss of both sensible and latent heat.

6.5 Building heat losses

For building heat losses, consider the heat conducted through all components of the building shell. Heat losses from air infiltration need only be considered when the building is not being fan ventilated. Otherwise infiltration can be considered as part or all of the incoming air for ventilation. A typical example of the need to consider infiltration heat losses is in determining the size of heating equipment needed to preheat a brooding area before stocking. Calculate the heat losses from the building shell and perimeter by finding the total building heat loss (Q_b):

$$Q_b = Q_{bc} + Q_{bp}$$

where

[6] $Q_{bc} = A(t_i - t_o)/R_{SIT}$

and

[7] $Q_{bp} = PF(t_i - t_o)$

where

Q_{bc} = rate of heat flow across the shell of the building (W)

Q_{bp} = building perimeter heat loss in watts (W)

A = surface area (m^2)

P = building perimeter (m)

R_{SIT} = total resistance to heat flow of building shell materials including surface coefficients ($m^2 \cdot °C/W$)

F = perimeter heat loss factor per unit of length (W/(°C·m))

t_i = inside air temperature (°C)

t_o = outside air temperature (°C) (ground temperature, for concrete slab on grade)

Values of R_{SIT} for materials can be found in Tables 62 and 63. Table 64 gives F values for common farm applications.

For outside air temperatures t_o, use the design temperatures (2.5% basis) listed in the supplement to the *National Building Code*. This is the point below which January temperatures fall for only 2.5% of the time, on average; the summer design temperature is the point above which July temperatures rise for only 2.5% of the time. Use the January design temperature for heating and the July design temperature for cooling.

Choose inside air temperatures for the specific animals, crops, or fruit and vegetables in storage. Desired ranges are given in the individual environmental requirements sections in Parts 2 and 3.

If we ignore losses of heat through the floor, the total building heat loss (Q_b) can be expressed in terms of the difference between inside and outside temperatures by adding up the respective area-to-resistance ratios of the building components. That is, we find the area of each component (ceiling, frame wall, concrete wall, perimeter, window, door). Divide each area by the R_{SIT} value of the material – for example, the door area divided by the R_{SIT} of its planking – and add up the resulting ratios. Remember to include the building perimeter heat loss, derived by multipying the total perimeter by the factor for heat loss from the perimeter. The sum of the ratios S (in watts per degree Celsius) is related to the building heat loss:

[8] $$S = Q_b/(t_i - t_o)$$

This building heat loss factor makes it simple to calculate heat losses or gains for various inside or outside temperatures within the working range.

For animal housing facilities, we can determine an exposure factor by dividing the building heat loss factor by the number of animals or animal units. For a dairy barn, for example, the exposure factor has units of watts per degree Celsius per cow.

When air infiltration heat losses are critical, as in poultry brooding, use the following method:

1. Estimate the rate of air infiltration. Common values are in the range of 0.5–2.0 air changes per hour. Use 0.5 for new tight construction and up to 2.0 for older buildings with loose-fitting windows and doors or no vapor barrier. Consider how sheltered the building is from wind.
2. Calculate the volume of the building or room to be heated or cooled (m^3).
3. Calculate the rate of heating or cooling required. Use the room volume and air change rate per hour, specific volume of air, specific heat of air, and temperature difference between inside and outside.
4. Add the requirement for infiltration heating or cooling to the total building heat loss to determine the size of heating or cooling equipment when ventilation is not required.

6.6 Methods of heat and moisture dissipation by animals

Birds and mammals are homeothermic; that is, they maintain a nearly constant internal body temperature despite environmental temperature changes. Internal temperatures only a few degrees from normal can be fatal. Excess cold and overheating can both cause stress and death.

Homeothermic animals regulate their body temperature by adjusting internal heat production and heat loss to the surroundings. Heat-stressed animals eat less to reduce the production of body heat, while cold-stressed animals eat more to increase it. Obviously if an animal eats less or converts much of its feed to heat, it will put on less weight, give less milk, produce fewer eggs, and generally be less productive. Depending on the animal's weight, age, and species, the effects of heat and cold on productivity can be considerable.

Equally obviously, there are temperatures that animals cannot survive; homeothermy can only go so far. Within the range of survivable temperatures there is a narrower range of thermal comfort, at which the animal is most productive. Part 2 gives comfort ranges for different types of livestock.

Animals transfer heat to the surrounding environment by four methods: radiation, conduction, convection, and evaporation. For most animals without a thick hair coat, radiation heat loss can be kept to a minimum by providing insulated housing with relatively warm inside surfaces.

Conduction is the transfer of heat by direct contact between bodies or elements at different temperatures, as when a warm hand touches a cold door. Animals adjust their conductive heat loss either by moving away from the object or by adjusting the rate of blood flow to the skin. Pigs, for example, like to lie on cool concrete floors in warm weather. Many pig breeders insulate the creep area of farrowing stalls to reduce the piglets' heat loss by conduction. The sow prefers a cooler, uninsulated floor.

Convection transfers heat from a body by movement of a fluid medium; consider a fan or a cold bath. As the body heats the fluid or gas, the transfer creates convection currents, which may or may not be noticeable. An animal's convective heat loss depends on the airspeed as well as air temperatures; hence the need to protect vulnerable animals from drafts. Convection is a major way of losing sensible heat. This process can be very useful during a heat wave, but it can also be detrimental to animals in a cool environment.

Evaporation of moisture is the other major means by which animals lose heat. Except for cattle and horses, few animals lose much water through the skin; instead they lose evaporative heat primarily from the upper respiratory tract. Expired air is warm and nearly saturated with water vapor. The transfer of this water vapor to the air represents latent heat and is part of the animal's total heat production.

In hot weather, animals can increase the ratio of latent to total heat output by panting. Under near-stress conditions wetting down an animal can increase cooling by external evaporation.

In considering building heat, we must determine both the production of animal latent heat and building latent heat. Depending on techniques used to measure latent heat production, the two contributions may be combined.

Building latent heat is generated by evaporation of moisture from sources other than respiration or sweating. These may include wet floors, water in feces and urine, drinkers, or other sources that vaporize water. Attempts have been made to quantify building latent heat by researchers in Alberta (see Tables 8, 27, and 36). Their research with dairy cows in free-stall barns (Table 8) also provides an estimate of the amount of animal sensible heat converted into building latent heat.

6.7 HOW TO VENTILATE FARM BUILDINGS

Air-cooled fruit and vegetable storage ventilation systems should be designed to remove field heat as quickly as possible, unless the crop requires a curing period (e.g. potatoes). After curing, the air exchange rates can then be reduced to remove the heat of respiration only. When the outside temperature drops well below the desired storage temperature, the building still needs some ventilation to prevent gas buildup. Low-level air exchange may involve using dampers to blend in fresh air in order to regulate the storage temperature while maintaining constant circulation of air.

Ventilation of livestock buildings normally requires a low rate of air exchange in winter, primarily to control moisture accumulation, and higher rates to control the temperature during hot weather.

Livestock buildings can be ventilated either naturally, by using differential air buoyancy (the chimney effect) and wind, or mechanically, by using fans. The choice depends on building type, orientation, and location, and on the degree of environmental control needed in the unit. Birds, young animals, and stock without a thick coat need the additional warmth and control of air movement made possible by mechanical ventilation.

For outside design temperatures for ventilation in winter and summer, use the January and July design temperatures (2.5% basis) listed in the *Supplement to the National Building Code of Canada*.

Inside design temperatures for fruit and vegetable storages should be based on Tables 55–56. For inside design temperatures for animal housing, see Part 2. Specific volume (v_a) of air should be based on inside air conditions for exhaust systems or on outside air conditions for pressure systems.

6.8 Ventilation for moisture control

The object is to remove water vapor at an average rate equal to production. The maximum relative humidity (RH) should be low enough to prevent condensation on cool surfaces. For well-insulated animal buildings the RH can usually approach 80%. For fruit and vegetable storages the upper RH required is usually as high as 90–95% to prevent the commodity from shriveling. The method is outlined below.

1. Since the rate of moisture removal should equal the rate of moisture production, first find the total rate of moisture production. It is most often available as latent heat production in kilojoules per hour per animal unit or per unit of product stored; include the building component when appropriate data are available.
2. Find the design outside and desired inside air conditions on the psychrometric chart. (See Figs. 33–34.)
3. From the psychrometric chart, determine the latent heat portion (q_l) of the difference in enthalpy between the inside and outside air in kilojoules per kilogram of dry air.
4. Calculate the mass flow rate of air flow V_m (kilograms of dry air per hour) needed to remove the latent heat produced; do this by dividing the latent heat production (from step 1) by q_l (from step 3).
5. Change the mass flow rate of air (V_m) to the ventilation rate (V) in litres per second by multiplying V_m by the specific volume of air v_a (cubic metres per kilogram) and 1000 (litres per cubic metre), and then divide by 3600 (seconds per hour) to get flow in units of litres per second.

[9] $$V = V_m \cdot v_a (1000/3600)$$

Example Determine the rate of ventilation for moisture control for a 500-kg dairy cow housed in a free-stall dairy barn with slotted passageways at Morden, Man., in January. Assume that the average inside temperature should be 7°C and that outside RH is 90%.

1. From the *Supplement to the National Building Code of Canada*, the January design temperature for Morden, Man., is –31°C.
2. From Table 8, the latent heat production (Q_{al}) is 1600 kJ/h per 500-kg cow.
3. Using Fig. 34

t_i = 7°C

t_o = –31°C

RH_i = 80%

RH_o = 90%

h_i = 19.6 kJ/kg dry air

h_o = –30.5 kJ/kg dry air

v_s = 0.80 m³/kg dry air

h_{tp} = 6.5 kJ/kg dry air

This last variable, h_{tp}, is the turning point enthalpy, the point on the psychrometric chart where the horizontal line (humidity ratio) for the outside condition intersects the vertical line (temperature) for the inside condition (h_2 in Fig. 39).

4. For the latent heat portion of enthalpy,

$$h_l = h_i - h_{tp} = 19.6 - 6.5 = 13.1 \text{ kJ/kg dry air}$$

5. The needed rate of air-mass flow:

$$V_m = Q_{al}/h_l = 1600/13.1 = 122 \text{ kg/h dry air per 500-kg cow}$$

6. The necessary ventilation rate:

$$V = (V_m \times v_a \times 1000 \text{ L/m}^3)/(3600 \text{ s/h}) = (122 \times 0.80 \times 1000)/3600 = 27.1 \text{ L/(s·cow)}$$

The ventilation rate for moisture control should be calculated by the same method for several outside temperatures above the winter design temperature.

Note that an increase in t_i can reduce V (the ventilation rate) by increasing h_l – the capacity of the air for carrying moisture. In some cases, simply changing the thermostat can vary the ventilation rate to control moisture. Similarly, in some cases the production of latent heat can be adjusted by designing or managing buildings so as to reduce wet floors and the load of evaporated moisture.

If you want a maximum inside relative humidity below 80% in winter, then obviously the minimum ventilation rate for moisture control must be higher.

6.9 Ventilation for temperature control

Thermostats regulate most ventilation systems, turning fans off or on to increase or decrease the ventilation rate while maintaining a nearly constant inside temperature. During cold weather, temperature can be controlled by maintaining an average ventilation rate such that the building heat losses and losses from ventilation equal the heat produced by the livestock, the produce, lights, motors, and other equipment. During warm weather, livestock buildings need enough ventilation to remove the heat produced without increasing the inside temperature more than about 2°C above the outside temperature.

To calculate the ventilation rate for continuous heat balance, first find the total sensible heat loss from the building.

Use this method for cold-weather ventilation:

1. Establish building heat loss factor or exposure factor per animal.
2. Find the sensible heat production (Q_{as}) per animal or unit product stored and, in the case of animals, the amount converted to latent heat.
3. Calculate how much sensible heat is actually available by reducing the amount of heat produced by the amount converted to latent heat and building heat loss.
4. Determine the sensible heat portion (h_s) of the enthalpy difference between the inside and outside air from the psychrometric chart (see Figs. 33–34).
5. Calculate the permissible rate of mass air flow, given the available sensible heat.
6. Change the rate of mass air flow to the ventilation rate.

Example Use the previous example of the dairy cow, and assume an exposure factor of 20 kJ/(h·cow).

1. At design conditions (t_i = 7°C, t_o = –31°C), the building heat loss

$$Q_b = 20 \times [7 - (-31)] = 760 \text{ kJ/(h·cow)}$$

2. From Table 8, the sensible heat produced is

   $Q_{as} = 2574\ \text{kJ/(h·cow)}$

   Of this, 27% is converted to latent heat

3. Available sensible heat:

   $= 2574 - (0.27 \times 2574) - 760$

   $= 1119\ \text{kJ/(h·cow)}$

4. The sensible heat portion of enthalpy difference:

   $h_s = h_{tp} - h_o$

   $= 6.5 - (-30.5)$

   $= 37$ kJ/kg dry air

5. The permissible rate of mass air flow:

   $V_m = (\text{available } Q_{as})/q_s$

   $= 1119/37$

   $= 30$ kg/h per cow

6. The permissible ventilation rate:

   $V = V_m \cdot v_a(1000\ \text{L/m}^3)/(3600\ \text{s/h})$

   $= 30 \times 0.80 \times 1000/3600$

   $= 6.7\ \text{L/(s·cow)}$

The ventilation rate for heat balance should be calculated by the same method for several outside temperatures above winter design temperature.

Comparing the ventilation rates for heat balance and moisture control shows a fundamental problem. To prevent condensation or fogging, the ventilation rate must be near or above the rate for moisture control most of the time. But the rate for moisture control is higher than the rate for heat balance. The barn will be either foggy or cold; if moisture production cannot be reduced, you must supply supplementary sensible heat.

The method for hot weather ventilation is outlined below.

1. Establish the solar gain potential (the rate at which the building gains heat from sunlight). If it can be determined, it must be added to the sensible heat produced by animals or stored produce.
2. Find the summer design temperature.
3. Calculate the sensible heat to be removed by reducing the value for sensible heat produced by the amount of sensible heat converted to latent heat.
4. Calculate the required rate for mass air flow to limit the temperature rise to 2–3°C.
5. Change the mass flow rate of air to the ventilation rate:

[10] $V_m = Q_{vs}/[c_p(t_i - t_o)]$

where

V_m = mass flow rate of air (kg/h)

Q_{vs} = sensible heat removal rate (kJ/h·animal)

c_p = specific heat of dry air, 1.006 kJ/(kg·°C)

t_i = inside temperature (°C)

t_o = outside temperature (°C)

Example Consider the same 500-kg cow housed at Morden, Man., during July. Assume that a temperature rise of 2°C is acceptable.

1. The barn is well insulated with adequate attic ventilation.
2. The July design temperature is 31°C. From the psychrometric chart, $v_a = 0.88\ \text{m}^3/\text{kg}$ and RH = 52%.
3. From Table 8, the sensible heat production is 2574 kJ/(h·cow) and 27% is converted to latent heat. This value is probably high, since animals reduce the production of sensible heat in hot weather. Use high-temperature values for sensible heat production whenever available.
4. According to Eq. 10, the mass flow rate of air needed to limit the temperature rise to 2 or 3°C is

   $V_m = [2574 - (0.27 \times 2574)]/1.006(t_o - t_i)$

   = 934 kg/h per cow for a 2°C temperature rise

   = 623 kg/h per cow for a 3°C temperature rise

5. The needed ventilation rate:

   $V = V_m \cdot v_a(1000\ \text{L/m}^3)/(3600\ \text{s/h})$

   $= 0.88 V_m \cdot 1000/3600$

   = 228 L/(s·cow) for 2°C temperature rise

   = 152 L/(s·cow) for 3°C temperature rise

Note that the allowable temperature rise is inversely proportioned to the required ventilation rate. To ventilate livestock buildings in summer, many operators open the sidewalls and ridge, but mechanical systems can be used. Directing air toward the animals can help cool them, unlike winter conditions in which incoming air must be directed away to prevent drafts.

6.10 Ventilation rate guidelines and control

Table 65 provides ventilation rates for comparison with the calculated values. Since these rates are general in nature, they do not reflect specific housing and management practices that can affect the production of animal heat, moisture, and airborne contaminants.

The minimum winter rate is typically about five-eighths to two-thirds that calculated for moisture control if the barn is full of animals. This ensures that the continuous ventilation rate (first step) is below the minimum rate required for moisture control if the barn is not full. Of course the second step of ventilation should be above the minimum rate. This helps to avoid wasting supplemental heat, especially if the heaters are not oversized and operate only during the first step of ventilation.

With livestock like baby calves and weanling pigs that are more susceptible than adults to the concentrations of disease organisms, manure gases, and dust contaminating the air, this minimum rate of ventilation may not be enough. The room air should be changed at least four times per hour regardless of the rate needed for humidity control. With densely housed animals like growing or finishing pigs and caged laying hens, the first-step rate usually exceeds four air changes per hour. Summer ventilation rates are often 20 or more times the winter rates.

Choose fan sizes and thermostats so that the ventilation rate is changed in several steps. One rule of thumb is to double the ventilation rate at each step. The first-step continuous rate is therefore about five-eighths to two-thirds the rate for moisture control; step 2 is double the step 1 rate or slightly above the moisture control rate, and so on. This allows small changes in the ventilation rates during cold weather and larger changes during warm weather, with a minimum number of fans.

6.11 Heat deficit temperature

When the ventilation rate for moisture control exceeds that for heat balance, the building undergoes a net heat loss. This situation often arises during cold weather in buildings housing young animals but it can also occur with adult animals, especially if the building is underfilled.

Use Eqs. 5, 8, and 10 to prepare a composite graph to find the heat deficit or critical temperature – that is, the outside temperature below which you must add heat to ensure adequate ventilation control without lowering the room temperature.

Fig. 40 shows a typical heat balance graph presenting critical temperature and supplemental heat requirements.

6.12 Exhaust ventilation systems for animal housing

Exhaust ventilation systems should be designed to operate at a pressure of 10–25 Pa. Thus all building openings, including cracks and holes in the vapor barrier, act as air inlets. This minimizes the transmission of water vapor into the building's structure and insulation.

Electrical ventilation equipment should be CSA-approved for its intended use. Motors should be totally enclosed and have built-in protection from thermal overload.

Unless the fans are connected to a duct system, exhaust fan ratings should be based on airflows at not less than 30 Pa of static pressure difference. The airflow rates should be established by independent testing. Gravity-type shutters should be provided on all exhaust fans except those that run continuously.

Protect all exhaust fans from the effects of winds. Putting fans only on the leeward side of the building is not always satisfactory or desirable. Instead, protect them by using hoods; these should be large enough and smoothly curved, and should turn the exhaust air a full 90° downward. The hood should extend more than halfway down the building wall, and the lip next to the wall should extend at least 100 mm out from the wall and 150 mm below the wall opening.

Wall fans must be made inaccessible to animals. Use appropriate safety guards to protect fans from inadvertent contact with operators or equipment. The fan enclosure should be at least 300 mm from the ceiling, other wall protrusions, or adjacent fans.

Exhaust fans can be evenly spaced along one or both sidewalls or banked in groups. If they are banked, the group should not contain more than three fans. The distance between banks of fans should not be more than 40 m or twice the building width, unless specially powered systems for air inlet are used. If a bank of fans is installed in an extended fanroom, size the wall opening to keep velocity below 2.5 m/s through the opening.

If liquid or semisolid manure is to be held below the animals for 2 weeks or more, exhaust some air from below the floor level. This procedure helps to remove manure gases (which are heavier than air) but does not provide a safe level of ventilation when the manure is agitated before removal.

Table 65 General ventilation recommendations for livestock and poultry

Type of livestock or poultry	Minimum temp. (°C)	Type of housing	Minimum (step 1) winter rate, L/s per unit	Maximun summer rate, L/s per unit
Dairy cattle				
450-kg cow	2	Conventional fall to spring stabling. Ventilation by windows or doors during summer. Walls insulated less than RSI 0.9	10/animal	160/animal
450-kg cow	2	Year-round housing. Windowless or non-opening windows. Walls and ceilings insulated to at least RSI 1.8	12/animal	190/animal
450-kg cow	5	Milking parlor	12/stall	190/stall
	5	Milk room	–	280/room
Calves, dairy replacements	7	Year-round housing in well-insulated barn		
Continuous housing				
50-kg (1 mo) average			5/calf[1]	40/calf
65-kg (2 mo) average			7.5/calf[1]	60/calf
All-in, all-out housing				
45 kg at start			5/calf[1]	40/calf
135 kg at finish			10/calf[1]	80/calf
Beef				
450-kg cow	2	Ventilation by windows and doors during summer. Walls insulated less than RSI 0.9	10/animal	160/animal
Chickens				
Laying hens	16	Cages, high density	0.14/hen[2]	2.9/hen
	16	Litter, up to 0.14 m^2/bird	0.19/hen	3.3/hen
Heavy breeder hens	16	Litter or mesh floor	0.19/hen	3.6/hen
Replacement pullets	32–21[3]	1 or 2 deck cages	0.02–0.19/pullet	2.4/pullet
Chicken broilers	32–21[3]	Litter, up to 0.09 m^2/bird	0.02–0.14/bird	2.4/bird
Turkeys				
Broilers, 0–14 wks	35–16[3]	Litter	0.05–0.3/bird	6.4/bird
Heavy broilers, 18–22 wks 7–9 kg max.	16	Litter	0.05–1.0/bird	9–15/bird
Breeders (light to heavy breeds)	16	Litter	0.5–1.0/bird	8–14/bird

continued

Table 65 *(concluded)*

Type of livestock or poultry	Minimum temp. (°C)	Type of housing	Minimum (step 1) winter rate, L/s per unit	Maximun summer rate, L/s per unit
Swine				
Dry sow, 180 kg	13	Group pens	3.0/sow	96/sow
	18	Individual pens	2.4/sow	96/sow
Farrowing sow and litter	18[4]	Farrowing pens	7.0/sow	144/sow[5]
Weanling pig, 7–25 kg	27–21	All-in/all out housing	0.4/pig	16/pig[5]
	24	Continuous housing	0.7/pig	12/pig[5]
Grower, 25–60 kg	21	Partly slotted floor	1.3/pig	32/pig[5]
Finisher, 60–100 kg	15	Partly slotted floor	2.0/pig	40/pig[5]
Combined, 25–100 kg	18	Partly slotted floor	1.6/pig	35/pig[5]
Horses, 450-kg	2	Year-round insulated stabling, ventilated by windows and doors during summer	10/horse	80/horse
Sheep, 45-kg	2	Ventilated by windows and doors during summer. Walls insulated less than RSI 0.9	1/ewe	8/ewe
Rabbits, doe and litter	12	Cage housing, 14 kg live weight/cage	0.08/kg	1.3/kg
		Lower density	0.06/kg	0.96/kg
Chinchillas		Mature animals. Year-round, insulated housing, in cages	0.05/animal	1.6/animal

[1] This ventilation rate is considerably greater than that required to control humidity. It may have to be further increased if it does not give at least four room air changes per hour.
[2] 0.14 L/s applies where manure is removed weekly. With deep pit manure storage, increase to 0.24 L/s and increase supplemental heating accordingly.
[3] Start day-old chicks, poults, and weanling pigs at the first temperature and gradually decrease the temperature as they grow.
[4] 18°C is a comfortable room temperature for the sow, but newborn piglets need 29–30°C minimum. Provide a heated creep and gradually decrease creep temperature to 24°C as piglets grow.
[5] Not over one air change per minute for sensitive stock.

For poultry buildings with a deep manure storage under cages housing laying chickens, all exhaust fans can discharge from the manure storage below the cages.

Whenever air is ducted to or from fans in animal barns, the delivery rate decreases because of the additional friction and static pressure head caused by the duct. Design the ducts in accordance with good engineering practice. For most applications, keeping air velocities below 2.5 m/s in ducts is desirable; 5 m/s is the upper limit. In any case, the duct design must ensure that the fan operates efficiently with the added resistance.

Install thermostats and other fan controls where they will sense average air conditions readily. Make them easily accessible for adjustment and cleaning. Keep them out of the way of, or protected from, animals and equipment.

All wiring for fans and controls must meet the requirements of the *Canadian Electrical Code* and provincial electrical inspection authorities.

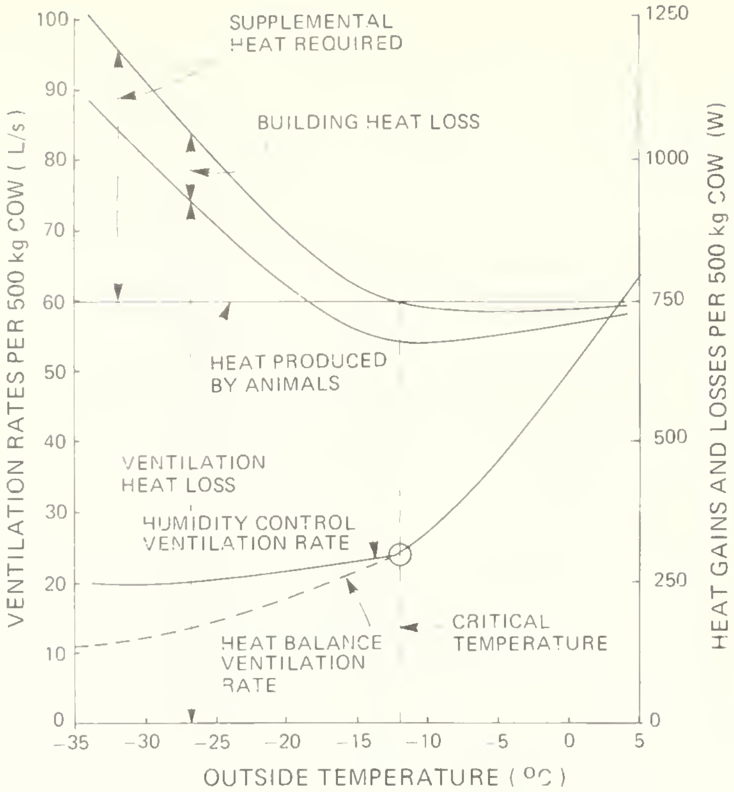


Fig. 40 Typical heat-balance, humidity control, and heat loss curves for an animal housing unit

If natural daylight must be excluded from animal buildings, fit all ventilation openings with light-control baffles, painted flat black. These should provide at least two light reflections for inlet openings and three for exhaust openings. Using baffles invalidates standard fan ratings, and fans must be selected on the basis of increased static pressure, estimated according to accepted engineering principles.

Exhaust fans determine the rate of air exchange, but no ventilation system performs well without a satisfactory air inlet system.

6.13 Air inlet systems for animal housing ventilation

The potential success of the overall ventilation system depends on the proper location and good design of the air inlet system. Where the air inlets are located depends in turn on the building width and the arrangement of the animal housing.

The air inlet system must distribute incoming fresh air uniformly to all animals in the building. The system must be able to distribute small quantities of air in cold weather without creating drafts. In hot weather, it must be able to supply 10–30 times as much air and to redirect the air as necessary to prevent heat stress.

In winter, directing the inlet air across a ceiling (which should be smooth in the direction of the airflow) at 4–5 m/s helps to prevent cold drafts on animals or birds. In barns housing sensitive animals, this incoming air should reach the dunging portion of the pen area before it moves through the resting area.

Use Eq. 11 to calculate the inlet air:

[11] $A = Q/(1000 \cdot V)$

where

A = area of inlet opening (m^2)

Q = fan exhaust capacity (L/s)

V = inlet air velocity (m/s)

1000 = number of L/m^3

Note: When air flows through small openings, the effective area of the jet is only 60–80% of the calculated area. In practice, use $V = 4$ m/s in Eq. 11 as an equivalent for jet velocities of 4–5 m/s. Alternatively, 0.25 m^2 of inlet opening per 1000 L/s of operating fan capacity should provide workable values.

The inlet opening must be adjustable to cover the range of airflows required. To increase evaporation and reduce summer heat stress in larger and adult animals, the air inlet system should allow incoming air to be redirected at the animals.

The system must be designed to minimize wind effects and prevent the entry of snow, rain, rodents, and birds. A vertical air intake set 100 mm or more from the face of the vertical wall may provide adequate wind protection. The air intake should be hooded to keep out rain and snow and fitted with a corrosion-resistant screen of 12 × 12 mm mesh to exclude rodents and birds. Screening of a mesh fine enough to keep out insects tends to plug up and seriously restricts the air intake.

The total intake system should allow air to flow in at velocities of 2.5 m/s or less for summer ventilation. When very low flow rates of winter air are required, using a long slot inlet makes it difficult to mix and distribute the incoming air. Good mixing is essential for air quality in all parts of the building, and especially for areas occupied by individual animals or groups. Forced-air blending and distribution is one possibility; another is to use a discontinuous inlet made up of several short inlets spaced along the length of the room.

All inlet ducting and adjustable baffles must be insulated or constructed from rigid insulating materials to prevent condensation and frost problems during winter.

6.14 Hot weather cooling

Given a good ventilation system, properly operated, few animals should die from heat stress unless a mechanical ventilation system fails. Most losses are less obvious – the result of lowered animal productivity or reduced reproductive capacity.

For some animal housing and greenhouse applications, the room air may be cooled as a supplement to ventilation. Evaporative cooling is the most common technique. It cools the air by misting it with water or by drawing it through a wet porous material. This process converts sensible heat to latent heat by vaporization, thereby lowering the temperature but increasing the humidity. The total heat content of the air does not change. See Fig. 38.

Whether or not evaporative cooling can improve the animals' comfort depends on the available wet-bulb temperature depression (dry-bulb temperature minus wet-bulb temperature). Further details on evaporative cooling can be found in *Ventilation of Agricultural Structures.*

You may spray water over the skins of finishing pigs to keep them cool. Details of this system are given in Section 2.55. Or you may supply a small flow of dehumidified cool air from a refrigeration unit towards the animals' snouts (snout cooling). Dehumidification makes it easier for the animal to lose respired (latent) heat.

6.15 HEATING AND REFRIGERATION

Heat may be needed to keep products or water from freezing, to remove ice from around waterers, to brood young birds or animals, to maintain desired environmental temperatures for animal or plant productivity, to keep workers comfortable, or to heat water for cleaning and sanitizing. Refrigeration is often used to lower the temperatures of food products in order to preserve their quality and extend their storage life.

6.16 SAFE INSTALLATION OF EQUIPMENT

All oil- or gas-burning or electric heating and refrigeration equipment should conform to the following requirements:

- *Canadian Farm Building Code*
- *Boiler, Pressure Vessel, and Pressure Piping Code*
- *Mechanical Refrigeration Code*
- *Installation Code for Oil Burning Equipment*
- *Installation Code for Natural Gas Burning Appliances and Equipment*
- *Installation Code for Propane Burning Appliances and Equipment*
- *Canadian Electrical Code*, Part 1, or the provincial equivalent

The installation of wood- and coal-burning appliances, including mounting, clearances, and requirements for safety devices, should conform to the *Installation Code for Solid-Fuel Burning Appliances and Equipment.*

If fuels are burned in greenhouses, provide a separate air and flue system for combustion. If the system uses carbon dioxide enrichment for growth regulation, use CO_2 generators specifically designed for the purpose.

Moveable gas-fired brooders and heaters should be connected to the fuel supply pipe with not more than 2.4 m of flexible hose, or as required by provincial regulations. Provide infrared brooders with suitable dust filters or shields to keep combustible material from contacting the radiating surfaces.

If you use any type of forced-air combustion unit in poultry houses or other dusty buildings, equip the cold-air return with a filter at least four times larger than that normally used for domestic or industrial heating units of similar size. Alternatively, the cold air return may draw in outside air, if the heating unit can add enough heat without overventilating the structure and if the heat exchanger is designed to handle cold outside air.

Electric heat lamps should be of the hardened-glass type. In buildings housing animals, install the lamps in CSA-approved lamp holders.

All suspended radiant heaters should be supported by chains or other means so that they put no load on the supply cord or hose. Make sure that the power supply disconnects if the radiant heater falls or is pulled down. For electric radiant heaters, fold and tape any extra cord to ensure that a falling unit will pull the plug from a ceiling-mounted receptacle.

6.17 HEATING APPLICATIONS

Most agricultural heating applications fall into one or more of the following categories: space heating, spot heating, floor heating, special purposes, or crop curing or drying. These are discussed below.

6.18 Space heating

Operators often need supplementary heating to protect materials from freezing, to provide comfortable working conditions, or to maintain the productivity of animals or plants. Natural and forced convection are the most effective methods of space heating. The heat supplied must be well distributed in the building space to provide uniform temperatures. If air is being circulated for other reasons, heat can be supplied to the air circulation system at one or more points by convection heaters.

Fan-forced unit heaters may be used individually or grouped in larger areas. In ventilated areas, direct heat toward the colder incoming air. For sensitive animals, it may be wise to warm incoming air in a separate preheat area. These heaters may be gas-fired, but electric or hot-water units are more common.

Large building areas with little ventilation, such as greenhouses or brooding areas, can be heated most effectively by well-distributed convection heaters along the perimeter. Black pipe or finned tubes carrying hot water are common. Use forced-air systems only in dust-free areas to eliminate filter maintenance.

Consider using air-to-air heat exchangers and solar preheat systems in continuously ventilated buildings that require heating. *Livestock Ventilation Heat Recovery Systems* presents useful information on the design and selection of heat exchangers. The Canada Plan Service has plans for a wall system using solar preheat with heat storage for animal buildings, and a passive solar wall system for farm shops.

6.19 Space heating systems

The size of space heating systems depends on the building's intended use.

Category 1 This group includes buildings with negligible internal heat gain and little or no ventilation heat loss (examples: poultry brooding space, greenhouse, farm workshop). The heating system must be able to maintain the desired temperature at January design temperature (2.5% basis) for the proposed building location. Building heat losses and infiltration heat losses must be considered.

Category 2 These buildings gain heat internally from animals, stored products, or equipment and need continuous ventilation for removing moisture and gases (examples: farrowing barn, weanling barn, calf nursery, fruit or vegetable storage). The heating system must be able to maintain the desired room temperature at the outside design temperature in January (2.5% basis) with ventilation at the recommended rate with the building stocked at 80% or more of its rated capacity. The heating system should make up the deficit when animal, product, or equipment heat gains are less than the combination of building heat losses and ventilation heat losses.

Some practical suggestions Whenever possible, select heating equipment and controls to provide two or three operating levels. For example, if you need 15 kW, design the system to operate at 5, 10, and 15 kW or 7.5 and 15 kW. This flexibility allows for reduced, continuous heating when the outside temperature is above design temperature; temperature and relative humidity in the building can be kept more or less constant.

Do not install oversized heating systems to provide a safety factor unless the equipment can be used at different operating levels. Oversized heating systems operate infrequently, causing large temperature and relative humidity swings. The operator may have to over-ventilate to keep the internal temperature down, and thereby waste heat.

6.20 Spot heating

Spot heating can reduce energy consumption by lowering the overall room temperature required. The radiant heating equipment normally used in farm buildings varies in capacity from 125 W to 2000 W. Select heaters on the basis of the canopy size and heat energy requirements. Electric or gas radiant heaters can direct heat to where it is needed – for example, toward newborn animals or frost-susceptible equipment such as water pumps.

Newborn animals, especially piglets, chicks, and poults, require a good deal of warmth. They can control the amount of heat they receive by moving toward or away from the heat source. If they huddle or pile up, they need additional heat.

Spot heating is ideal for newborn piglets. The brood sow is normally held in colder gestation facilities and reacts adversely to temperatures over 30°C, which newborn piglets need. The heat and light from radiant heaters also attract the piglets away from the sow, reducing the chance of injury or death by crushing.

For each litter, use a 250-W unit in winter and a 125-W unit in summer, or provide a 500-W unit with a rectangular canopy for two litters in adjacent side creeps Some operators start with radiant heat at the rear of the pen to help dry off newborn piglets. Then, as the piglets grow, the lamp is moved to the nursing area beside the sow and finally to a creep area in front of the sow.

When brooding turkey poults with radiant heating equipment, keep the number of birds under 250–275 per heater to reduce social stress.

If you use radiant heaters in Category 2 buildings, remember to include the radiant heat in calculating the total energy output for sizing space heating systems.

6.21 Floor heating

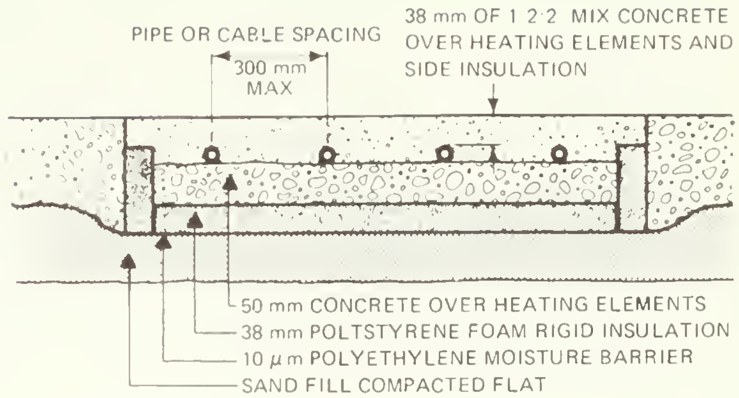
Concrete floors may need to be warmed for some purposes; for example, to keep workers comfortable in milking parlor pits and workshops, to brood young animals or keep them comfortable, to dry concrete floors, or to supply heat in naturally ventilated livestock housing.

Determine the watt density (W/m^2) required to warm the room and slab to the desired temperature (Fig. 41).

Concrete floors can be warmed with piped hot water or electrical heating cable. Table 66 provides the requirements for heating cable, based on watts per linear metre of cable used and watt density required. Details for designing hot water floor and space heating systems are available in CPS plans.

Urine and other corrosive liquids can seep through cracks in the concrete and corrode the cable; therefore the type of cable must be approved for farm applications. Nylon-covered cable is the usual material. Choose piping for hot-water systems for its corrosion resistance and temperature–pressure rating. Copper piping is not recommended.

In most cases, floors need to be kept warm, not hot. Floor temperatures at or above body temperatures are generally too warm for animals.



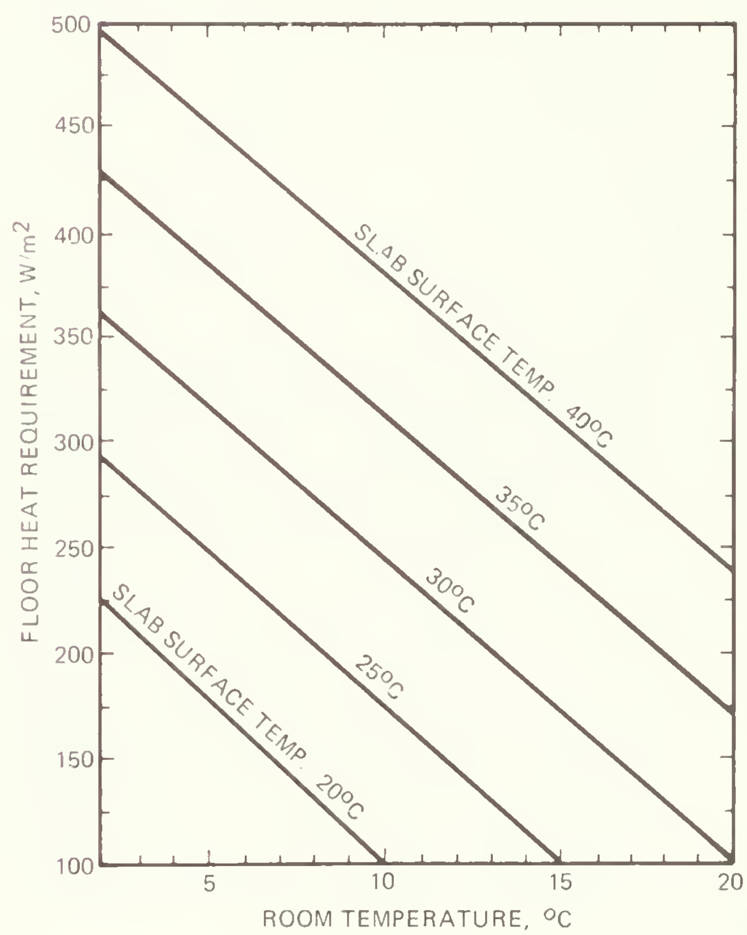


Fig. 41 Temperature of heated concrete floor slab with 38-mm rigid insulation

Table 66 Spacing of heating cable for systems to warm concrete slabs[1] (mm)

Watt density (W/m^2)	Watts per linear metre of cable									
	15	20	25	30	35	40	45	50	55	60
100	150	200	250	300						
200	75	100	125	150	175	200	225	250	275	300
300	50	67	83	100	117	133	150	167	183	200
400		50	63	75	88	100	112	125	138	150
500			50	60	70	80	90	100	110	120

[1] Spacing should not be less than 50 mm or greater than 300 mm.

Warm floors are principally conduction heaters. Unless the warmed floor area is almost the same as the area of the building or room (as in a machine shop) the convection component is relatively small and can be neglected in calculating the heat balance.

Electric heating cable can also be set in concrete to remove ice on watering bowl aprons, gutter cleaner ports, or the entrance ramp to a milking parlor. For these intermittent operations, use a high watt density (250 W/m^2).

The heating pipe or cable may be placed either in or below the concrete floor. Details concerning system design and installation can be found in the CPS plan, *Hot Water Floor and Spacing Heating*. Insulation under full-area heated floors such as farm shops is probably not worth the expense. On the other hand, insulating around the foundation is important. Insulating under the heated portions of livestock floors improves comfort and heat distribution.

For safety, all heating cable installations should be equipped with a thermostat that cuts out the power supply if the cable overheats. If the cable is laid over reinforcing rods or mesh, it should not be attached to the reinforcement by wire or other heat conductors.

6.22 Special purpose heating

Specialized heating units are available to prevent water from freezing in pipes and the animals' drinking units. Use only equipment approved by the CSA for that application. Check for specific installation instructions to prevent or minimize stray voltage in livestock buildings (see Section 6.31).

6.23 Crop curing or drying

Heaters for crop curing or drying are normally purchased as complete operating systems. Manufacturers must obtain regulatory safety approvals before offering these units for sale. In special cases, operators can seek on-site approval of a system.

The rating of equipment for crop curing and drying can be questionable. Two standards of the American Society of Agricultural Engineers (ASAE) can be used, though only for purposes of comparison. These are *Construction and Rating of Equipment for Drying Farm Crops* and *Energy Efficiency Test Procedure for Tobacco Curing Structures.*

The Prairie Agricultural Machinery Institute (PAMI) also provides performance reports on hot-air grain dryers and associated equipment (for small grains, not corn).

6.24 REFRIGERATION SYSTEMS

Systems can be air-to-air, liquid-to-liquid, or a combination, depending on requirements. Base the size of the refrigeration system on the rate of heat removal needed to lower the product's temperature within the time specified by regulation, or within the desired time when regulations do not exist.

For fruit and vegetable storage, choose equipment on the basis of heat of respiration, field heat at time of harvest, heat gain and losses from other sources, including the building shell, and desired cooling rate. In cooling high-humidity storages for fruits and vegetables, the evaporator surface must be oversized so that its surface temperature can be held only a few degrees below air temperature, to keep dehumidification and evaporator icing to a minimum.

6.25 ELECTRICAL SERVICES

Almost all farm buildings require a separate electrical service or subservice. All electrical equipment should be CSA-approved for the intended use and location, and must meet the requirements of the *Canadian Electrical Code*, Part 1, and provincial or local requirements.

6.26 FARM ELECTRICAL SERVICE

Most farms are served by a central step-down transformer. The service is normally a nominal 120/240 V, 60 Hz, single-phase type, but three-phase service can be used if needed and if it is available nearby.

You may need to purchase a phase converter to provide three-phase power for larger motors (7.5–75 kW) from a single-phase power source. If you expect to use three-phase power or anticipate a large service load, contact the power supply authority as soon as possible. The authority can also advise you on permissible arrangements for main service and on special provision for metering and standby power connection.

6.27 SIZING BUILDING SERVICE CONDUCTORS

The ampacity (amperage capacity) of overhead or underground conductors supplying one or more buildings should be 100% of the rating of the largest service switch plus 75% of the sum of the ratings of all other service switches supplied by that set of conductors.

New overhead yard wiring should be neutral supported cable with a minimum of No. 2 AWG aluminum. Table 67 shows the maximum allowable ampacity for other sizes of neutral supported cable.

The minimum size of the grounding conductor is proportional to the ampacity of the service conductor. Table 68 provides data for choosing grounding conductors.

6.28 SIZING INDIVIDUAL SERVICE SWITCHES

The maximum continuous load, as calculated in the following manner, should not exceed 80% of the service switch capacity (ampacity) for buildings supplied at 120/240 V, and can be calculated by adding up the following current values.

- Full-load current of the largest motor × 1.25; where two or more motors of equal size are concerned, apply this factor to one only. See the *Canadian Electrical Code* for full-load current of common sizes of motors.
- The full-load amperage of all other stationary equipment that is likely to be operated simultaneously.
- One-half the full-load amperage of all portable equipment operated at 120 V.
- All convenience outlets at 0.25 A per outlet.
- All lighting outlets at 0.25 A per outlet. If low-level lighting is used, e.g. 25, 40, or 60 W per outlet in a poultry house, calculate one-half of the total connected lighting load in amperes.

6.29 EMERGENCY ELECTRICAL REQUIREMENTS

All farm buildings housing animals or sensitive products should be equipped with a warning system connected to an independent power source. It can warn the owner of any one of the following conditions:

- building temperature above or below critical limits
- electrical supply interruption
- low water pressure
- intruders
- other special requirements.

The warning system should flash a light or sound an alarm in the farmhouse or ring telephones at one or more locations. Often it turns on a standby electrical generator. It may include an intercom system for hearing distressed animals, malfunctioning equipment, or intruders.

Table 67 Maximum allowable ampacity of neutral supported cable, types NS-1 and NSF-2

Size, AWG	Ampacity with two insulated aluminum conductors	Ampacity with three insulated aluminum conductors
8	55	45
6	70	60
4	95	80
3	110	95
2	125	105
1	145	120
0	165	140
00	190	160
000	215	185
0000	250	215

Table 68 Minimum size of grounding conductor

Ampacity of largest service conductor or equivalent for multiple conductors A	Size of copper grounding conductor, AWG
100 or less	8
101–125	6
126–165	4
166–260	2
261–355	0
356–475	00
Over 475	000

6.30 Standby generator connection

All emergency power generators must be connected to the electrical utility's power supply through a double-throw switch to prevent feedback into the utility's system.

The standby generator should be large enough to start the largest motor and operate all essential portions of the service load – equipment for ventilation, refrigeration, watering, milking, and feeding and for other loads, if necessary. Electrical heaters, if not essential, may be disconnected to reduce the power supply and capacity required for the standby generator.

Locate the double-throw switch at the main farm service entrance if more than one building requires emergency power. The switch must be rated for total service ampacity on the line side and ampacity of the generator on the standby side.

Grounding, wiring, and connection receptacles for the generator must meet provincial requirements.

6.31 WIRING IN FARM BUILDINGS

All wiring and fixtures must meet the requirements of the *Canadian Electrical Code* and provincial regulations. The following recommendations are good practice and should be consistent with the code's regulations.

- Protection and grounding are especially important in animal housing where floors can be wet. Animals have a lower body resistance to electrical current flow than do humans. Voltages that humans cannot detect can cause animals to balk and refuse feed and water.
- Install a grounding electrode at every building on the farm where service is provided. The electrode should consist of one or more ground rods driven into earth and suitably interconnected. Ground rods should be at least 3 m long.
- To reduce the hazard to humans and livestock from lightning, electrical failure, and induced voltages in equipment or wiring, all metal components (including those not directly linked to the electrical system, such as stanchions, reinforcing steel in floors, drain gratings, water and feed bowls, and metal pens) should be bonded together by a copper conductor not less than No. 6 AWG and connected to the ground for the electrical system.
- Provide proper receptacles for grounding parts of electrical equipment that do not carry current, especially portable tools and equipment. Ground the metal parts of water systems, including remote pumping systems, to the system ground by a separate conductor. When plastic pipe is used, install a separate ground conductor.
- Milking parlors are of special concern. For new facilities, install equipotential grids. (See Section 2.16 for specific recommendations.)
- Protect each branch circuit by fuses or circuit breakers whose ratings do not exceed ratings of circuit conductors.
- For current to start motors, use time-delay fuses or circuit breakers with suitable operating characteristics.
- For a branch circuit, the fixed electrical heating load should not be more than 80% of the ampacity of the conductor or overcurrent device.
- Install ground fault circuit interrupters (GFCI) on branch circuits supplying frost-proof waterers, water pumps, and outdoor outlets.

6.32 Sizing and selection of branch circuit conductors

Branch circuit conductors must be large enough to minimize power losses in conductors and to provide adequate voltage to equipment. The *Canadian Electrical Code* gives conductor lengths for 1% voltage drop on 120-V circuits. For 240-V circuits, the lengths given can be doubled. The voltage drop on branch circuits should not exceed 3%.

All wire should be copper and be enclosed in PVC rigid conduit, nonmetallic sheathed cable (NMW type), or other material approved by the inspection authority.

If rodents might damage the conductor insulation, mount the wiring on surfaces or protect it by rigid PVC conduit or other approved material. If surface-mounted wiring is likely to be damaged by animals or by impact with moving objects, protect it with rigid PVC conduit.

Remember to use corrosion-resistant cable for heating concrete floors (see Section 6.21).

Where conductors penetrate a vapor barrier, seal around the opening to prevent vapor transfer and subsequent condensation and corrosion.

6.33 WIRING DEVICES IN FARM BUILDINGS

Install outlets, switches, receptacles, and other wiring devices only in nonmetallic boxes made of and covered by insulating material. Rigid PVC and bakelite boxes are common.

6.34 Convenience and special-purpose outlets

Locate convenience outlets as high as you can easily reach. This precaution helps prevent damage by animals or moving objects. Mount outlets flush to the wall surface if possible.

Provide convenience outlets for portable equipment such as power washers or clippers to eliminate the use of extension cords. Use three-prong grounded outlets.

Use special-purpose outlets for permanent or semipermanent equipment; wire them with conductors of adequate size for the load. To avoid misuse, use the right types of outlet for specialized equipment. The *Canadian Electrical Code* gives configurations for nonlocking and locking receptacles.

In some cases, special-purpose outlets should be specifically located for additional safety. Receptacles for heat lamps should be mounted in the ceiling directly overhead to make sure that the lamp disconnects if it falls or is knocked over.

6.35 Wall switches

All lamp outlets should be controlled by means of wall-mounted switches. Mount wall switches at least 1.5 m above floor level. Do not locate them in areas where livestock are penned unless the switches are adequately protected.

If a building has two or more principal entrances, install light switches at all entrances. This recommendation also applies to all stairways that are not adequately lighted by other sources.

6.36 MOTORS AND ISOLATED SERVICES

Most farm motors are on fixed equipment in farm buildings, but some motors and other electrical devices – the water pump and silo unloader, for example – may be isolated.

6.37 Motors on fixed equipment

All motor controls should be approved for use with the specific motor or associated equipment.

Motors of 0.25 kW or less may be connected to convenience outlet circuits if the motors have built-in motor overload protection. Each motor over 0.25 kW should be operated on a separate circuit and connected to a special-purpose outlet. All permanently installed motors, especially those over 0.38 kW, should be operated on 240 V.

6.38 Isolated motors and electrical equipment

Motors and electrical equipment located a considerable distance from farm buildings may have separate service or a circuit from the farm service. Consult your electrical utility company for recommendations.

Water pumps and silo unloaders should be supplied by underground or overhead conductors of adequate size. Install and wire submersible pumps for water supply and manure handling in accordance with the manufacturer's instructions and the *Canadian Electrical Code*.

Silo unloader motors should be totally enclosed or fitted with suitable screens to keep foreign material out of the ventilating passages of the motor. Provide the motor with individual overload protection, not the automatic reset type.

The silo unloader motor should be controlled by a magnetic motor controller, with a control station at the silo that can be secured to keep the motor from being started when someone is inside the silo. In addition, install a jog pushbutton at the motor inside the silo, or alternatively install a "local or remote" switch for selecting operations at the controller. In the latter case, a remote control station on a cable that the operator can carry into the silo is an alternative means of control, provided that the remote "start" pushbutton performs a jog function only. A suitable disconnect should be installed within sight of the controller.

All boxes and fittings installed outdoors or in silo rooms should be weatherproof. Consult local inspection authorities about the type of cable, restrainers, and takeup mechanisms acceptable for top unloaders.

6.39 Underground cables to service-isolated motors or frostfree waterers

All underground cable should be of a type approved for underground use. Protect underground cable at entrance and exit points and in rocky or stony ground, where it might suffer mechanical damage by imposed ground loads.

Cable should be sized in the same way as branch circuits to keep voltage drop below 3% for the total circuit length.

Obtain approval from local inspection authorities before proceeding with underground cable installation, especially if other services are to be located in the same trench.

6.40 LIGHTING

Adequate levels and quality of light are essential in many farm buildings. Good lighting is essential for workers' safety – on stairways, for example – and for tasks.

Although the quality of natural light is excellent, its intensity or duration may not be adequate. Plants may need additional light for year-round growth and some animals and plants require specific periods of light to stimulate reproduction or flowering.

Windows in heated or humid buildings may create special problems. They allow a good deal of heat loss and condensation and need periodic cleaning to let in enough light.

6.41 Lighting for safety and security

In wet or damp locations use lamp receptacles with nonmetallic coverings. Switchless weatherproof pigtail lampholders should be used for lighting outlets in barns and stables.

Avoid setting light fixtures where they might be damaged. Fixtures that might be rained or dripped on should be incandescent weatherproof lights with gasketed globes.

Lighting fixtures in feed-grinding rooms, feed-storage areas, hay mows, or other dusty areas should be suspended vertically and should have totally enclosed gasketed globes.

Never mount light fixtures directly over feed stores or bulk milk tank openings, or at other locations where broken glass could contaminate food or feed.

For each stairway, use enough lighting outlets to illuminate the whole stairway, controlled by three-way switches.

For safety, put an outside light near main doorways where regular access or loading and unloading is likely to occur.

For security lighting around farm buildings, provide high-intensity discharge (HID) lighting equipment specifically approved for outside use.

6.42 General lighting requirements

Table 69 gives the minimum recommended lighting levels for specific tasks. The following recommendations for lighting outlets are based on incandescent lamps. Fluorescent or HID lighting can be substituted where applicable, if it is approved by inspection authorities, but it is not recommended in areas with high humidity or low temperatures or where light dimming is required. Fluorescent fixtures with special low-temperature ballasts can, however, be considered for milkhouses, milking parlors, or other areas where excellent illumination is necessary and the temperature is kept above freezing. Use an enclosed fixture to retain heat, for efficiency.

The quality of a lighting installation can be affected by several factors. High-reflectance matte finishes are better than glossy finishes; these can create glare if the light shines on them directly. If there is a ceiling, use a non-reflectored fixture to illuminate the ceiling. In areas without ceilings, such as free-stall housing or greenhouses, use a reflectored fixture to direct the light downward for maximum benefit.

6.43 OUTLETS FOR LIGHTING AND CONVENIENCE

Outlets for lighting, convenience, and special purposes (each on its own circuit) should be provided in facilities for animals and crops and in service areas as suggested below. Lighting fixtures should provide the levels of lighting recommended in Table 69.

6.44 Dairy structures

Tie stalls For face-out stalls, set lighting outlets along the centerline of the litter alley, with one outlet directly behind every other stall divider. For litter alleys more than 3 m wide, or where an air inlet or pipeline runs along the centerline, use two rows of outlets, 300 mm to the rear of each gutter line, set alternately across the alley. For face-in arrangements, set lighting outlets about 300 mm to the rear of the gutter line, directly behind every other stall divider.

Provide one lighting outlet for every 3–3.6 m of feed alley and one ceiling lighting outlet for each special bull pen, maternity pen, or calf pen 9 m^2 or larger. For the special pens, control the lighting outlets by individual wall switches outside the pen.

Install a convenience outlet at least every 15 m along litter alleys. These outlets may be on the outside walls if the cows face in, or on structural posts if the cows face out. For each maternity pen, provide one convenience outlet out of the animals' reach. If the partitions between the pens are less than 1.5 m high, one outlet over the partition may serve two pens.

Loose housing For open-front barns, provide one lighting outlet for every 40 m^2. In closed barns, allow one lighting outlet for every 20 m^2.

Provide one convenience outlet at each location where equipment such as clippers, groomers, or immersion heaters are to be used. Also provide a convenience outlet on an inside wall near each major entrance, and one convenience outlet out of the animals' reach for each maternity pen. Additional outlets should be provided in the calf pen area.

Table 69 Recommended illumination for farm operations[1]

Area of work	Minimum light on at any time (lux)	Explanation/tasks
POULTRY		
Breeding, production and laying houses, feeding, inspection, and cleaning	200	Provide lighting circuit independent of circuit used to stimulate production and growth
Charts and records	300	Localized lighting needed where charts and records are kept
Thermometers, thermostats, and timers	500	Localized lighting for accurate reading or setting
Egg handling, packing, and shipping		
General cleanliness	500	General lighting to keep area clean and to detect unsanitary conditions
Egg quality inspection	500	Examining and grading eggs; candling and other specialized equipment used separately
Loading platform, egg storage area	200	Needed for operator to move easily and safely, safe operation of mechanical and loading equipment
Feed storage		
Grain, feed rations	100	Needed to read labels and scales; to detect impurities or spoilage
Processing	100	Needed for safety, to read labels, scales, and equipment dials; supplementary light needed for machine repairs
DAIRY FARMS		
Milking area (milking parlor and stall barn)		
General	200	Cleanliness of cow; detect poor-quality milk; handle equipment easily; detect unsanitary conditions. Lights should be available at edge of floor gutter facing the cow
Cow's udder	500	Supplemental; to examine and clean udder
Milk-handling equipment and storage area (milkhouse or milk room)		
General	200	For operator's convenience; to detect unsanitary conditions
Washing area	1000	For sanitation; supplementary, portable ultraviolet fixtures should be available to help detect milkstone on equipment

continued

Table 69 (*continued*)

Area of work	Minimum light on at any time (lux)	Explanation/tasks
Bulk tank interior	1000	To inspect tank for cleanliness; may need additional spots to light dipstick or scales
Loading platform	200	Required for operator to move about readily and safely
Feeding area (feed alley, pens, mangers)	200	To detect foreign objects in feed
Feed storage area, forage		
Haymow	30	For moving about safely
Hay inspection area	200	For detecting foreign objects in hay
Ladders and stairs	200	Safety
Silo	30	Mount fixtures at top near ladder chute for ease in cleaning and replacing bulbs
Silo room	200	For detecting foreign objects in silage
Feed storage area, grain and concentrate		
Grain bin	30	For determining amount and condition of grain; if grain may be moldy or may contain foreign objects, inspect it under stronger light
Concentrate storage areas	100	For reading labels; stronger light needed to detect impurities or spoilage
Feed processing area	100	For operator to move about readily and read labels, scales, and equipment dials. Supply extra lighting if machine repairs are needed
Livestock housing (community, maternity, young animal pens; loose housing, holding and resting areas)	70	To observe animals' condition; to detect hazards to humans or animals. Use portable lights to examine or treat individual animals when necessary
GENERAL AREAS		
Machine shed and garage	50	For moving machinery safely; use supplemental lighting for minor repairs to equipment
Workshop		
Storage area	100	For operator to move easily and safely

continued

Table 69 (*concluded*)

Area of work	Minimum light on at any time (lux)	Explanation/tasks
General shop	300	Machinery repair, rough sawing
Workbench	500	Painting, small parts, storage, ordinary sheet metal work, welding, medium bench work. May need localized lighting for fine work
MISCELLANEOUS		
Farm office	700	
Washrooms	300	
Pumphouse	200	
Exterior		
General inactive area	2	To discourage prowlers and predatory animals
General active areas (paths, rough storage, barn lots)	10	For operator to move about safely
Service areas (fuel storage, shop feed lots, building entrances)	30	For servicing machinery

Free-stall barns Provide lighting outlets over passageways spaced 3.6 m on center and as required to facilitate chores. Lighting outlets should be installed over feed bunks, spaced 3.6 m on center. Every third light should be on a separate circuit for all-night free-choice feeding.

Install a convenience outlet on an inside wall near each major entrance, 1.8 m above the floor. Provide a convenience outlet for clippers and veterinary equipment in any treatment area.

Milking parlors Install lighting outlets along the center line of the milking pit, opposite the rear of each cow, to provide at least one lighting outlet for each 3 m^2 of working area. One lighting outlet should be provided at each exit and entrance for cows. Provide one weatherproof convenience outlet at each end of the operator's pit. A separate radiant heater or heat lamps may be installed over work areas for the workers' comfort.

Milkhouses Place one lighting outlet in the middle of the ceiling and one or two lighting outlets over each work area. Set lighting outlets so that they illuminate the inside of bulk milk tanks when their lids are open but *not* directly over the opening. Provide at least the equivalent of 20 W (incandescent) for each square metre of floor area.

Each work area needs one convenience outlet; these should be set high enough to escape splashing. Special-purpose, 240-V individual circuits should be provided for water heaters, milkroom heaters, coolers, vacuum pumps, and a pump outlet for tank trucks. This last should be on an outside wall near the hose port; control it with a switch on the inside near the hose port.

For electric heating, a fan-forced heater with a thermostat can be permanently installed. A separate radiant heater or heat lamps may be installed over the washup area for workers' comfort.

If ventilating fans are used in the milkhouse, they should blow in so that a positive pressure is created in the milk room and room air flows toward the cow housing, not the reverse.

6.45 Beef structures

Install one lighting outlet for every 40 m^2 in open-front barns and one outlet for every 20 m^2 of closed barns. Provide one lighting outlet for every 10 m^2 in feed rooms and control areas for power equipment, one lighting outlet over each maternity pen and bull pen, and one lighting outlet with wall switch control outside the pens. Lighting outlets over feed bunks and feeding areas should be spaced 4.5 m on center. Every third outlet should be on a separate circuit for all-night feeding. One lighting outlet over each automatic waterer encourages all-night use.

Convenience outlets should be provided in the treatment area. Feed-handling equipment, concentrate conveyors, bale elevators, and automatic livestock water bowls with electrical frost protection will all need special-purpose outlets.

6.46 Horse structures

Tie stalls Install one lighting outlet at the rear of every other tie-stall divider along the centerline of the litter alley and one lighting outlet every 5 m along the center of the feed alley. Provide one lighting outlet for each feed room and box stall.

Install one convenience outlet at the rear of every other tie stall. In barns with a center litter alley, one outlet may serve two to four stalls, depending on the structure. Each harness tack room and feed room should have two outlets.

Box stalls Install one lighting outlet every 5 m along the centerline of feed alleys and one lighting outlet per box stall. One lighting outlet should also be provided for each harness room and feed room.

Convenience outlets should be provided in the feed alley so that one outlet serves every four stalls. Provide one convenience outlet for each harness and feed room.

If your feed system uses an oat crusher or roller mill, install a special-purpose circuit for the equipment in the feed room or near the feed cooker.

6.47 Sheep and goat structures

Sheep barns and lambing sheds Install one lighting outlet every 5 m along the center of feed alleys. One convenience outlet for heat lamps should be provided for each pair of pens. Install a convenience outlet for sheep shearers on the wall or post of the shearing area.

Goats Provide one lighting outlet every 5 m along the center line of feed alleys. One convenience outlet, set on a wall or post, should serve every four pens.

6.48 Swine structures

Farrowing Set lighting outlets over every other pen partition or at 3-m intervals over the center line of the farrowing crates. One lighting outlet should be provided for each 10 m^2 of feed, isolation, and wash areas.

Provide one convenience outlet over the creep area of each pen or farrowing crate, or one duplex outlet centered over the partition dividing two adjacent creep areas. For pens with the creep area at the head, an additional convenience outlet should be provided over the rear of the pen. Install one convenience outlet on the inside wall at each main entrance and one near the wash area.

Weanling Install one lighting outlet over every other pen partition or at 3-m intervals over the center line of the weanling pens. One duplex convenience outlet should be provided over the partition dividing two adjacent pens. Provide one convenience outlet on the inside wall at each main entrance.

Breeding and gestation area Place one lighting outlet over every other pen partition or at 3-m centers along the center line of breeding, boar, and gestation pens. For gestation stalls, install one lighting outlet every 3 m over each row of stalls. Install one convenience outlet for every four pens or every 8–10 gestation stalls, and one on the inside wall at each main entrance.

Hog finishing Provide one lighting outlet for every two pens or 20 m^2 of floor area, and one for each 10 m^2 of feed-preparation area and isolation area. Provide one convenience outlet on the inside wall beside each main entrance and one for heat lamps in the isolation area.

6.49 Poultry structures

Laying houses If the birds are on litter, slats, or wire, install ceiling light outlets in rows every 3.6 m on center, but with lights in adjacent rows staggered by 1.8 m. In addition, provide a 10-W dimlight outlet for each 40 m^2 of floor area. These outlets should be on a separate circuit, set in a row slightly behind the bright-light outlets toward the roosts. Both types of outlet should be controlled by wall switches and timers.

If the birds are in cages, provide lighting outlets along the center of the aisles every 3.6 m (between double-tier cages) or every 3 m (between triple-tier cages). All outlets should be controlled by wall switches and a timer. One lighting outlet should be provided for every 10 m^2 of feed and preparation area.

For floor housing, provide convenience outlets at 30-m intervals around the building's perimeter and beside each main entrance. For cage housing, provide convenience outlets over each alley at 30-m intervals.

Special-purpose outlets should be provided for mechanized systems such as feed conveying and automatic feeding, pit or gutter cleaners, and egg-gathering systems. An outlet may be required for a water heater.

Brooder houses In brooder houses, lighting outlets should be spaced every 3.6 m in rows 3.6 m apart. Lights in adjacent rows should be staggered by 1.8 m. For variable lighting levels, install a solid-state dimmer control in addition to wall switches and a timer.

In housing for starter pullets, lighting outlets should be spaced 3.6 m apart in rows 3.6 m apart. Lights in adjacent rows should be staggered 1.8 m. For cage brooding, the rows of lights should be along aisles. Lights should be controlled by wall switches and a timer. For variable lighting levels, install a dimmer in addition to wall switches and a timer. Provide one lighting outlet for each 10 m^2 of feed room and service area.

For floor brooding, put convenience outlets at 30-m intervals around the building's perimeter and beside the main entrances and loading doors. For cage brooding, set convenience outlets over each alley at 30-m intervals.

Egg storage and handling rooms Allow one lighting outlet for every 10 m^2 of floor area. Install two incandescent or one fluorescent light fixture over each work area. Egg candlers, washers, graders, conveyors, vacuum pumps, and refrigeration and heating equipment will need special-purpose and convenience outlets. Provide one outlet for each electric water heater.

6.50 Structures for small animals

Set lighting outlets every 3.6 m along feed passages. One lighting outlet should be provided for every 10 m^2 of floor area in feed preparation and utility areas. Locate a convenience outlet beside each main entrance and over every passageway at 30-m intervals.

6.51 Field crop structures

Feed-grinding rooms Install one lighting outlet for every 10 m^2 of floor area and over work areas where required. Feed grinders and mixers need special-purpose outlets. In the feed room, all motors should be the totally enclosed type. Light fixtures and switches should be dustproof. This precaution is a minimum; some electrical inspection authorities may require Class II, Group G motors, light fixtures, and switches in feed-grinding rooms.

Grain and feed storage Provide one lighting outlet for every 40 m^2 of floor area. Use dustproof fixtures; switches should also be dustproof unless they are mounted ouside the room. Provide convenience outlets for grain aerators, augers, and elevators as required, and remember that corn or grain driers or elevators require special-purpose outlets.

Mow areas Provide a lighting outlet for every 100 m^2 of floor area. Light fixtures should be dustproof. Set the lighting outlets near the roof peak so that hay chutes and ladders are well lit. Locate convenience outlets beside each main doorway and each filling door for use with elevators. Special-purpose outlets are needed for equipment such as hay dryers.

Silos Install two light outlets, one inside the silo and the other at the top of the chute. Set the wall switch at the foot of the chute or at the entrance to the tunnel leading to the chute. Lighting outlets should be placed so that they can be reached from the top of the chute ladder for cleaning the fixtures and replacing bulbs. You may need a convenience outlet for self-unloading wagons.

For information on silo unloaders and their electrical requirements, see Section 6.38, above.

6.52 Fruit and vegetable structures

Fruit and vegetable storage Because of the high humidity in these structures, all electrical service must resist moisture and corrosion. Fixtures, outlets, and conduits should be surface mounted.

Provide one lighting outlet for every 30 m^2 of floor area, except in bulk storages where lighting outlets with reflectors should be set every 5–8 m over alleyways. Supplemental tasks and equipment will need convenience lighting. Bulk storages usually require special-purpopse 220-V outlets along bins or storage walls for operating equipment for piling and handling.

Grading, washing, and packing rooms need both general and special lighting services. For room lighting, provide one outlet for every 10 m^2 of floor area. Grading tables or conveyors require more intense light; they should have rows of fluorescent lights over each unit or individual outlets every 1.5 m. Lights may be permanently installed or mounted on the machinery; they should be controlled by individual switches.

Machinery for grading and handling may require 230-V or 3-phase power.

6.53 Greenhouses

For lighting outlets, provide

- one lighting outlet for every 5 m through the center of the greenhouse
- one lighting outlet over each work bench in the head house, with a minimum of one lighting outlet for every 1.5 m of work bench
- one or more lighting outlets for the boiler room.

Special-purpose circuits for soil heating, pasteurization, and sterilization should be installed where required. Provide convenience outlets for portable spray pumps.

6.54 Farm workshops and machinery storages

Farm workshops Provide one lighting outlet for every 20 m^2 of floor area and one for each permanently placed piece of equipment, or at least one for each 3 m of bench length. Install one convenience outlet for each 1.5 m of bench length. At least one convenience outlet should be near the doorway. It should be weatherproof if it is outdoors.

Provide special-purpose 230-V outlets for space heaters and arc welders. One special-purpose circuit should be provided for each permanent piece of equipment. Consult local power supply authorities about the installation of large electric welders.

Machinery sheds One lighting outlet should be provided for every 40 m^2 of floor area. Convenience outlets for use with trouble lamps, portable drills, and similar equipment should be located on the walls 1.5 m above the floor at 12-m intervals. If you plan to start up equipment regularly during the winter, you will need engine-block heaters; these use standard 115-V grounded outlets.

6.55 WATER SUPPLY

Finding a satisfactory water supply at the site should precede any other planning, since without it the enterprise cannot succeed.

6.56 QUALITY

Water may come from a municipal water supply system, deep well, shallow well, pond, or spring, provided that the source provides water of satisfactory quality as determined by local health authorities. If you use surface water (pond or spring), or if testing the water shows contamination, you must provide adequate facilities for treatment. Treated water should be tested at regular intervals. Take precautions to avoid water contamination.

6.57 QUANTITY

A good-quality water source must provide an adequate supply for animals and all other necessary purposes. As a guideline, animal daily requirements must often be met in two 1-h periods. For water requirements for animals, see Part 2 of this book. Consult similar farm operations or use your own experience to determine your water needs for other purposes. This guideline will help you to determine pumping rate or storage capacity.

6.58 WATER FOR FIRE PROTECTION

Water from any source accessible to fire pumpers may be used for fire protection. Firefighting equipment requires a storage supply with a minimum capacity of 20 000 L; this supply must be readily accessible and no more than 150 m from major farm structures. Farm pumps for controlling the spread of fire between buildings should have a minimum capacity of 20 L/min at 200 kPa pressure. If these pumps are intended to extinguish fires, the minimum capacity should be 60 L/min at 350 kPa pressure.

Electric motors on farm fire pumps should be supplied by an electrical service independent of all buildings.

6.59 SOURCES

6.60 Wells

Wells must be safe from pollution. Drilled wells should have a casing of watertight material, effectively sealed against pollution for a minimum distance of 30 mm above grade and 3 m below grade; they should also be equipped with a sanitary well cap. Dug wells should have a tight-fitting impervious cover and a watertight casing extending at least 3 m below and 300 mm above grade. They should be located and graded so as to divert surface water.

After construction or repair, wells should be pumped until the water runs clear, and then disinfected.

6.61 Springs

Springs may be used as a source of water, but special precautions should be taken to avoid contamination. Provide fencing to exclude animals, and protect the spring by a surface diversion ditch or mound and a box of durable, nontoxic material such as concrete or galvanized metal, or other suitable material. The box should have a tight-fitting cover.

6.62 Surface sources

If it is to be drunk by humans or animals, water from a surface source (spring, pond, or stream) must be treated. Consult your local health authorities. If possible, provide fencing around sources of open surface water to minimize contamination by animals and to prevent accidental drownings.

6.63 HOT WATER FOR FEEDING AND CLEANING

Many farm buildings require hot water for feeding, cleaning, and sanitizing. Water heaters should heat a sufficient quantity of water to the preferred temperature at a rate that ensures total recovery before the next demand for hot water.

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