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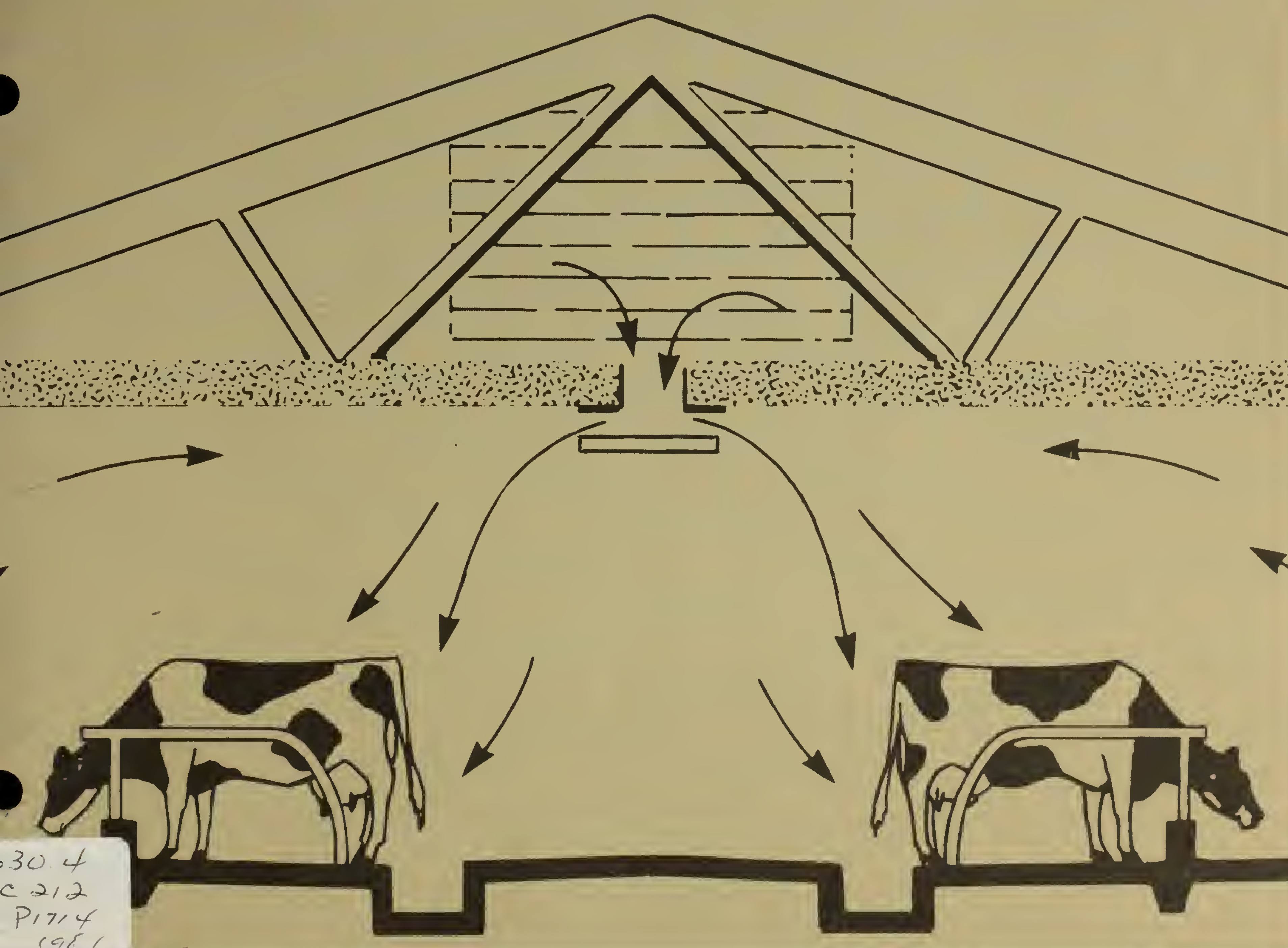
# TIE-STALL DAIRY CATTLE HOUSING



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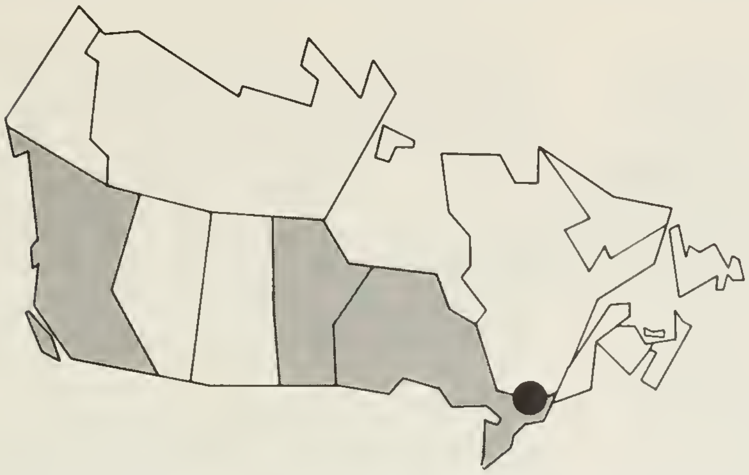

# TIE-STALL DAIRY CATTLE HOUSING

This publication is a compilation of research results, producer experience, and engineering practice. It is for the guidance of Canadian dairy farmers planning to build new dairy facilities or to renovate existing ones. The sections on basic requirements, construction of insulated housing and ventilation were authored by J.A. Munroe, Engineering and Statistical Research Institute, Agriculture Canada; the section on tie-stall design and housing layout by R.J. Milne, Extension Branch, Ontario Ministry of Agriculture and Food; the section on milking by D. Hodgkinson, Technical Services Branch, Manitoba Department of Agriculture; and the section on manure removal and management by E. Barber, formerly of Agricultural Engineering Branch, British Columbia Ministry of Agriculture.

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## INTRODUCTION

This dairy cattle housing series is written in three parts. This bulletin deals with tie-stall housing for mature cows and includes descriptions of building construction details, stall arrangements, manure removal, milking and ventilation systems.

A second bulletin will deal with free-stall housing for mature stock and includes descriptions of building construction details, free-stall layouts, milking parlors, ventilation and manure-removal systems.

Dairy calf and heifer housing as well as maternity facilities will be described in a series of leaflets issued through the Canada Plan Service. The various housing systems for young stock will be able to fit in with either the tie-stall or free-stall housing system.

As each part is intended to be complete, there is duplication of material on topics such as building construction details or manure-removal systems. For example, many of the construction details for a post-frame building are the same whether the building is used as part of a tie-stall or free-stall housing system. Where possible, we have reproduced well-proven designs and ideas from the Canada Plan Service.

It is assumed a prospective builder or renovator will have already decided between tie-stall or free-stall housing for his milking herd, so very little space is devoted to the advantages and disadvantages of the two systems. Rather, each part of this series provides details of alternatives within each of the two systems.

## 1. BASIC REQUIREMENTS

In choosing a design or system for tie-stall housing of mature dairy cattle, the dairyman must consider the well-being of the animals and the production and handling of milk. He must give his cattle feed and water as well as a satisfactory environment.

Feeding systems, including manger design, conveyors, and feed storage are described in Section 2. Further information on feed processing and handling is given in Agriculture Canada Publication 1572, *Farm Feed Processing and Handling*.

Clean water should be continuously available and is normally provided by water bowls — one for each two cows. These bowls should of course be durable and easily cleaned. Section 2 shows suggested locations in conjunction with manger and stall designs. The environmental conditions discussed will be limited to temperature, humidity, rate of air exchange, and space per animal. The last item does not have much bearing on animal performance in a tie-stall barn provided the stall dimensions are adequate. Dimensions normally recommended by the Canada Plan Service and provincial agricultural offices are listed in Section 2. The average overall barn space per animal is, however, sometimes used in comparing the efficiency of design of different barns.

Some attempts have been made to establish the ability of an animal to thrive and produce under different environmental conditions. A study showed no change in milk production for Holsteins over a temperature range from −12° to 25°C (Figure 1). As

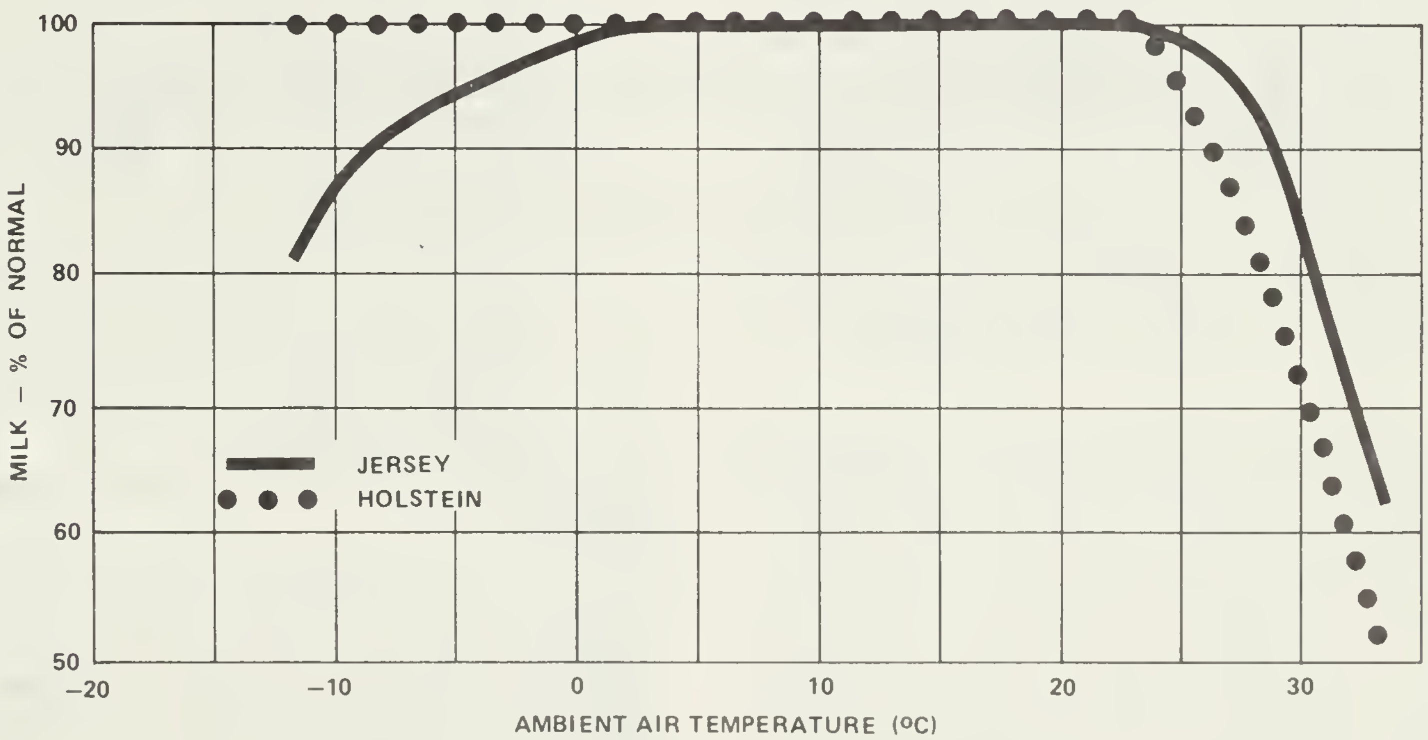



Figure 1 Percent of milk production at various environmental temperatures for Jersey and Holstein cows. Relative humidity ranged from 55 to 70%. (Adopted from Yeck and Stewart, 1959).

temperature rose from 25° to 35°C, production dropped by 50%. Jerseys did not seem as cold tolerant as Holsteins since their milk production dropped as soon as temperatures fell below freezing. At temperatures above 25°C, their production also declined, although the smaller Jersey cattle did not suffer quite as much as the Holsteins.

High humidity accompanied by high or low temperature further stresses dairy cows. For example, relative humidity (RH) held between 90 and 100% can drop production by 7% at −4°C for Holsteins. On the other hand, some of the stress caused by heat and high humidity is relieved when wind blows across the animals; a breeze blowing through large open doorways can help relieve heat stress for cattle confined to the stable during hot weather.

High humidity has frequently been reported to leave animals more susceptible to respiratory diseases, particularly at low temperatures. Also, building materials rot and deteriorate more rapidly when subjected to dampness for extended periods. Avoid high humidity in an animal building if possible; allow a maximum RH of 80% during cold weather. In hot weather (above 25°C), counteract the effects of high humidity by providing rapid air movement in the barn. Open doors or adjust air inlets to direct air onto the cattle.

## 2. TIE-STALL DESIGN AND HOUSING LAYOUT

Tie-stall housing is the most acceptable, economical and efficient housing system for herds of up to 50 or 60 milking cows, if the cattle are housed inside, at least during the winter months. Unless you are considering future herd expansion, other housing systems will not likely be competitive in either building costs or labor use.

This type of housing appeals to many people because it is the system with which they are familiar. Also, the operator works in an environment that is more comfortable for him than in any other dairy housing system. Many farmers depend on the sale of purebred cattle for some of their income and the tie-stall system offers a more convenient and advantageous showcase for these animals.

SIZE OF HERD The tie-stall system should consist of two rows of milking cows for herds of up to 50 or 60 cows. For larger herds, where the owner does not wish to adapt to a free-stall housing and management system, other design arrangements exist.

Many dairy enterprises relying solely on family labor have between 25 and 40 cows. Larger herds will likely need additional labor, and an arrangement that allows about 30 cows per herdworker will be most efficient. Since each water bowl, vacuum line stallcock, milk line inlet and stall divider can serve two cows, an even number of stalls in each row helps economize on equipment. A stabling system that groups cows in multiples of 28 or 32 in two rows will take best advantage of both labor and equipment.

When a dairy herdsman works an 8-hour day, he can manage from 46 to 69 cows, depending on how efficiently he does chores. If barn chore time is limited to 5 hours daily, to allow time for field work and caring for young stock, he can only manage 29 to 43 cows.

FACE-IN VS FACE-OUT About 60 to 65% of the chore time in a tie-stall dairy barn is spent behind the cows, 15 to 20% is in front, and 20 to 25% in other areas of the barn. Consequently, time and physical effort can be saved by having a face-out stable arrangement. It also helps keep walls clean. However, for large herds in tie-stall barns with a pipeline milking system and mechanical feeder, a face-in arrangement gives some equipment economies and layout advantages. This is especially true if the feed alley is reduced to 2 m or less in width, with one mechanical feeder serving both rows of cows. For herds of 60 cows or less a face-out arrangement will be most practical, but for herds larger than 60 cows, consider a face-in arrangement. A typical face-out arrangement is shown in Figure 2.

BARN WIDTH A barn 10 800 mm wide will prove adequate for two rows of cows. This is convenient for the operator and allows stalls large enough to insure good herd health and comfort.

Dimensions for a tie-stall barn are listed below with letter references to Figure 3.

A. This distance represents the cow stall length and varies from 1350 to 1800 mm depending on stall style and the sizes of the cows. Recommended lengths are given in Table 1.
B. This distance includes the center work alley and the manure gutters. It should not be less than 3000 mm since all milking and cleaning activity occurs in this area. If grate-covered gutters are used, this distance may be reduced slightly.
C. This distance serves as the feeding and feed-handling area and any variation in barn width should occur in these areas. However, it should be a minimum of 2250 mm. Increasing the distance results in greater ease in feeding.

Figure 4 shows a typical cross section of a two row face-in barn.

COW STALLS Long wide cow stalls reduce leg and udder injuries and prolong the productive life of cows, as well as add to operator convenience and comfort. In selecting cow stall sizes, remember that most modern breeding, feeding and selection programs result in larger animals than in the past; select stall sizes accordingly. Stall sizes taken from Canada Plan Service leaflets are given in Table 1.

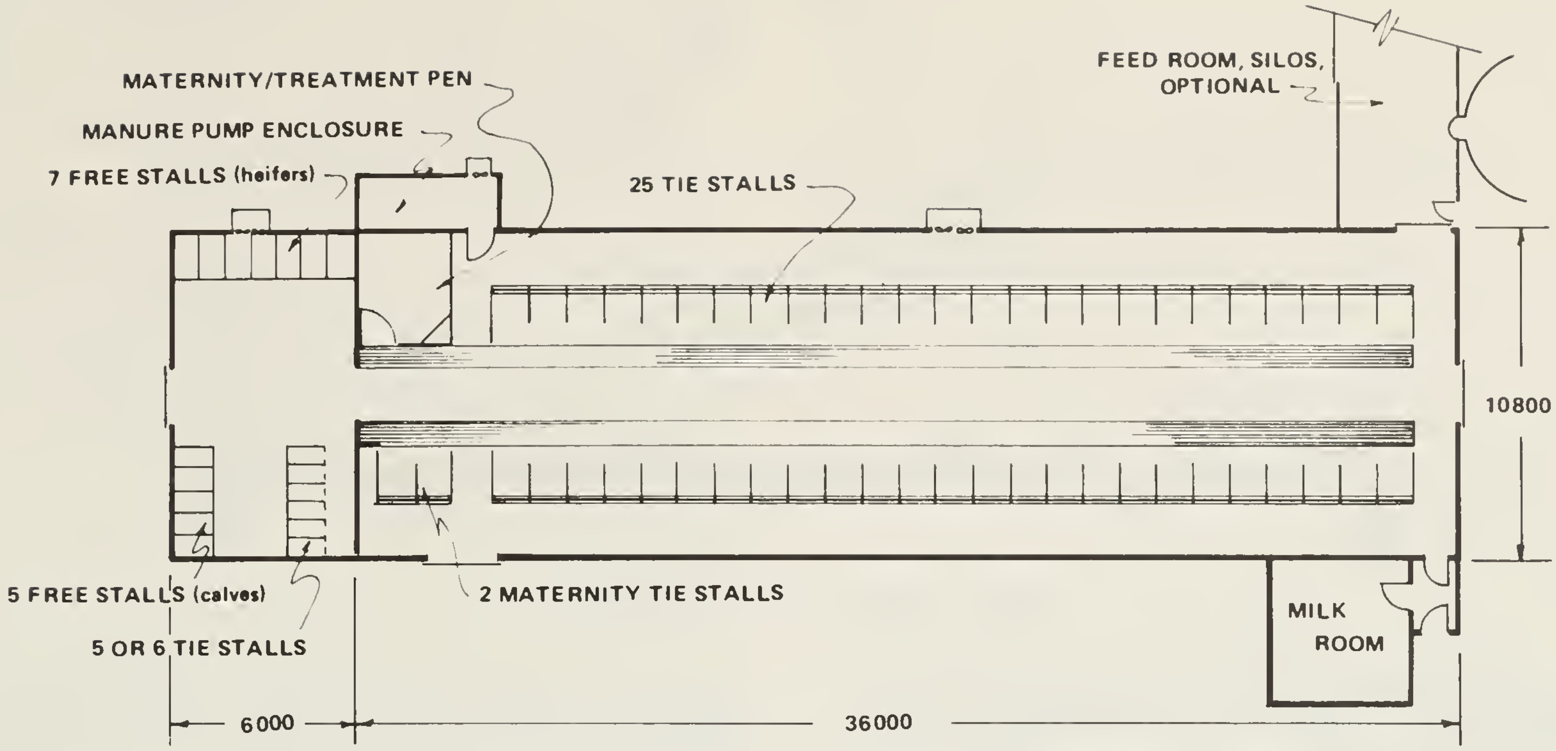



Figure 2 Face-out, two row tie-stall dairy barn.

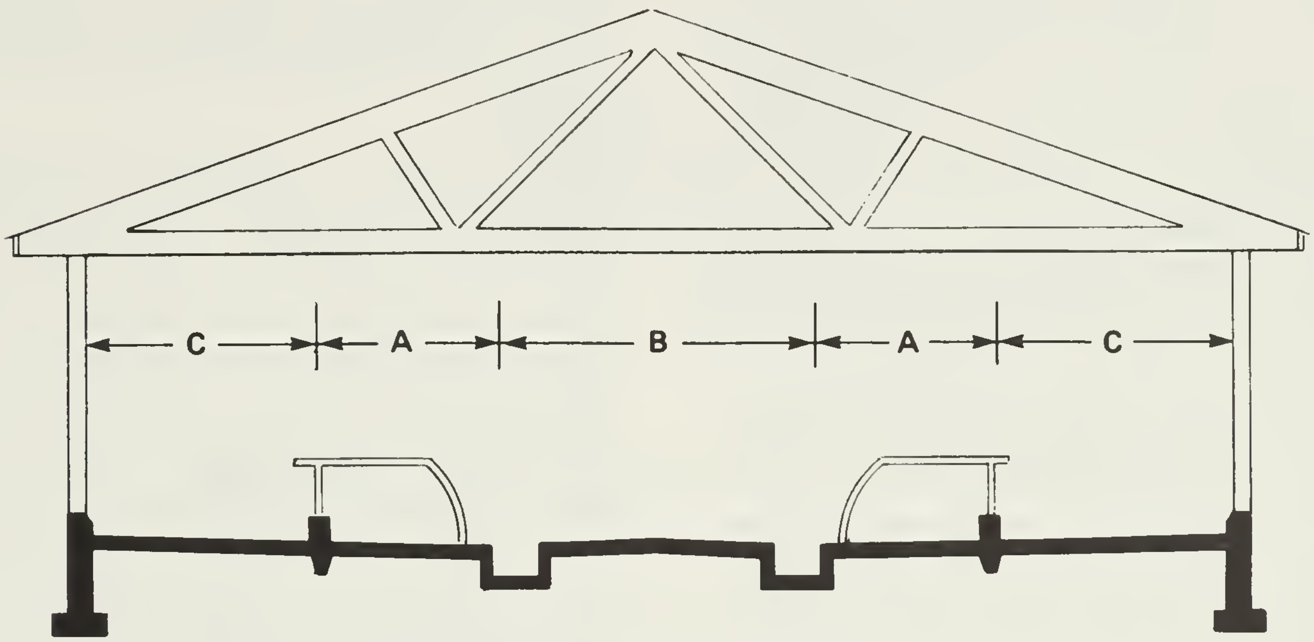



Figure 3 Face-out, two row arrangement.

TABLE 1 Dimensions for Tie Stalls for Dairy Cattle

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

*Make stalls 100 mm shorter if used without trainers.

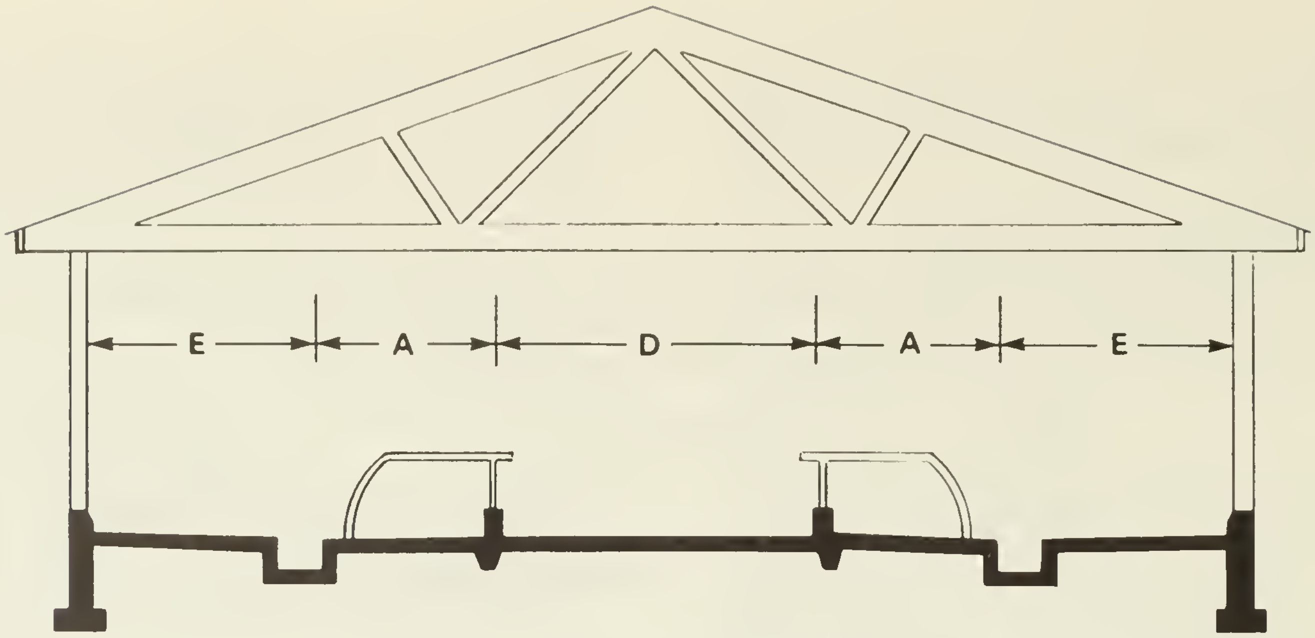



Figure 4 Face-in, two row arrangement.

Electric cow trainers used with large stalls help keep both the stalls and the cows clean with a minimum of bedding.

Three popular types of stalls are shown in Figures 5, 6, and 7. Construction details of each are available in Canada Plan Service Leaflets M-2821, M-2822, and M-2823, respectively. The single headrail stall allows cows to move forward with heads down for feeding, but makes them stand back at other times; this keeps the stall cleaner with minimum care. Cows are tied by a strap and chain which is passed under the rail and over a chain hook. Cows can be released individually or the headrail can be constructed so that it rotates and releases groups of cows at one time.

The low arch chain tie stall is similar to the single headrail type. However, cows have more freedom of movement, so electric trainers are highly recommended.

A number of dairy farmers have installed some type of bedding keeper at the back of the stalls. If one is installed, provide drainage channels from the cow stalls to the gutter. Commercially manufactured stainless steel or galvanized metal units are available; however, a galvanized pipe, a narrow plank or board fastened to the gutter edge, or a lip of concrete formed when the floor and gutter are placed can serve. The bedding keeper holds the bedding in place under the cow, protecting the udder from irritation and injury on the concrete floor.

FEED ALLEYS AND MANGERS A combination feed alley – manger will accommodate a variety of feeding equipment including manual and mechanical feed carts, and any permanently installed mechanical feeding device. It simplifies construction significantly as there is less elevation difference between service and feed alleys, less form work necessary, and less time spent placing, screeding and finishing the concrete floors.

Where separate manger and feed alley are desired, the manger should be 500 to 600 mm wide and 100 to 200 mm deep, and the alley a minimum of 1200 mm wide. Based on a manger 600 mm wide, a separate alley and manger will require a minimum of 1800 mm in a face-out stable arrangement or a minimum of 2400 mm in a face-in arrangement. A combined feed alley – manger still requires 1800 mm for a face-out stable but only 2100 mm for a face-in. Other advantages of the combined feed alley – manger include ease of cleaning and more room to operate either manual or mechanical feed carts. It will not likely take any more time to keep the feed within reach of the cows in this system than where there is a separate manger and feed alley.

CROSS ALLEYS These should be at each end of each row of cows to allow circular travel around the barn, whether the stabling arrangement is face-in or face-out. Additional cross alleys in rows containing 24 or more stalls save many steps when doing chores. Cross alleys should be a minimum of 1300 mm wide and be ramped from the service alley to the feed alley. If cows enter and exit the stable by a cross alley, increase this alley to at least 1500 mm wide and keep it as level as possible with the service alley; the door leading outside in this case should be at least as wide. Concrete surfaces should not be too smooth; give them a rake finish or, preferably, cross hatch them with grooves.

The combined width of service alleys and gutter in face-out stable arrangements should be a minimum of 2700 mm in new construction. This allows the gutter width to vary depending on whether the manure system is "dry" or "liquid". With dry systems, the service alley is likely to be a minimum of 1500 mm and with liquid systems 1200 mm. Service alleys should be crowned about 25 mm to provide drainage to the gutters. Concrete surfaces in service alleys should be given a rake finish or cross hatched with grooves to reduce cow slippage and injury. Avoid sloped ramps in service alleys cows may have to cross. Steps from 75 to 175 mm high are much more acceptable to cattle as there is less slippage and chance of injury. Steps do offer some difficulty for wheelbarrows and carts.

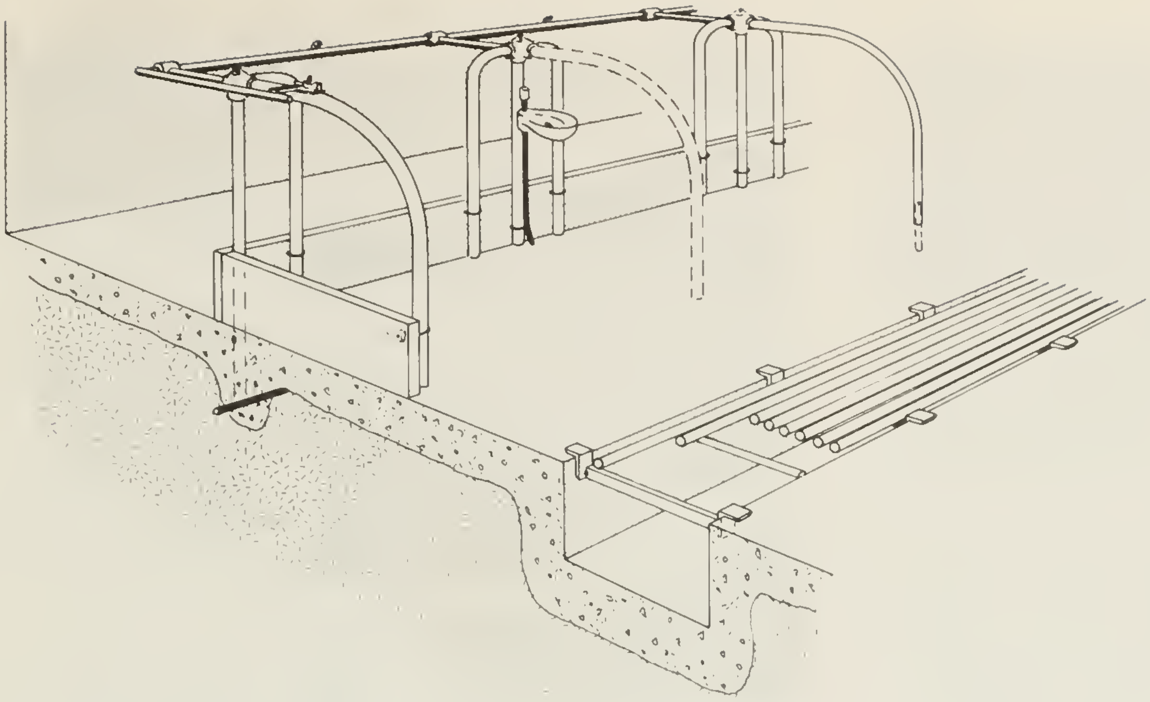


Figure 5    Single headrail tie stall.

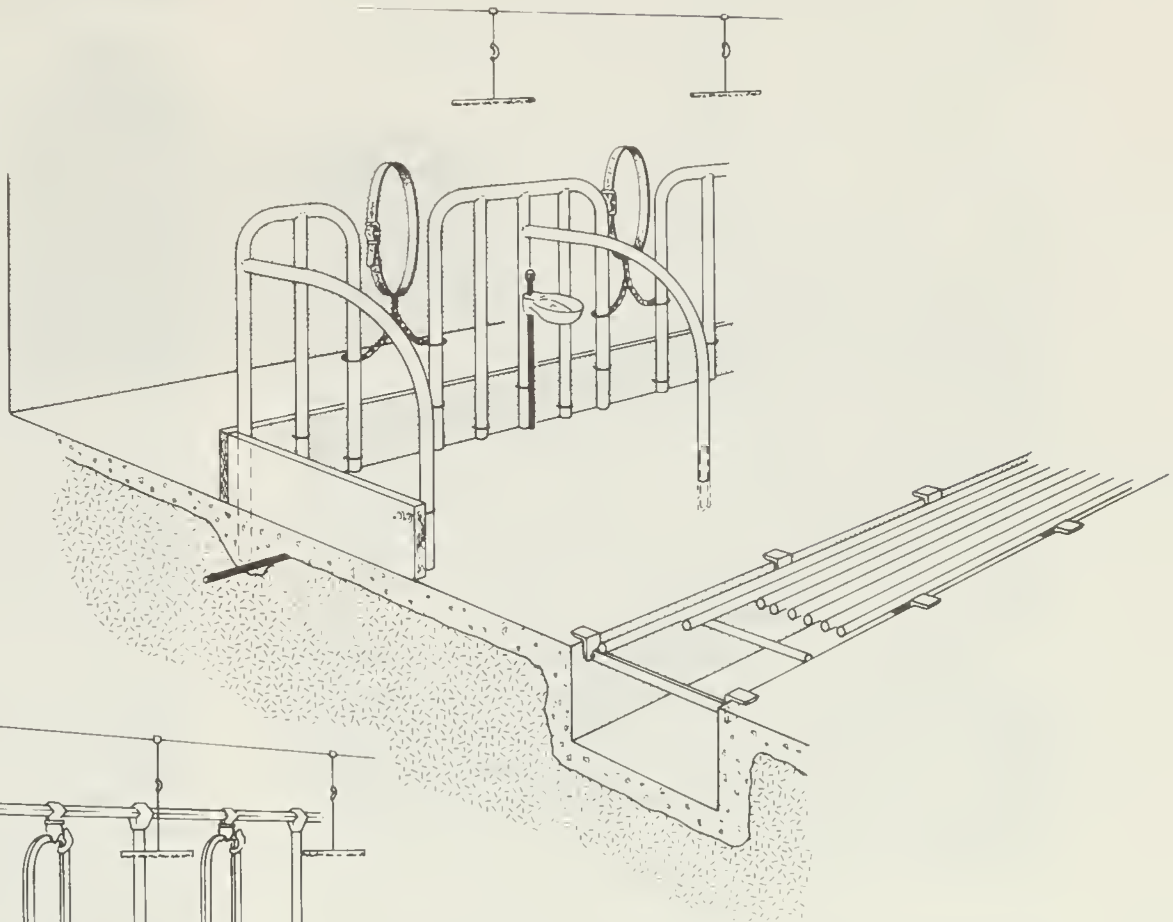


Figure 6    Low arch chain tie stall.

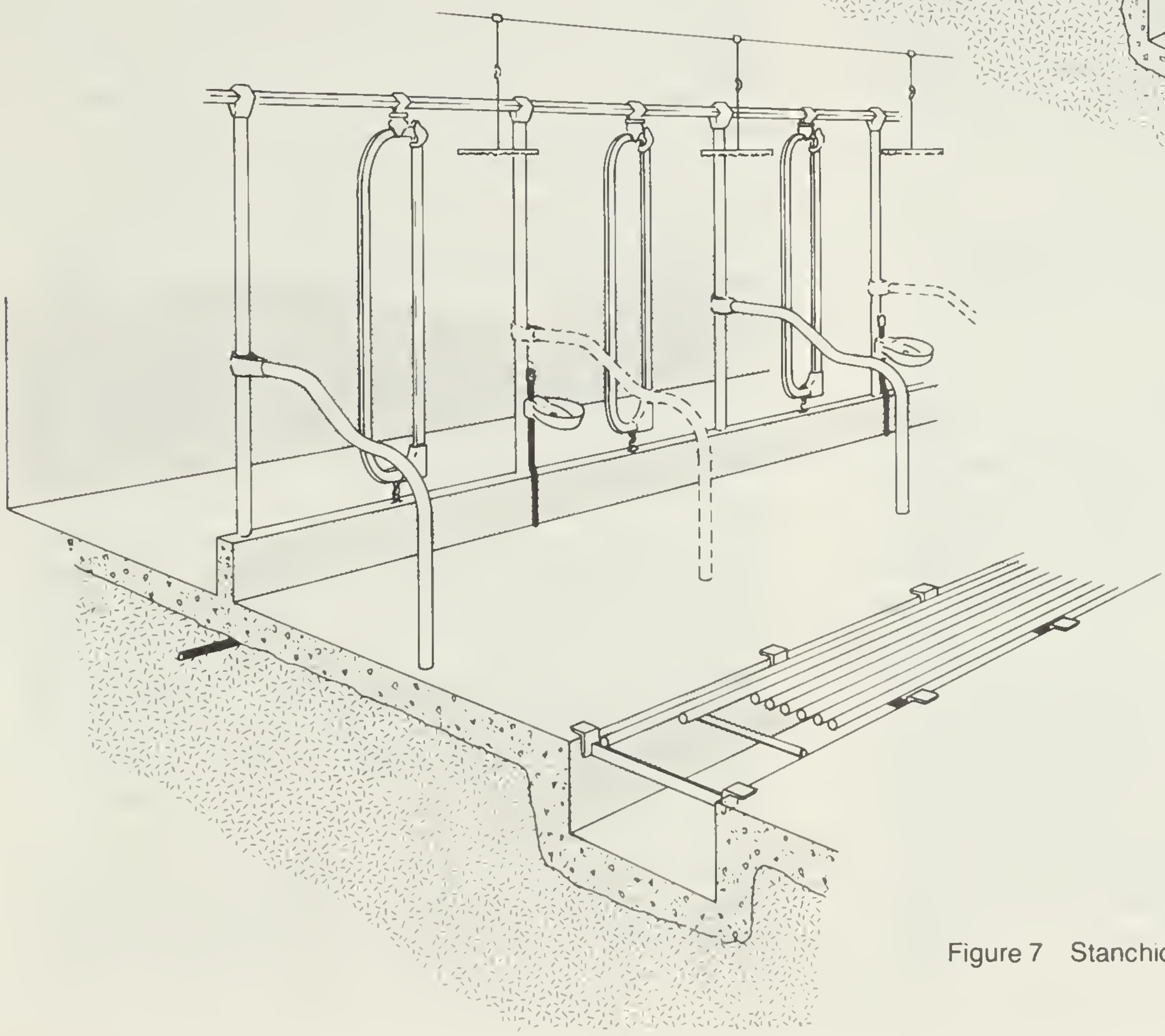


Figure 7    Stanchion tie stall.

FLOOR SLOPE The floor of the barn should slope toward the milkhouse end of the barn at the same gradient as recommended for a milk pipeline installation. This is usually a minimum of 1:80. Sloping the entire floor puts the pipeline at a low uniform height, making it more accessible to the operator. It also minimizes the height milk has to be lifted in the line. This helps stabilize the vacuum level ahy teat cup, reducing the chances of mastitis. A lower line also reduces the likelihood the milk will become rancid. If the milk room is at one end of an extremely long barn, it may be advantageous to slope the entire barn (floor, structure and pipeline).

MATERNITY AND TREATMENT PENS Pens in the milking barn should be limited to those required by the milking herd. For health reasons, never house calves from birth to 6 months of age with mature animals. Calves and heifers from 6 months to freshening can be housed more conveniently and more economically in adjacent facilities.

Maternity pens or stalls may be provided in the milking barn to avoid the stress of moving cows to another area at calving time. One maternity pen or stall for approximately 20 milking cows appears to be adequate. Maternity or calving stalls are becoming popular to confine cows during calving. The cow and calf are then moved to a maternity pen for the period that the newborn calf receives colostrum milk from its dam. Maternity stalls are from 1300 to 1500 mm wide for Holstein cows. The stall has no gutter at the back, but may have a small step about 50 mm high for drainage. These stalls are more convenient than a pen for treating the cow during freshening, and require much less space.

Additional pens may be desirable for treatment of sick animals or to house older, more valuable animals that have foot and leg problems. Usually, an additional pen for each 20 milking cows will suffice. Pens should be a minimum size of 3000 mm by 3000 mm.

## 3. CONSTRUCTION OF INSULATED HOUSING

Since tie stalls restrict the movement of cattle as compared to free stalls, an effort must be made to ensure comfortable environmental conditions throughout the stall area. In most parts of Canada, this means an insulated barn with ventilation controlled by fans. Supplemental heat may also be required.

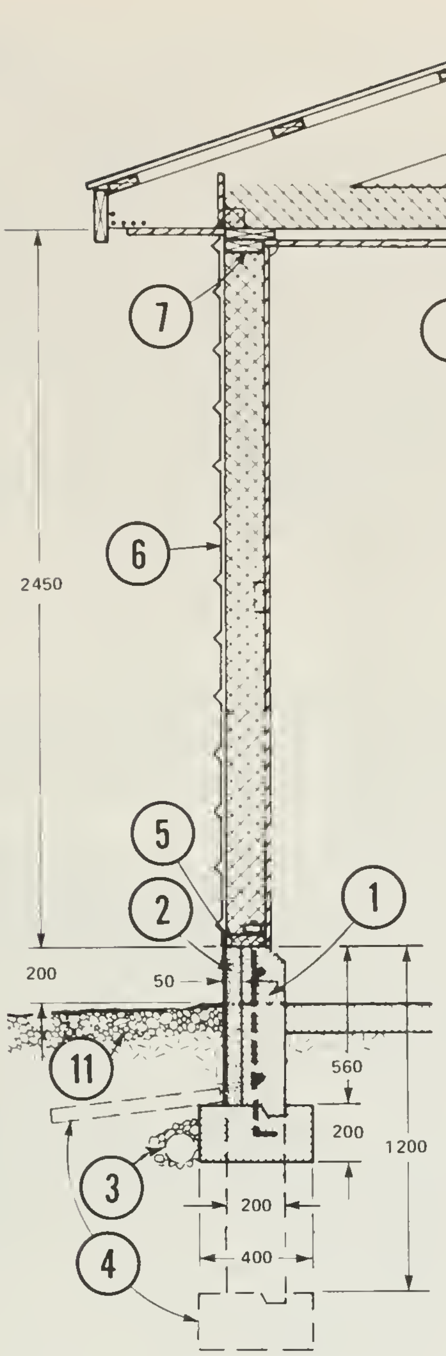
Single-story dairy barns have generally been recommended for new facilities. They make it practical to use clear span roof trusses to support the ceiling and roof. This gives a smooth, dust-free ceiling without supporting beams or posts that could interfere with ventilation or future alterations. A truss roof single-story barn and separate feed storage is cheaper to build than a floor system to support overhead feed storage. However, hay and bedding storage must be in an adjacent building. In some cases the storage may be in the old dairy barn, converted to store hay and bedding from the ground up. In other cases a new pole barn nearby with ground-level storage may be used. A covered alley to connect the hay storage area to the dairy barn is handy, but for safety, have a fire separation (a fire wall or open space) between the dairy barn and hay storage. This must include a fire door at the alley entrance to the dairy barn. An alternative is a covered area attached to the barn, large enough to park a farm wagon. Hay and bedding are then transported from the main storage to the dairy barn by this wagon.

Figure 8 shows a cross section of a typical insulated stud-frame wall using 38 × 140 mm studs on a concrete foundation. Until recently, RSI 2.1 mineral wool or friction-fit fiberglass insulation was recommended for the wall and RSI 3.5 in the ceiling. With the rising cost of energy, consider increasing the amount of insulation. Rigid polystyrene insulation is suggested for the building foundation perimeter. Use 50 mm for milder climates, and 75 mm for more severe winter climates. Attach the polystyrene with finishing nails to the inside face of the outer concrete form before the foundation is poured. When the forms are stripped, the finishing nails pull through the insulation, leaving it firmly bonded to the concrete. This lets you finish the exterior of the building neatly with high-density recompressed cement asbestos board at the base, which is essential for rodent protection, and horizontal metal siding above.

Select sheathing exterior grade plywood is a good interior sheathing material. It adds structural rigidity to end walls and ceiling, and can be cleaned repeatedly. All nails used to attach outside and inside finish materials should be hot-dip galvanized; this is a small extra that is frequently overlooked, but is very important for long-term durability and appearance. Caulk with a top-grade elastomeric or synthetic rubber caulking compound at wall panel joints, especially where the wall panels meet the foundation.

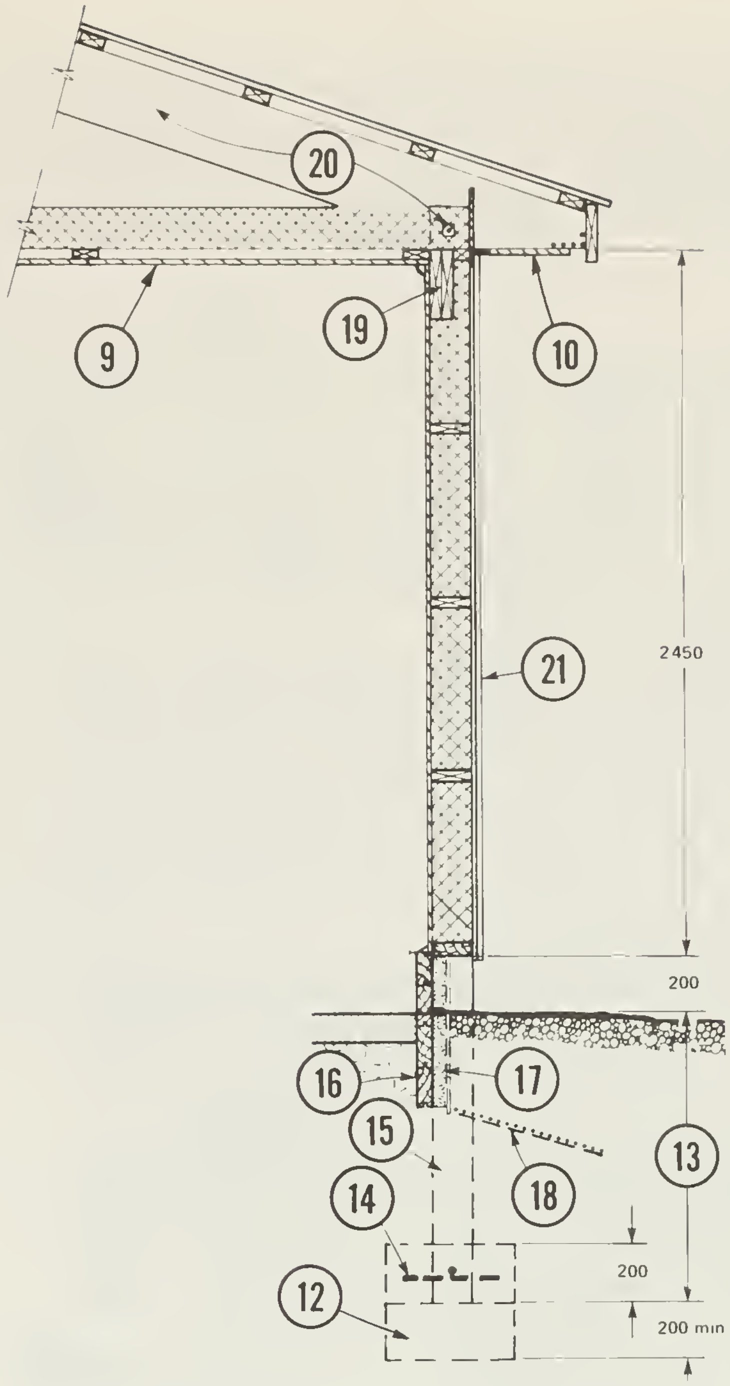
Construction details for a pole frame wall are shown in Figure 9. Pressure-treated tongue and groove wood planking replaces the concrete foundation and rigid insulation described previously for conventional stud-frame walls. You may want to add a rodent guard to prevent rats from tunnelling under the building. This can be a band of hardware cloth attached to the wall and extending horizontally under the surface of the ground a distance of 500 mm from the building. Regardless of the construction used, keep the area next to the building free from tall weeds, board piles and debris that could shelter rats and mice.

Buildings should have good cladding and enough structural strength to stand up to wind, snow and driving rain. Figures 8 and 9 include important details taken from complete building plans prepared




1. concrete foundation, anchor bolts @ 1 200 mm oc., 2 horizontal rebars continuous
2. rigid polystyrene insulation (Dow SM or equal), drill and nail 5 mm high-density recompressed asbestos board to sill, exterior cladding laps over
3. optional 100 mm footing drain, cover with coarse gravel
4. for deep frost add horizontal insulation over packed sand, or use deeper footing
5. 38 x 140 mm pressure-treated sill
6. exterior wall: exterior cladding; asphalt wind stop; 38 x 140 mm studs @ 600 mm oc; RSI-3.5 friction-fit insulation; 0.15 um polyethylene vapor barrier; 9.5 mm exterior sheathing plywood with face grain horizontal
7. 38 x 140 mm and 38 x 184 mm plates
8. trusses, purlins and roofing to suit local design snow loads, anchor trusses to wall with galvanized steel framing anchors
9. insulated ceiling: 7.5 mm exterior sheathing plywood perpendicular to trusses, end joints staggered, 0.15 um polyethylene vapor barrier, friction-fit insulation (RSI-3.5 min.) see individual CPS plans for strapping, blocking, and nailing requirements
10. 18.5 mm soffit, 50 mm continuous vent with galvanized bird screen
11. 900 mm wide x 100 mm deep coarse gravel splash pad, or add eavestroughing

Figure 8 Insulated stud-frame wall construction.




12. concrete footing under poles increase diameter for wider building spans and softer soil
13. footing depth to below frost, or at least 800 mm
14. concrete wind anchor; 2 - 15M x 400 mm rebars through or 8 - 150 mm spikes into poles, place concrete around butt of pole after pole is positioned
15. 89 or 140 x 140 mm pressure-treated poles @ 2400 mm oc; see leaflet M-9311 for safe wind and snow loads
16. 38 mm pressure-treated tongue and groove splash planking; joints staggered
17. optional 50 mm rigid polystyrene insulation, cover with 5 mm recompressed high-density cement asbestos board between poles ; planking must be CCA or ACA treated since other treatments containing petroleum solvents will dissolve polystyrene
18. optional rodent stop, 12 x 12 mm galv. hardware cloth
19. 2 - 38 mm plates, (see leaflet M-9312 for joint details and safe roof loads)
20. trusses to suit local design snow loads, M12 bolt and washers, truss to pole; intermediate trusses secured with two galv. framing anchors to plate
21. exterior wall: exterior cladding; asphalt felt wind stop; 38 x 140 mm girts @ 600 mm oc, bottom girt pressure-treated; RSI-3.5 friction-fit insulation; 0.15 um polyethylene vapor barrier; 9.5 mm exterior sheathing plywood with face grain vertical

Figure 9 Insulated pole-frame wall construction.

by the Canada Plan Service. Before starting a new building, obtain the complete plans, which can be adjusted for climatic conditions in your area, from extension engineers in local provincial agriculture offices.

## Construction details for built-in air inlets

Principles of dairy barn ventilation were described earlier in this bulletin, but some types of air inlets are easier to build into the structure of the barn at the time of construction. Details of these are therefore included here.

Figure 10 (from CPS leaflet M-9712) shows how to build an adjustable wall inlet. Figure 11 is a photo of this inlet. Rigid polystyrene foam insulation board is inexpensive and ideal for inlet flaps, as it does not warp or sweat with moisture. Be sure to use the extruded, high density type (Dow SM, or equal), as it is stiffer and more durable than the cheaper bead-board type.

The amount of air coming through the inlet is controlled by the capacity of the exhaust fans, but the velocity of the air is affected by both fan capacity and air inlet opening size. Adjust the air inlet opening to provide an air velocity of at least 4 m/s.

The two-cable system is more convenient than the one-cable system to discharge air down the sidewall for hot weather ventilation, but is slightly more difficult to install and initially adjust. The two-cable system is also more susceptible to air leakage and may be less desirable in colder climates.

A small but very effective design change from previous inlet designs is the use of sheet metal angle stiffeners to provide better alignment of inlet baffles. This gives a more uniform slot opening through the length of the baffle.

Marine steering cable and pulleys work well and are widely available. A boat winch is recommended, not to provide a mechanical advantage, since the inlets are light, but rather to allow small precise adjustments of the inlet baffle. This system is much better than such arrangements as a chain and nail.

Figure 12 shows the center ceiling inlet that receives fresh air via an insulated duct built into the attic, using the roof trusses for framework. Adjustable, it can discharge air both ways across the ceiling, vertically downward, or a combination of both. As with the side wall inlet, the amount of air entering is controlled by the capacity of the exhaust fans, but the velocity is affected by both fan capacity and air inlet opening. Again, adjust the air inlet opening to provide an air velocity of at least 4 m/s.

Loosening wing nuts and manually separating the baffle halves allows air to discharge vertically downward. This may help relieve heat stress during very hot weather. Like the wall inlet, marine pulleys and cables and a boat winch will allow small, precise adjustments of the inlet slot.

## Floors

All concrete floors must be constructed on a firm base that will not settle. If fill is added, it should be sand or gravel so that it can be compacted easily. Since fill is cheaper than concrete, it is advisable to add and compact more and then reduce the concrete thickness to 100 mm. When ordering ready-mix concrete, specify a strength of at least 20 and preferably 30 megapascals (MPa).

Use a wood float finish on the concrete where cattle will walk. In feed alleys, mangers and gutters use a smooth, steel trowel finish.

## Painting

Painting farm buildings not only beautifies the farmstead, but preserves the buildings both inside and out. The two basic types of paint are water paints and solvent paints.

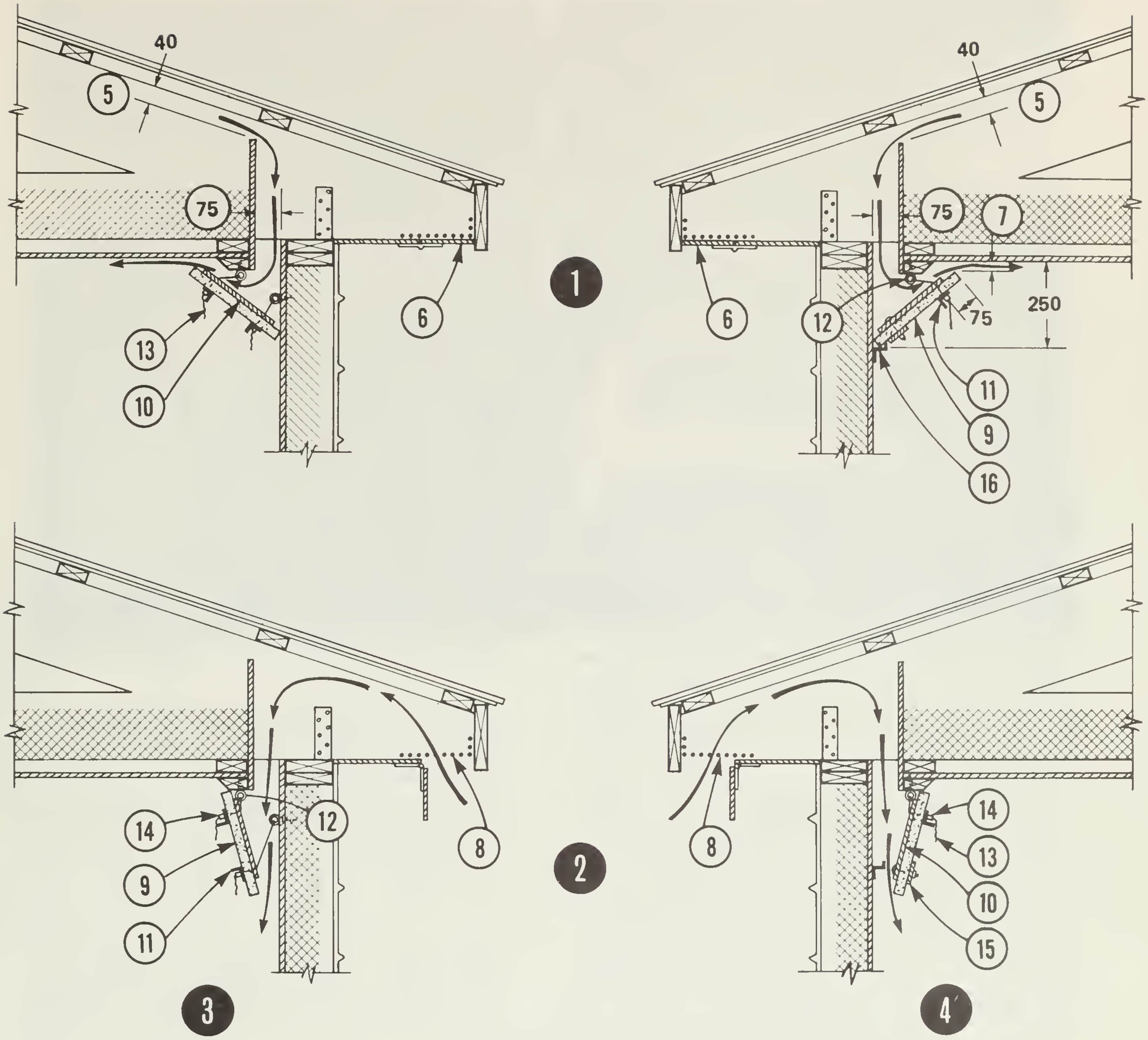
Water paints include latexes such as acrylic or polyvinyl acetate, and emulsions based on linseed oil or alkyd resin. Latexes are popular because they are easy to apply, dry quickly, have little odor and permit easy cleanup. Acrylic latex paints are well suited for exterior applications to wood and galvanized metal surfaces and stand up well to exposure providing no unusual conditions exist. They provide a wide color choice and look good.

Solvent paints contain pigments and a binder such as oil, varnish or resin. Conventional exterior house and barn paints use linseed oil as the binder, while paints that give harder coatings (such as machinery enamels) use alkyd resin. High-gloss alkyd enamel has excellent water resistance, is sometimes mildew resistant, washes easily with water, adheres well to properly primed wood and metal, and is usually quite suitable for interior surfaces in dairy barns.

# 4. VENTILATION

The importance of a good ventilation system for animal housing is frequently overlooked until problems with the animals or the structure occur. This section will attempt to define the range of environmental conditions that are desired in a tie-stall barn and suggest how to achieve these.

Mature dairy cattle, as illustrated by Figure 13, give off body heat (sometimes called dry or sensible heat similar to that produced by an electric heater) that goes towards heating the barn. They also add heat in the water vapor they breathe out, which diffuses throughout the air in the room. Water vapor is also added by evaporation from waterbowls and gutters. The study (Yeck and Stewart, 1959) most commonly cited for predicting quantities of moisture produced by mature dairy cattle includes that produced within the tie-stall barn from these sources.




1 Normal setting

2 Emergency hot weather setting

3 Two-cable system

4 One-cable system

5 Winter ventilation from attic

6 Hinged soffit closed for winter

7 Slot adjustment, 0 to 50 mm

8 150 mm screened soffit inlet open for spring, summer and fall

9 25 x 300 mm wide extruded high-density polystyrene board continuous, cut 600 mm polystyrene exactly in half for uniform baffle width and trim to 2 400 mm long, pre-drill for bolts and (13)

10 100 x 250 mm plywood strips @ 1 200 mm oc, pre-drill and bolt thru (9) to (11)

11 25 x 25 mm –0.40 mm sheet metal angles, trim to 2 400 mm long before bending, pre-drilled for bolts and (13) at center and ends

12 Plated screw eyes 1 200 mm oc, vinyl covered steel marine control cable runs thru screw eyes to winch control at one end and return spring at other end

13 Heavy nylon string(eg. masons line) clamped to control cable with electrical No. 2 Marr connector, thru screw eye, thru hole in (9), (10) and (11), adjust with Marr connector (14)

14 No. 1 Marr electrical connector to adjust string (13)

15 Plywood washer, pre-drill for bolts

16 0.40 mm galv. steel ledge continuous to form lip 30 mm from wall surface, nail to wall and caulk behind
OR
Continuous wood 38 x 89 mm ledge bevelled approx. 60° from wall surface

Figure 10 Adjustable wall air inlet.

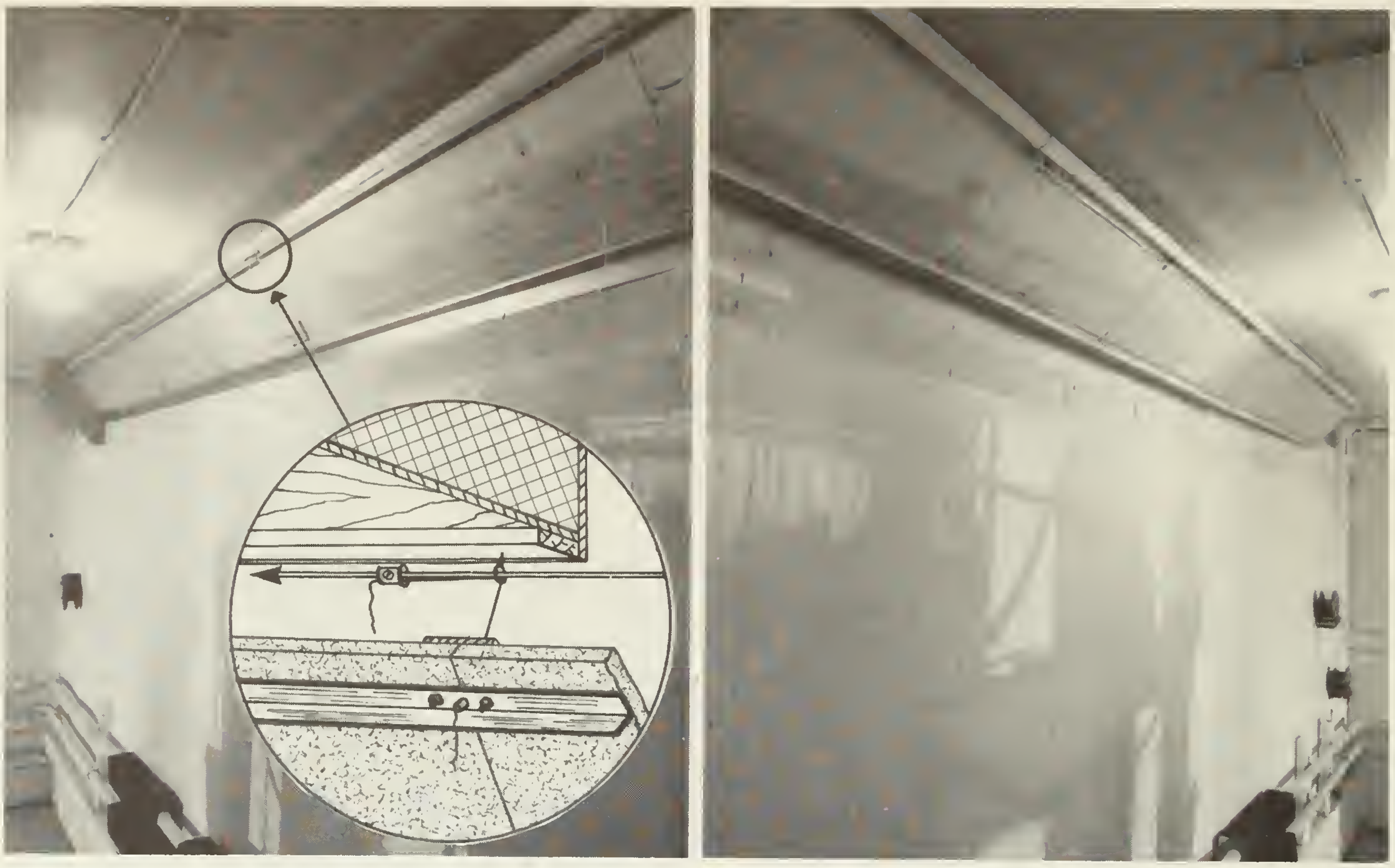
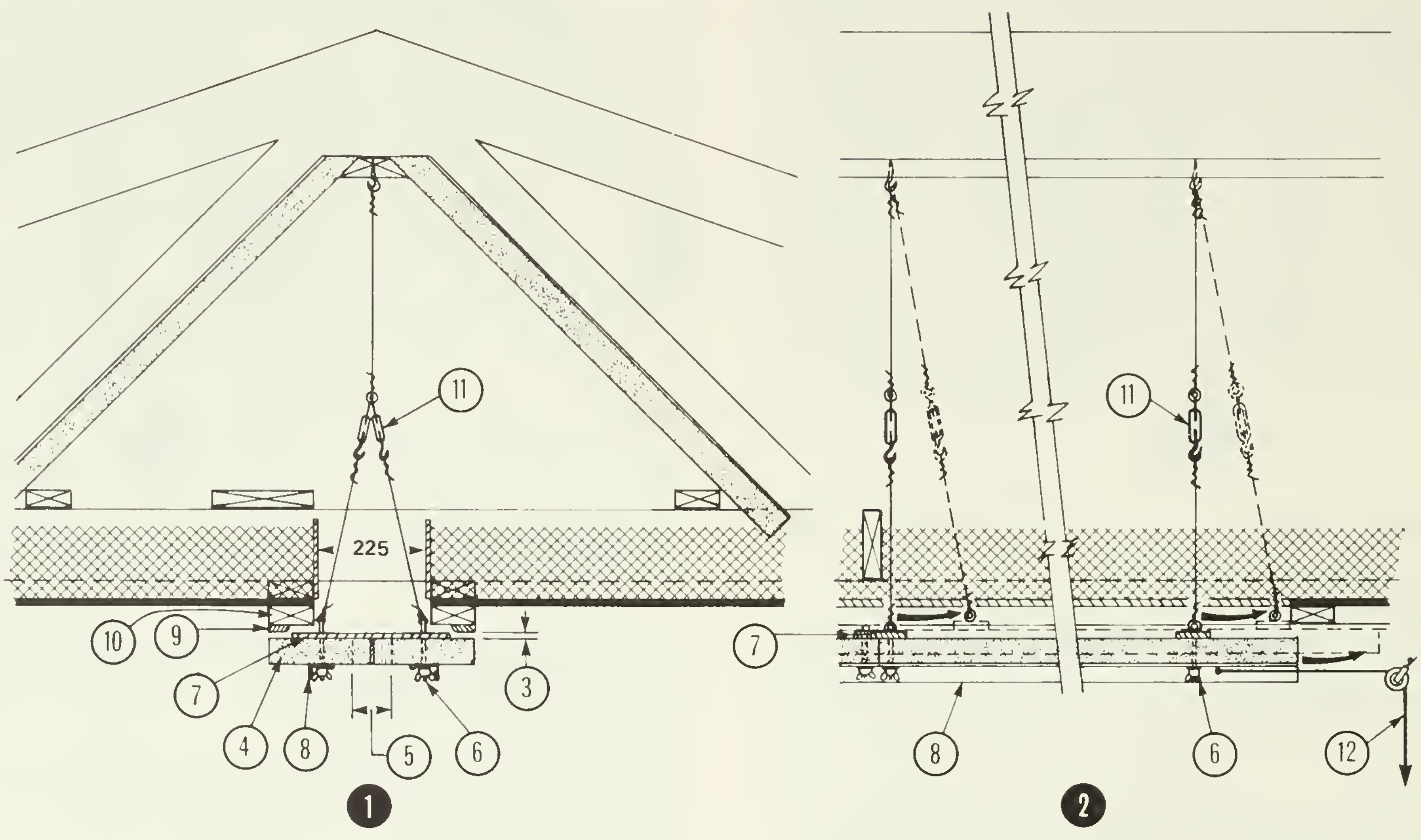


Figure 11 Photo of adjustable wall air inlet.




1. CROSS SECTION THRU INSULATED ATTIC DUCT & CEILING
2. LONGITUDINAL SECTION AT CONTROL END OF INLET
3. CEILING SLOT, ADJUSTABLE 0 - 50 mm
4. 38 x 200 x 2 400 mm SLABS OF HIGH-DENSITY EXTRUDED POLYSTYRENE BOARD
5. OPTIONAL SLOT 0 - 50 mm WIDE FOR VENTILATION TO FLOOR DURING HOT DAYS;
6. PLATED EYEBOLTS 1 200 mm oc, WASHERS, WING NUTS, GALV. SUSPENSION WIRE
7. PLYWOOD STRIPS 9 x 75 x 267 mm @ 1 200 mm oc, PRE-DRILLED FOR (6)
8. 0.4 x 25 x 25 mm GALV. STEEL ANGLES 1 200 mm LONG FOR STIFFENING, PRE-DRILLED FOR (6) AND (7) AT CENTER AND 25 mm FROM ENDS
9. SHOE MOULD, ALL AROUND
10. DOUBLE 38 x 89 x 4 800 mm JOINS STAGGERED 2 400 mm oc
11. WIRE & 5 mm TURNBUCKLES, ADJUST FOR EQUAL SLOTS (3) ALL AROUND
12. PULLEY AND CONTROL ROPE TO BOAT WINCH CONTROL

Figure 12 Adjustable center ceiling air inlet.

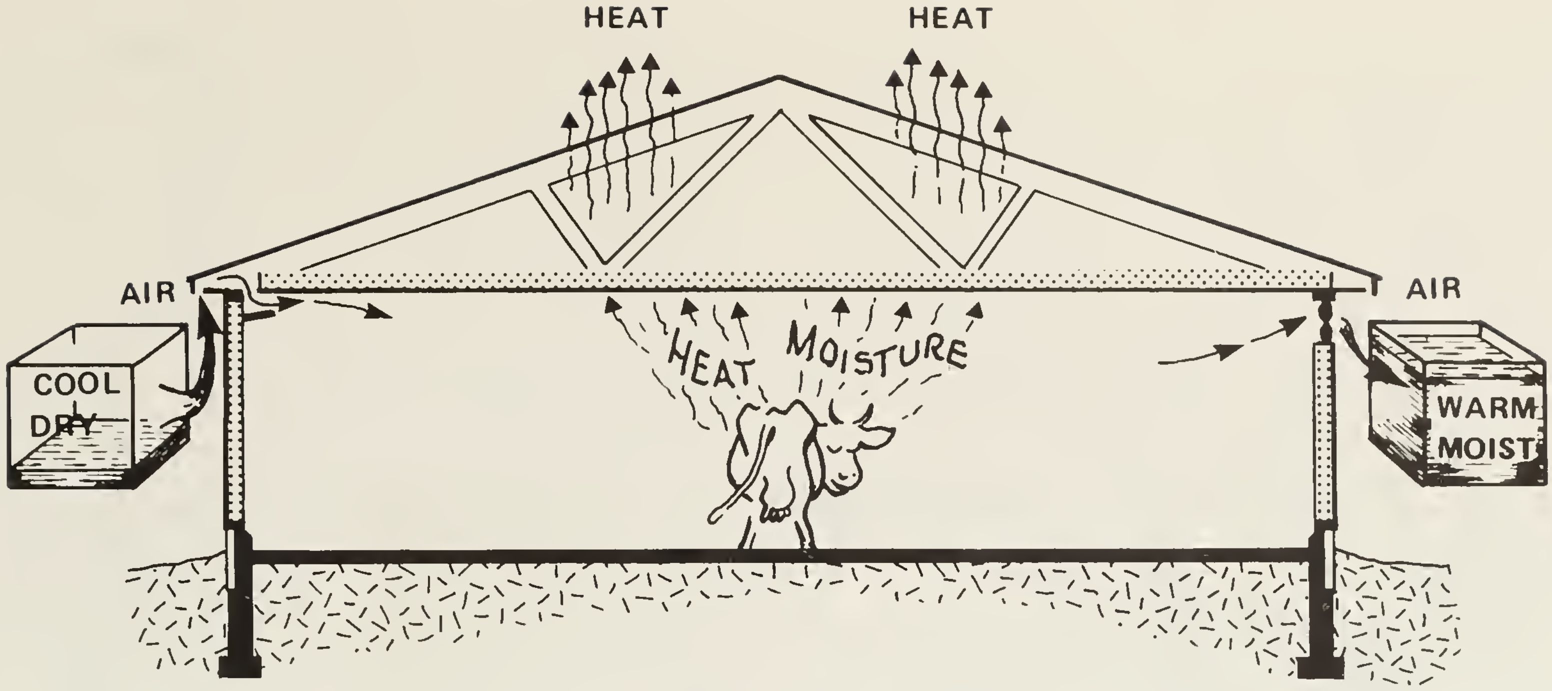



Figure 13 Heat and moisture production.

To conserve heat during cold weather, the ventilation rate (the major source of heat loss) is kept to a minimum; however, it should be sufficient to remove the moisture produced by the animals and still maintain RH below the maximum recommended 80%.

Cattle housed in a warm barn (10°C) produce water vapor at the rate of approximately 0.53 kg per 500 kg cow per hour. One kg of cold air at −30°C and 100% RH, typical of outside conditions in cold winter weather, holds 0.3 g of water vapor. When this amount of air is drawn into the barn, mixed, and heated to 10°C, it can absorb an additional 5.8 g of moisture before reaching 80% RH. Therefore, to keep inside RH below 80% in cold winter weather the minimum required ventilation rate for one cow (500 kg) would be 0.53/0.0058 = 91.4 kg of air per hour. Ventilation exhaust fans, however, are usually specified on a volume flow rate basis. Considering an inside temperature of 10°C, 1 kg of air occupies 810 L. The ventilation rate per cow therefore becomes (91.4 kg/L × 810 L/kg)/3600 s/h = 21 L/s.

This ventilation rate should be considered the minimum allowable to prevent moisture building up in the room beyond 80% RH during periods of cold weather. It assumes a barn temperature of 10°C could be maintained for this ventilation rate; however, the body heat given off by the animals is not enough to make up for the ventilation heat losses and building heat losses during very cold weather.

## Heat balance problem

As can be seen in Figure 14, the heat lost by the ventilation system is five to eight times greater than the amount lost by conduction through the building walls and ceiling (the building in question was assumed to have RSI-3.5 insulation in the walls and ceiling). As the outdoor temperature drops, a point is reached where the heat gain from the cows is insufficient to balance the building and ventilation heat losses. This is referred to in Figure 14 as the critical temperature.

Fan operation is normally controlled by thermostats that react to room temperature. When the outside temperature is higher than the critical temperature, the ventilation rate to maintain a given room temperature is sufficient to keep the room RH below the recommended maximum of 80%. The rate required to keep the RH below 80%, and the maximum rate permitted to still maintain a heat balance are shown as two separate curves in Figure 15. The curves shown are for a typical well-insulated tie-stall dairy barn with no supplemental heat and an inside temperature of 10°C. When the outside temperature drops below the critical temperature, the ventilation rate that will maintain the desired room temperature is insufficient to keep the RH below 80%. As a result, humidity builds up in the room and fogging and condensation probably will occur. This condition, although undesirable, is not very harmful if it continues for only a short time. However, over a long period it can lead to respiratory problems for cattle, and contribute to structural deterioration of the building.

One solution to this heat balance problem is to add heat. This warms the additional air needed for moisture control. It is important to have a fan small enough to provide the lowest allowable rate of ventilation (Step 1). The Step 1 rate should be equal to or preferably much less than the rate that will control moisture under cold winter conditions. In this way, Step 1 should be able to run continuously with the next fan (Step 2) cutting in and out to maintain the desired room temperature.

Alternatively, if supplemental heat is not provided, a humidity problem may be alleviated slightly by lowering the inside room temperature. The variation of RH with inside temperature for a dairy tie-stall barn without supplemental heat is shown in Figure 16.

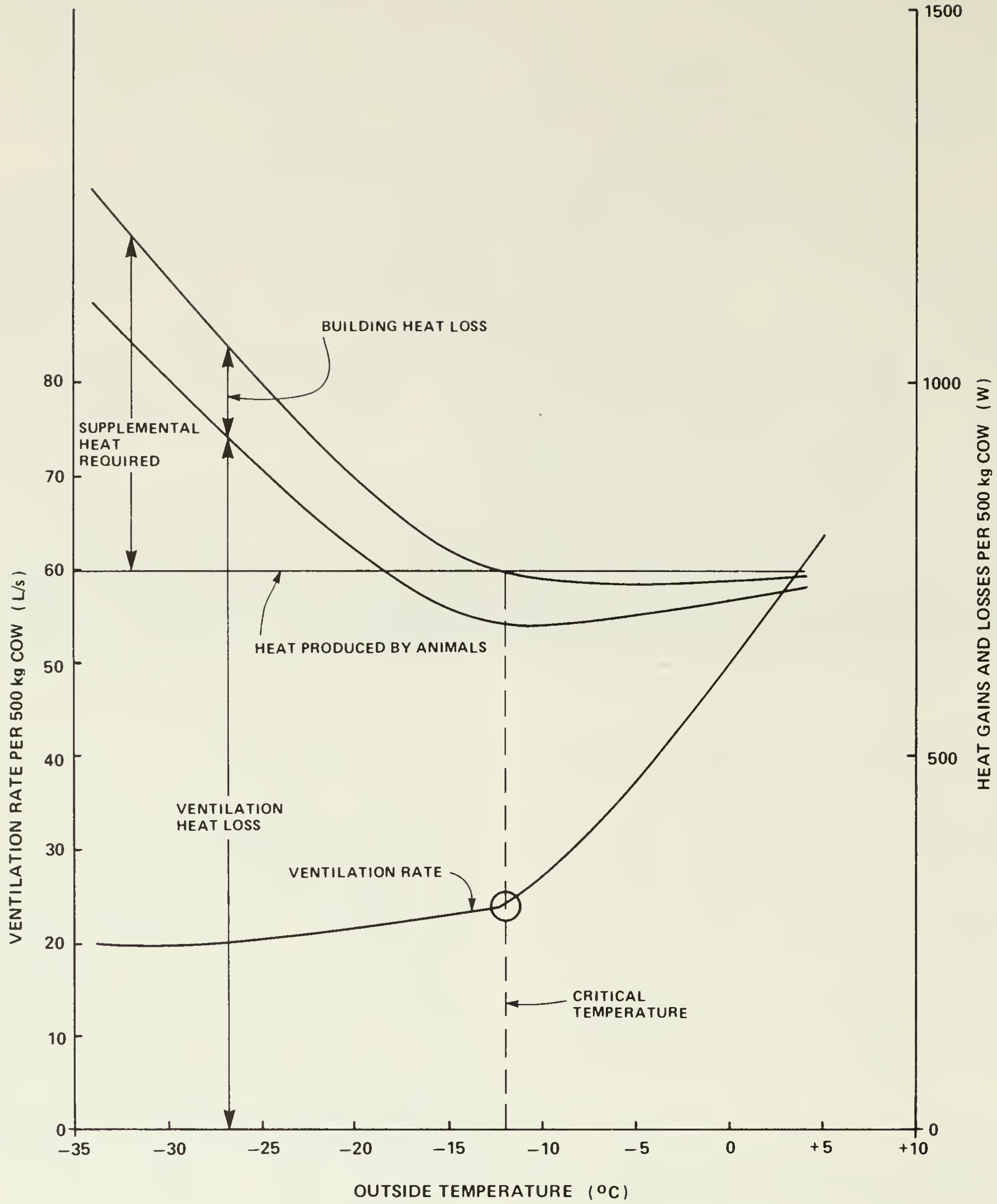



Figure 14 Heat gains and losses, and supplemental heat required for a barn temperature of 10°C.

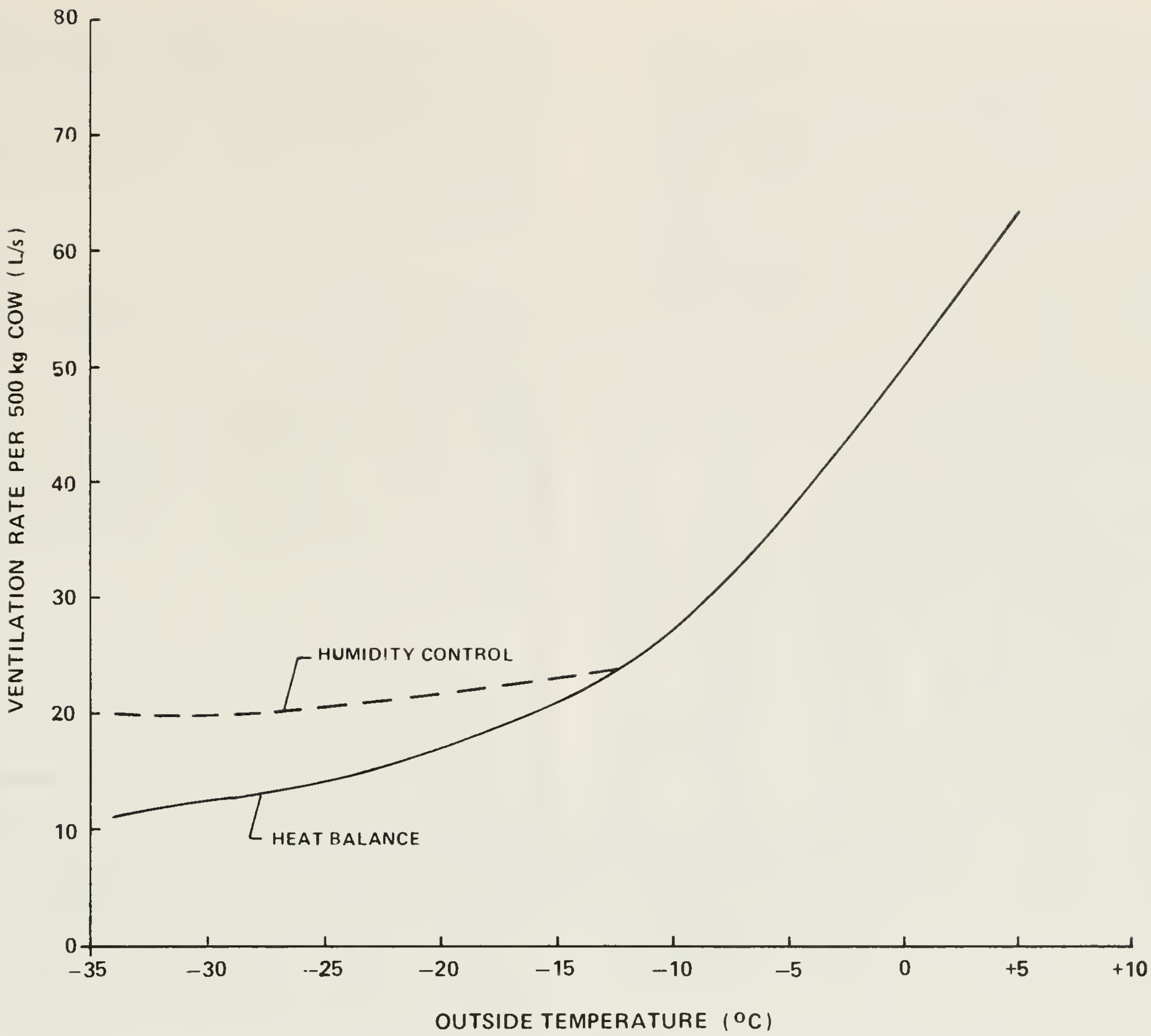



Figure 15 Ventilation rates for heat balance and humidity control in a tie-stall dairy barn.

## Fan controls

Figure 14 shows that as the outside temperature rises above 0°C the required ventilation rate greatly increases. If a single large fan is switched on and off to control the ventilation rate over the whole temperature range, it will run possibly less than 10% of the time during cold weather. As a result, large air inlet openings are required when the fan is operating; but, when the fan is not operating, air can move freely in or out through the inlets due only to wind and gravity. Large volumes of cold air may then drift in slowly, causing drafts and poor air circulation within the room. In winter, moist warm air can flow backwards through the inlet into the attic when the fan is off, since warm air is lighter than cold. Wind blowing against the fan side of the building can cause the same problem. In either case, this backflow may cause serious condensation and frosting problems on the underside of the roof. Figure 17 shows a better system; four fans or sets of fans, controlled by separate thermostats set to provide stepped rates of ventilation, approximate the ideal ventilation curve. The upper diagram shows the same ventilation rate curves as Figure 15 for humidity control and heat balance. Superimposed on these are practical rates that can be obtained by careful selection of fan sizes and thermostat settings.

The Step 1 rate must be below the minimum ventilation requirement so that it can provide continuous ventilation even in the coldest weather. Step 1 is therefore shown as 10 L/s per cow. Steps 1 and 2 can be obtained by using a two-speed fan wired to run continuously at low speed, switching to high speed on thermostat demand. Alternatively, you can use two single-speed fans; this has the advantage that either fan can be designated Step 1 in case the other fails. The thermostat controlling Step 2 should be set approximately 2 Celsius degrees above the minimum desired room temperature while the thermostat controlling Step 3 should be set approximately 5 degrees higher still. The thermostat controlling Step 4 in turn should be set another 5 Celsius degrees above this. If large doors and windows are used for summer ventilation, the Step 4 rate may be omitted.

To avoid wasting heat, supplemental heat should be switched on only during Step 1 ventilation, and switched off when the ventilation increases to Step 2. This is done by using the same thermostat to control both heating and Step 2.

Some thermostats (such as the Honeywell T631A) have two sets of contacts and three electrical terminals (SPDT type) so that the same thermostat can be wired for both heating and cooling control. Typically, there is a fixed temperature differential of about 2 Celsius degrees between start and stop. Figure 17 shows how in cold weather the Step 2 thermostat keeps inside temperature cycling between 10°C and 12°C. This thermostat starts the Step 2 fan at the same instant it stops the heating. With more ventilation and no heat, the inside temperature is pulled down until the thermostat switches the Step 2 fan OFF and the heat ON. Room temperature rises again and the cycle repeats.

Figure 18 shows how stepped ventilation can be wired using several single-speed fans. The Step 1 fan should be small enough to run continuously. The Step 1 thermostat ($T_A$) should be set at well below the desired room temperature but above freezing, since it serves only as a safety device in case the heating fails or the building is only partly stocked with animals. A warning buzzer (preferably battery-powered) can also be wired to thermostat $T_A$ to indicate low temperature problems due to a power or heating failure. Typical thermostats may be capable of directly controlling the Step 2 fan (usually 0.12 to 0.25 kw) but the heating, if electric, will require a relay. The voltage rating of the heating relay coil must match the line voltage used for the Step 2 fan (115V or 230V).

Figure 19 shows stepped ventilation with one two-speed fan for both Steps 1 and 2. This method is useful in smaller buildings, where the smallest 1725-rpm fan sold moves too much air for Step 1. Using a two-speed motor (850/1725 rpm, for example) can reduce the Step 1 ventilation rate to about one-half the Step 2 rate. This also reduces the number of components (fans, thermostats, etc.) to be purchased.

In this case a two-stage ventilation thermostat ($T_A$) is wired with the two stages in series; the higher temperature stage has two sets of contacts wired to run the two-speed fan motor at fast speed on temperature rise, and slow speed on temperature drop. Another connection from the fast speed terminal of the thermostat to the interlock relay opens the heating circuit whenever the fan is switched to fast, to prevent wasting heat. The relay coil must be chosen to match the line voltage (115 V or 230 V) used for the fan.

The low-temperature stage of thermostat $T_A$ serves only to stop the two-speed fan if barn temperature drops to a temperature that might freeze the watering system or chill young livestock. However, it is better to have the barn adequately stocked so that the two-speed fan never shuts off. Some two-stage thermostats (such as the White-Rogers 2A38-14 or Penn A19 BBC-2) permit independent adjustment of the high and low temperature stages; with this feature adjust the high stage to 2 Celsius degrees above the minimum desired room temperature and the low stage well below this but above freezing.

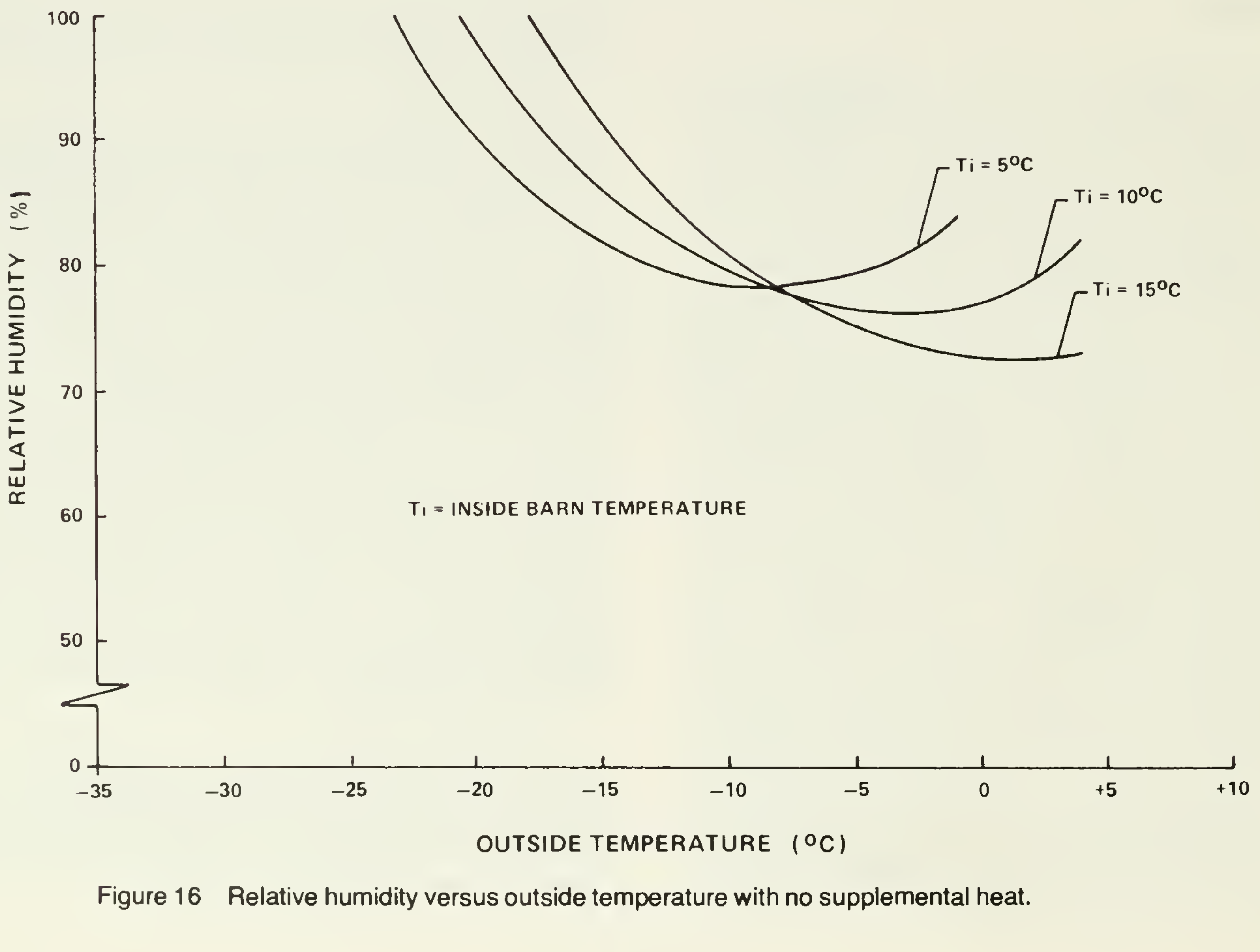



Figure 16 Relative humidity versus outside temperature with no supplemental heat.

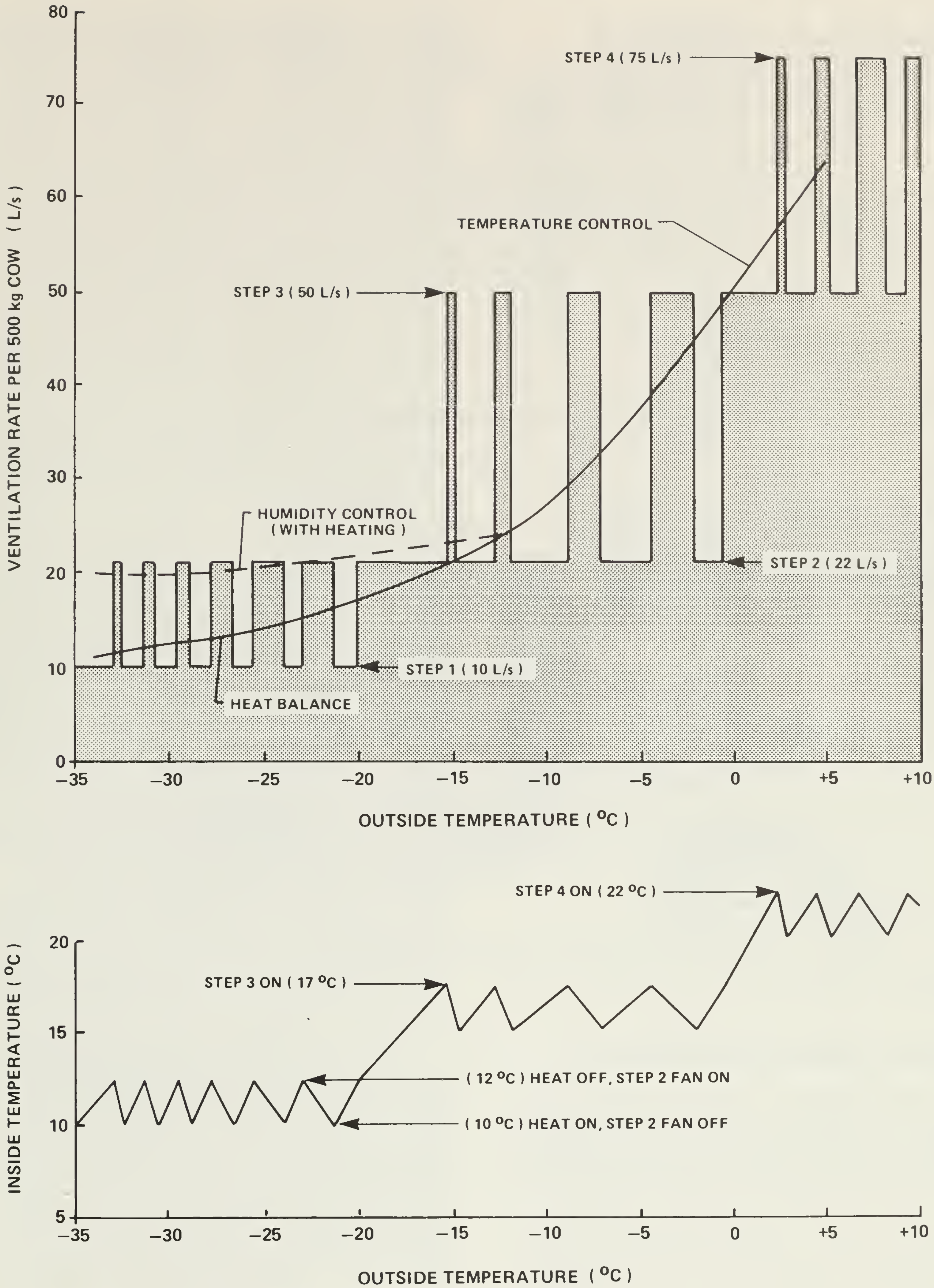



Figure 17 Stepped ventilation with interlocked heating control.

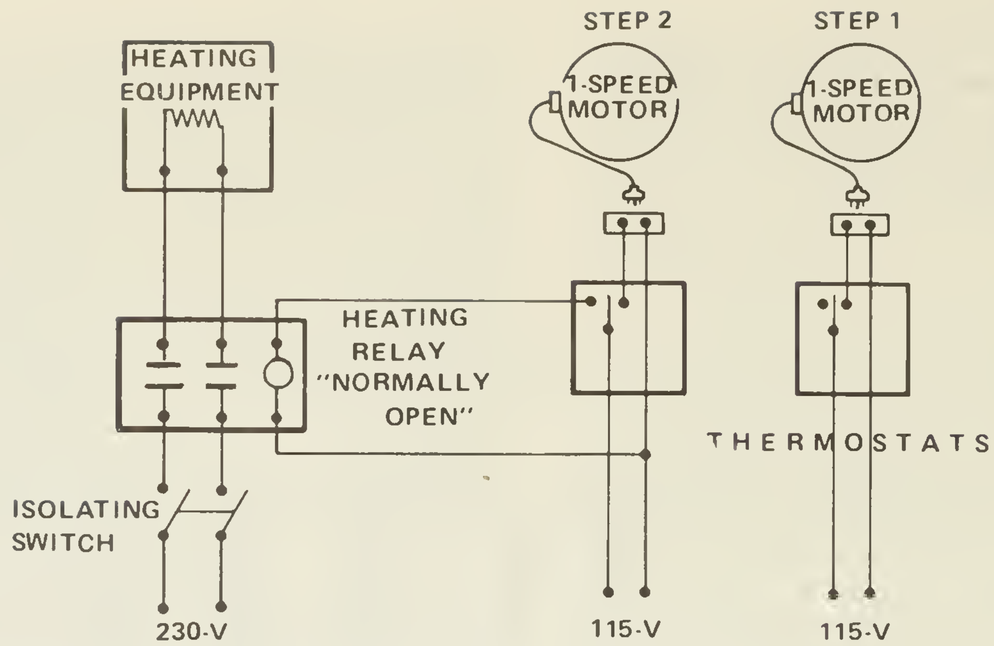



Figure 18 Control diagram for ventilation with single-speed fans (Step 4 not shown).

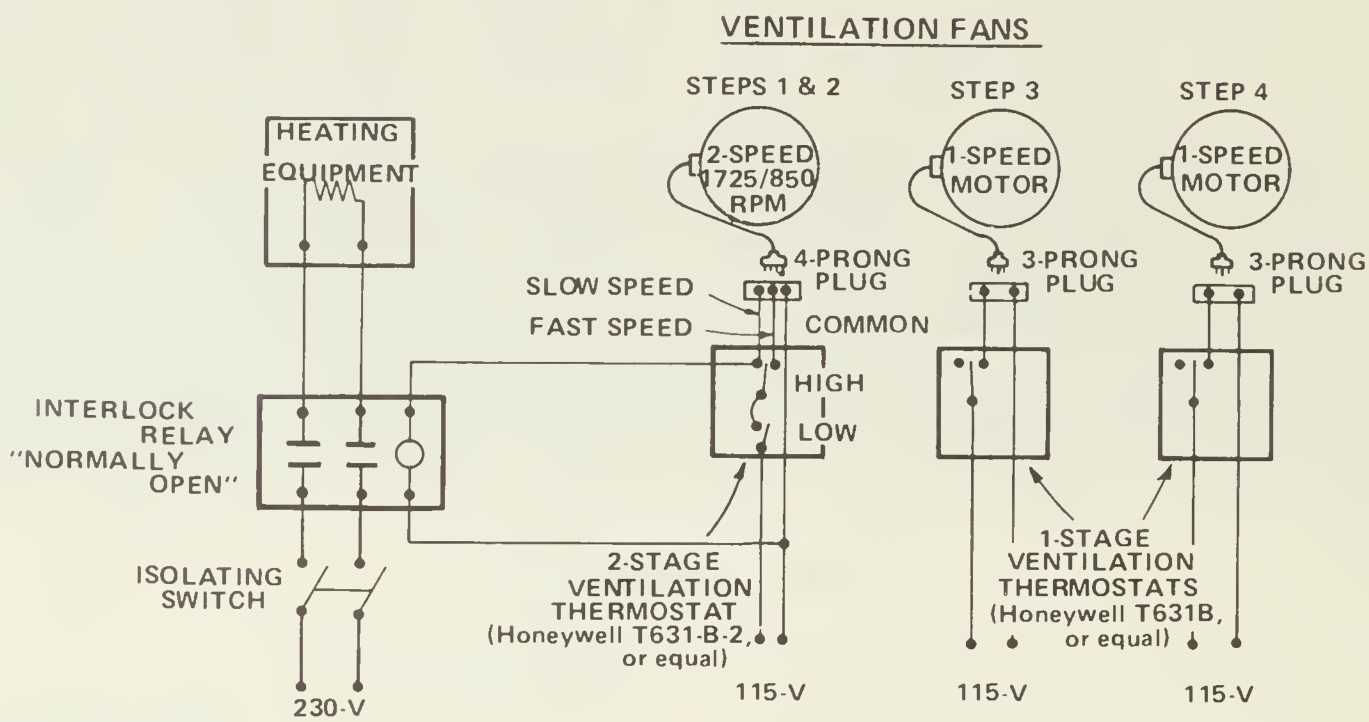



Figure 19 Control diagram for ventilation with two-speed fans for Steps 1 and 2.

## Fresh air inlets and air distribution

The exhaust fans and their controls are only half of the ventilation system; the other important part is the air inlet. The fresh air inlet determines the movement and distribution of air within the room and is thus the most important element in the system.

Fresh air distribution involves two distinct temperature situations. In fall, winter and spring, outside air is usually much cooler than the controlled conditions inside the building and care must be taken to avoid cold drafts hitting the cattle. In summer, however, it may be desirable to direct air onto the cattle to relieve stress due to high temperature and humidity.

When cold air enters the warm barn, it is heavier than surrounding warm air and sinks rapidly to the floor, causing cold drafts (Figure 20A). To solve this problem, the cold air must be directed along the ceiling and jetted forcefully into the room to promote rapid air mixing and prevent sinking (Figure 20B). An air jet velocity of 4 to 5 m/s through the inlet opening is recommended. Also, the incoming air will stay up and move further horizontally if it can skim along a smooth surface such as the ceiling, since it does not have to mix immediately with warm air at both upper and lower surfaces.

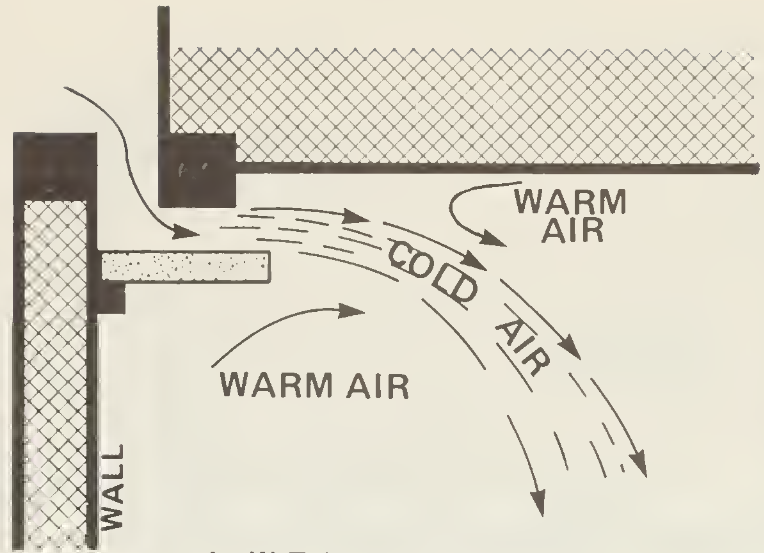
The amount of air coming through the inlets is controlled by the capacity of the exhaust fans. The velocity, however, is controlled by both the capacity of the fans and the size of the inlet openings. To maintain the velocity recommended for good mixing, air inlets must be adjustable. Automatic systems are available to adjust the size of the inlet slots as the stepped ventilation switches up and down, but careful operators can make these adjustments manually. With manually adjusted inlets, set the opening to give an air velocity of approximately 4 m/s for the Step 1 ventilation rate in cold weather. Of course, this setting will give a higher velocity when the rate increases to Step 2. If a velocity meter is unavailable, figure that the ventilation rate equals the area of the air inlet opening times the inlet air velocity. From this you can determine the inlet slot size you need. For spring and fall weather, when the Step 3 rate is required, open the inlets to accommodate the higher airflow rates but continue to maintain at least 4 m/s velocity for good mixing. For hot summer ventilation, it is best to rely on large sliding doors as the air inlets. If you can only use fans for hot weather ventilation, try opening the inlet wide enough to give a low velocity jet; air will tend to drop onto the cattle and reduce some of the hot weather stress.

Air movement in a room is influenced much more by the direction and speed of incoming fresh air than by the location of the exhaust fans. Figure 21 shows the results of smoke tests in a typical building with a center air inlet. In Figure 21A, fresh winter air comes through the attic into the center slot and is directed both ways along the ceiling. This sets up a turning of the air that is supplemented by convection currents due to heat rising from the animals. Figure 21B shows the inlet opened full to reduce velocity during hot summer days.

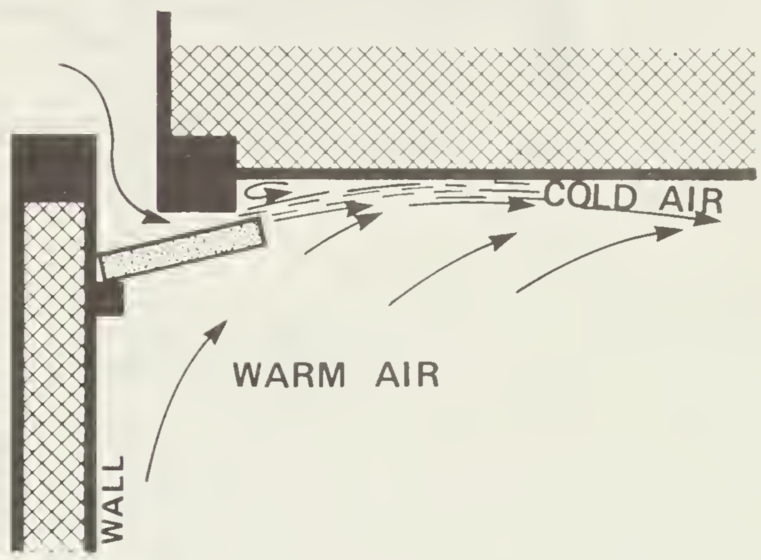
The area directly influenced by the exhaust fans is comparatively small; with properly designed and operated inlets, the location of exhaust fans is relatively unimportant in buildings up to 30 m long.

Figure 21A shows another useful ventilation principle. In cold weather, fresh air comes to the inlet slots from the attic by way of doors into the insulated duct. This lets the sun preheat the inlet air slightly and recaptures heat lost through the ceiling, helping maintain a heat balance in the barn. This will not help at night when the heating requirement is greatest but it can help dry out a dairy building having insufficient supplemental heating.

In summer attic temperatures under a hot roof can rise dramatically above outside temperatures. The doors from the attic to the insulated duct should be closed, forcing air to enter the duct at both gable ends rather than from the attic. Attic gable end doors must be big enough to supply the full summer ventilation rate without developing appreciable suction in the attic duct. This ensures ventilation directly from outside without picking up attic heat. These doors are closed during cold weather.

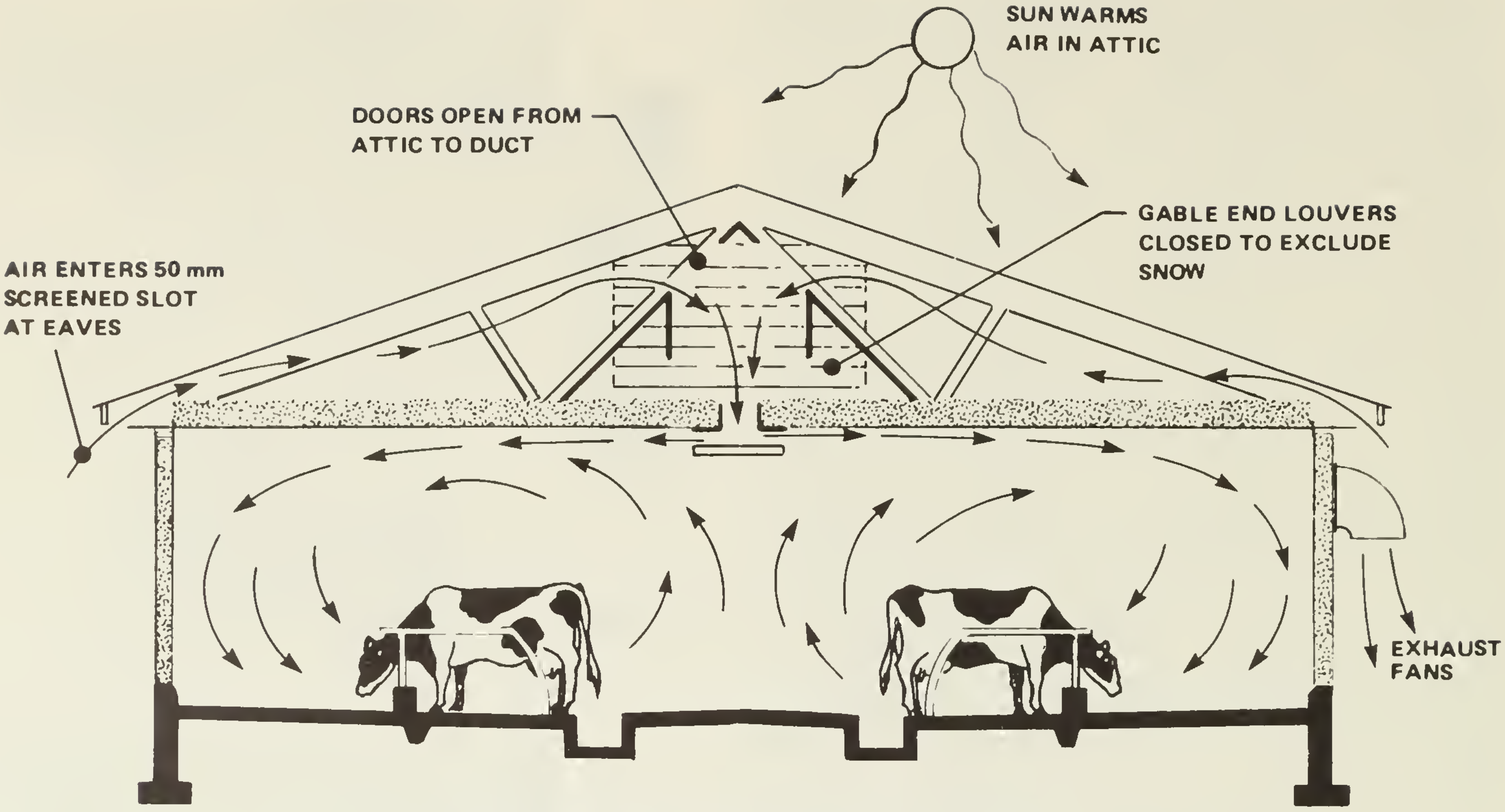



A. WITH INLET OPEN TOO WIDE, LAZY STREAM OF COLD AIR SINKS TO FLOOR CAUSING COLD DRAFT

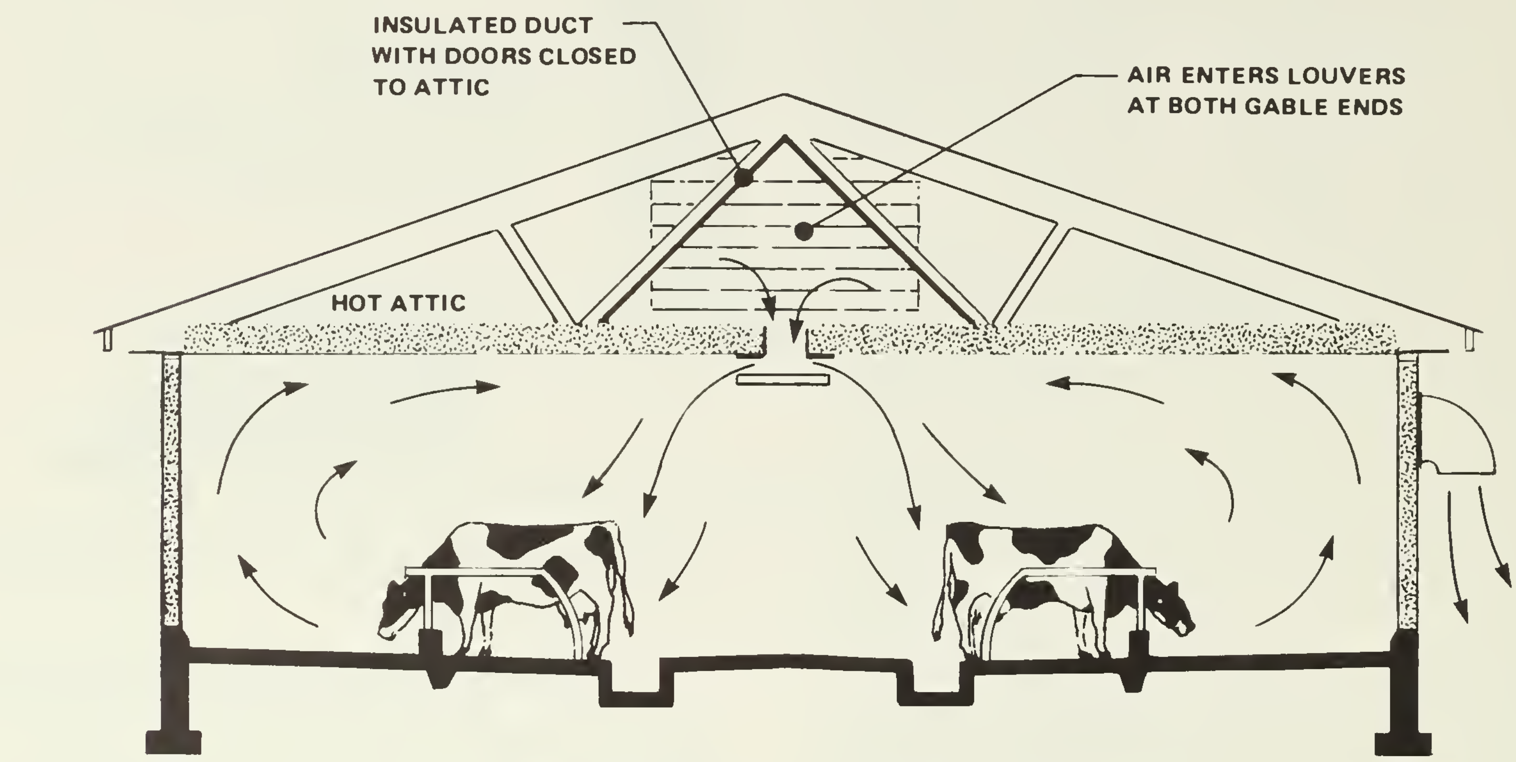



B. WITH INLET ADJUSTED CORRECTLY, HIGH-VELOCITY COLD AIR SWEEPS THE CEILING AND MIXES WITH WARM AIR

Figure 20 How the size of an air inlet slot affects the jet of cold air.




A. NORMAL OPERATION WITH INLET SLOTS DIRECTED HORIZONTALLY AT CEILING




B. HOT WEATHER OPERATION WITH INLET SLOT WIDE OPEN

Figure 21 Tie-stall barn with center air inlet.

## Fans, inlets and static pressures

Up to this point little mention has been made of the forces that cause ventilation air movement. With exhaust fan ventilation, the fans suck air from the room, reducing air pressure to less than that outside. Outside air slips through any openings, large or small, to try to equalize the two. The importance of maintaining a high inlet velocity has already been emphasized. Inlet velocity however is directly related to the pressure difference, outside-to-inside. This difference is usually measured in mm of water, sometimes called water gauge. Figure 22 shows how static pressure is measured and the relation between static pressure and inlet velocity. The small glass U-tube partly filled with colored water gives a direct measurement of the pressure reduction inside the building. For example, to get a velocity of at least 4 m/s for good mixing, the static pressure must be about 12 pascals (Pa) (1.3 mm of water).

Of course, the higher the static pressure, the harder the fans must work to remove air. They must do more than just draw air through the inlets. Figure 23 shows the pressure effects of a 30 km/h headwind blowing against the exhaust side of the building. If this fan blows straight into the wind without the protective hood shown, it has to put out 42 Pa (4.3 mm of water) static pressure just to open the fan louvers. Yet another 20 Pa (2.0 mm of water) of suction has to be developed to draw air to the inlet slot through the leeward wall. Thus the total pressure at the fan is 20 (leeward suction) + 12 (inlet slot) + 42 (headwind) = 74 Pa (7.6 mm of water). This is dangerously close to the point where many ventilation fans stop moving any air. Furthermore, wind pressure increases as the square of the wind velocity; a 60 km/h wind develops pressures four times as great as a 30 km/h wind.

One possible answer is to place exhaust fans in a leeward wall. Unfortunately, the wind can blow from any direction and the leeward wall today may be the windward wall tomorrow.

Part of the solution is to hood all inlets and outlets so that air enters and leaves the building vertically (perpendicular to the wind flow). Fan hoods should turn down a full 90° as illustrated in Figure 23, and extend more than halfway down the wall. Wind effects may also be reduced if the hood is set out about 100 mm from the wall as shown. Inlets can be partly sheltered by the eaves. This also helps to keep out snow, especially if the eave slot is placed just behind the face board and not against the wall.

Wind can reduce ventilation rate by interfering with fan output, or it can cause overventilation. Where unprotected inlets are open at both walls, wind can force air through a building even with the fans stopped. This can be a serious problem in cold weather, when ventilation requirements are small.

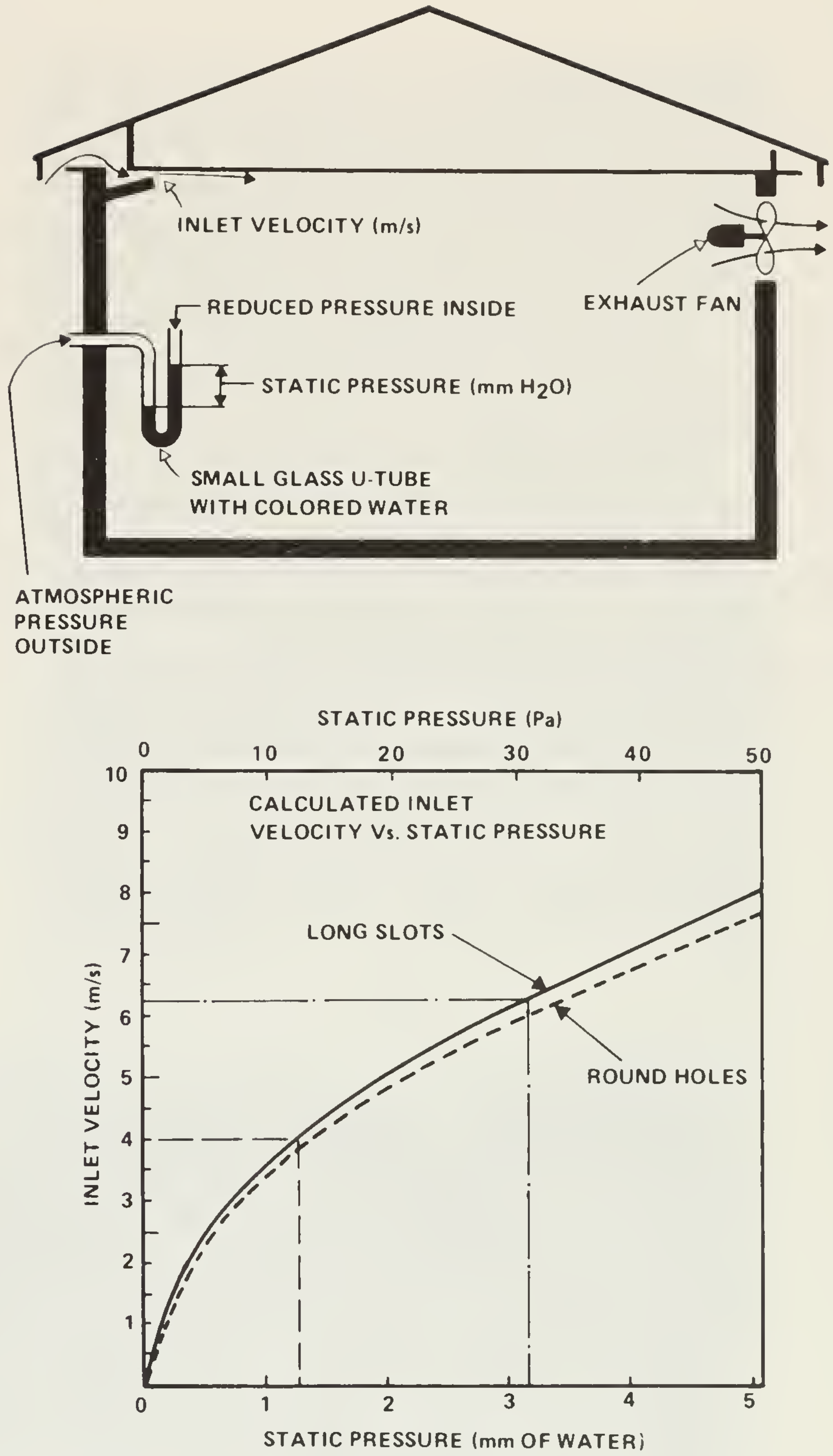



Figure 22 Measuring static pressure, and its relation to the velocity of the inlet air stream.

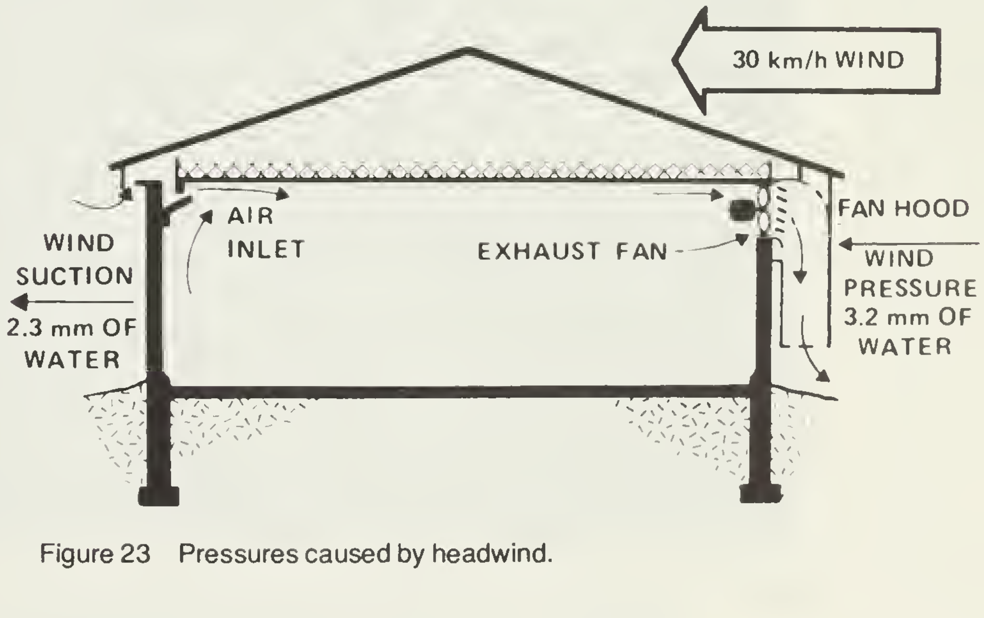



Figure 23 Pressures caused by headwind.

## Other systems

Ventilation systems discussed up to this point all use exhaust fans (Figure 24) to reduce the room pressure to a little below that outside. This has the advantage that small cracks in the structure act as fresh air inlets, preventing moisture from penetrating the spaces within the walls and ceiling. This helps keep the building dry and prevent decay. However, if a door is accidentally left open, the doorway becomes the air inlet.

Long slot air inlets are not always easy to build into older buildings when remodelling. An insulated rectangular panel suspended below a slightly smaller ceiling opening makes a good inlet for remodelled barns. The panel should be adjustable up and down for various rates of ventilation.

Manufacturers now offer a variety of ventilation equipment designed to make installation easier and to improve the control of airflow to the animals. Several powered inlets and air blenders are available. An important advantage of these recirculating air blenders is that good air distribution can be maintained even at low ventilation rates. These systems recirculate air to the inlet openings at a high constant rate, and fresh outside air is blended into the recirculated air at a rate that varies with building temperature. This eliminates the need for frequent adjustment of the winter air inlets to maintain the required inlet velocity for good mixing. Powered air blenders use more electric energy than small exhaust fans for winter ventilation. However, a large part of this energy is not wasted but returned as supplemental heat. Each of these units should be installed according to the manufacturer's recommendations.

A number of suppliers also offer variable-speed fans. In theory, variable-speed fans provide a continuously variable ventilation rate as opposed to the stepped rate of single- and two-speed fans. However, some of these units have shown poor performance due to difficulty in wiring, difficulty in setting thermostats or controllers, and motor burn-out when running at low speed for extended periods. As well, when the variable-speed fan is running at low speed it can't develop much pressure and is very susceptible to being overcome by pressure or suction caused by wind. Check first with neighbors or extension personnel to verify the performance and reliability of any particular unit before you install it.

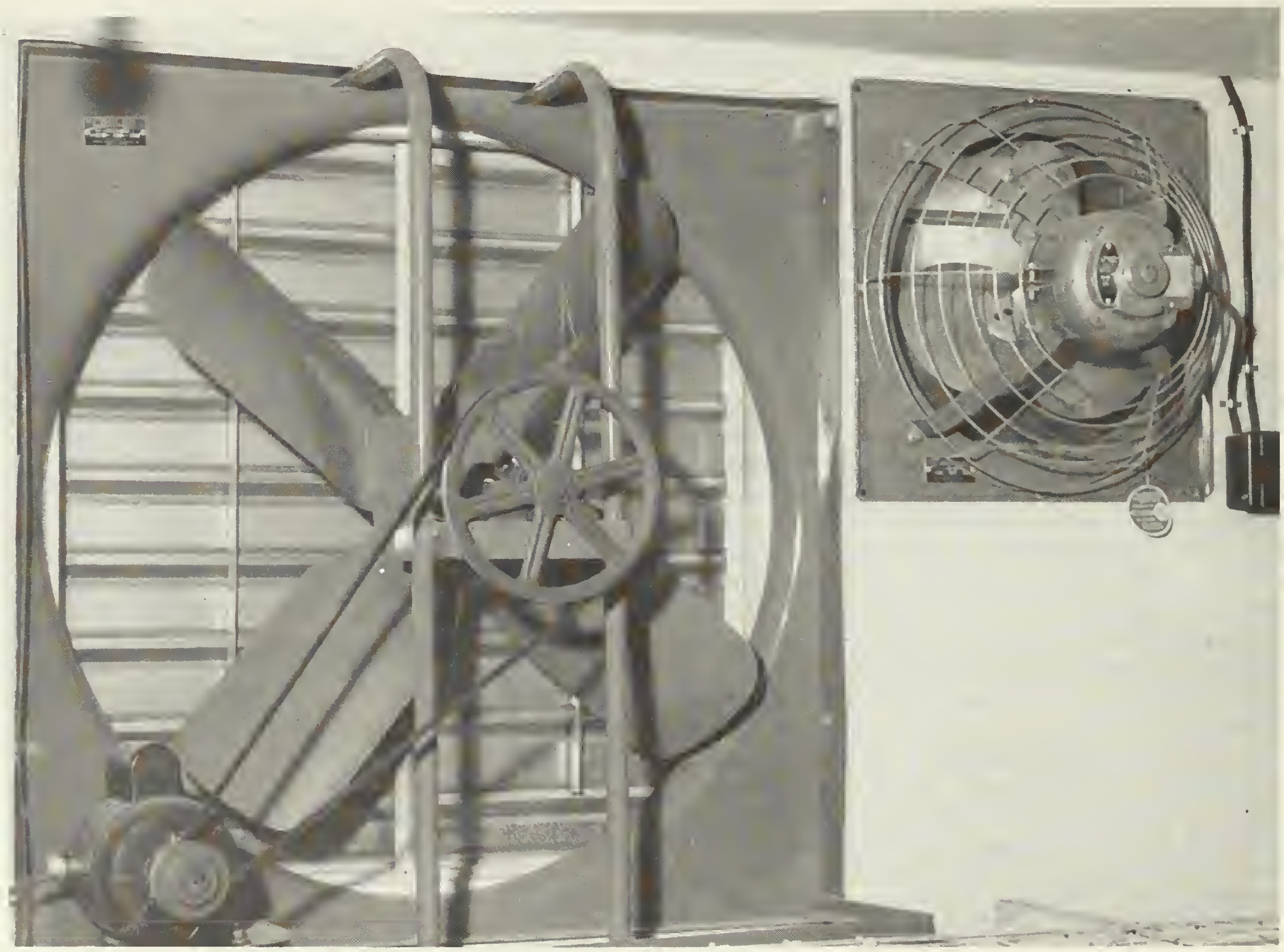


Figure 24 Two-fan exhaust system for stepped ventilation. The small fan is two-speed direct drive for good winter performance against headwinds. The large fan is the low-speed belt-driven type for high output per watt in hot weather. Photo courtesy of Ontario Hydro.

## Porous ceilings

The greatest amount of heat lost from a tie-stall building is that lost through ventilation. It is of course directly proportional to the ventilation rate, which in turn is based on the moisture the fans have to remove from the building. If moisture could be removed in some other fashion, then the ventilation rate, and consequently the ventilation heat loss, could be reduced. Porous ceilings are currently being tried in some barns as a way to get rid of moisture without losing as much heat as with the more conventional ventilation systems.

The construction of one type of porous ceiling is shown in Figure 25. The attic is open to outside conditions as much as possible through the use of eave slots, an open ridge, and large doors in the gable ends. The porous ceiling then acts as an air inlet to the building. The incoming air, as it passes through the ceiling, picks up some of the heat that normally would be lost from the building. However, looking back at Figure 13, it can be seen that even if all the building heat losses were reduced to zero, a net heat deficit could still occur. Since the ceiling is porous, and since in cold weather the vapor pressure inside the barn is greater than that outside, some moisture can diffuse through the porous ceiling into the attic. This in turn means that the amount of moisture to be removed by the exhaust fan is reduced and the ventilation rate and resultant heat loss can be lowered.

Although the exact amounts of heat saved and moisture transferred with the porous ceiling are not known, several porous ceiling installations in colder areas such as northern Ontario and Quebec indicate that such a system can be quite worthwhile.

One method of constructing a porous ceiling is with 100 to 150 mm of friction-fit fiberglass insulation laid over a wire mesh, such as galvanized chicken wire. The porous portion of the ceiling is normally a strip down the middle of the building stopping about 2400 mm short of either end. The remainder of the ceiling can be solid. The proportion of the ceiling that should be porous has not been defined; installations where the porous portion comprises approximately 30% of the total area seems to work well.

Another system is to place about 300 mm of chopped hay or straw over 140 mm ceiling boards spaced 20 mm apart. Again the best proportion of board to space has not been well defined, but a ratio of 8:1 seems to work well. Proponents of this system suggest 75 to 100% of the ceiling be built this way.

With either the spaced boards or fiberglass-over-mesh system, it is important to maintain the attic conditions as close as possible to outside conditions; thus, good natural attic ventilation is essential. This helps prevent condensation in the attic, and increases the vapor pressure difference between the barn and the attic, promoting moisture diffusion. Open eave slots and an open ridge are beneficial. Gable doors, cable controlled to permit closing during stormy weather, could also help. Snow should not be a big problem with an open ridge provided no roof ridge cap is used; however, keep a close check on the attic during winter. The use of a porous ceiling, of course, requires the installation of exhaust fans for winter ventilation.

There is considerable potential for porous ceilings; however, considerable research remains to be done on the effects of insulation thickness, porous ceiling proportions and attic ventilation. Research is also needed to establish best ventilation rates, and develop ridge and eave designs for use with porous ceilings.

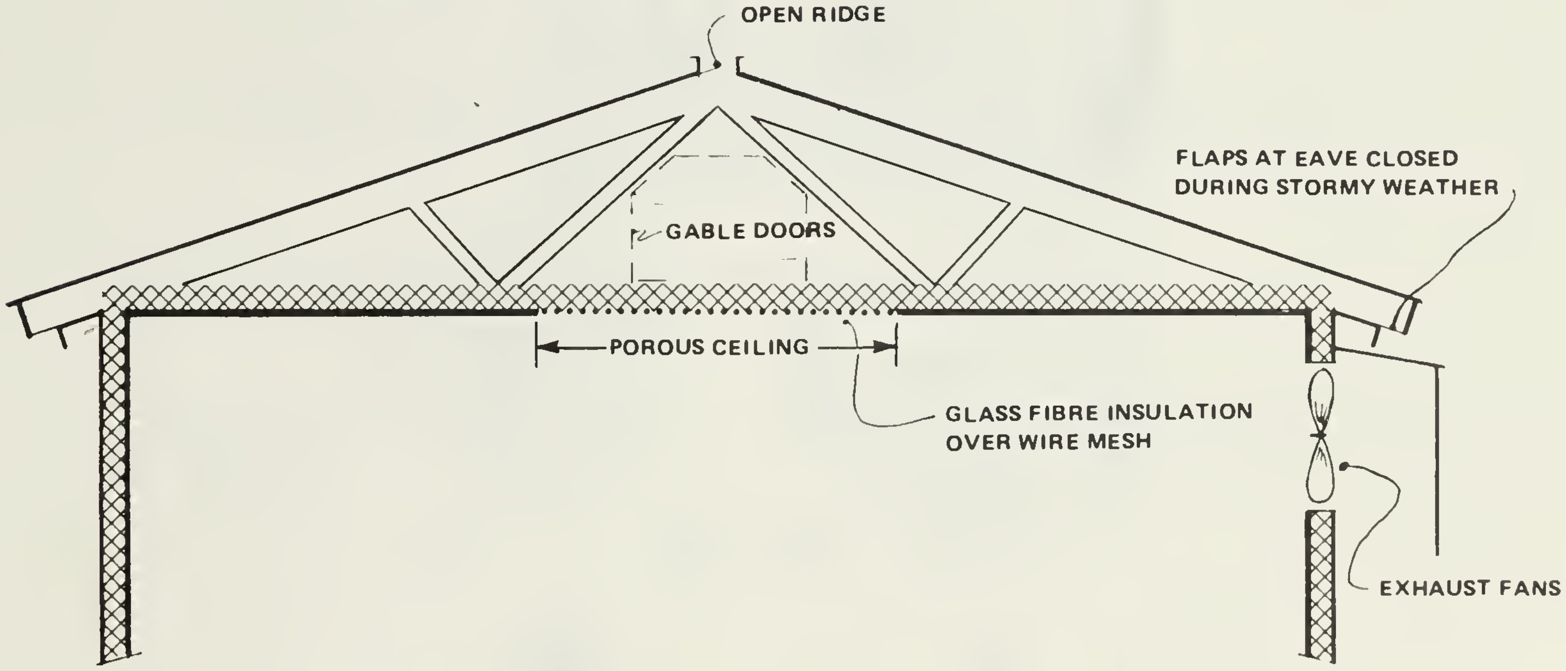



Figure 25 Cross-section of a barn with porous ceiling ventilation.

## 5. MILKING

### Mechanics of milking

To understand the requirements of a milking system, it is essential to have a basic understanding of both the biology and the mechanics of milking.

Each quarter of the cow's udder contains millions of tiny sacs, called alveoli. These are surrounded with blood vessels providing blood for milk synthesis. The outside of each is also surrounded by tiny muscle fibers which contract upon stimulus, compressing the alveoli. Milk is produced in the alveoli continuously and is slowed down only by pressure buildup when the alveoli are full of milk. The alveoli are connected via a duct system to the udder cistern and to the teat itself, as illustrated in Figure 26.

At milking time a stimulus, in the form of an udder massage or familiar sounds associated with milking, induces the release of a hormone, oxytocin, from the pituitary gland. Oxytocin is transported via the bloodstream to the udder where it activates the muscle fibers surrounding the alveoli. The fibers contract, forcing milk out of the alveoli into the duct system and udder cistern. This is known as "let down". The reaction occurs about 1 minute after stimulation and lasts for 6 to 8 minutes.

Another hormone, adrenaline, is released if the cow is frightened, hurt, or irritated and rapidly counteracts the effects of oxytocin, blocking the release of milk.

The action and counteraction of these two hormones emphasize the importance of careful and well-timed handling and milking of each cow.

Figure 27 illustrates the basic operation of.the milking machine. A constant vacuum exists in the milker pail. This vacuum is transmitted through the milk tube to the teat end. A pulsator is situated between the vacuum line and the chamber created by the teat-cup shell and the inflation. The pulsator alternates the pressure in this teat-cup chamber between atmospheric pressure and line vacuum.

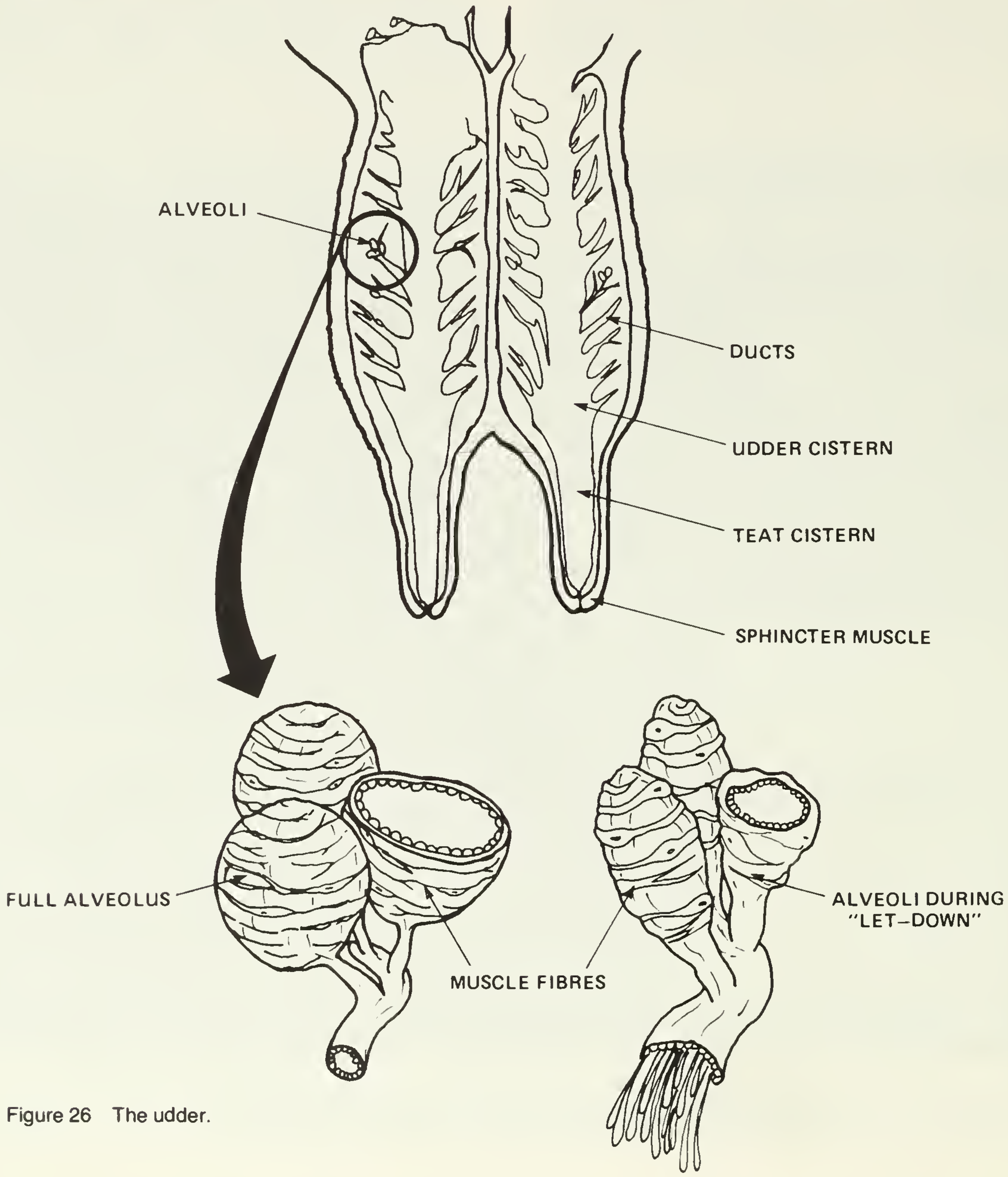



Figure 26 The udder.

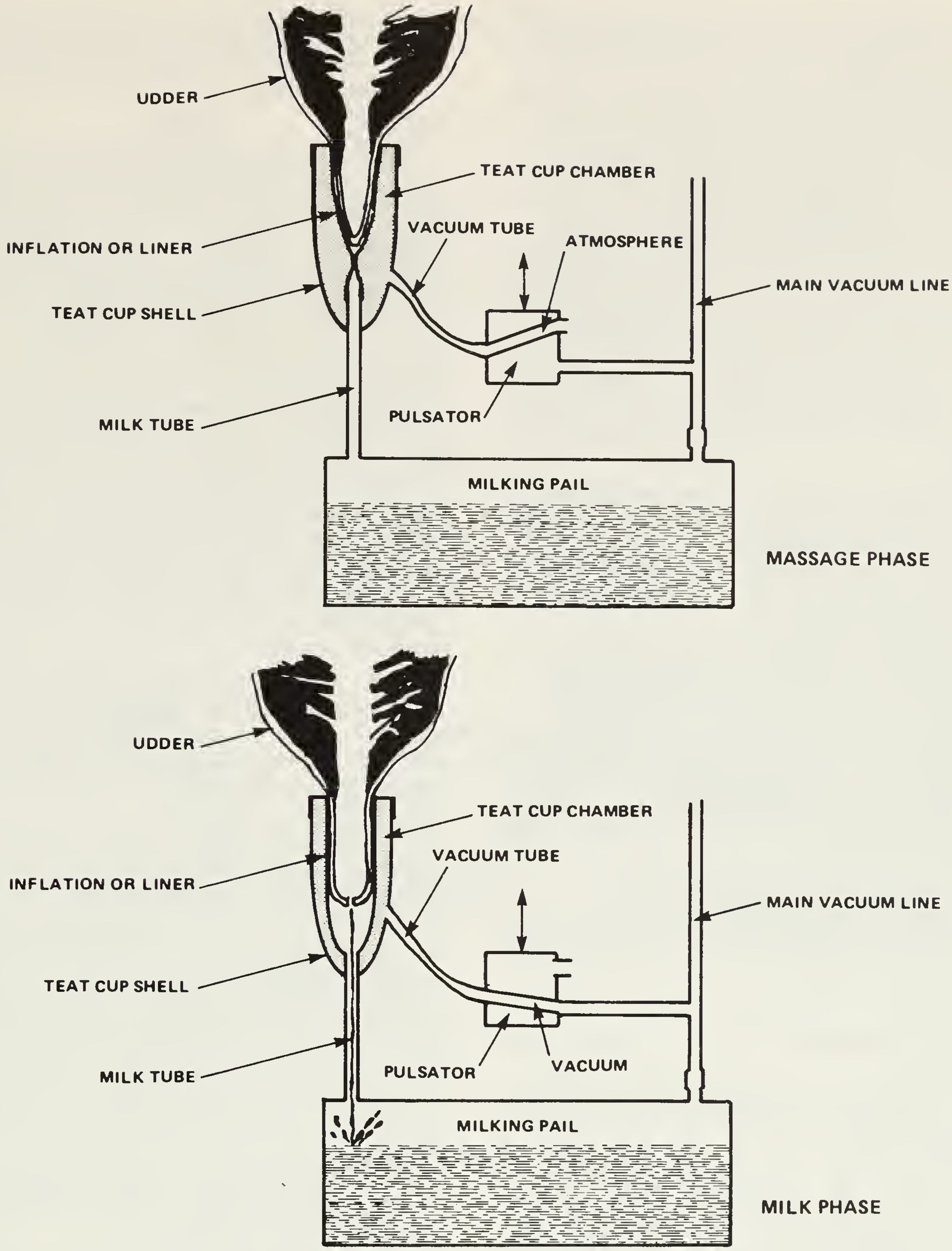



Figure 27 Schematic of the principles of operation of milking machine.

When there is atmospheric pressure between the inflation and shell, and vacuum inside the inflation, the inflation collapses around the teat as shown in Figure 27A, providing the rest or massage phase of the milking cycle. This phase is essential to prevent tissue damage caused by body fluids congesting at the teat end if the teat is not relieved from the continuous milk vacuum. When the pulsator restores vacuum to the chamber between the inflation and shell, the inflation is then subjected to vacuum on both sides and returns to its normal open position. The pressure inside the inflation is less than the pressure inside the udder. This draws the sphincter muscle open and milk is expelled for the duration of the cycle. This process is repeated until all milk has been removed. Failure to remove the machine when this occurs will result in serious injury to the cow.

An organized milking routine will establish operator efficiency and good cow response at milking time. A suggested routine is:

1. Clean and massage udder with a single-service towel that has been immersed in hot udder-wash solution.
2. Remove three or four streams of milk into a strip cup and check milk for abnormalities.
3. As soon as teats fill with milk attach milker.
4. When milk flow stops or is reduced to a minimum, machine strip by running the hand down the sides of the quarter being stripped a few times. Remove the machine gently by breaking the vacuum at the mouth of the liner.
5. Dip teats in a teat-dip preparation.
6. Dip teat cup assembly in clean water followed by a sanitizer solution before you use it on another cow.

## The vacuum system

PUMPS Rotary vane and piston pumps are the most common pumps used to provide the vacuum for milking systems.

Vacuum pumps are volume flow rated at specific vacuum and rpm levels. There are two methods used to rate vacuum pumps, the ASME (commonly known as the American Standard method) and the New Zealand method. Figure 28 illustrates the difference between the two ratings.

The New Zealand method measures the volume flow rate of air on the vacuum side of the pump, which is expanded to twice the volume measured on the atmospheric pressure side (where the ASME method takes its measurements). Thus, for a given pump, the New Zealand rating will be double the ASME rating.

The size of vacuum pump required depends upon a number of factors, including:

1. number of milker units
2. operating vacuum level
3. size and length of vacuum lines
4. type of pulsator
5. type of system (i.e., bucket or pipeline)
6. requirements of other vacuum-operated equipment

Minimum airflow requirements of some components of milking systems are given in Table 2. The total airflow capacity is the sum of the ratings of each of the components (plus reserve airflow capacity in the case of pipelines). Consult manufacturer's specifications for specific airflow ratings for an individual component; however, in no case should the values in Table 2 be reduced.

RESERVE TANKS Many vacuum systems use a reserve tank. This provides a cushion to absorb any sudden inrush of air that would otherwise cause a vacuum drop, and acts as a trap to prevent liquids from accidentally entering the pump. The reserve tank should be galvanized or otherwise protected to withstand corrosive cleaning solutions. A tap should be installed to drain any trapped liquids. A rule of thumb for sizing the rank is 20 L per milker unit. Larger tanks, however, cannot compensate for an undersized pump.

TRAPS Sanitary traps are required in the vacuum line between the pump or reserve tank and the milk receiver vessel to prevent accidental overflow of milk into the vacuum system. These should be drained and cleaned between each milking.

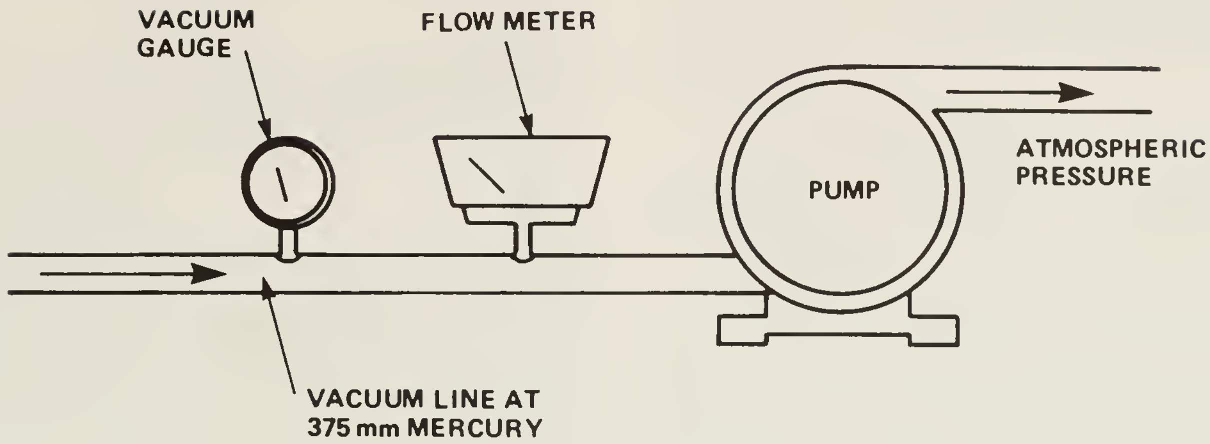
VACUUM REGULATOR These units regulate the operating vacuum level. When the system reaches operating level the regulator opens to admit enough air to maintain this level. As additional milker units are connected to the vacuum line the regulator compensates by reducing the amount of air admitted. It must have a minimum capacity equal to full capacity of the vacuum pump at operating vacuum. Install the regulator in a dust-free location near the pump. Spring- or weight-loaded valve types are the most common. Check them regularly and follow the manufacturer's recommendations for maintenance and service.

It is essential that a vacuum gauge be tapped into the vacuum system to aid in setting up and maintaining proper operation.

Set vacuum levels according to milker manufacturer specifications. Vacuum requirements for each milker unit are determined by the design of the unit, therefore the manufactorer's recommendations should be followed.

VACUUM LINES Install vacuum lines as complete circuits or loops to eliminate dead ends and ensure uniform vacuum levels throughout the system. A gate valve, with stallcocks on each side, will facilitate cleaning if installed in the crossover pipe furthest from the pump. Clean lines are essential to maintain proper vacuum. Clean them once a month and whenever milk is known to have entered the system.

NEW ZEALAND STANDARD METHOD




A.S.M.E. STANDARD METHOD

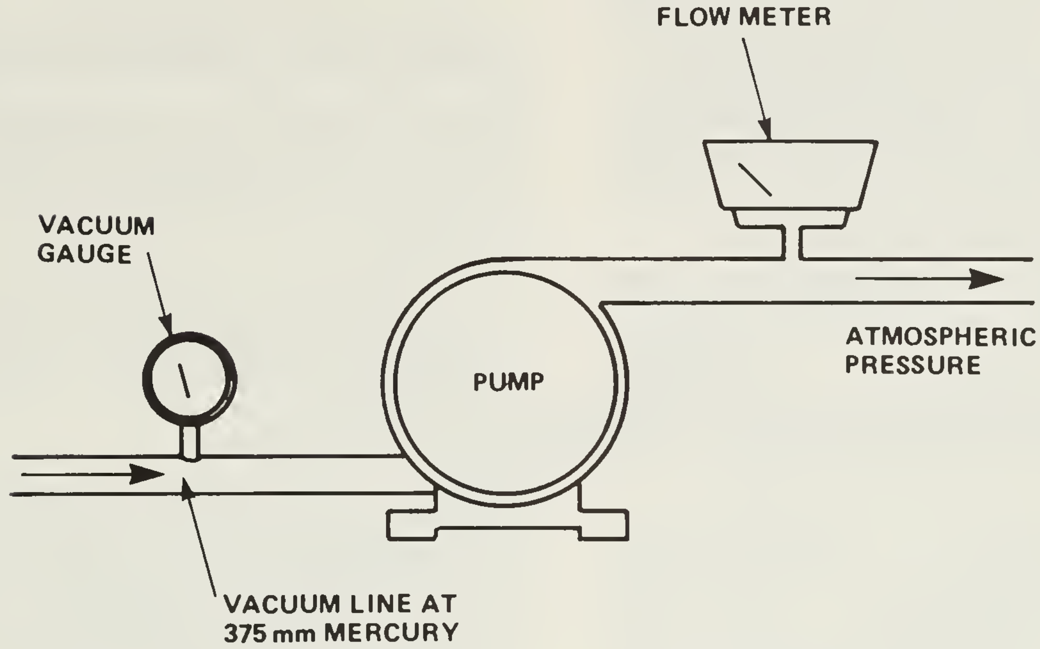



Figure 28 Vacuum pump testing methods.

TABLE 2 Minimum Air Flow Requirements (New Zealand Ratings)

| Component | Air flow (L/s) (New Zealand rating) |
|---|---|
| Milker unit (bucket system | 5.0 |
| Milker unit (pipeline) | 2.0 |
| Vacuum releaser | 5.0 |
| Vacuum bulk tank | 1.0 |
| Milk meters | 1.0 |
| Sanitary couplings (per 20) | 1.0 |
| Step-saver | 5.0 |

Pipeline systems require 50% reserve capacity
(i.e. 1.5 × requirements of components).

TABLE 3 Minimum Size of Vacuum Lines

| Minimum diameter of line (mm) | Distance (pump to furthest point) | | |
|---|---|---|---|
| | 30 m | 60 m | 90 m |
| | (no. of milker units) | | |
| 31 | 4 | 3 | 2 |
| 37 | 8 | 6 | 6 |
| 50 | 10 | 10 | 8 |

Lines may be constructed of any material that will withstand 600 mm Hg vacuum and the cleaning process used. Galvanized steel and rigid plastic are the materials most commonly used. Plastic pipe requires support at every stallcock. Have a minimum slope of 1:500 for drainage of condensate and cleaning solutions. Put drain plugs at all corners, low spots and at the base of all risers. Tees with plugs should always be used in place of elbows in vacuum lines to allow access for cleaning.

Pipe size depends on length of pipe and number of milker units. Table 3 gives the minimum recommended sizes.

Install stallcocks in the upper half of the vacuum line to prevent line condensate from entering the air tube to the machine and the machine pulsator.

PULSATOR A pulsator (Figure 27) controls the action of the teat-cup inflation. It controls both the milk:massage (M:M) (% milking time:% rest or massage time) and pulsation rate (cycles per minute). The pulsation rate should be set at manufacturer's specifications.

Specified pulsation rates vary from 48 to 60 cycles/min. On many pulsators the M:M ratio is fixed or preset, usually at 60:40 or 50:50; however, some are adjustable.

There are three main types of pulsators currently in use — vacuum operated, magnetic, and electric. Vacuum-operated pulsators use airflow to move a plunger or slide valve that covers and uncovers an air port to produce pulsations. The M:M ratio is fixed at 50:50 but the pulsation rate can be adjusted. Temperature changes alter the pulsation rate and occasional manual adjustment may be required. Magnetic pulsators use an electric current fed to each stallcock to operate an electromagnet that moves a slide valve, alternating vacuum and atmospheric pressure. The M:M ratio is preset but the pulsation rate is adjustable. Electric pulsators are set and controlled by a central master control or timer. Both pulsation rate and M:M ratio are adjustable. These units provide the most consistent and sharpest action and are recommended.

## Milking systems

Either bucket milkers or pipeline milkers may be used in tie-stall barns. The major difference between the two is the method of milk handling.

BUCKET MILKERS The simpler and lower cost systems utilize bucket or pail milkers. Bucket milker units are of two basic types, claw-type floor units, and suspended units. Both perform well if operated properly.

The simplest bucket milking system uses manual transport of the milk from the bucket to the milk storage tank. This requires considerable time and effort by the operator.

To reduce the labor of manual milk transport various "step-saver" systems have been developed. These consist of a portable stainless steel receiver pail that is wheeled into the barn for each milking, and a vacuum milk line to a vacuum releaser or to a vacuum bulk tank. The milker bucket can then be emptied into the step-saver in the barn rather than at the bulk tank. The step-saver milk line should be at least 25 mm in diameter; and, if permanently installed, should be of rigid plastic supported to maintain a consistent slope of 1:100 toward the vacuum releaser or vacuum bulk tank. The operation of a step-saver requires as much airflow as an additional milker.

Vacuum releasers for step-savers systems are usually much simpler than the receiver in pipeline systems. This is because the step-saver is not connected directly into the line providing the milking vacuum. Line flooding and vacuum fluctuations in the step-saver milk line do not influence milking vacuum. Simple releasers for these systems generally consist of a receiver vessel to which a vacuum line and the milk line are connected. Milk is drawn by vacuum into the step-saver line, then flows by gravity to the receiver vessel. When the vessel fills, a float rises and opens an air inlet port. Milk transport is temporarily stopped while the milk drains by gravity into the bulk tank. When the receiver empties, the float falls, closes the inlet and milk transport resumes.

In vacuum bulk tank installations the milk is transported, under vacuum, directly to the tank. Vacuum releasers are often used as washer-receivers for cleaning the step-saver milk line in such a system.

PIPELINE SYSTEMS Pipeline systems (Figure 29) are somewhat more complex than bucket milkers because of their cleaned-in-place and special milk-releaser functions.

In pipeline systems the milk is lifted directly from the milker claw into the milk-line. The claw is usually equipped with an air vent to permit air to flow into it and push the milk up the tube into the pipeline. The 50% reserve airflow capacity of pipeline systems is to provide for milk lift. The pipeline should not be more than 2 m above the stall floor and milk tubes should be limited to 3 m in length, otherwise milk will not be raised fast enough to prevent claw and teat cup flooding. If flooding occurs, vacuum fluctuations and improper machine operation will follow.

Milk pipelines must be rigidly supported and self-draining, with a minimum slope of 1:80 in the direction of flow. Since uniform vacuum level throughout the pipeline is necessary, the milk must flow by gravity. Vacuum can induce milk flow only if the line is flooded and a pressure differential exists across a "plug" of milk in the line. This differential results in a vacuum fluctuation as the milk moves down the line. The pipeline must be sloped continuously with no level spots or risers which will cause line flooding.

Glass or stainless steel are the most common materials for milk pipelines. Glass affords visibility while stainless steel gives the most problem-free connections.

Pipeline hangers must permit free horizontal movement due to temperature changes. Around the barn, pipelines should be looped to form a complete circuit to maintain vacuum stability, and sloped down from both sides of a central high point towards a multiple-inlet receiver. This is referred to as a "double-slope" pipeline. A single-slope pipeline is one that slopes continuously from one end, around the barn to the receiver. Because milk must flow by gravity, a double-slope line increases the capacity and performance (Table 4).

Milk inlet ports must be located in the upper half of the pipeline to prevent milk from flowing into the milk tube and flooding the claw or breaker-cup.

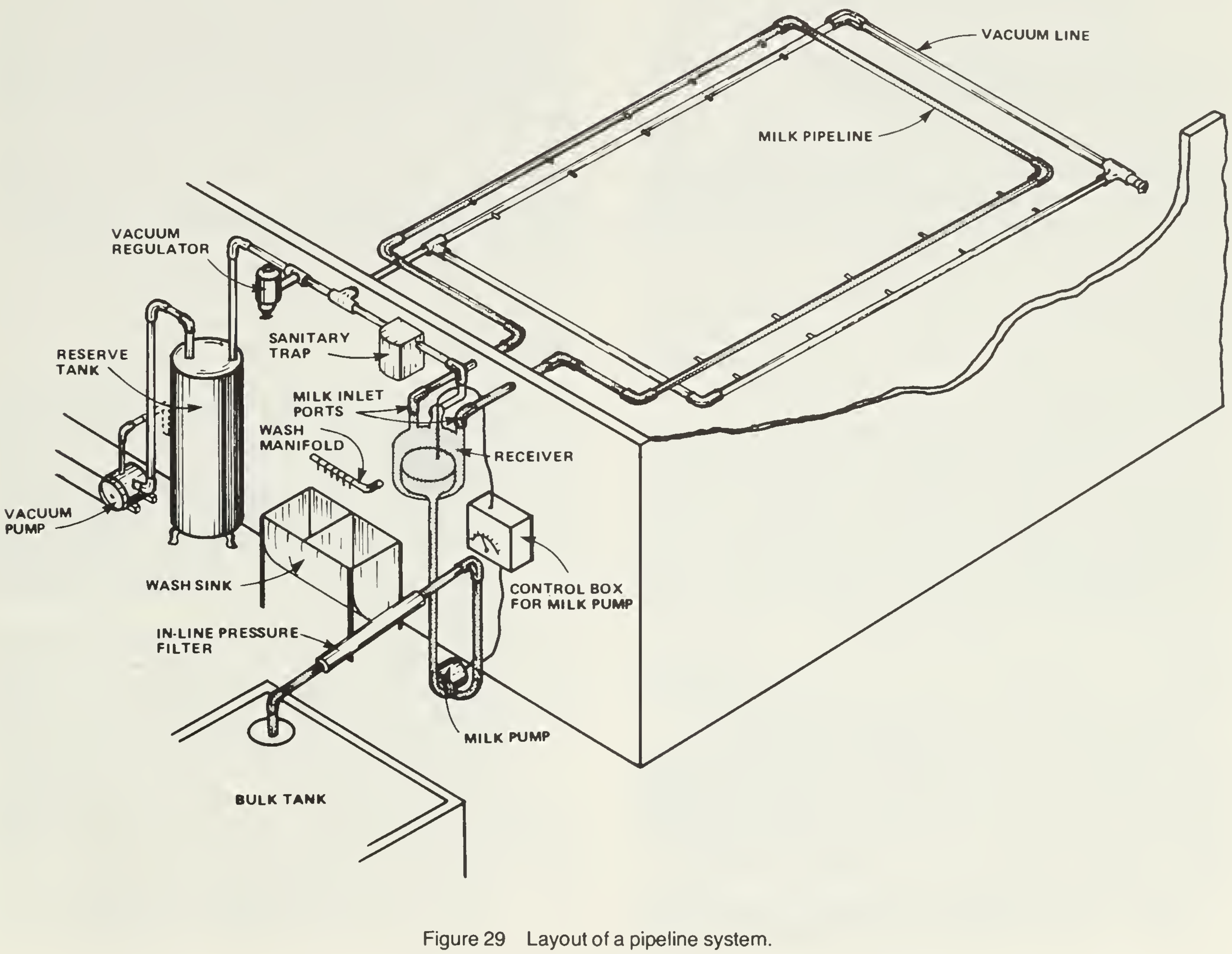



Figure 29 Layout of a pipeline system.

TABLE 4 Minimum Pipeline Sizes

| No. of milker units | Slope (min. 1.80) | Line diameter (mm) |
|---|---|---|
| 2 | single | 37 |
| 4 | double | 37 |
| 4 | single | 50 |
| 8 | double | 50 |
| 6 | single | 62 |
| 12 | double | 62 |
| 9 | single | 75 |
| 18 | double | 75 |

NOTE: On double-slope pipelines only half of the milker units can operate on one slope.

The main supply pipe from the vacuum pump to the receiver should be the same size as the pipeline.

RECEIVER The receiver serves three basic functions in the pipeline system:

1. Receives milk without line flooding, providing an entrance for each slope.
2. Serves as a reservoir for milk before transfer to the bulk tank.
3. Provides a sanitary break between the vacuum system and the milk line.

Most commonly, a liquid-level control in the receiver operates a pump that transfers milk from the receiver to the bulk tank. The control must be set to ensure that the receiver does not fill to the inlet level of the pipeline and cause line flooding. Milk transfer pumps are usually centrifugal pumps controlled by probes in the receiver. Vacuum-operated pumps are available but place additional load on the vacuum system. Milk pumps must be easy to clean and drain and have sufficient capacity to prevent receiver flooding.

A glass receiver permits observation of pipeline system performance. Milk should flow into the receiver gently and continuously. Spurts of milk gushing into the receiver are indicators of line flooding and vacuum fluctuation. The cause should be determined and corrected before milking efficiency and herd health are impaired.

CLEANING SYSTEMS FOR PIPELINES Pressure circulating and vacuum circulating are the two systems generally used to clean pipelines.

Pressure circulating systems use the milk pump or an auxiliary booster pump to force the rinse water and the cleaning and sanitizing solutions through the milking system. This method requires full flooding of the system and therefore uses large quantities of hot water and cleaners.

With vacuum circulating systems, the milking vacuum is used to draw cleaning solutions from the solution tank through the milker units and into the pipeline. The cleaning solution travels through the pipeline to the milk receiver from where it returns to the solution tank. A pulsated air injector near the milker units' wash-manifold intermittently admits air to provide turbulence and scrubbing action. This system is very simple and gives maximum turbulence while using considerably less hot water and cleaners.

Automatic wash controls are available for vacuum circulating systems; however, the convenience and time saved must be weighed against the increased maintenance and high cost of installation.

## Milk filters

Filters remove suspended dirt particles from the milk prior to storage and can be divided into four major types.

1. Unit filters are installed in the breaker cup or milk tube. When they become clogged they drastically reduce milking vacuum and milking speed. For this reason they should not be used.
2. In-line suction filters are common in vacuum bulk tank systems. When located in a pipeline leading to the tank they can alter milking vacuum throughout the system and should be watched closely during use. If there is a milk receiver prior to the bulk tank a pressure filter or gravity filter should be used instead. In-line suction filters are satisfactory for use in vacuum bulk tank step-saver systems since vacuum alterations in the milk transport line do not affect milking.

3. In-line pressure filters are common where a milk pump is used. They do not affect milking but may rupture when clogged.
4. Gravity filters do not affect milk vacuum nor are they subject to rupture. They are used wherever milk flows by gravity into the bulk tank.

## Cleaners and cleaning

ALKALI CLEANERS Alkali cleaners are sold under numerous brand names and are usually referred to as "general-purpose dairy cleaners" or as "chlorinated alkaline dairy cleaners". They remove the fat and protein from dairy equipment. The water softening ability of the cleaner is important in selecting one for a particular water. If the cleaner turns water milky, it does not have sufficient water softening ability and will not clean the equipment. Exchange it for one with greater water softening ability (and usually greater cost) which does not react in this way.

ACID CLEANERS Acid cleaners remove milk stone buildup from equipment. Milk stone buildup will depend on the hardness of the water, the temperature of the cleaning solution, and methods employed in rinsing equipment after washing. The frequency of acid cleaning will vary from farm to farm and can be from once in 10 days to every other day. Generally, if even a slight trace of milk stone is visible on dry equipment, incease the frequency you use acid cleaners.

SANITIZERS Sanitizers perform only one function — killing bacteria on contact. They do not possess any cleaning ability and can perform satisfactorily only on clean surfaces. Sanitizers react in the same manner as alkali cleaners in hard water, and the same selection procedure applies.

DETERGENT SANITIZERS Detergent sanitizers combine the properties of alkali and acid cleaners. They can be used instead of an alkali cleaner and though they will not completely eliminate the need for acid cleaners they will reduce the frequency of acid cleaning. The same product can also be used as a sanitizer. Follow label directions to determine strengths required for cleaning or for sanitizing.

LYE SOLUTION Lye is a strong alkali used to remove the milk fat that builds up in the pores of rubber components. Rubber components are usually cleaned by soaking in a 5% lye solution. This solution can also be used to clean vacuum lines.

CLEANING (MANUAL) The following sequence is recommended for manual cleaning of dairy equipment.

1. Rinse all surfaces with cool or lukewarm water immediately after use.
2. Dismantle.
3. Soak and brush all parts in hot alkali cleaner solution.
4. Rinse with cold or tepid water with acid cleaner.
5. Hang in draining position for storage.

For acid cleaning repeat above procedure except substitute acid cleaner in step three and soak for 30 minutes at 60°C or higher, then brush thoroughly.

CLEANED-IN-PLACE CLEANING (C.I.P.) C.I.P. cleaning is required for all milk transport systems. The following steps are recommended.

1. Rinse with cold or lukewarm water. Do not recirculate rinse water.
2. Circulate alkali cleaning solution according to the manufacturer's recommendations, usually 10-20 minutes at 70°C. Make sure cleaner is non-foaming and compatible with water.
3. Drain wash solution and rinse with lukewarm water to which acid cleaner has been added.
4. Hand clean all components not designed for C.I.P.

When acid cleaning, repeat above steps, substituting acid cleaner in step 2.

SANITIZING Just prior to milking rinse all surfaces that come in contact with milk with clean lukewarm water to which a properly selected sanitizer has been added according to manufacturer's recommendations. Make sure all C.I.P. systems are adequately drained before milking.

## Bulk tanks

The bulk tank must provide adequate storage capacity and rapid milk cooling. Consider, for example, that 40 cows are being milked, each producing 10 kg of milk per milking and that milk is picked up every other day. The bulk tank should be sized to hold the regular pickup (in this case four milkings) plus the milk from 1 extra day (two milkings) for a total of six milkings. The tank size would be: $(40 \times 10 \text{ kg} \times 6) \times (1 \text{ L/kg}) = 2400 \text{ L}$. Table 5 gives guidelines for determining the cooling capacity required.

Heat removed from the milk by the cooling system can be effectively used to heat the milkhouse in winter. Details are shown in Canada Plan Service plans for milking centers and milk rooms. Commercial units that use this waste heat to preheat milkhouse water are also available.

Follow manufacturer's recommendations for servicing of bulk tanks and cooling units and ensure that the condenser radiator is kept clean.

## Water requirements and waste disposal

Large volumes of potable water are used daily in milking centers. Table 6 gives estimates of water consumption for some of the operations associated with milking. All equipment cleaning requires hot water (45-50°C for hand washing and 70-75°C for C.I.P. washing). Consider using booster heaters for solution tanks of larger C.I.P. systems.

Two recommended procedures for disposing of milkhouse wastes are to pass the wastes through a sediment tank and disposal field, or to dump the wastes into the main manure storage, if a liquid or semisolid manure system is being used.

Details for the design of the sediment tank and disposal field, including trench dimensions and construction procedures, are given in Agriculture Canada Publication 1620, *Planning Your Milkhouse*.

## Milkhouses

The milkhouse must be big enough to accommodate all necessary equipment and provide adequate working space and storage. Table 7 is a guide for determining minimum milkhouse sizes. Interior walls should be light in color, easily washable and stain resistant. RSI 2.5 or better insulation is recommended for walls and RSI 3.5 for ceilings. Foundation perimeter insulation of RSI 1.4 or better is also recommended.

A double floor or removable wall panel is required to facilitate bulk tank installation or replacement. A hose port and 220 volt switched electrical outlet is usually needed for bulk milk pickup.

Floors should be good-quality concrete (30 MPa minimum), laid on well-compacted granular fill and steel reinforced to prevent unsanitary cracks. Finish them with a textured non-skid surface that is easy to clean. A wood-float finish is acceptable; however, a steel-troweled floor with carborundum or aluminum oxide grit worked into the surface is not slippery even when wet. Slope the entire floor at least 1:50 to a 100 mm floor drain, complete with grated cover, sediment bucket and gas trap. Locate the drain near the bulk tank outlet and at least 600 mm from the outlet valve, but not under the bulk tank or between the outlet valve and hose port.

Minimum facilities must include a two-basin wash sink with each compartment large enough to accommodate the largest piece of equipment you must wash.

Lighting is needed over the wash sink and counters as well as near the bulk tank. Do not locate light fixtures directly above the bulk tank openings; broken glass could fall into the tank.

Detailed plans for milkhouses and milkhouse-office combinations are available through the Canada Plan Service.

Consult local regulations and requirements for milk production before building milk production facilities.

TABLE 5 Recommended Consensing Unit Cooling Capacity

| Number of milking machines | Milk production (kg/h) | Cooling capacity (kJ/h) |
|---|---|---|
| 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 |

## TABLE 6 Volume of Milkhouse and Parlor Wastes*

| Washing operation | Water volume |
|---|---|
| Bulk tank | |
| Automatic | 200-250 L/wash |
| Manual | 120-160 L/wash |
| Pipeline | |
| In parlor (Volume increase for long lines in a large stanchion barn) | 300-400 L/wash |
| Pail milkers | 120-160 L/wash |
| Miscellaneous equipment | 120 L/d |
| Cow preparation | |
| Automatic | 4- 18 L/(wash/cow) |
| (Estimated average) | 8 L/(wash/cow) |
| Manual | 1- 2 L/(wash/cow) |
| Parlor floor | 160-300 L/d |
| Milkhouse floor | 40- 80 L/d |
| Toilet** | 20 L/flush |

Note: Hot water tank capacity approximately 1 L/cow plus 0.2 L/m of pipeline.

*_Livestock Waste Handbook_, MWPS-18, Midwest Plan Service, Iowa State University, Ames, Iowa, July, 1975.

**Before installing toilet, contact local health officer to get approval for method of toilet waste disposal. In many locations, toilet wastes must be disposed of through a septic tank and tile field completely separate from other milkhouse wastes.

## TABLE 7 Minimum Recommended Milkroom Dimensions

| Herd size | Size |
|---|---|
| Up to 25 | 4.3 m × 4.9 m |
| 25 to 35 | 4.3 m × 5.5 m |
| 35 to 50 | 4.9 m × 6.2 m |
| 45 to 70 | 4.9 m × 6.8 m |
| 65 and over | 5.5 m × 8.0 m |

## 6. MANURE REMOVAL AND MANAGEMENT

Manure management is an important part of dairy production. A good manure handling system is convenient for the operator, maintains the health and safety of humans and animals, conserves the manure for fertilizer, minimizes the handling cost, allows for expansion, is not a nuisance and does not pollute.

The system for tie-stall dairy facilities will include: (a) equipment or facilities to collect manure and transfer it to the main storage; (b) sufficient manure-tight storage to permit timely land application and avoid surface water and groundwater pollution; (c) equipment to remove manure from storage, and agitate it if necessary; and (d) sufficient land area and the equipment to incorporate the manure back into the soil.

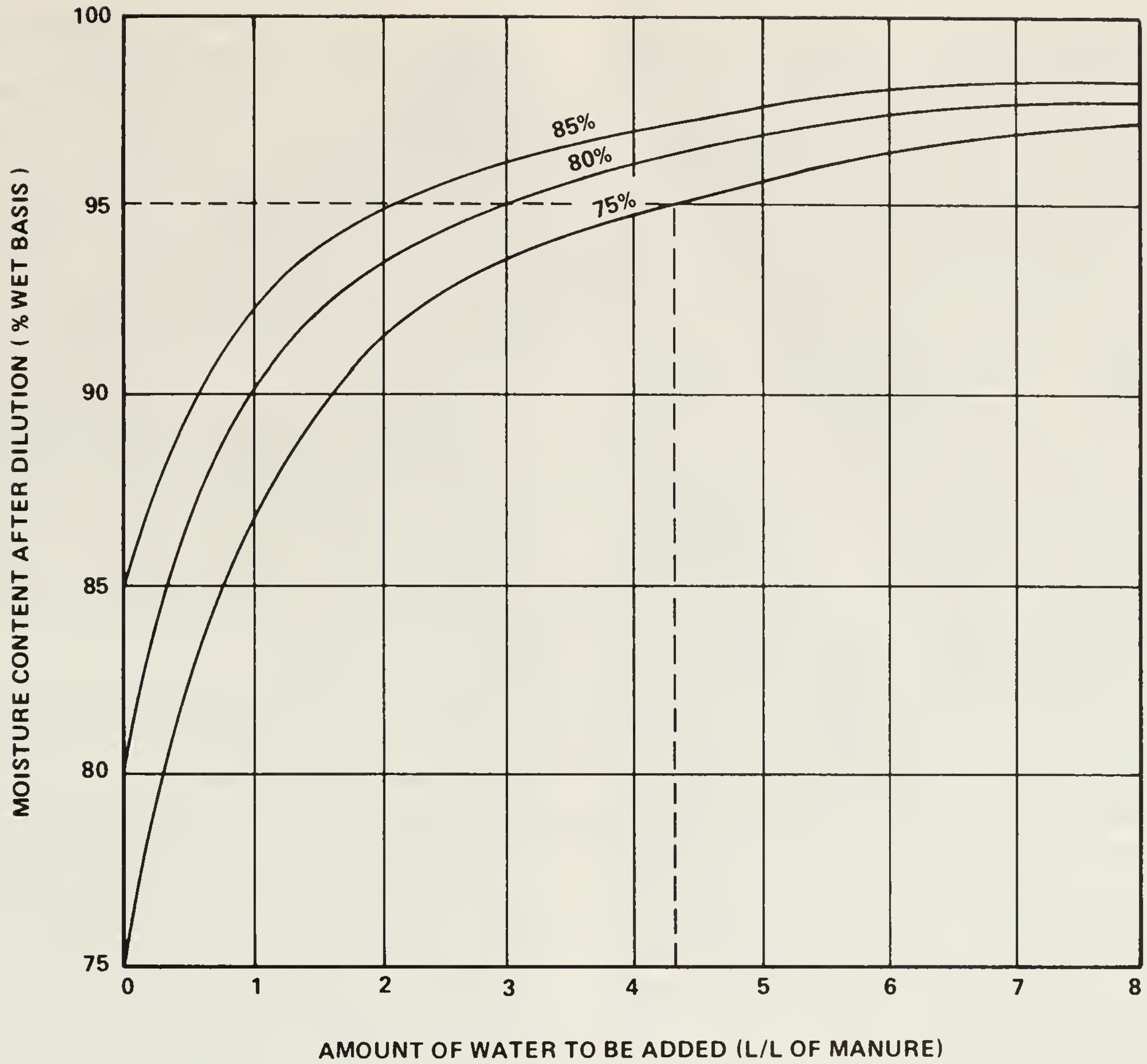
Because of differences in the methods of animal management and individual operator preferences, various manure handling systems exist. Many of the alternatives differ simply in their degree of automation. Some are specifically tied to certain methods of animal management and particularly to the way fresh manure is modified in its consistency.

The consistency of fresh manure often is changed somewhere within the handling system by such things as addition of bedding, dilution with water (intentionally or otherwise), or natural or forced air drying. The moisture content of manure affects its consistency, and hence is most important when considering the selection of handling equipment and facilities. In each of the systems outlined in this publication, manure consistency is taken into account when specifying the type of handling facilities and the equipment required (Table 8).

Manure is generally handled as either a liquid, semisolid, or solid. Dairy cattle manure as excreted, including feces and urine, has a moisture content of approximately 85% (wet basis). This is equivalent to saying it contains 15% solids. Liquid manure with a thin consistency may be produced by adding water when animal management excludes or restricts the use of bedding. At 85% moisture content or greater, manure will flow by gravity from a deep horizontal gutter while at 90% or greater, it can be pumped readily. Although this may not sound like much difference, consider that at 90% moisture manure is 10% solids while at 95% it is 5% solids — only half the concentration. To change manure from 90% moisture to 95% requires doubling the volume by the addition of water. Figure 30 shows how much

TABLE 8 Manure Handling Systems for Dairy Cattle

| Type of manure | Collection | Transfer to storage | Storage | Removal from storage | Application onto cropland |
|---|---|---|---|---|---|
| Liquid | shallow gutter<br><br>deep gutter | shuttle conveyor or barn cleaner<br><br>continuous gravity flow | circular or rectangular concrete storage<br><br>earth bank storage | centrifugal pump, vacuum pump, auger enclosed chain conveyor | spreaders: top-loading hopper type, auger load-tanker type, top-loading or pump-filled vacuum tanker<br><br>irrigation |
| Semisolid | shallow gutter<br><br>deep gutter | shuttle conveyor or barn cleaner<br><br>continuous gravity flow | rectangular concrete-roofed storage<br><br>earth bank storage | front-end loader<br><br>scrape ramp | spreaders: conventional box type or box-type hydraulic pushout chain-flail tank type, top-loading hopper type, auger-load tank type |
| Solid | shallow gutter | shuttle conveyor or barn cleaner, and manure stacker | concrete slab with low curb | front-end loader | spreaders: conventional box type, chain-flail tank type |




**EXAMPLE:** To bring manure that has 75% moisture content up to 95% moisture, 4 1/3 litres of water must be added to each litre of manure

Figure 30 Volume of dilution water required to change the moisture content of manure.

water is needed to dilute manure from a given moisture content to a higher one.

In contrast to liquid manure, solid manure usually is produced when ample bedding is used or where manure is subjected to natural or induced air drying. Solid manure has a stiff nonflowing consistency and may be handled by traditional fork loaders and spreaders. Manure with 8% bedding or greater will have this consistency. This amount of bedding would be 3 to 4 kg of bedding per cow per day.

In many modern tie-stall dairy facilities where bedding is minimized and drying is limited, a manure is produced that is neither a liquid nor a solid, but rather a thick semisolid. This does not flow as readily as liquid manure nor will it pile the same as solid manure. To handle it, you must make some modifications to conventional solid manure storage and handling facilities and equipment.

## Collection and transfer of manure

Odor in confinement barns may be minimized if manure is transferred to separate storage at frequent intervals. Two collection and transfer systems are recommended for new tie-stall barns: shallow gutter with gutter cleaner to storage and grate-covered deep gutter with continuous gravity flow to storage.

Systems involving flushing gutters require the addition of water to give the manure a high moisture content, and are not recommended unless the water can be recycled. Flushing with fresh water each time will increase storage requirements enormously. Large below-barn storages are not recommended, because of the higher cost and the danger that manure gases will be released into the animal environment.

SHALLOW GUTTERS WITH GUTTER CLEANER Shallow gutters with gutter cleaners have been a characteristic of tie-stall barns for many years. They are simple to build and have a long history of good performance. The system adapts to all kinds of manure and is easy to manage. Gutter cleaners may pose some difficulties in colder climates due to freezing where the chain goes outdoors. Chain breakage, slow speed in long loops, and overloading may also cause difficulties. Always follow the manufacturer's recommendations for design, installation, management and maintenance.

The two types of mechanical gutter cleaners commonly used in tie-stall dairy barns are the conventional continuous-chain barn cleaner and the shuttle type gutter scraper. Conventional barn cleaners (Figure 31) consist of a continuous chain with flites spaced at about 600 mm on center. Chain lengths in excess of 150 m in a single installation are available but shorter lengths are more typical. Gutter widths of 350 to 500 mm are recommended and, of course, should be matched to the particular equipment to be installed. Uncovered gutters should be at least 200 mm deep. A clearance of 500 mm above the gutter bottom is required where a loaded cleaner passes under a cover or grating; unloaded flites require a clearance of 100 mm above the paddles. Barn cleaners normally are available with two flite options, depending on the type of manure; flites approximately 50 mm deep are used for solid manure whereas flites closer to 100 mm deep are more suitable for semisolid manure.

Conventional barn cleaners are limited to applications where the conveyor can make a complete circuit. In cases where the installation involves a single or an odd number of alleys, shuttle stroke cleaners (Figure 32) may be more useful. Shuttle gutter scrapers consist of a series of folding blades on a rod or cable. The blades are first pulled backward, folded against the rod or cable, to the section to be cleaned. The direction is then reversed; the blades open and carry out the manure. Recommendations for gutter widths and depths for conventional barn cleaners apply to shuttle scrapers as well.

Gutter cleaners normally are powered by electric motors. The power required will depend on the width and length of the gutter, the size of the paddles, the amount of manure routinely carried, the length of elevator section, and the speed at which the flites move. Always consult the recommendations of the equipment suppliers for each particular motor application. Power units up to 6 kW are commonly available.

Mechanical gutter cleaners normally operate at a rate of approximately 0.1 m/s. Higher speeds reduce waiting time and help move the more liquid types of manure, but require more power.

Shallow gutters may be used in tie-stall facilities regardless of the amount of bedding used. If bedding is minimal it may be desirable to cover the gutter with a grate (Figure 23) to keep cows' tails clean. Some farmers who have tried grates feel they are an asset to management; cows also cross covered gutters more readily when moving in and out of stalls and through the barn. Grates constructed of smooth steel rods are most satisfactory.

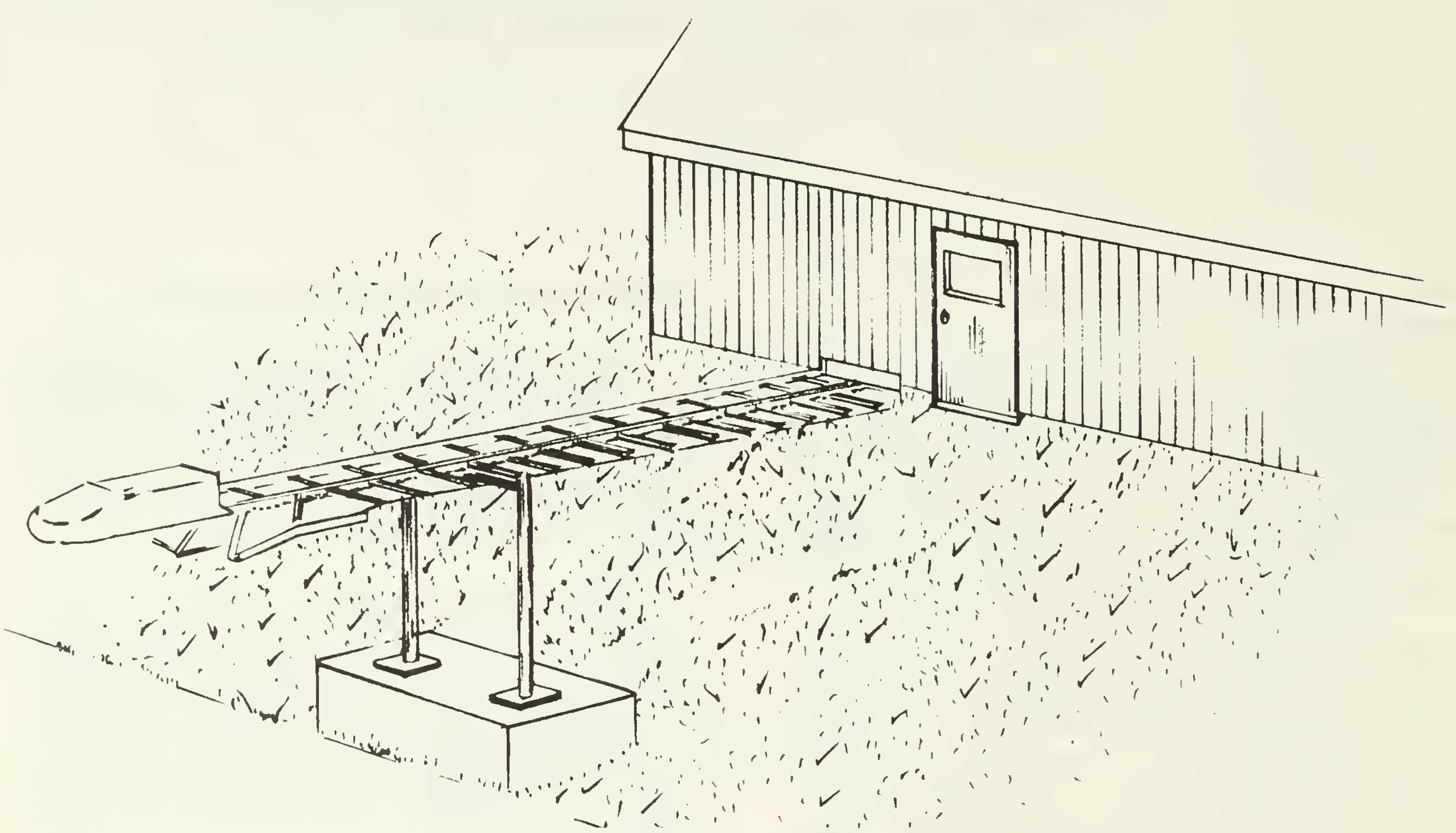


Figure 31 Conventional barn cleaner.

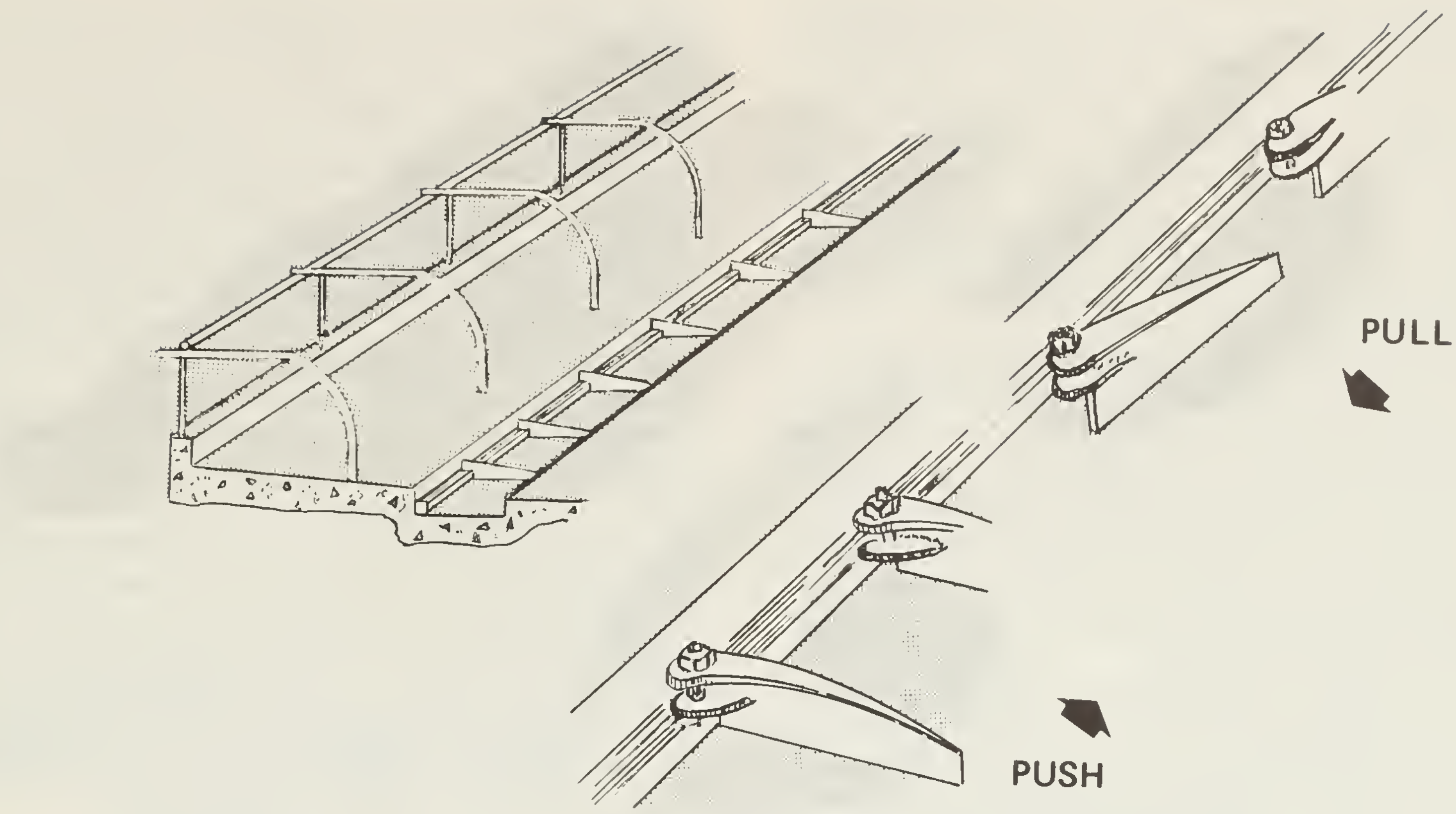



Figure 32 Shuttle-stroke cleaner.

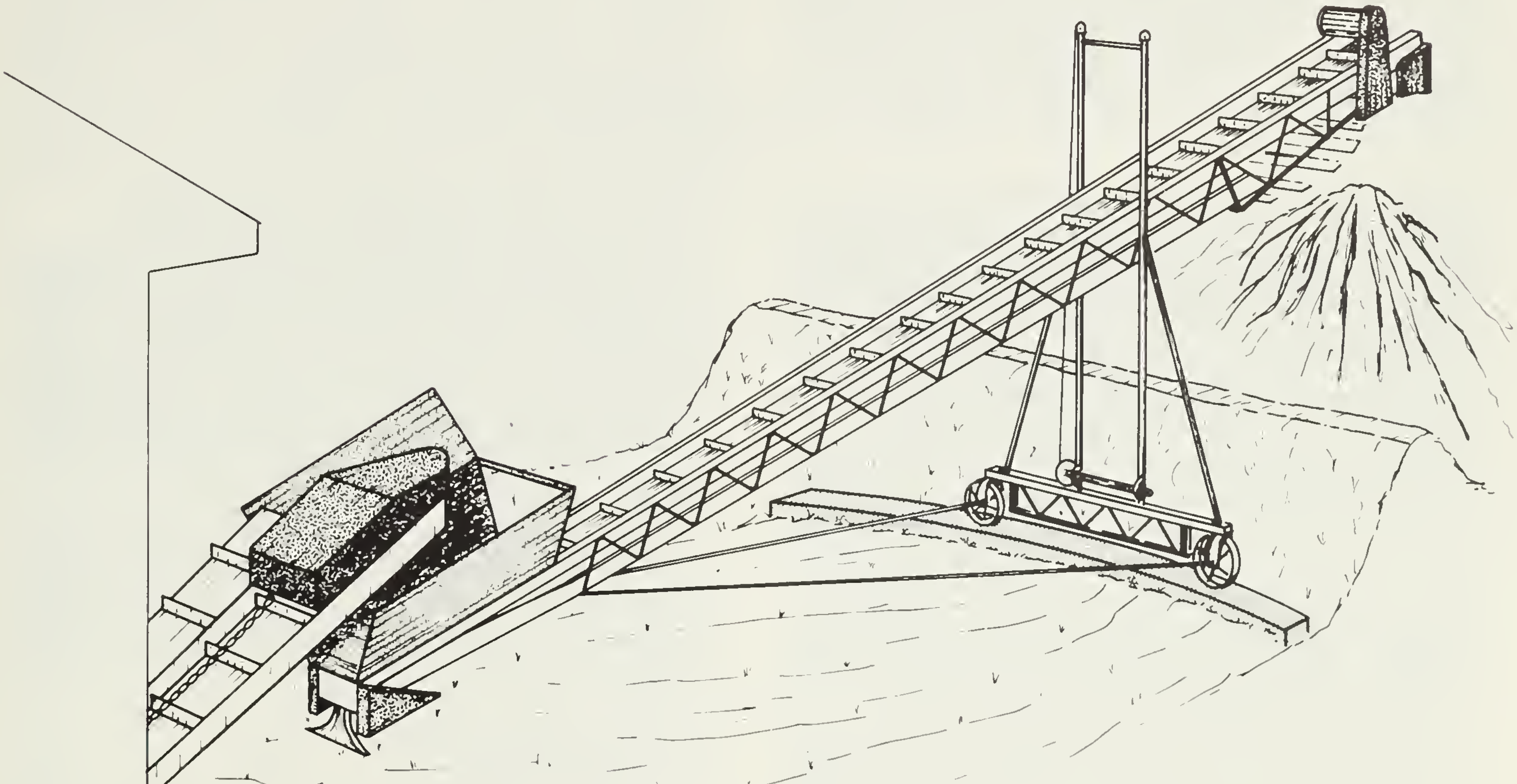


Figure 33 Manure stacker.

The recommended construction is of smooth bars approximately 20 mm diameter, spaced about 60 mm on center, running the length of the gutter. Cross supports should be placed a maximum of 400 mm on center. You may have to pass over the grates once or twice a day with a stiff broom or scraper to work through any manure that hangs up on the grate. When less bedding is used, more frequent scraping may be necessary to keep animals and the animal areas clean.

During cold weather, manure freezing may be a problem with mechanical cleaners. Conveyor sections located outside the barn should be protected from the weather, and be designed to drain completely after each use. Discharging the Step 1 continuous ventilating fan over the gutter-cleaner exits provides a continuous outflow of warm air, preventing freezing at the critical point where the outside elevator must drain.

As previously mentioned, mechanical gutter cleaners may move the manure from the barn into a manure spreader or to storage. In some cases only a single conveyor installation is required; however, in many cases it may be necessary to use a second conveyor or elevator to move manure from the point of collection to long-term storage. Manure stackers (Figure 33) are available to do this job where solid manure is involved. These are very similar to gutter cleaners but generally don't exceed 20 m in length. Alternatively, barn cleaners may be equipped with an elevator section that is an integral part of the cleaner and is operated from the same power unit. Where very little bedding is used, install the elevator section at a slope no greater than 1:5. A third alternative uses positive displacement pumps or augers. This will be discussed in greater detail in the next section.

DEEP GUTTER WITH CONTINUOUS GRAVITY FLOW TO STORAGE Continuous-flow gravity channels will remove slurry from underneath a slotted grate behind the cows. Slurry continually oozes along the channel, propelled only by gravity. This method does not agitate slurry within the building, no mechanical energy is required to remove the slurry as is the case with scrapers, and there is virtually no maintenance. Continuous-flow slurry channels are designed to handle slurry with a moisture content of 85% or greater, and are limited to manure where bedding is excluded or at least kept to a minimum and chopped fine. If manure solids fail to flow due to mismanagement the system provides no easy recourse except adding some dairy wash water to dilute and flush the manure.

The flat-bottom manure channel is primed by adding about 100 mm of water which is retained by a small, level, sharp-edged weir or dam across the outlet end. As the manure builds up, it oozes over the weir to the outlet. The top surface assumes a slope of up to 1:40 depending on the consistency of the manure. The channel must be deep enough to accommodate the dam in the channel plus the height of the slope of the manure without overflowing the channel at the far end. With this system, the gutter is typically 700 to 1000 mm wide; greater widths are not recommended. The maximum length for continuous-flow slurry channels appears to be about 70 m. However, it is probably cheaper to try to keep the channels short, say 25 m, since the longer channels must be deeper and cost more to build. Where the long-term storage is located below ground and close to the barn, the gravity flow gutters may drain directly into the manure tank if a gas trap is included in the design to prevent dangerous gases from coming back into the barn. Where the storage is farther from the barn or where it is above grade a pumping system from a collection sump is necessary. Where more than one parallel continuous-flow gutter is involved, another deeper channel at right angles to the first gutter is used to move manure to the pump or to storage. Manure in the cross gutter may be moved by mechanical scrapers or by continuous gravity flow. The sump should be large enough to accept the manure produced in 1 day, or preferably, 1 week.

TRANSFER PUMPS Several types of transfer pumps are available to move slurried or liquid manure from a sump to storage. Large piston pumps designed to move slurry manure with minimal bedding through an underground 200 to 400 mm PVC pipe are becoming popular. These are commonly powered by a 6 to 7.5 kW electric motor.

The operation of the two basic piston pumps is shown in Figure 34. With type A, manure enters through a large hollow piston via loose-fitting flapper valves. This pump is suitable for manure that does not have much bedding. With type B, a large solid piston moves horizontally through a pipe. Manure enters the pipe when the piston is pulled back and is pushed ahead when the piston moves forward. This pump can handle manure with some bedding.

The recommended maximum pumping distance with either piston pump depends on manure consistency and is generally less than 75 m for semisolid manure; however, it may not be possible to pump stiffer manure further than 20 m. As the consistency of manure is difficult to define, visit several installations and compare them to your own operation before deciding on a maximum pipe length.

Other types of transfer pumps are available that are more suitable where the storage is above grade and adjacent to the sump. These will be discussed later when dealing with removal of manure from storage.

## Manure storage

Dairy manure is a valuable byproduct of normal daily operations; however, to realize the potential value of the manure and to avoid pollution problems, most dairymen need a well-planned manure storage system.

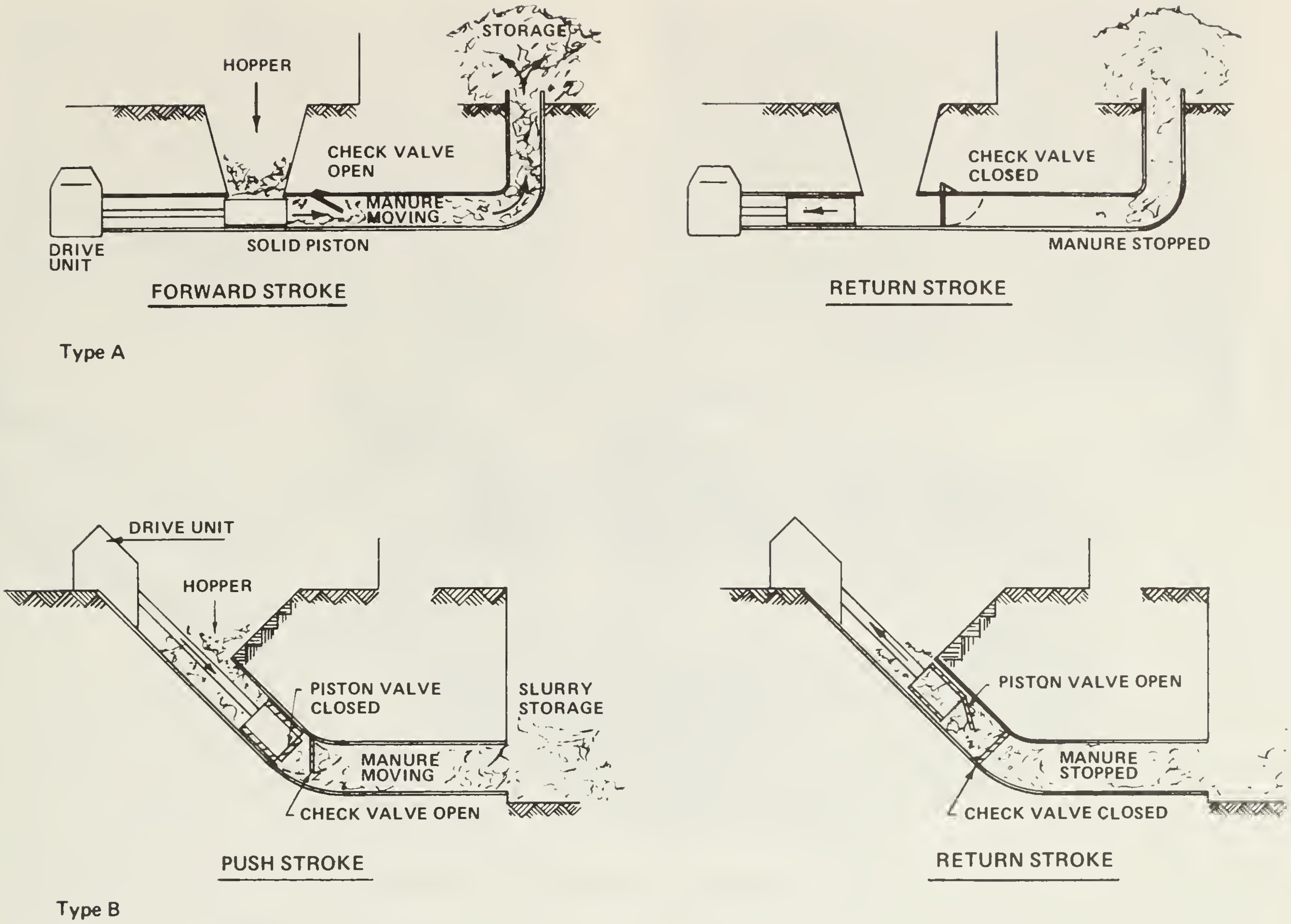



Figure 34 Piston-type manure pumps.

Manure may be loaded into a spreader and hauled to the field on a daily or other regular short-term basis, particularly in the case of smaller dairy operations. With a daily haul system, the investment in facilities is low, there is no accumulation of manure around the barn, and the labor of hauling is distributed throughout the year rather than being concentrated during peak periods. However, for most dairy farmers, daily hauling does pose a number of problems. The operator must be out in all kinds of weather, often with great discomfort. Manure spread on the surface of the soil and allowed to weather before being turned under loses a substantial percentage of its fertilizer value. Probably the greatest problem is the increased potential for pollution because of the necessity to spread on frozen, snow-covered or saturated ground. For these reasons, most farmers need sufficient storage to avoid spreading under these conditions; in some cases storage up to 8 months may be necessary.

Specific requirements for storage differ for solid, semisolid and liquid manure. Detailed plans for several types of storages prepared by the Canada Plan Service are available through extension engineers at provincial agriculture offices.

The manure storage should be near the barn, but at a site that will allow future expansion of both the animal facilities and the storage. It should be accessible by good farm roads to allow easy transport of manure and equipment. Choose a site where surface water runoff can be diverted away. For below-ground storages, avoid areas with a high water table.

If liquid or semisolid manure storages are constructed entirely or partially above grade, put tight-fitting closures on loading and unloading ports. If built entirely below grade and covered, fit access ports with nonfloating, child-proof covers strong enough to support the weight of a man. Ensure surface drainage around the tank prevents entry of surface water. If built with less than 1.5 m of the wall above grade level and not covered, liquid or semisolid storages should be adequately fenced to prevent humans, farm animals and machinery from accidently entering the tank.

LIQUID MANURE STORAGES Suitable liquid manure storages include: (a) rectangular or circular reinforced concrete structures, (Figures 35 and 36), (b) above-grade silo-type storages of either concrete stave, monolithic concrete or corrosion-protected metal construction (Figure 37) and (c) earth bank storages (Figure 38). Earthen storages are the least expensive, but they require a suitable dock to place a tractor and a pump agitator near the deepest part for manure removal. Alternatively, a concrete ramp and floor can be added to the pit if tractors and removal equipment require such access. Where roofs are necessary, rectangular storages can be covered at less cost than circular ones.

The plumbing system is the most important part of above-ground silo storages. It must be able to transfer manure into the storage at convenient intervals, agitate it before removal, and then remove it to a tanker spreader. In areas where there are a number of experienced silo contractors, the construction cost of covered above-ground silo storages is generally less than covered below-ground structures, but the overall cost including the pump and plumbing is similar. With above-ground storage, it is essential to prevent accidental discharge of the manure back into the barn.

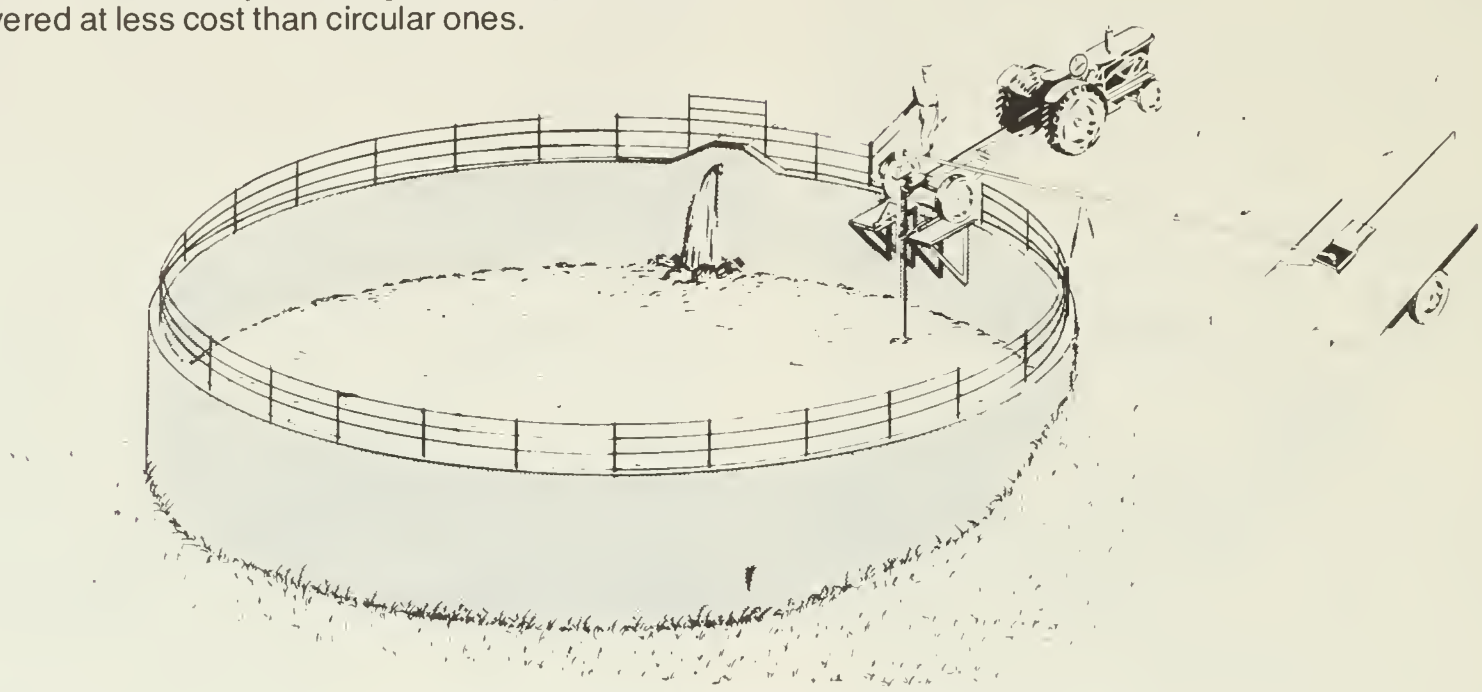


Figure 35 Circular open reinforced concrete manure storage.

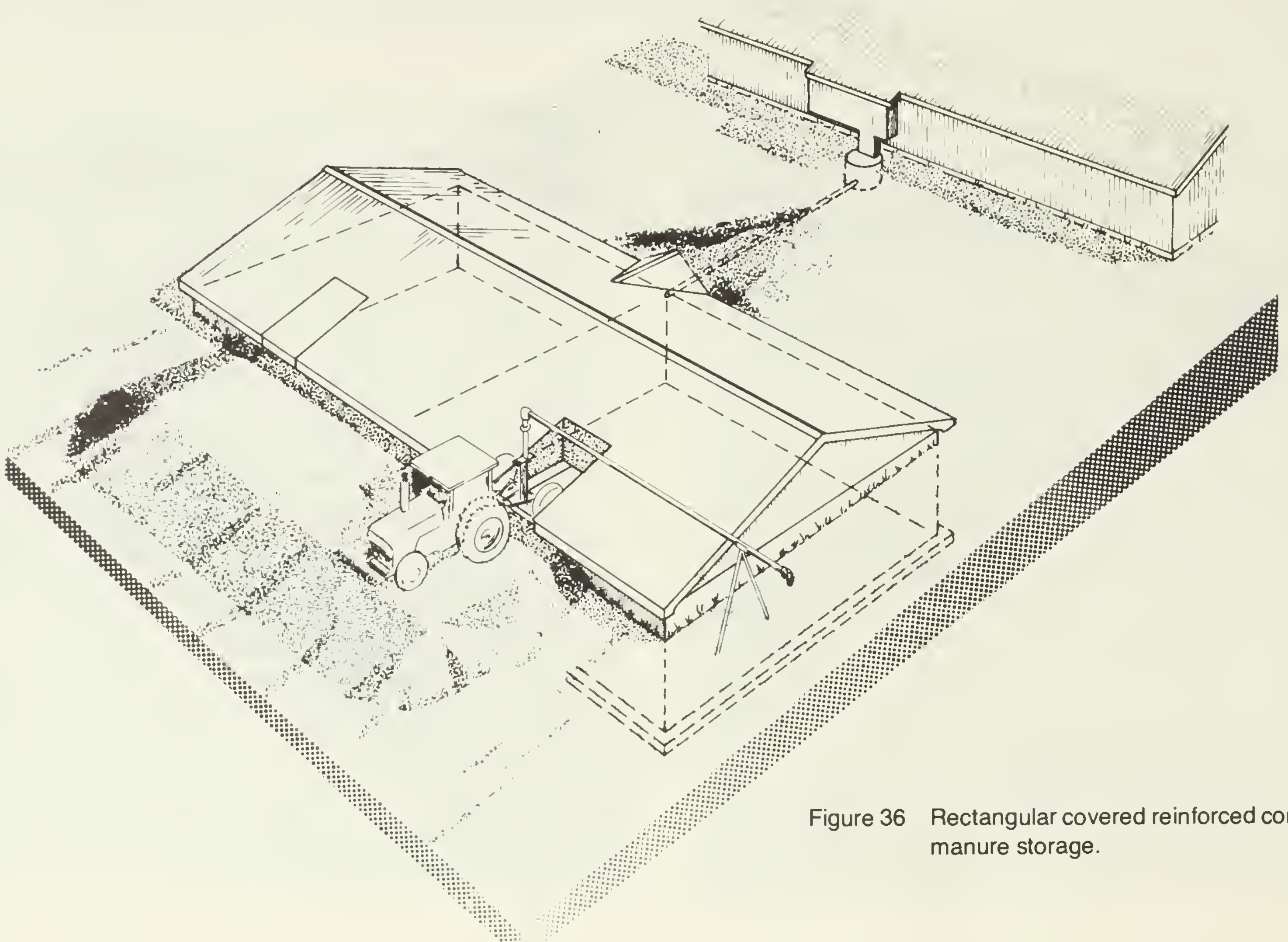


Figure 36 Rectangular covered reinforced concrete manure storage.

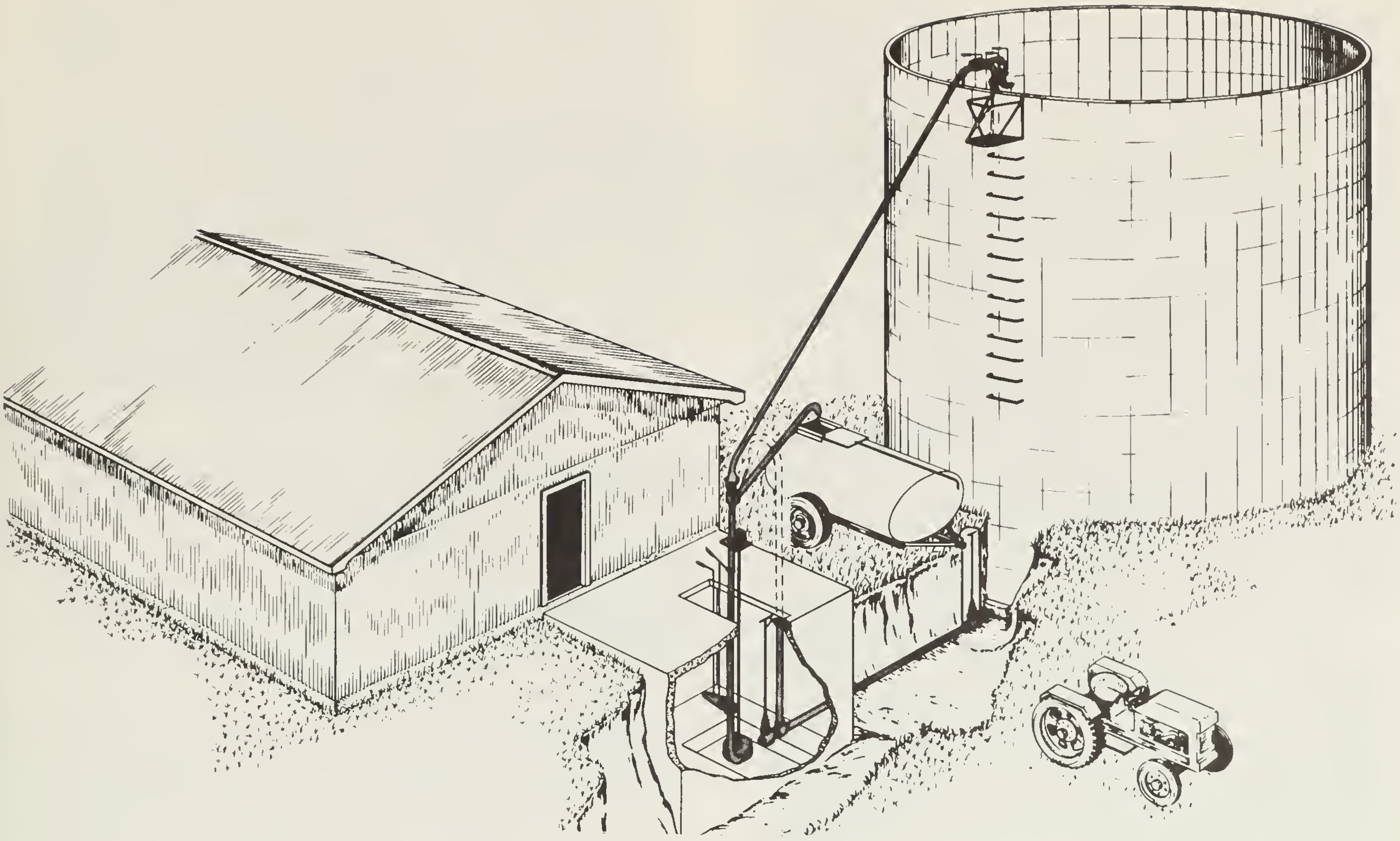


Figure 37 Above-grade silo-type concrete manure storage.

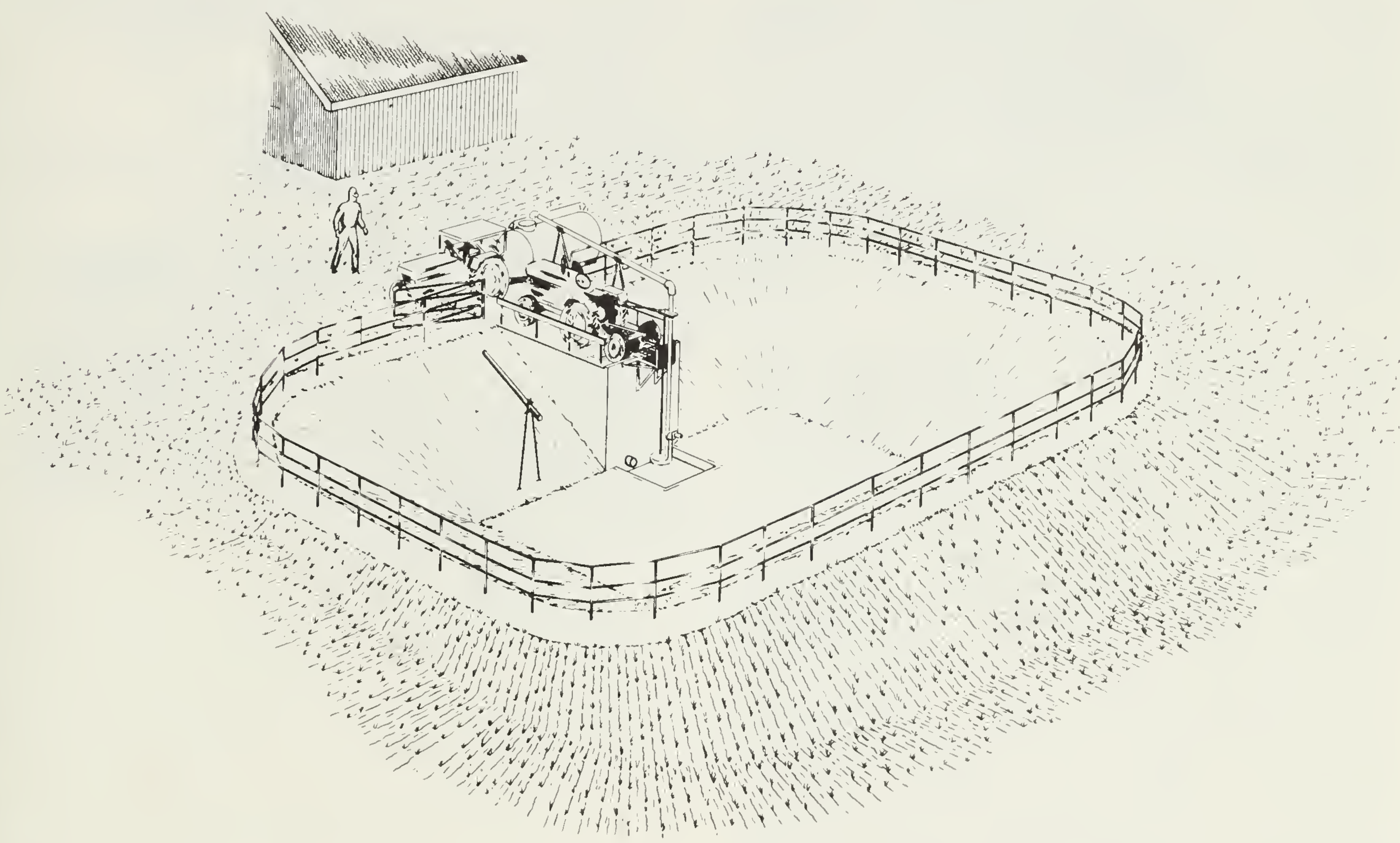


Figure 38 Clay lined manure storage pond.

If built below a slotted floor within the barn, liquid manure storages should be designed to allow 0.3 m of freeboard space at the top of the tank and should be adequately ventilated to minimize the accumulation of hazardous gases. To avoid gas hazards, remove livestock and open all doors for maximum ventilation when agitating open storages within the barn. When manure enters a separate covered storage through barn openings, exhaust ventilate from the storage or provide a gas trap to prevent backflow of odors and dangerous gases into the barn. Do not enter an indoor or covered storage without taking special precautions. Make sure it is well ventilated and wear a rope safety harness with at least two men standing by on the rope outside the storage. You can take the additional precaution of wearing a self-contained breathing apparatus. Do not smoke, use matches or an open flame while inspecting an unventilated storage tank; some gases produced, particularly methane, can be explosive when mixed with air.

Disturb liquid manure in storage as little as possible to minimize the emission of odors. Further reduction of odor can be achieved by covering the storage. Add only the minimum amount of dilution water necessary to allow agitation and pumping. Excess water increases storage requirements and the quantities of manure to be hauled to the field. On the other hand, sufficient water to properly dilute manure for agitation is necessary to avoid a buildup of solids in the tank.

Where an earthen pit is used rather than concrete or metal tanks to store liquid dairy manure, locate the storage at least 150 m from any residence and 300 m from any public water supply. It should be on land so graded that surface drainage from adjacent areas does not enter. If constructed in other than clay soils, earthen storages must be lined with an impervious material such as clay to prevent seepage and possible contamination of ground water. Earthen storages should be adequately fenced to prevent the accidental entry of humans, animals or machinery.

SEMISOLID MANURE STORAGES Semisolid manure storages require a concrete slab surrounded by either a concrete wall or an earthen embankment (Figure 39). In areas with high water tables, build them entirely above grade to minimize seepage of ground water into the structure; this will also facilitate the cleaning-out operation. In areas of high annual or seasonal precipitation, they should be roofed to keep out rain and snow. If roofed, these storages (Figure 40) should be well ventilated to prevent the accumulation of hazardous gases. Build all access doors of tight tongue and groove pressure-treated timber or equivalent. To prevent pollution, any seepage should be diverted onto a grassed waterway or drained into a catchment pond or underground concrete storage tank. Semisolid storages with a ramp should be fitted with guard rails and safety stops on the ramp to prevent a tractor from being accidentally buried in the manure.

SOLID MANURE STORAGES Solid manure storages require a slab to provide footing for loading equipment and a perimeter curb to contain the liquid runoff. They should be on a well-drained site, properly graded to divert surface water away from the structure (Figure 41). Stockpiling manure directly on the ground is not recommended and should never be done in areas of high rainfall and high water table. Where possible, locate stockpiles of manure away from and out of sight of public places and nearby residences. They should not be in natural drainage ways or on coarse-textured or gravelly soils. Solid manure storages should be managed in such a way that odors, flies and pollution hazards are minimized.

SIZING MANURE STORAGES Manure storages should be designed with enough capacity that the operator can avoid spreading manure on sensitive crops during the growing season, or at any time when surface runoff could occur. The size of the storage will depend on the type and number of animals, the length of time that manure can be spread and, with liquid manure, the volume of dilution water added.

The manure production per 500 kg cow is approximately 0.42 $M^3/d$. Semisolid manure storage should be designed on this basis, adjusting up or down for the size of the animals. If bedding is used, the storage should be increased to 0.47 $m^3/(cow.d)$. In either case the total storage volume V(s) equals the number of cows times the number of storage days times the required storage per cow per day plus the volume of any dilution water added (or precipitation if the storage is uncovered), i.e.

$$V(s) = N \times T \times V(m) + V(w) \text{ where}$$

N = number of cows
V(m) = manure production per day per cow including bedding
T = storage time in days
V(w) = volume of dilution water added (or precipitation if the storage is uncovered)

The Canada Plan Service has leaflets and plans that contain detailed information on capacities for various sizes, for both solid and semisolid manure storages. These plans and leaflets are available from extension engineers and local provincial agriculture offices.

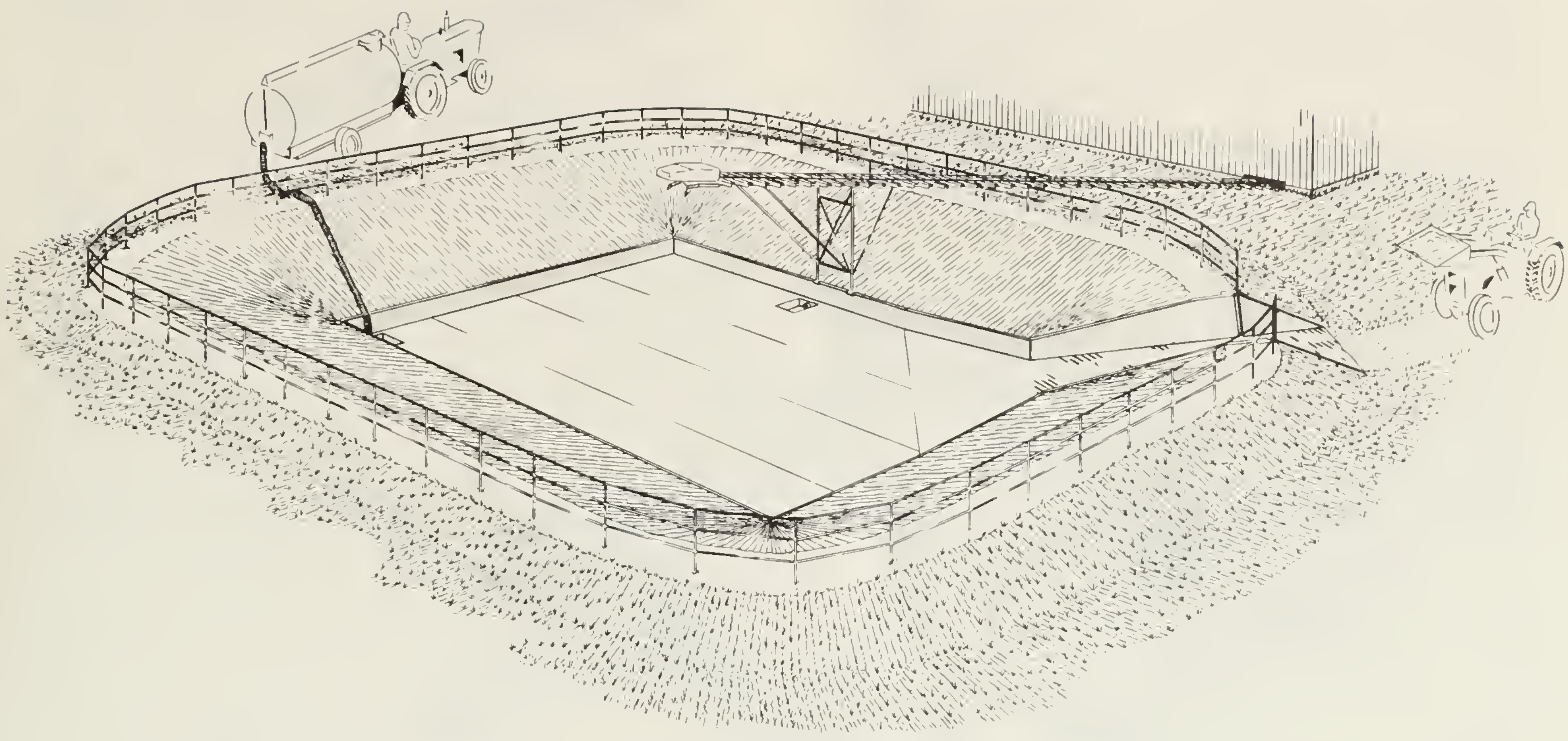


Figure 39 Curbed slab manure storage with earth banks.

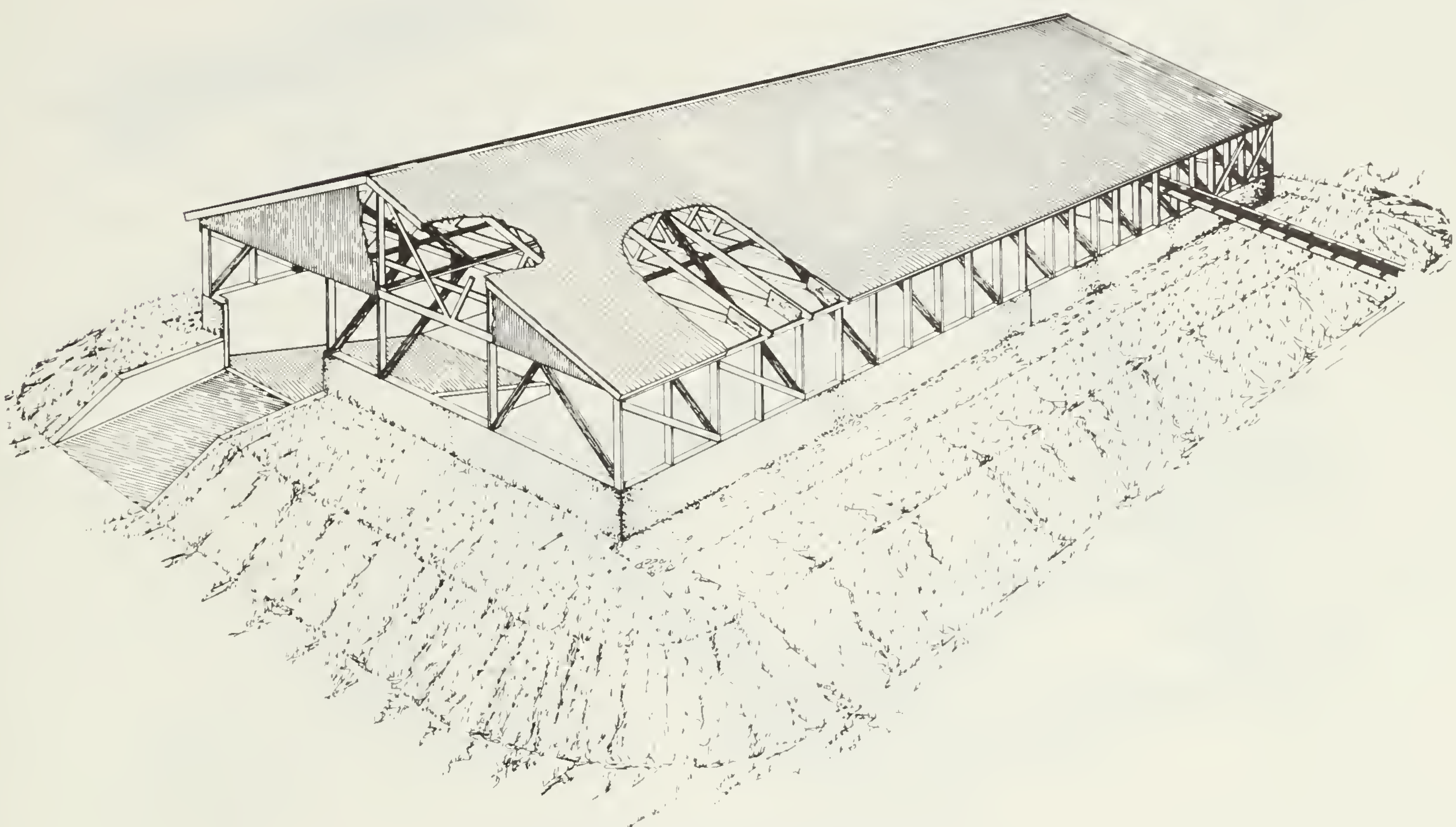


Figure 40 Rectangular concrete roofed storage for semisolid manure.

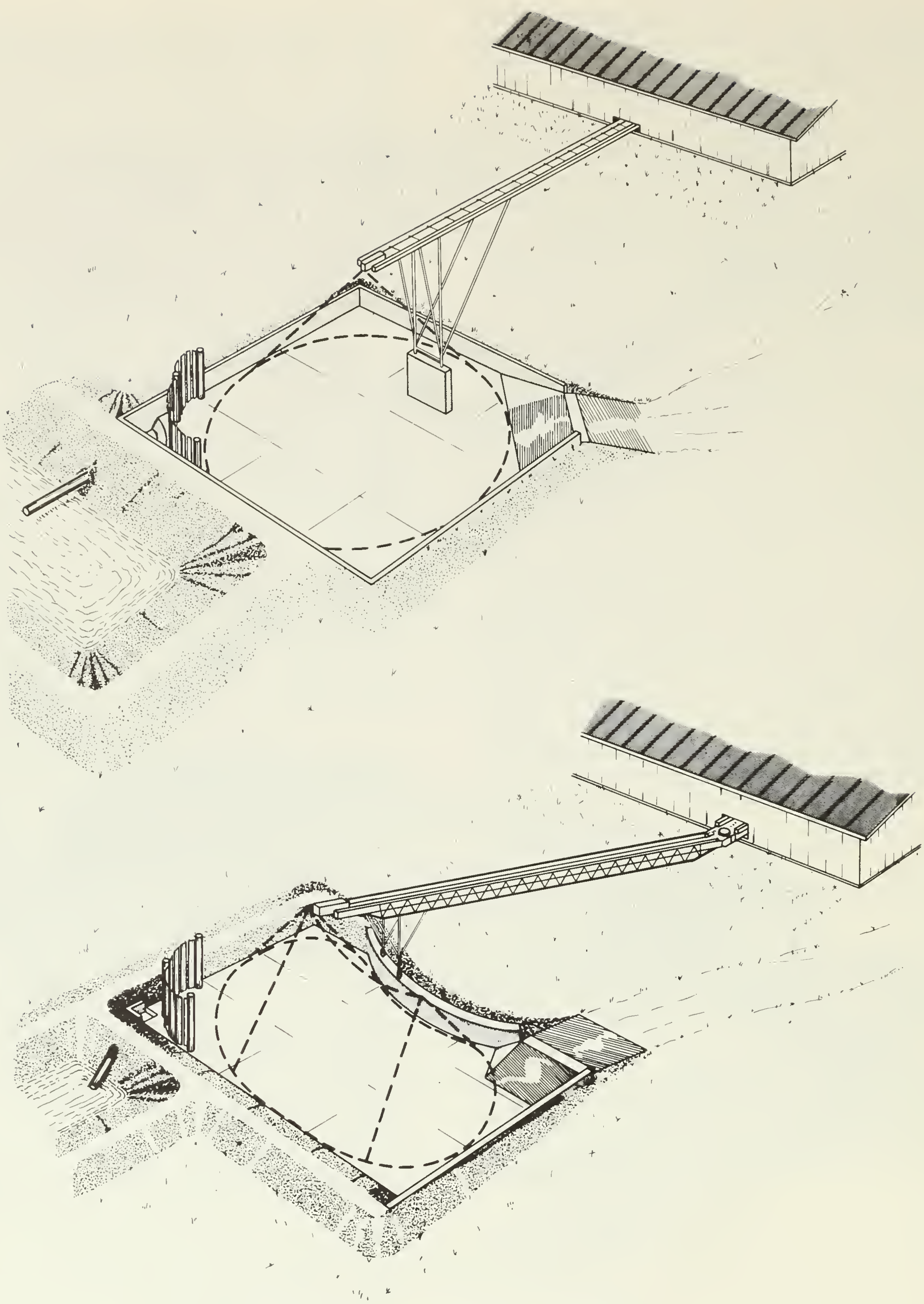


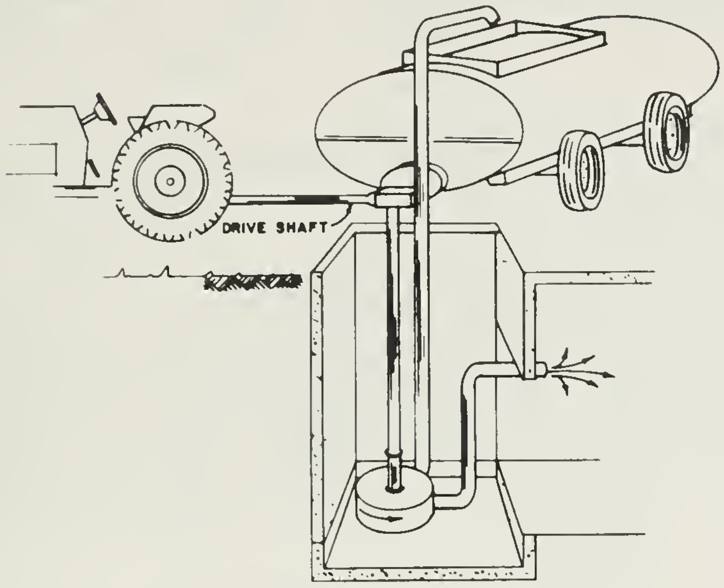
Figure 41 Curbed storage slab for stacked manure.

## Removal of manure from storage and application onto cropland

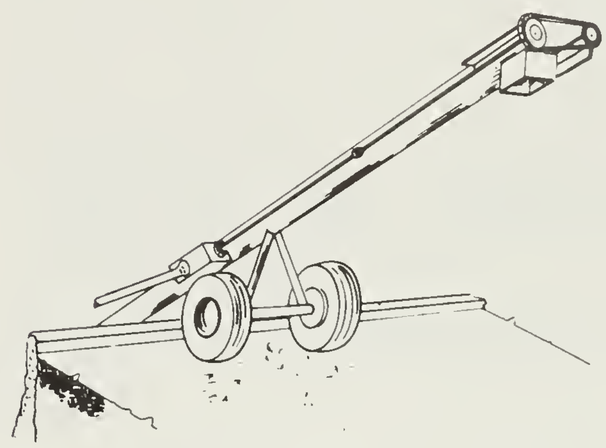
If manure is properly handled, its fertilizer and soil-building properties will exceed the cost of storing, hauling and spreading. At this time, recycling of manure onto cropland is the only method of ultimate disposal that can be generally recommended. In this publication, only those methods involving manure spreader application onto cropland are considered. Irrigation with dairy manure has not proven acceptable for many farmers in Canada. If irrigation is contemplated, manure must be diluted to 95% moisture content to provide a mixture dilute enough to be properly pumped and sprinkled.

LIQUID MANURE  Liquid manure may be unloaded from storages by any of a number of centrifugal chopper pumps (Figure 42), or may be removed by gravity where the topography allows. Vacuum pumps, augers and various enclosed chain conveyors also may be used.

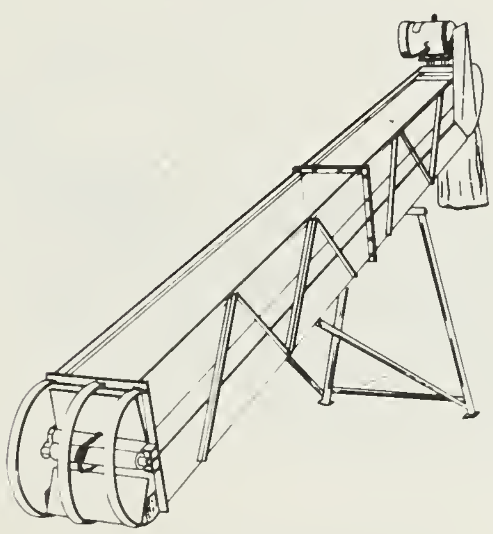
Regardless of the method, agitation will be necessary and commonly is done with a tractor pto-powered liquid manure pump or with a propellor agitator. The effective agitation radius using pto-powered pumps is commonly 8 to 10 m, whereas the propellor agitators have been effective up to 15 m in relatively dilute manure. For agitation, rectangular storages work best if divided into compartments no larger than 8 by 15 m. Avoid additions of hay and bedding to liquid manure tanks, as such fibrous material will create problems during agitation. Always provide adequate agitation before manure removal begins.



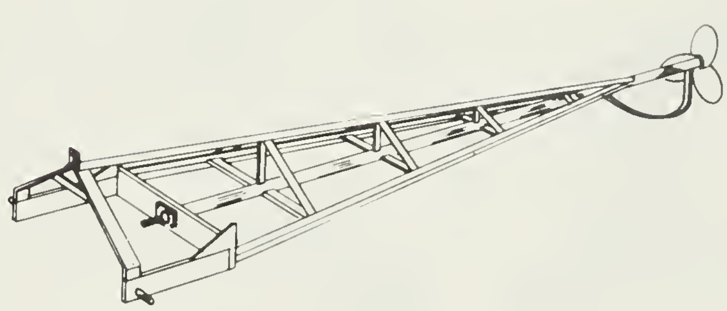

CENTRIFUGAL CHOPPER PUMP



AUGER



ENCLOSED CHAIN CONVEYOR

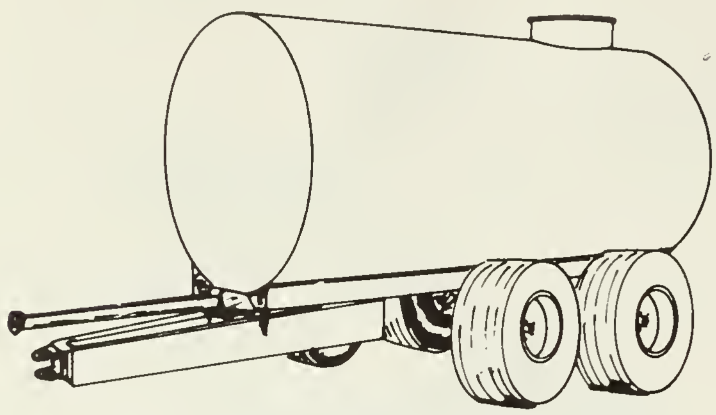


PROPELLOR TYPE AGITATOR

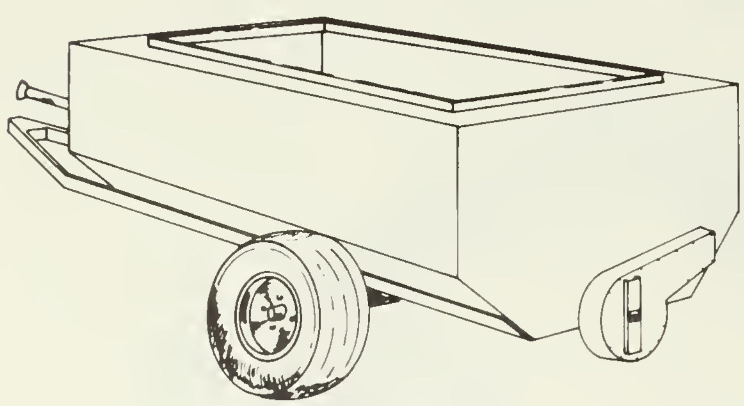
Figure 42  Various types of liquid manure agitators and conveyors.

A wide range of spreaders (Figure 43) are available to handle liquid manure, for example: vacuum tanker spreaders, top-loading pump-filled tank spreaders, auger-loading tank spreaders and top-loading hopper spreaders. Although not designed specifically for liquid manure, chain-flail tank spreaders and conventional box spreaders equipped with hydraulic end gates may be used.

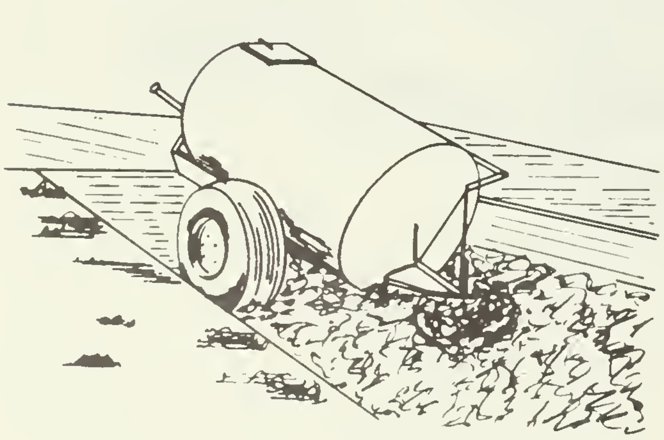
SEMISOLID MANURE Semisolid manure to which no water has been added is not readily agitated, and hence is not easily handled by conventional liquid manure handling equipment. Semisolid manure may be handled however, without agitation, by a tractor-mounted front-end loader or by a tractor-mounted scraper blade working on a specially designed ramp. Sludge pumps that mount on the pto of tractors also are being developed; these can handle unagitated dairy cattle manure where minimal amounts of bedding have been used.



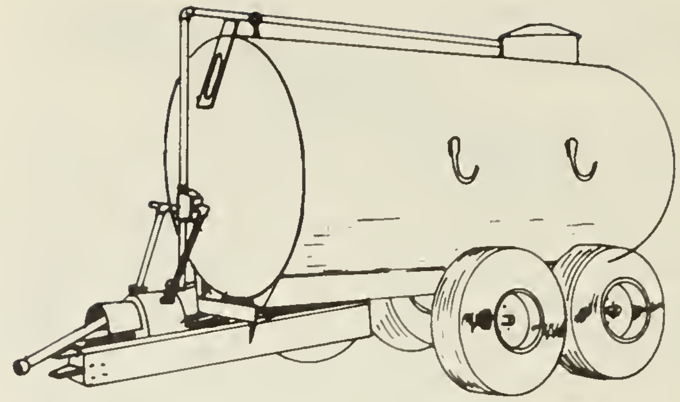
TOP LOADING PUMP FILLED TANKER



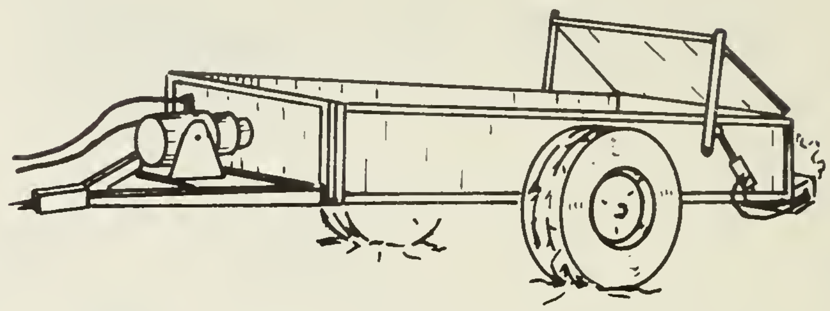
TOP LOADING HOPPER



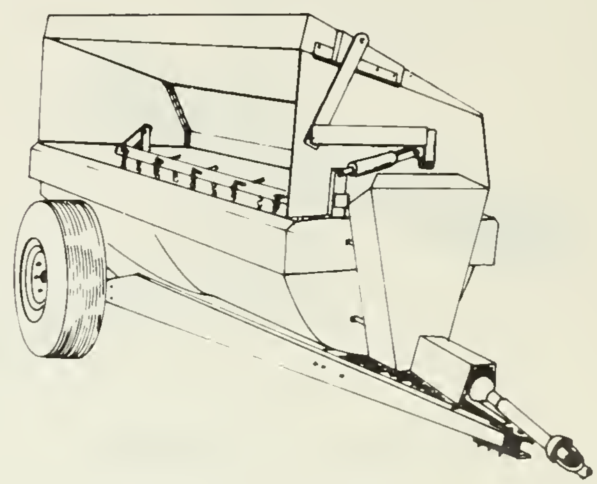
AUGER LOADING TANKER



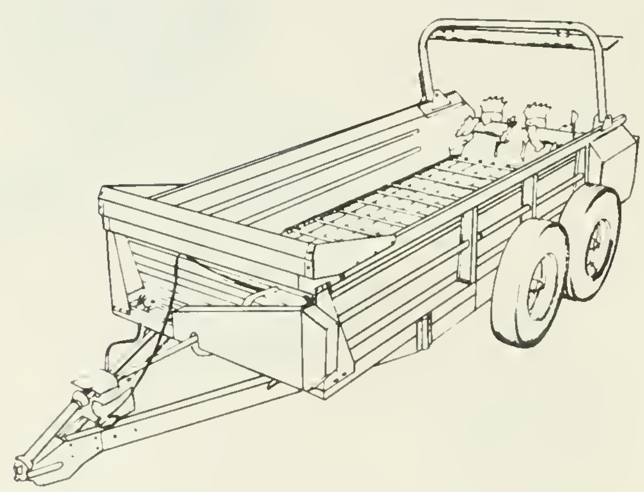
VACUUM TANKER



HYDRAULIC PUSH-OUT BOX



CHAIN FLAIL TANK



CONVENTIONAL BOX

Figure 43 Various types of manure spreaders.

Where a front-end loader is to be used to remove manure from storage, tractor access into the storage is necessary. This is normally afforded by removable bulkheads or by suitable ramps. A concrete pad should be provided outside the storage where the spreader can be parked during loading. A tractor (at least 45 kW) equipped with a good industrial bucket is recommended. Large industrial loaders will do the job much quicker.

A second method, recently developed, of handling unagitated semisolid manure involves a tractor equipped with a rear-mounted scraper blade that drags manure from the storage up a ramp and over a grate (Figure 44). The manure then falls into an open-top tanker. The time required to load a 6 $m^3$ spreader ranges from 2 minutes when the storage is full to around 5 minutes when nearly empty. Safety stops should be installed on the ramp to prevent the tractor from accidentally backing down and submerging in a full storage. This type of ramp may be built into any shallow concrete tank or earth bank storage and provides a quick and relatively inexpensive method of loading spreaders.

Conventional box spreaders and tanker wagons have been modified and improvements have been made to enable the handling of semisolid manure.

Conventional box spreaders with hydraulic end gates, box type hydraulic push out spreaders, chain-flail tank spreaders, top-loading hopper spreaders, and auger-loading tank spreaders may all be used successfully with semisolid manure. Vacuum tankers and tanker wagons requiring loading with pumps are generally not satisfactory.

SOLID MANURE Manure removal from solid manure storages normally will involve a tractor-mounted front-end loader. Loading will be done directly into an open-top spreader. The range of suitable spreaders is limited to conventional apron-slat spreaders and chain-flail spreaders. Solid manure should be spread evenly onto croplands, insuring that lumps are partially broken up, particularly if being applied to grassland.

SUBSURFACE DISPOSAL OF MANURE Covering manure by plowing or discing as soon as possible after spreading greatly reduces odors and prevents it from washing off fields with surface run-off. Up to 25% of the nitrogen will be lost the first 24 hours after application unless the manure is immediately incorporated. Plowdown methods and injectors are available to incorporate manure into plowed as well as uncultivated fields. A plowdown method is not efficient for most farm operations with only one tanker, but neighbors could pool equipment. Soil injection holds the greatest potential for odor control, for prolonging the application period in the spring, for incorporating manure into hay and pasture without completely destroying the crop, and for achieving an acceptable application rate. Soil injectors (Figure 45) presently available use pressure to pass liquid manure from the tanker through tubes behind deep cultivator teeth and into the soil. Refinements still are required to ensure adequate coverage behind the unit and to make it suitable for row crop application under a wide range of soil conditions. Existing rapid-cover plow-down and soil-injection equipment is designed for liquid manure and is not suitable for solid manure.

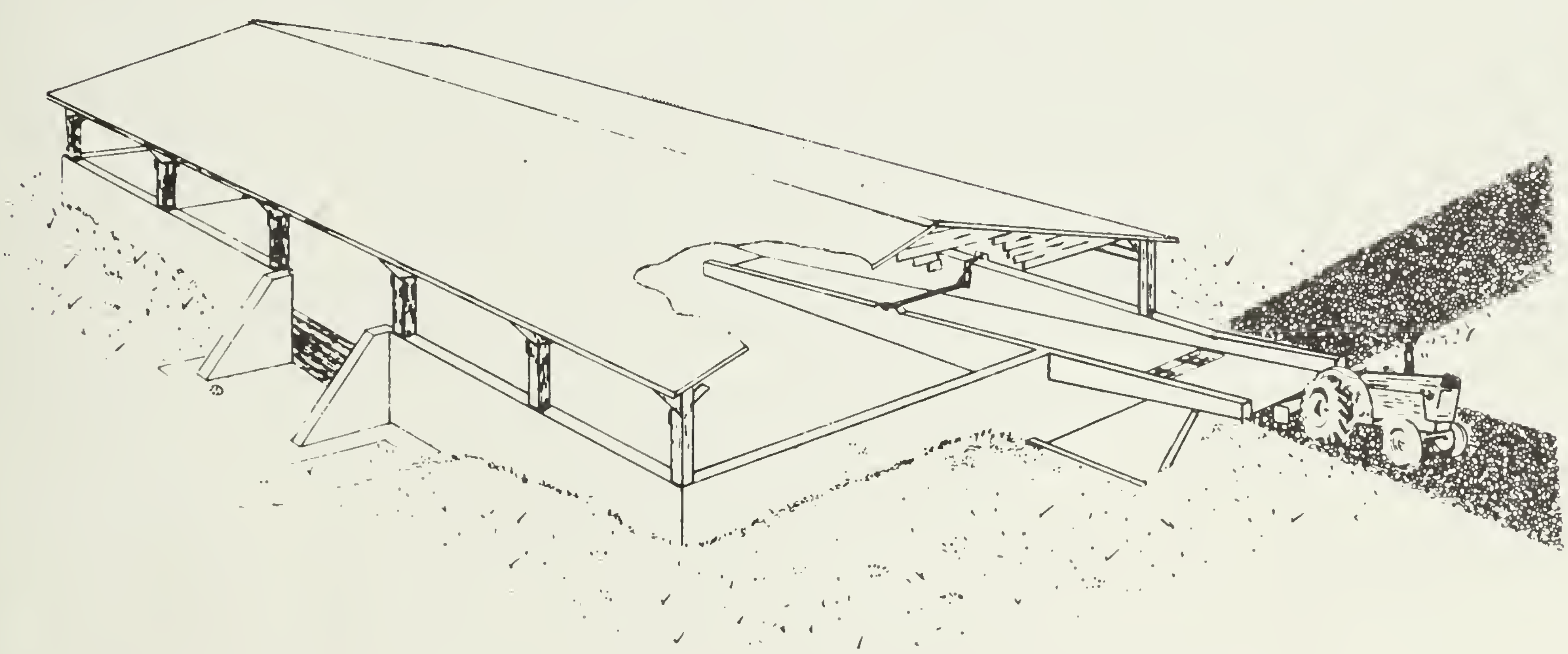


Figure 44 Tractor scrape ramp for unloading manure storage.

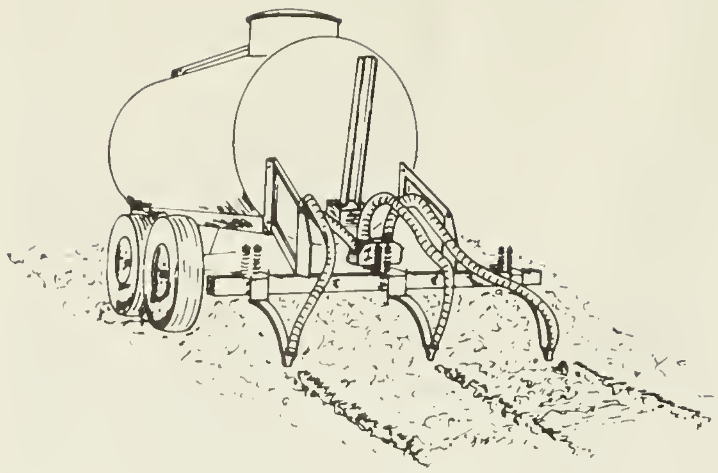


Figure 45 Tanker fitted with soil injectors.

## Milkhouse waste water disposal

Most provinces have legislation against the contamination of streams and water supplies, and regulations to determine the permitted methods of disposal of waste from milkhouses and milking parlors. It is unsatisfactory to directly drain these wastes onto the surface of the ground (some provinces do allow surface irrigation), or to empty them through a field drainage system into an open ditch, creek or river. Instead, the wastes should be drained through a system designed to provide proper treatment.

Recommended procedures for disposing of the milkhouse wastes are to pass them through a sediment tank and disposal field or to dump them into the main manure storage if a liquid or semisolid system is being used. If surface irrigation is used, a separate holding pond may be desirable.

Details for the design of the sediment tank and disposal field, including trench dimensions and construction procedures, are given in Agriculture Canada Publication 1620, *Planning Your Milkhouse*. Keep in mind that milkhouse wastes include sanitizing additives in the waste water and possibly spilled feed and some manure from the milking parlor. This combination makes the wastes difficult to treat. As well, bacterial action is low and sludge builds up rapidly; it must be removed and spread on the land every 6 months or so.

If waste water from the milkhouse is emptied into the main manure storage then additional storage space must be provided; add 15 litres per cow per day. If a milking parlor is used even more space will be needed. This additional volume must all be hauled to the field, and the material to be handled when emptying the storage will be more liquid.