INSULATION IN FARM BUILDINGS

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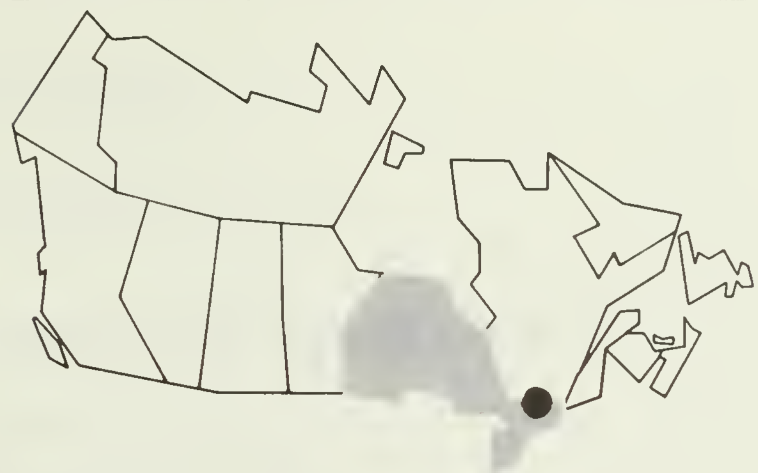

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INSULATION IN FARM BUILDINGS

Insulation has become an important component in modern livestock and poultry buildings. It is indispensible in the construction of fruit, vegetable and frozen food storages.

WHY USE INSULATION?

Insulation is used in buildings for some or all of the following reasons:

- to reduce heat loss in winter (or heat gain, in summer)
- to reduce condensation
- to provide fire resistance (fire walls, etc.)

Heat loss

The main reason for insulation is to reduce heat loss from a building. A well-insulated livestock building may need little or no supplementary heat over and above that given off by the livestock themselves.

Insulation reduces heat loss caused by conduction, convection, radiation, and air leakage.

Conduction of heat occurs when heat passes by contact from particle to particle. Lightweight materials such as air and insulation conduct much less heat than heavy materials such as metals.

Convection losses occur when cool circulating air moves in a confined space (such as within a stud wall), picking up heat as it rises in contact with a warm surface and then losing the heat as it sinks over a cool surface. Filling the space with insulation minimizes air movement.

Radiation losses occur when heat energy is transmitted directly across an open space. Air transfers radiant energy, but insulative materials and reflective surfaces block it significantly.

Air leakage heat loss is mostly caused by wind that blows cold air into the windward side of a building and draws a corresponding amount of warm air out through the leeward side. Tight construction, using a tightly sealed vapor barrier near the interior wall surfaces and vapor-breathing wind-stop materials near the outside, minimizes air leakage losses.

Condensation

Condensation, and the building deterioration it causes, can be a much greater problem on interior walls and ceilings of livestock buildings than in houses. This is because of the much higher relative humidity and often lower inside temperatures. Water from the humid room air condenses on the cool wall and ceiling surfaces. If these surfaces are kept warm by using enough insulation, the air that contacts them is kept above the dew point and no wetting occurs.

Figure 1 illustrates how a poorly insulated wall (such as plain concrete block) has a wet interior surface, while a well-insulated frame wall is warm and dry. Note that the inside and outside air temperatures and humidities are the same for both walls. However, the interior surface of the poorly insulated concrete block (at 1°C) is much cooler than the dew point temperature (10.5°C) of the moist room air. On the other hand, the interior surface of the well-insulated frame wall is only slightly cooler than the room air (13°C, versus 15°C). This is warmer than the dew point, and no condensation occurs.

TYPES OF INSULATION

Insulation materials

Fibrous blanket insulation

Mineral wool and glass fiber Both of these materials are relatively low in cost, fire-resistant, and very effective in reducing heat flow. They are packaged as blankets that are either stacked or rolled, depending on thickness.

Blankets are made in widths to fit between typical wood framing, spaced 400-600 mm on center. This is an important consideration in the construction of farm building frames where insulation may be installed either at the time of construction or added later.

Blanket insulation may be paper-wrapped, often with one paper surface sealed to provide a built-in vapor barrier. Be careful to install the blanket with the vapor barrier surface facing the warmer side of the wall or ceiling. Because this sealed paper is discontinuous and easily damaged by rodents, an additional vapor barrier such as polyethylene film is usually recommended.

'Friction-fit' insulation is an improved form of glass fiber blanket insulation. It is more elastic and has an improved binder that eliminates the need for a paper cover. Friction-fit insulation fits the spaces between the studs and joists better than the older paper-wrapped materials, and has less tendency to sag out of position. It usually comes without an integral vapor barrier.

Loose-fill insulation

Loose mineral wool Mineral wool insulation can be purchased loose, packaged in paper bags. It costs more per square metre than the blankets; its only advantage is that it can be poured or blown into awkward horizontal spaces such as attics where blanket material would be difficult to install.

Vermiculite Vermiculite is a mineral (mica) that has been expanded (like popcorn) into a lightweight granular insulation. It pours into confined spaces better than loose mineral wool. It is sometimes used to fill the spaces within light-

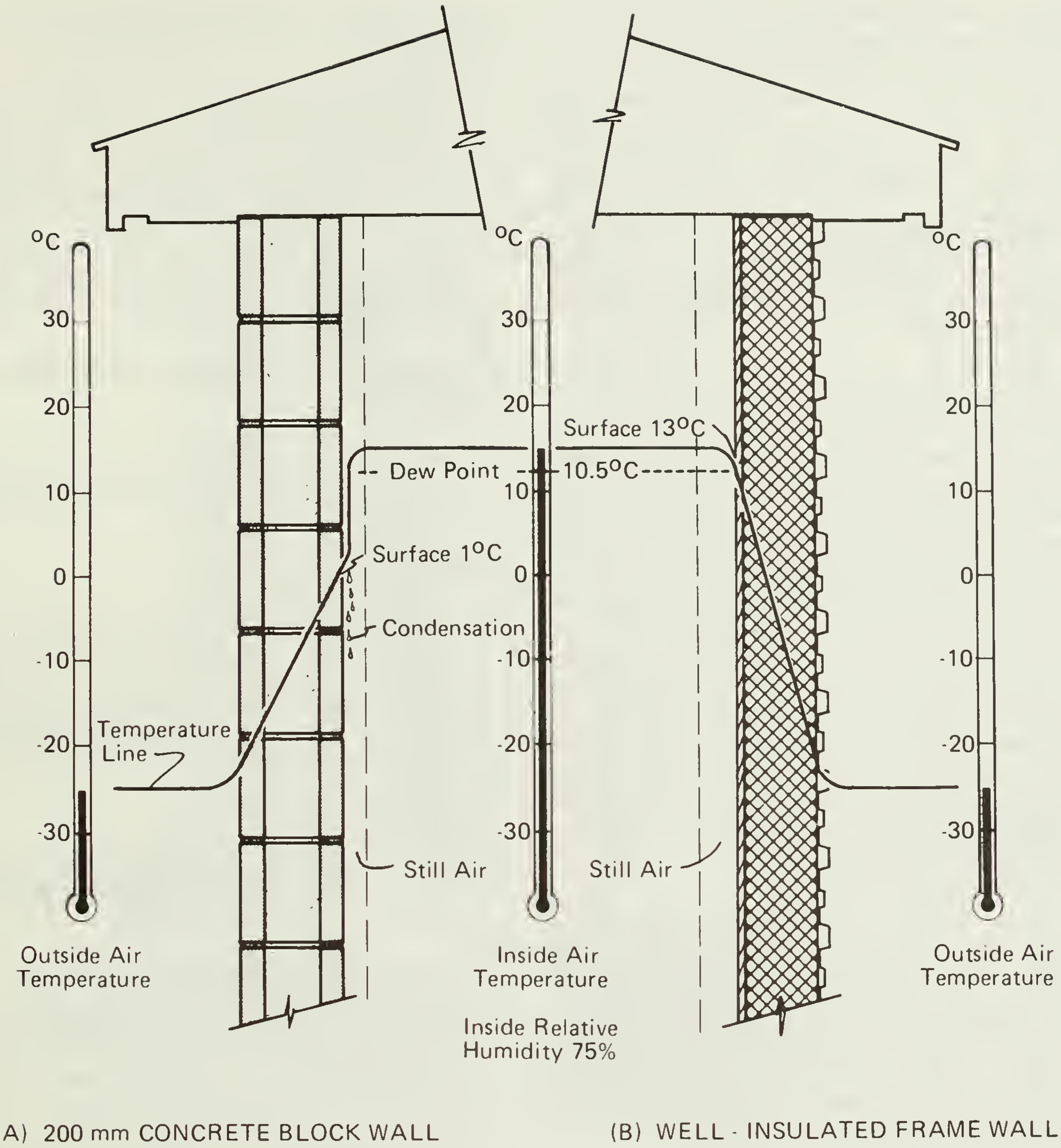


Fig. 1. Preventing wall surface condensation with well - insulated construction.

aggregate concrete blocks to increase the insulation value of concrete masonry walls.

Cellulose fiber Macerated wood pulp or newsprint paper makes a good loose-fill insulation provided it is treated with fire-retardant chemicals. Some treated cellulose fiber insulations in contact with moisture have been blamed for corrosion of electric wiring and lighting fixtures.

Pulverized polystyrene plastic foam Scraps and cuttings from the manufacture of rigid plastic foam can be granulated for loose-fill insulation. In wet situations, this material probably absorbs less moisture than other loose-fill insulations.

Rigid plastic foam insulation

Polystyrene foam This plastic foam is produced as either 'beadboard' or 'extruded' insulation board. The beadboard is made by expanding polystyrene plastic beads in a mold, forming slabs about 1200 × 2400 mm. After hardening, the slabs are sliced with a hot wire into sheets from 13 to 100 mm thick. Beadboard can be used in contact with dry soil, such as under light-duty concrete floors (farrowing creeps, for example) and for foundation perimeter insulation provided it is protected from weather and rodents (see Figure 2).

The extruded polystyrene board is a denser product formed by continuous foaming and extrusion. It can have smooth waterproof skin, or can be recut to give a cellular surface texture for use as a plaster base. Extruded polystyrene has better resistance than beadboard to both water and water vapor, making it superior in wet locations. A typical application is in making adjustable air inlet flaps for ventilating livestock barns. It is frequently used to support and insulate under concrete floors that receive heavier loads, such as tractors and forklifts.

Polyurethane foam Polyurethane foam can be made into rigid sheets in the same way as polystyrene foam, or it can be foamed in place to insulate cavity-wall construction. Its other uses include prefabricated 'sandwich' panels for buildings and in manufactured articles such as refrigerators. On farms, contractors using special equipment usually spray the raw foam onto surfaces to be insulated. The foam 'froths up' and hardens rapidly, then continues to expand very slowly as it ages. This is the reverse of polystyrene, which shrinks slightly on aging. Because polyurethane can be sprayed over cracks and irregularities to provide a continuous layer, and because it expands on aging to maintain this layer, it can produce an airtight seal. This is especially advantageous in controlled atmosphere food storages where a gas seal is required in addition to insulation.

Polyurethane foam is structurally similar to polystyrene foam except that the foamed bubbles are filled with freon instead of air. Since freon is a better insulator than air, polyurethane foam has a greater resistance to heat flow. However, it costs more. The insulation value of new polyurethane foam is greater than that shown in Table 1 (see Appendix) but, as the freon gas gradually escapes, the value declines.

Polyurethane and some grades of polystyrene insulation present a special FIRE HAZARD when left exposed and unprotected (see section on fire protection).

Urea formaldehyde foam Urea formaldehyde foam is produced from a urea formaldehyde resin put under air pressure with a foaming agent. It can be injected into difficult or inaccessible locations. It is light in weight, with a standard density of 11 kg/m^3. While curing, it shrinks as much as 3% by volume in the first year, with the shrinkage continuing for an indefinite period. This causes cracks and voids to appear in the insulation; consequently, a Canadian Government Specification Board standard has derated U.F. foam to 60% of its laboratory-tested RSI value. There is also the possibility of slow release of formaldehyde gas.

Comparing insulation values

Most insulations have been tested in laboratories to determine their relative insulation capabilities (RSI values). The larger the RSI value per unit of thickness, the better the insulation.

In Table 1 (see Appendix), the RSI values of various insulating materials are listed. An approximate cost is also given for most insulations, as is the cost per RSI unit. The latter indicates the comparative cost in relation to effectiveness of insulation. It is determined by dividing the RSI value at the thickness listed into the material cost. For example, for RSI 2.3 batt insulation, the cost per unit of RSI value = \$1.66/2.3 = \$0.72/(m^2·RSI).

HOW MUCH INSULATION SHOULD BE USED?

Several factors influence how much insulation you should install in the ceiling, walls and perimeter of a farm building.

Wall thickness

In many building walls, the stud space between inner and outer cladding limits the amount of insulation. Most conventional stud-frame and pole-frame farm buildings are now built using members sawn and dressed to 140 mm, which usually leaves enough space for insulation.

Ceilings

Ceiling insulation in truss-roofed buildings (Figures 2 and 3) can be increased beyond 140 mm if desired.

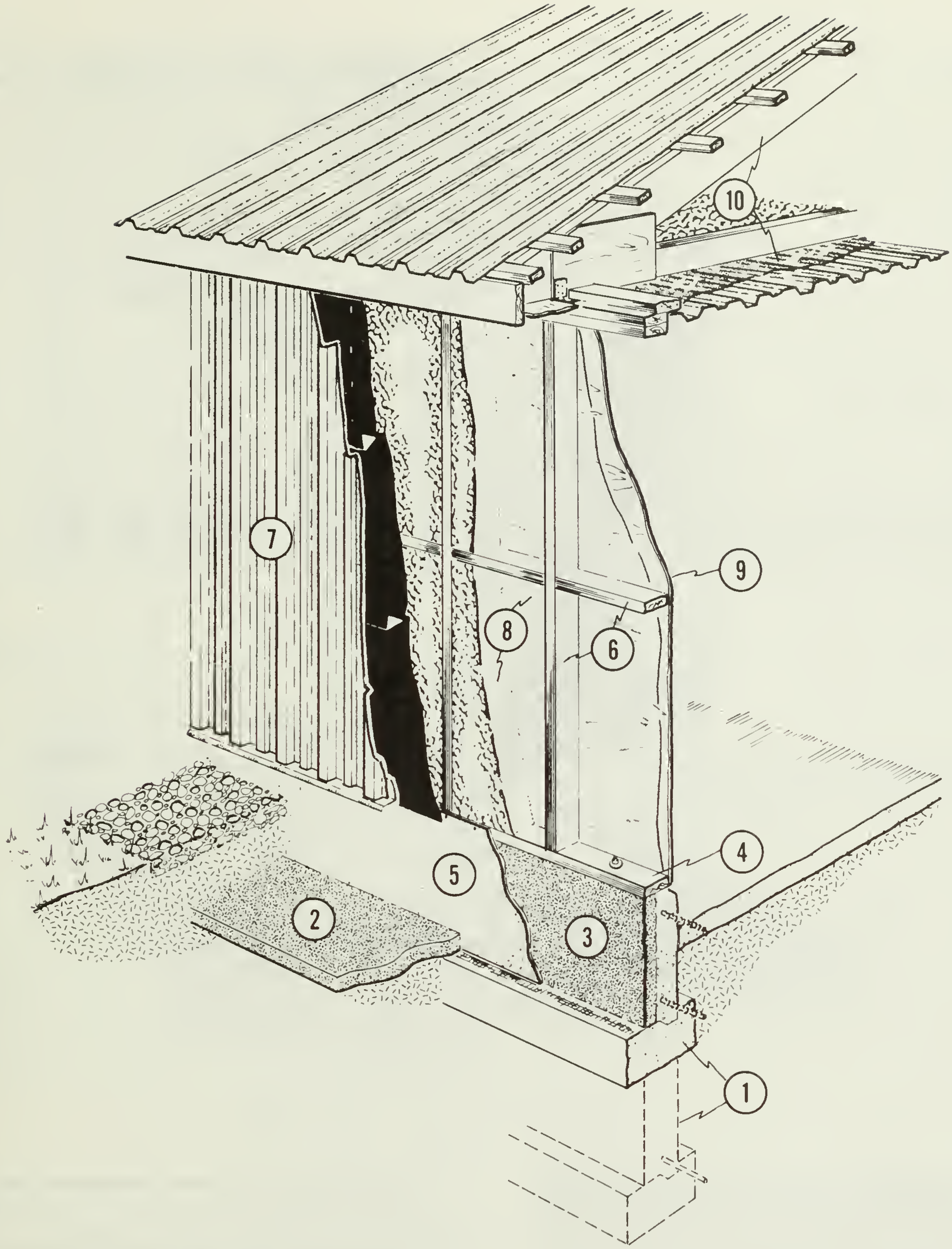
Foundation perimeter

This part of the building is most often overlooked when insulation is being installed. In new buildings, it's best to tack a strip of polystyrene (either bedboard or recut extruded type) to the inside face of the outside concrete forms, using finishing nails. When the concrete is poured, it bonds with the face of the polystyrene, so that the nails pull easily through the insulation when the forms are stripped.

This leaves the insulation board bonded into the outside face of the foundation, where it is most effective at controlling heat loss and temperature changes in the concrete. An outside covering of high-density asbestos board, or stucco-lath and cement plaster, protects the insulation from weathering and rodent damage (see Figure 2).

Condensation

Always install enough insulation in walls and ceiling to control condensation on the interior cladding, even if this is more than you need to maintain a heat balance (when heat produced in the building equals heat lost from all sources, such as ventilation, ceiling, walls, doors, windows, perimeter and floor). The heat produced can come from livestock, respiration of stored fruits and vegetables, or a heating system.



(1) deep or shallow footing, below frost

(2) 50 x 600 mm extruded polystyrene horizontal perimeter insulation (required with shallow footing in cold climates)

(3) 50 x 550 mm extruded polystyrene perimeter insulation, tack to concrete forms with finishing nails before placing concrete

(4) 38 x 140 mm CCA-pressure-treated sill, anchor bolts @ 1200 mm oc

(5) 5 x 600 mm high-density asbestos cement board, drill and screw to (4)

(6) 38 x 140 mm studs @ 600 mm oc, blocking and top plates to match

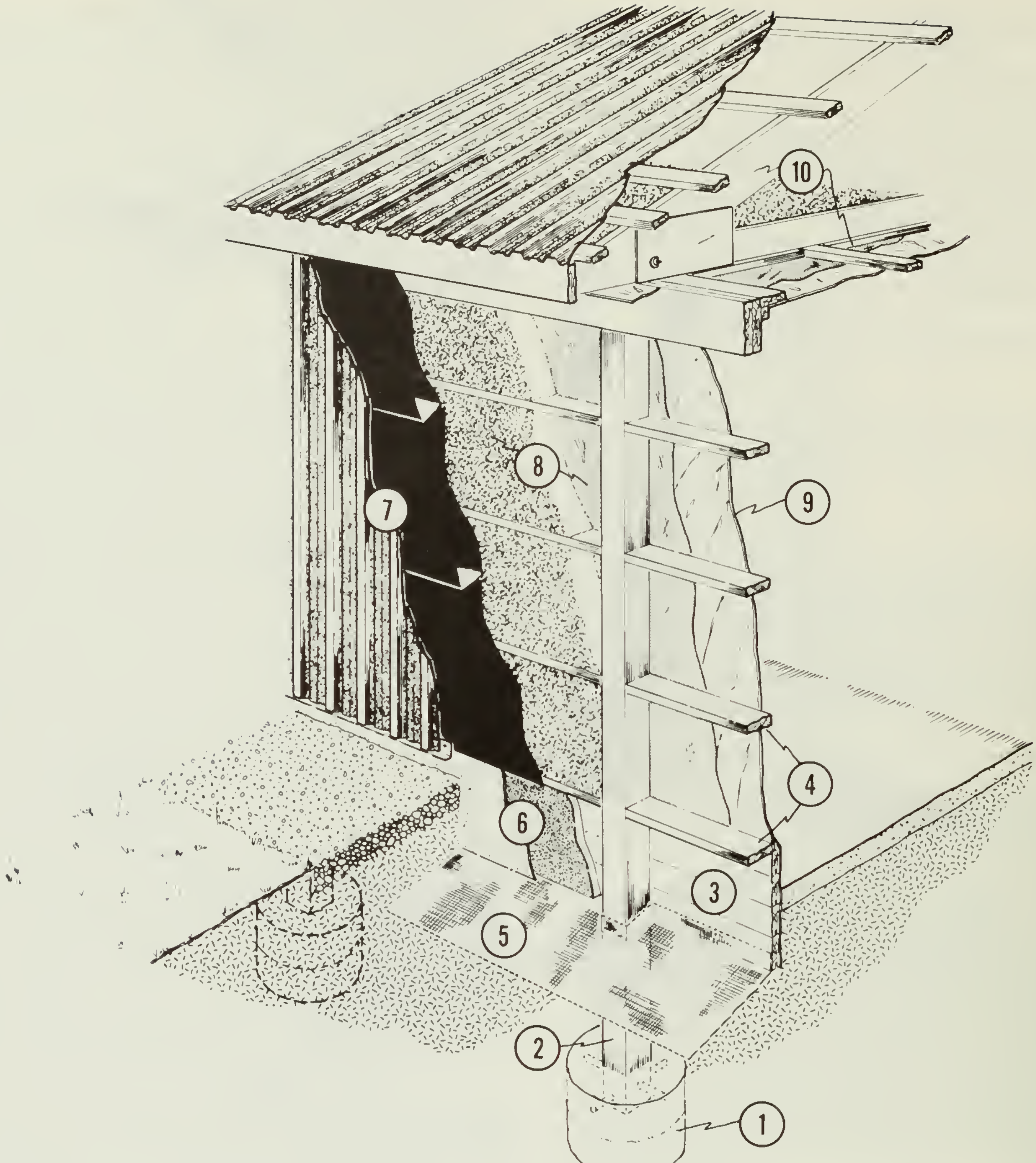
(7) asphalt felt wind-stop, vertical or horizontal exterior steel siding screwed to (6)

(8) 140 mm (RSI-3.5) friction-fit glass-fiber insulation, polyethylene vapor barrier

(9) interior cladding (horizontal plywood, etc.)

(10) roof trusses, polyethylene vapor barrier, steel diaphragm ceiling, insulation RSI-3.5 (minimum)

Fig. 2. Insulated stud-frame wall construction (from Canada Plan Service, plan M-9324).



(1) concrete footing and anchor plug, 750 mm diam. min., below frost

(2) 140 x 140 x 4200 mm CCA-pressure-treated poles @ 2400 mm oc, steel pins to (1)

(3) 38 x 140 x 4800 mm CCA-pressure-treated tongue and groove splash planking, top plank rabbetted for (9)

(4) 38 x 140 mm wall girts toe-nailed between poles @ 600 mm oc, bottom girt pressure-treated

(5) 12 x 12 mm galv. hardware cloth rodent stop

(6) optional perimeter insulation; 50 x 600 mm extruded polystyrene, 5 mm high-density asbestos board cover, between poles

(7) asphalt felt wind-stop, vertical exterior steel siding screwed to (4)

(8) 140 mm (RSI-3.5) friction-fit glass-fiber insulation, polyethylene vapor barrier

(9) interior cladding (vertical plywood, etc.)

(10) roof trusses, bolt to pole (2), and bear on plate beam notched into poles

Fig. 3. Insulated pole-frame wall construction (from Canada Plan Service, plan M-9314).

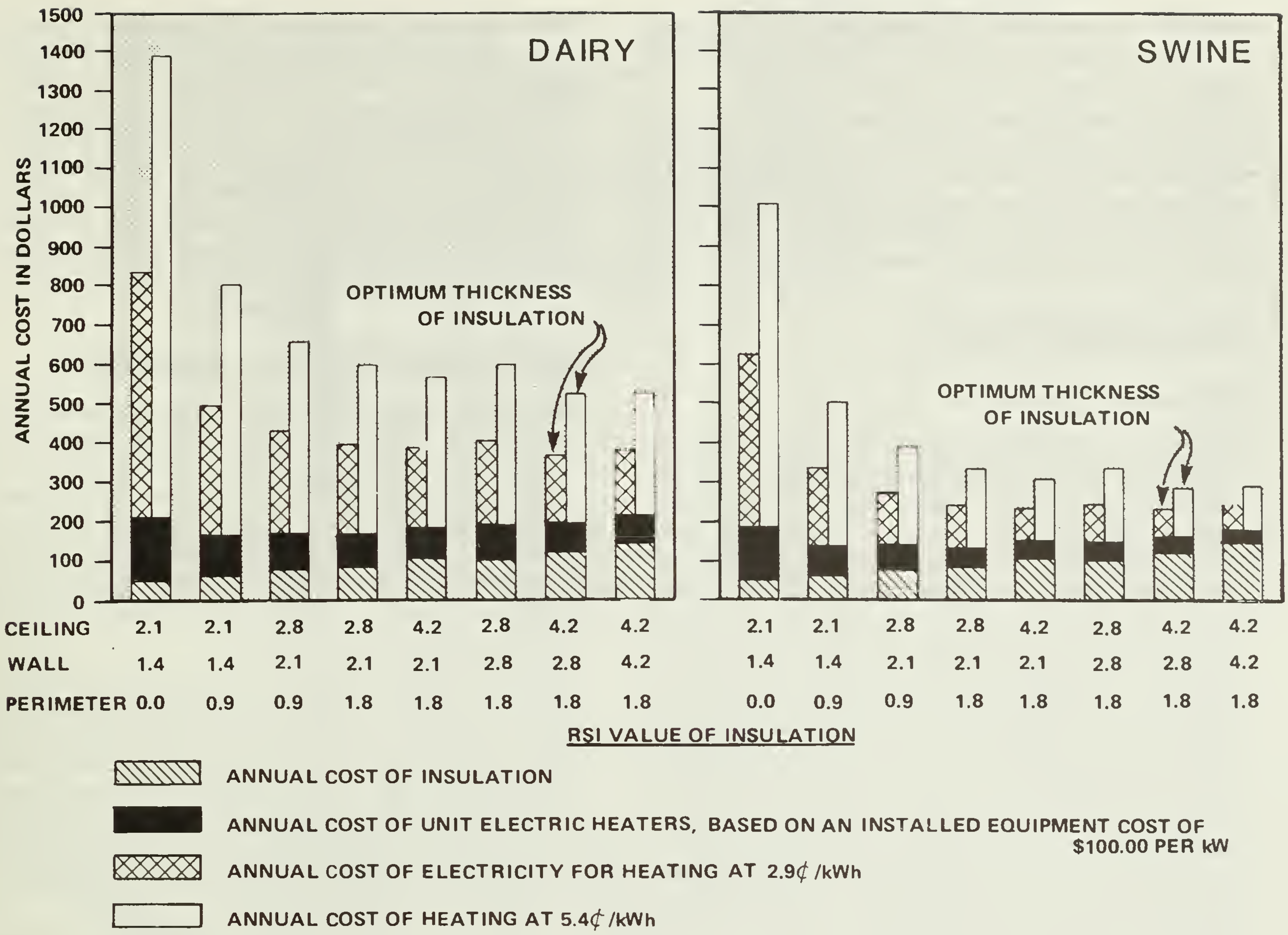


Fig. 4 Annual insulation, heating system and electrical resistance heat cost vs amount of insulation based on a typical Saskatoon winter and a metal-clad stud wall building 10.8 x 28.8 x 2.4 m built like Figure 2, housing 42 dairy cows of 540 kg average weight at 13°C, or 420 market pigs of 57 kg at 18°C.

Minimum annual cost

Many insulated farm buildings, especially in colder parts of Canada, need a supplementary heating system. This maintains inside temperature when outside temperatures drop so low the livestock or stored product cannot produce enough heat to equal heat losses. In this situation, you have to decide how much insulation will result in the least annual total cost for the insulation plus heating equipment and heating energy. When determining the cost of thicker insulation, include the cost of the extra framing depth sometimes required to make space. Although the insulation and heating equipment costs are part of the initial cost of the construction, amortize them over the life of the building to arrive at an annual figure.

Figure 4 shows how annual insulation, heating system and electric heating costs vary with insulation thickness for a typical farm building. Examples are given for dairy cow and finishing hog structures. Notice that the total costs dip to a minimum for the best amount of insulation and tend to increase for greater or lesser amounts. In both examples, with electrical energy priced at 2.9¢/kWh, the best results are when ceiling insulation is RSI 4.2, walls are 2.8 and foundation perimeter is 1.8 (50 mm thick polystyrene).

If heat energy costs continue to increase, a well-insulated building becomes even more important. Increasing the energy cost to 5.4¢/kWh (white bars) makes a poorly insulated building much more costly to operate. Note, however, that there is no real benefit in increasing the wall insulation from RSI 2.8 to RSI 4.2, since 140 mm wall studs as shown in Figure 2 would no longer be deep enough to provide insulation space.

Notice also from Figure 4 that the capital cost saving in using less insulation is significantly offset by the added cost of the electrical heating system. This may not be as true with other heating systems, such as those fired with natural gas, oil or propane, where a large system would cost less per unit of capacity than a small one.

INSULATION IN USE

Method of installation

Figures 2 and 3 show typical installations of insulation in two common types of farm building construction. Figure 2 uses 50 mm rigid polystyrene cast into the concrete foundation wall and protected by cement-asbestos board. Friction-fit batts are placed between 38 × 140 mm studs in the walls and between the roof trusses at the ceiling. The pole-frame wall shown in Figure 3 uses CCA pressure-treated, tongue-and-groove planking at the base. The polystyrene perimeter insulation and asbestos board cover ⑥ is optional, since wood is considerably 'warmer' than concrete. However, it is probably worth the extra cost where the winter is very cold or where the building is to be kept quite warm (for example, farrowing or poultry brooding rooms). In the upper part of the pole-frame wall, friction-fit batts are fitted lengthwise between 38 × 140 mm girts, which are placed horizontally between sawn poles and spaced vertically 600 mm on center. The poles are usually spaced 2400 mm on center.

For fruits and vegetables, insulated pallet storages may be pole-frame or stud-wall and insulated with batts (see section on vapor barriers), polystyrene or polyurethane.

If the storage is to be a controlled atmosphere unit, foam polyurethane directly on the wall and ceiling at the site. This provides both insulation and a gas seal. Walls may be stud-frame, pole-frame, or concrete block. Frameless steel arch construction is also popular, but foaming directly on the metal introduces the possibility of moisture buildup in the insulation and resulting adhesion failure.

Whenever polyurethane is exposed, cover it with a fire-protective finish, being sure to provide a good seal around light fixtures, doors, and at the floor, etc. The National Building Code of Canada requires a 15-minute fire protection. Where the Canadian Farm Building Code (1983) applies, this protection may consist of a liner of plywood or galvanized steel, with no air space allowed between the liner and the insulation. The easiest way to achieve this is to spray the polyurethane onto the *outside* face of the *inside* cladding ('inside-out construction', described later).

Bulk vegetable storages must have strong walls framed with wide studs spaced to resist the pressure of the product heaped against the walls. These may be insulated with batts, polystyrene board or sprayed urethane foam. If the storage is not refrigerated, the storage temperature will seldom be lower than outdoors, so the insulation can be economical glass fiber batts with an inside vapor barrier as shown in Figure 5. See Agriculture Canada publication 1508 for further information on bulk potato storage.

Roof insulation in cold livestock barns

Naturally ventilated barns for cattle and sheep do not have to be kept warm all winter, but a little insulation is needed under the roofing steel. Otherwise, frost will accumulate here during cold winter nights. During the night there is no problem, but in the morning the sunshine on the roof melts the frost. Annoying moisture then wets the barn framing and drips from the rafters onto the livestock and bedding below.

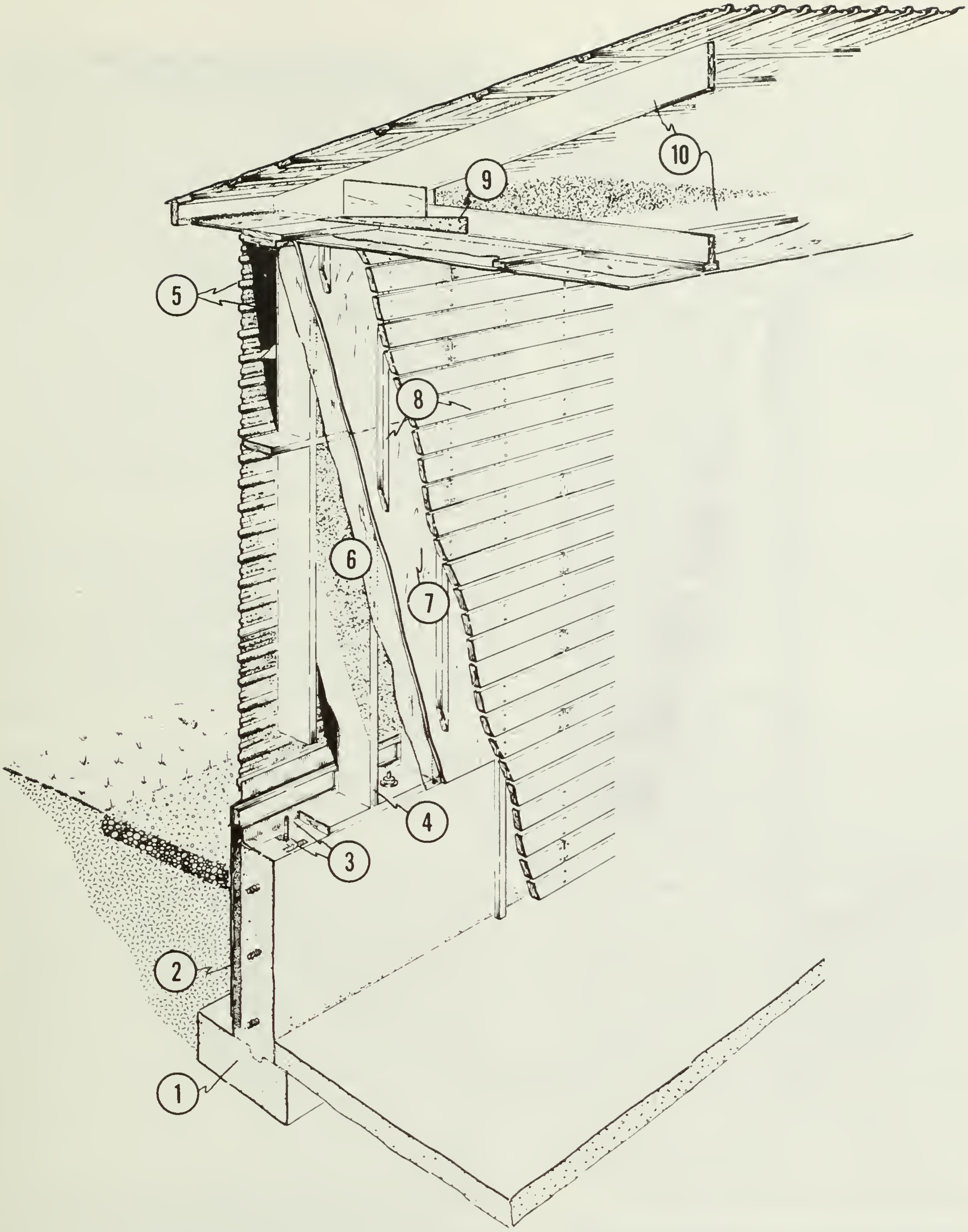
An earlier solution for this was to sandwich a 25 mm layer of polystyrene insulation board between the wood roof purlins and the steel roofing. This nicely solved the morning drip problem, but two serious difficulties remained. Birds pecked large holes in the soft polystyrene wherever they could find a perch, and the exposed plastic foam created an extreme fire hazard. This solution is not recommended.

A safer and more durable solution to the morning drip problem is to use inexpensive exterior plywood sheathing under the steel. If more insulation is required, an insulated, prefabricated roof sandwich construction has been developed by the Canada Plan Service (see plan M-9302). This consists of plywood ceiling, vapor barrier, wood roof purlins on edge, glass fiber insulation between the purlins, and finally, the steel roofing.

Vapor barriers

Insulation is used to maintain the greatest possible temperature difference between inside and outside building surfaces. Warm air normally contains much more moisture (by weight) than cold air, causing a vapor pressure difference. Moisture tends to push through the building materials from the warm side to the cold side, condensing out at any location in the insulation where the temperature gets low enough to reach dew point. Blanket and batt insulations, when wet, have less insulation value and tend to sag from the weight. Even plastic foam insulation can absorb some water and lose insulation value.

To minimize wetting in insulation, install a vapor barrier on the warm side. The vapor barrier can be 0.1 mm (4 mil) clear polyethylene or paper-reinforced aluminum foil. Use large rolls to



① footing and foundation to below frost, reinforced for soil and storage pressures

② 50 x 1 200 mm extruded polystrene perimeter insulation, tack to forms with finishing nails before placing concrete

③ steel angle and anchor bolts hold sill and studs against storage pressures

④ 38 mm studs, width and spacing depend on storage depth

⑤ asphalt felt wind-stop, vertical or horizontal exterior steel siding screwed to ④

⑥ friction-fit glass-fiber insulation, polyethylene vapor barrier

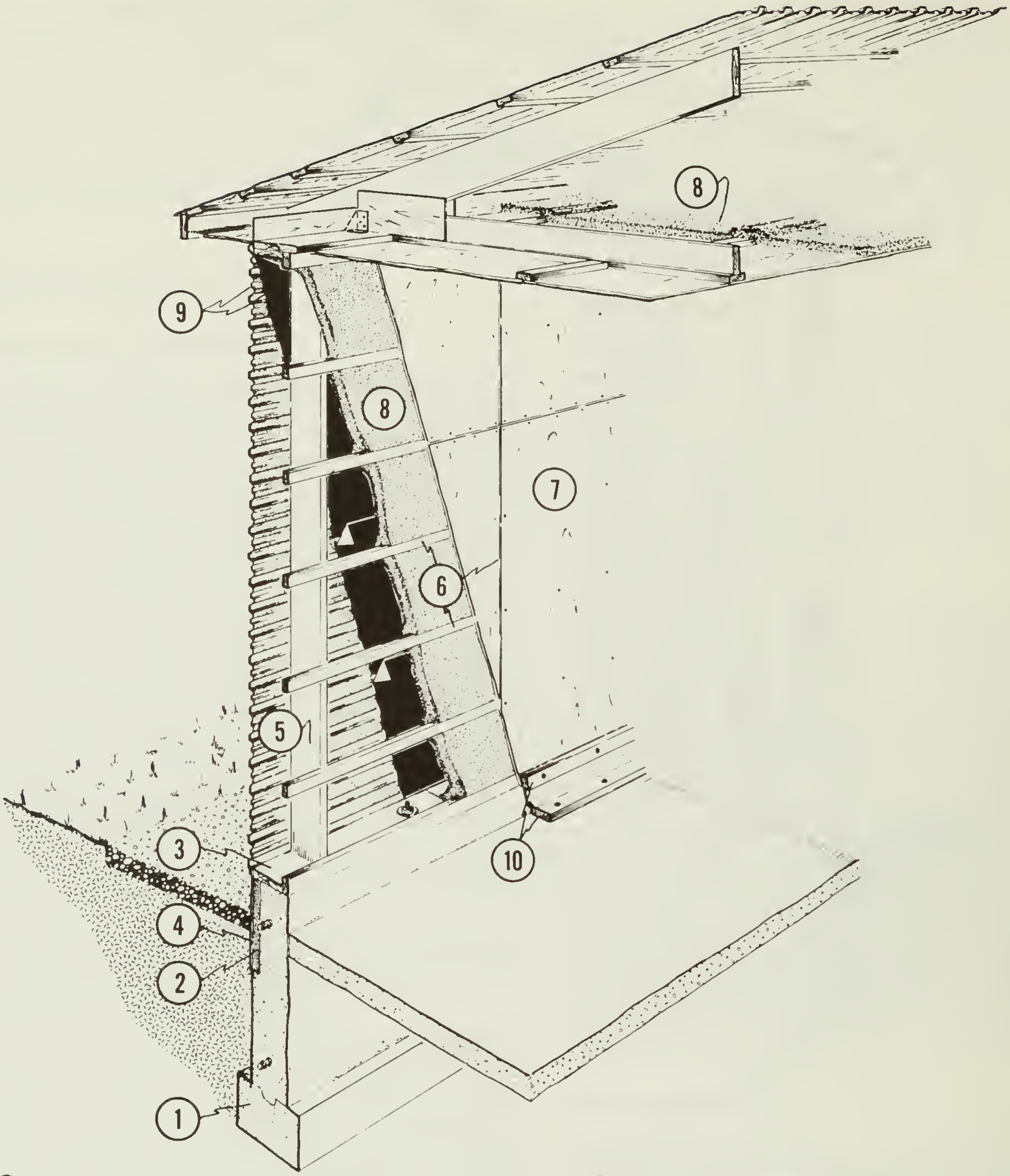
⑦ 7.5 mm 'exterior sheathing' softwood plywood

⑧ 38 x 38 mm strapping and 19 mm spaced boarding separates product from cool, wet wall

⑨ galv. steel anchor straps tie wall to trusses to resist product pressures

⑩ roof trusses, polyethylene vapor barrier, plywood diaphragm ceiling, insulation RSI-3.5 (minimum)

Fig. 5. Typical wood stud-wall construction for bulk vegetable storage (from Canada Plan Service, plan M-6110).



(1) concrete footing and foundation, to below frost

(2) 50 x 550 mm extruded polystyrene perimeter insulation, tack with finishing nails to concrete forms before placing concrete

(3) 38 mm pressure-treated sill, anchor bolts @ 1 200 mm oc

(4) 5 x 600 mm high-density asbestos cement board, drill and screw to edge of (3)

(5) 38 mm studs @ 1 200 mm oc, stud width depends on wall height and design wind pressure

(6) 38 x 64 mm strapping @ 600 mm oc

(7) 11 mm medium-density overlaid fir plywood interior cladding, galv. fasteners, joints spaced 2 mm, nails and joints caulked with silicone rubber caulking

(8) 75 mm (min.) polyurethane foam insulation sprayed from outside and attic in good weather

(9) asphalt felt wind-stop, horizontal exterior steel siding screwed to (5)

(10) membrane gas seal, caulked and clamped to floor and wall

Fig. 6. Controlled-atmosphere (CA) storage wall for fruits and vegetables stored in pallet boxes (from Canada Plan Service, plan M-6113).

minimize the number of joints. Staple to hold in place, overlapping at studs or other framework.

The location of the vapor barrier is very important. In warm livestock buildings this is on the inside; in frozen food 'cold' storages, place the vapor barrier on the outside.

There is a special problem in refrigerated 'cool' storages used for fruits and vegetables. These are held at 0° to 7°C, and the outside temperature can be colder than the storage in winter but considerably warmer in summer. In this situation it is difficult to decide where the vapor barrier should go. It should not be placed on both sides of the insulation because moisture could be trapped between the two barriers. The best rule is to place the vapor barrier on whichever is the 'warm' side when the temperature difference through the insulation is greatest for a considerable part of the year.

For example: a storage is held all year at 0°C at Brighton, Ontario, where winter design temperature is −22°C, and summer design temperature is +30°C. Since in January the temperature of this storage would be 22°C *above* that outdoors, but in July it could be 30°C *below* the outside temperature, the vapor barrier should be outside the insulation.

A better solution in 'cool' storages is to use one of the more moisture-resistant plastic foam insulations, such as polyurethane, without a vapor barrier.

A special moisture problem exists where polyurethane insulation is sprayed onto the inside of a single-skin steel building to make warm livestock housing or a temperature-controlled winter food storage. The steel building shell then becomes an effective vapor barrier on the cold (wrong) side of the insulation. Water vapor from the livestock or vegetables accumulates all winter in the insulation. This reduces the value of an already expensive (see Table 1) and hazardous insulation, and in extreme cases causes the foam to separate and fall off. A better way is to strap the inside of the building with wood furring strips spaced 600 mm on center, then insulate with batts and line with vapor barrier and sheathing.

A vapor-breathing material (usually asphalt felt) is recommended under the exterior cladding of buildings, particularly where the cladding is sheet metal and where the vapor barrier is on the inside of the insulation. It will help prevent wind-driven rain or cold drafts from penetrating the exterior cladding but will allow any water vapor in the wall spaces to escape.

Fire protection

Polyurethane and polystyrene foams are often used in modern farm buildings in exposed interior applications. However, exposed plastic foams (polyurethane, especially) have contributed to a number of disastrous farm fires. Some formulations of polyurethane foam are highly combustible and will ignite and burn when exposed to a flame or spark. Flames flash over the surface very rapidly, producing dense black toxic smoke and hot gases.

Polystyrene foam melts when exposed to heat, producing drops and pools of molten plastic that can burn if exposed to fire for enough time to drive off the fire retardants.

Many foams now have fire-retardant additives that may prevent burning when the foam is exposed to a match or cigarette. However, an 'experiment' to test such a foam might have disastrous results. Therefore, any foam, even if treated with additive, should be considered combustible and treated as such.

The National Building Code of Canada does not permit exposed plastic foam insulation for the interior surfaces of buildings — it must be covered with an acceptable 'thermal barrier' (such as plywood or galvanized steel) or special fire-resistant coatings.

Inside-out construction

A special case is the use of foamed-in-place polyurethane as a combined insulation and gas seal, for refrigerated and controlled-atmosphere food storages. Here, an improved technique is to build the structure inside-out. The framing is put up and the interior cladding (plywood, or galvanized steel) is applied. The polyurethane is then foamed onto the outside, between the frame members and against the interior cladding. Finally, exterior cladding (usually galvanized steel) is screwed on to protect against weather and rodents. The only disadvantage here is that you need a period of warm, dry weather before and during the insulating operation. If the storage is to be controlled-atmosphere, the interior gas seal cladding is usually medium-density overlaid plywood, with the joints and nail-heads sealed with high-grade caulking such as silicone rubber (see Canada Plan Service plan M-6113).

Porous ceiling ventilation systems

Porous ceiling ventilation systems have been used to reduce problems with cold winter condensation in controlled environment livestock buildings. They are particularly effective in the colder parts of Canada where livestock do not produce enough heat to make conventional ventilation systems work.

From a quarter to two-thirds of the ceiling area can be porous. One design uses a layer of dry loose hay or straw as attic insulation, supported on a ceiling of spaced boards; another supports the exposed part of the ceiling insulation with galvanized chicken wire. As air is drawn by fans into the livestock room from the ventilated attic space, it warms up in passing down through the porous insulation. At the same time, moisture and odors migrate upward through the spaced boards or chicken wire and porous insulation. Moisture that has migrated to the attic is dispersed to the outside by wind passing through the vent slots and doors in the eaves and gables. For the porous ceiling to operate successfully, the attic must be so well ventilated that its atmosphere is almost like outdoors. Keeping fine windblown snow out of the large attic ventilation openings is the most critical problem.

Rodents

Rats and mice must be prevented from damaging perimeter insulation or entering wall cavities and attic space. Most insulations have no food value for rodents but considerable damage can still be done by burrowing, chewing and nesting. The additional cost and effort to rodent-proof farm buildings is justified, in preventing loss of insulation value, increased air leakage, and increased consumption and spoilage of livestock feed.

One way to protect perimeter foundation insulation from rodents is shown in Figure 2. Make sure that interior and exterior claddings are well installed, leaving no openings to the wall and floor, especially at ground level. Install steel flashing along the edges of deep-profile metal wall cladding to prevent rodent access, and leave no exposed edges of wood cladding that rodents can chew to gain access. Be careful to leave no opportunity for rats or mice to reach the attic space from side or end walls. Finally, make sure insulation spaces in walls are blocked with 'rodent-stopping' at intervals no greater than 3 m vertically and 6 m horizontally.

APPENDIX

Calculating RSI values and heat losses for typical farm building construction

The total insulation value (RSI) of a particular construction can be estimated by adding the resistances of all the layers of material, including the air spaces.

The following example shows the calculation of the total RSI value for Figure 2, and may be used as a guide when calculating for similar construction. Note that some insulation value (f_i) is included for the thin film of still air that clings to the inside wall surface. An air film resistance f_o is also included for the outside, but its resistance is less than f_i because of the sweeping effect of the wind. Other factors, including surface roughness, temperature and light reflectivity also have a bearing on actual surface resistance values. Typical values for f_i and f_o are included in Table 1.

Estimating the insulation value (RSI) of ceiling, wall, foundation and floor for Figure 2

	RSI value (from Table 1)
Ceiling	
Inside air film, surface resistance (f_i)	0.03
7.5 mm plywood ceiling	0.05
Polyethylene film vapor barrier	0.0
RSI-3.5 glass fiber blanket insulation	3.5
Still air film, surface resistance (f_i) to attic	0.11
Total ceiling RSI =	3.69
Wall	
Inside air film, surface resistance (f_i)	0.12
9.5 mm plywood interior sheathing	0.08
Polyethylene film vapor barrier	0.0
RSI-3.5 glass fiber blanket insulation	3.5
Vertical air space — asphalt wind stop	0.21
Sheet metal exterior	0.0
Outside air film, surface resistance	0.03
Total wall RSI =	3.94
Foundation wall (loss between concrete floor and bottom of stud wall)	
Inside surface resistance (f_i)	0.12
150 mm concrete, 0.150 × 0.55 =	0.08
50 mm polystyrene rigid insulation, 0.05 × 24.7 =	1.24
5 mm high-density, recompressed cement asbestos board	0.01
Outside surface resistance (f_o)	0.03
Total foundation RSI =	1.48
Floor	
Concrete floor to soil below	1.76
Total floor RSI =	1.76

The rate of heat loss H from a building surface in watts can be calculated using the formula $H = A(T_i - T_o)/RSI$ where A is the surface area in m^2, RSI is total insulation resistance value, T_i is inside temperature, and T_o is outside temperature, all in metric units.

The heat loss (H_p) from the perimeter of a concrete floor slab through the foundation must be estimated by another method, since the area through which heat escapes is not clearly defined. The U.S. National Bureau of Standards suggests that a perimeter loss factor (F) be used, together with the inside-to-outside temperature difference ($T - T_o$, in °C) and the perimeter (P, in metres) of the building. Insulating the first 300 mm below grade is the most important although some heat loss occurs below this.

The formula for perimeter heat loss is

$$H_p = PF\,(T_i - T_o),$$

where
H_p = perimeter heat loss, W
P = building perimeter, m
F = perimeter heat loss factor (see Table 3), W/(m·°C)
T_i = inside temperature, °C
T_o = outside temperature, °C

Example

What is the heat loss (not including ventilation) from a livestock building 10.8 × 21.6 × 2.4 m, with walls and ceiling insulated as in Figure 2, when the inside temperature is 18°C, outside temperature is −23°C and the ground temperature is 10°C?

(For calculations, the inside dimensions 10.5 m × 21.3 m are used and the foundation wall is assumed to be 300 mm high.)

Ceiling heat loss H =
$A(T_i - T_o)/RSI$ =
$(10.5 \times 21.3)(18-(-23))/3.69 = 2485$ W

Wall heat loss H =
$A(T_i - T_o)/RSI$ =
$2 \times 2.4 \times (10.5 + 21.3)(18-(-23))/3.95 = 1588$ W

Foundation wall heat loss H =
$A(T_i - T_o)/RSI$ =
$0.3 \times 2(10.5 + 21.3)(18-(-23))/1.48 = 528$ W

Floor perimeter heat loss H =
$PF(T_i - T_o)$ =
$2(10.5 + 21.3)(0.43)(18-(-23)) = 1121$ W

Floor heat loss to soil H =
$A(T_i - T_o)/RSI$ =
$10.5 \times 21.3(18-10)/1.76 = \underline{1017}$ W

Total building heat loss = 6739 W

Note that in the above example that there are no windows in the building (which, if included, can be a major source of heat loss). Also, heat loss has not been calculated for doors. Buildings lose heat through air leakage according to how tightly they are constructed; in farm buildings with fan ventilation this air leakage is usually considered as part or all of the ventilation requirement.

In residences and other buildings without controlled ventilation, the air leakage part of the heat loss can easily exceed the heat lost by conduction through the building shell.

TABLE 1 INSULATION VALUES AND COSTS OF COMMON INSULATION MATERIALS

Material	Thickness (mm)	RSI value[a] Per thickness shown	Per metre thickness	Approximate cost[b] $/m²	Cost/unit of RSI value $/(m²·RSI)
Mineral wool or glass fiber blanket insulation (including paper faced and friction fit, density 24-64 kg/m³)	25	0.65	25.7		
	64	1.1		1.30	0.80
	90	1.3		1.66	0.72
	100	2.6		1.95	0.75
	150	3.5		2.80	0.80
Macerated paper	100	2.5	25.0	1.55	0.62
Cellulose fiber (cotton, wood pulp, etc.)	1000		25.0		0.64
Expanded vermiculite (density 64-96 kg/m³)	1000		15.7		0.77
Dry sawdust or wood shavings (density 130-240 kg/m³)	1000		15.4		
Straw (cut, dry)	1000		9.9		
Corkboard			25.7		
Polystyrene foam					
Expanded beadboad (density 16 kg/m³)	25	0.61	24.7	1.50	2.46
Extruded type (density 29-35 kg/m³)	25	0.69-0.87	27.7-34.7	2.80	4.06-3.22
Polyurethane foam (applied at site, density 24-40 kg/m³)	25	1.04[c]	41.5[c]	5.30[d]	5.10[d]
	50	2.08[c]		10.60[d]	5.10[d]

[a] Resistance values taken from Canadian Farm Building Code 1977 and other sources

[b] These costs are included as guide to selection only. For up-to-date price information, consult a building materials supplier.

[c] These are 'aged' values for sprayed-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 in time air with a lower insulation value tends to replace the freon, the claimed values cannot be maintained unless the faces are factory sealed with a gas tight material such as metal foil.

[d] Installation costs are included. Do not make direct comparisons to the costs of other materials unless installation costs are first added.

TABLE 2 INSULATION VALUES OF TYPICAL BUILDING MATERIALS, AIR SPACES, WINDOWS AND CONCRETE FLOORS

Materials	Thickness (mm)	RSI value: At thickness listed	RSI value: Per meter thickness
Building boards and papers			
Asbestos board	5	0.01	
Fir plywood	9	0.08	
Aspen flakeboard (Aspenite, etc.)	6	0.08	
Fiberboard (Ten-test, etc.)	12	0.23	
Asphalt felt		0.01	
Polyethylene film vapor barrier	100 μm	0.00	
Frame construction			
Wood sheathing and building paper	19	0.20	
Same, add lap siding		0.35	
Lap siding or wood shingles		0.14	
Solid wood sheathing, pine or fir	25	0.22	
Roofing materials			
Built-up bitumen and felt	9	0.06	
Asphalt shingles		0.08	
Concrete and masonry			
Plain or reinforced concrete (density 2240 kg/m^3)	200	0.11	0.55
Lightweight concrete (density 1900 kg/m^3)	200	0.26	1.32
1280	200	0.55	2.77
640	200	0.19	5.96
480	200	1.54	7.69
320	200	1.98	9.91
Concrete block oval cores	200	0.20	
Concrete block, oval cores plus vermiculite fill	200	0.32	
Lightweight block (expanded shale, clay, slate, slag or pumice)	200	0.35	
Same, plus vermiculite fill	200	0.70	
Surface resistances			
f_o for outside wall (24 km/h wind)		0.30	
f_i 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, air space 12 mm		0.32	
Two vertical glass sheets, air space 25 mm or greater		0.33	
Air 150 mm above concrete floor to ground (temperature difference 11°C)		1.76	

TABLE 3 TYPICAL FLOOR PERIMETER HEAT LOSS FACTORS

Description of floor perimeter	Perimeter heat loss factor (F)
Normal concrete not insulated	1.42
Normal concrete insulated near the exterior face to 300 mm below exterior grade with rigid insulation having RSI = 0.7	0.85
Normal concrete insulated near the exterior face to 300 mm below exterior grade with rigid insulation having RSI = 1.4	0.43

CONVERSION FACTORS

Imperial Units	*X*	*Conversion factor*	*=Metric Units*
R $\frac{(hr \cdot ft^2 \cdot {}^\circ F)}{(BTU)}$		0.176	RSI $\frac{(m^2 \cdot K^*)}{(W)}$
¢/ft^2		0.108	\$/m^2
¢($ft^2 \cdot {}^\circ R$)		0.611	\$/($m^2 \cdot$RSI)
R per unit of thickness:			
R $\frac{(hr \cdot ft^2 \cdot {}^\circ F)}{(BTU \cdot in)}$		6.934	RSI $\frac{(m^2 \cdot K^*)}{(W \cdot m)}$
Perimeter heat loss factor per unit of length:			
F $\frac{(BTU)}{(hr \cdot {}^\circ F \cdot ft)}$		0.001556	F $\frac{(W)}{(K \cdot m)}$

* The K is the unit of temperature interval and is equivalent to a temperature difference of 1°C.