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ENGINEERING FOR INTENSIVE HOUSING OF LIVESTOCK

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ENGINEERING FOR INTENSIVE HOUSING OF LIVESTOCK

CONTROLLING THE ENVIRONMENT

Many problems with poor winter ventilation in controlled-environment animal buildings can be traced to a deficit of heat. This is especially true where higher temperatures are not required, and farm operators attempt to use the building without any supplemental heat. Supplemental heating, however, increases investment and operating costs, and several alternative methods are being tried. These include heat exchangers, solar heating, reducing inside temperature, vapor diffusion, and management changes that can reduce water vapor (latent heat) production.

Various methods of cooling the animal environment are available for the hot summer weather. Mechanical refrigeration is usually not economic in the Canadian climate. Evaporative cooling of the intake air is not effective except in an extremely dry climate. Sprinkler cooling of pigs, on the other hand, has been shown to be effective in terms of improved animal performance.

Control of light involves windowless buildings, full mechanical ventilation, and lightproof ventilation openings, all of which may be economic depending on the response of a particular breeding animal to light.

Pollution control regulations are forcing changes in the design of livestock production systems. More beef cattle, for example, will probably be housed in total confinement in order to control feedlot runoff. Ventilation of beef confinement barns may be by open eaves and ridge to provide a colder but healthier animal environment without supplemental heat, and manure storage for 6 or more months will be required.

Odor control is an additional requirement for large livestock units located near sensitive neighbors. This problem can usually be resolved by adequate manure storage and covering it quickly with soil when it is spread on farmland. Aeration of manure in storage is another odor control, and the oxidation ditch is a promising method of partly treating pig waste to control odor production.

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Under Canadian climatic conditions, the engineer's main interests in the intensive housing of livestock are protective housing to optimize the animal environment, mechanization of chore operations, and the disposal of waste

products. This publication outlines important principles in the control of animal environment and the disposal of animal wastes, but does not describe the mechanization of chore operations.

THE TEMPERATURE-HUMIDITY ENVIRONMENT

The amount of animal housing that must be used to economically modify the natural outdoor environment depends partly on the sensitivity of the animals to climatic extremes. Animals with thick insulating coats of hair, wool, or feathers can tolerate low temperatures better than seminaked animals, such as pigs. On the other hand, most domestic species are homeotherms that cannot sweat readily and do not thrive at high summer temperatures.

It is important to provide a good environment for pig production. Growing pigs are sensitive to both high and low temperatures. Research by Heitman and Hughes (17) has shown (Fig. 1) that the best temperature for

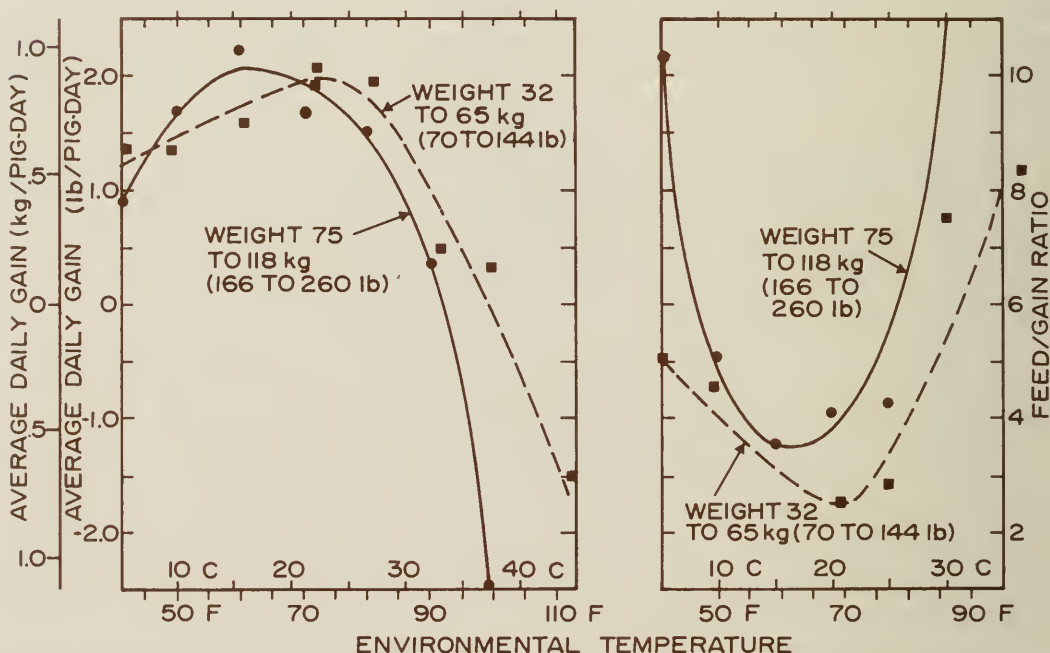


Fig. 1. The effect of environmental temperature on average daily gain and efficiency of use of feed by pigs.

the growth of pigs is between 16 C and 24 C (60 F and 75 F), younger pigs preferring the warmer limit. Fig. 1 also shows that the rate of gain, especially of the larger pigs, falls off very sharply at temperatures over 30 C (85 F). High humidity combined with high temperature is especially bad.

Sheep, beef cattle, and dairy cattle, on the other hand, are well-coated animals and can tolerate cold much better than pigs. For these animals, less sophisticated environmental control may be acceptable for winter. For summer where control of light is not required, the best practical type of environment may be a building with large open areas in the walls, and a roof to provide shade from the sun.

HEAT BALANCE AND WINTER VENTILATION

Heat balance is of fundamental importance to the operation of animal ventilation systems. Winter heat balance is defined by the following equation:

$$\text{ANIMAL TOTAL HEAT} + \text{SUPPLEMENTAL HEAT} = \text{BUILDING HEAT LOSSES} + \text{VENTILATION HEAT LOSS}$$

In practice, the heat gains (left) must always balance the heat losses (right). This balance is achieved by natural or mechanical adjustments to the factors controlling one or more of the four main components of the equation.

Animal total heat varies with several factors, including the animal number, size, species, state of activity, level of nutrition, and temperature. Animal heat production includes two components: *sensible heat* (radiation, conduction, and convection), and *latent heat* (evaporated moisture). Typical animal heat production relationships are illustrated in Fig. 2, from Blaxter

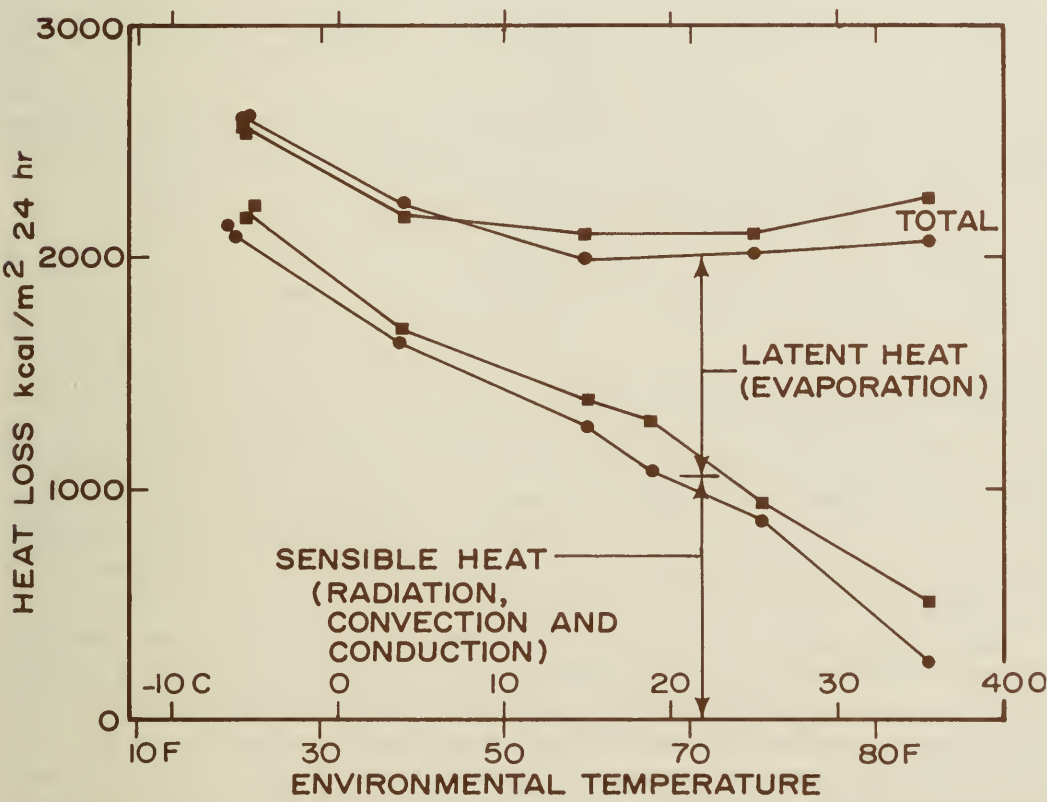


Fig. 2. The effect of environmental temperature on the total heat emission and the sensible heat loss of the two steers.
■ steer Amos; ● steer Andy.

and Wainman (3). Much research on animal physiology has reported latent heat production from the animals only. However, the moisture evaporated from pen floors, water bowls, and other surfaces also uses up heat of vaporization, and requires ventilating air exchange for its removal. Therefore,

for ventilation design it is most essential to calculate latent heat production of the animal—pen combination, which some researchers call the “room latent heat” or “stable moisture.”

Supplemental heat includes all heat sources other than the livestock, such as heating equipment, lights, and motors. This is the variable most readily controlled, but it can also be the most expensive since it usually involves purchased energy and extra equipment for conversion to heat.

Building heat losses include the flow of heat energy through ceilings, walls, foundations, and floors. Building heat losses vary directly with building surface areas and the inside-to-outside temperature difference, and inversely with the amount and quality of insulation materials. Increasing the number of animals in a building of given size decreases the building surface area per animal and thus decreases the building heat loss per animal.

Ventilation heat loss is the heat lost from the building when cold dry outside air is exchanged for warm humid inside air. Ventilation heat loss is a direct function of ventilation rate, as well as inside-to-outside differences in temperature and absolute humidity.

Ventilation rate in turn must be adequate to remove the evaporated moisture (or latent heat), and therefore the theoretical ventilation heat loss is related back to the animals. In practice, ventilating fans controlled by thermostats automatically balance the heat equation by exchanging air whenever there is enough heat accumulated in the building to bring the inside temperature up to the ‘start’ temperature of the thermostat. Thus, actual ventilation rates are based on surplus heat, not on control of moisture, or gases such as CO_2 , H_2S , CH_4 , and NH_3 , which may be present. Usually these other gases can be kept below critical concentrations if ventilation is sufficient to control moisture.

If a heat deficit occurs, the effective ventilation rate is reduced by the thermostats controlling the ventilating fans. The most obvious result is increased humidity. Engineers customarily design winter ventilation for a maximum inside relative humidity of 75% to 80%; this is based on control of excessive condensation on the interior walls and ceilings, not necessarily on the well-being of the animals housed.

An important fact is the relative magnitude of the four main components of the typical heat balance equation. In Fig. 3, the two heat loss components (shaded areas) have been added to show total heat losses. Note, for example, that at -29°C (-20°F) outside temperature, ventilation heat loss is 1,565 kcal/cow-hr and building heat loss is only 118 kcal/cow-hr, or less than 7% of the total loss.

With animal ‘total heat production’ superimposed in Fig. 3, another fact emerges. The crossing of this animal heat production curve over the ‘total heat losses’ curve establishes a critical outside temperature above which a heat surplus exists, and below which there is a heat deficit. As outlined earlier, a heat surplus is usually of no concern since the resulting overventilation will keep the atmosphere a little dryer. However, below the critical temperature, the heat deficit results in underventilation and the inside humidity rises out of control. Cases of 100% relative humidity (fog) are often reported where for one reason or another a cold-weather heat deficit occurs. Note that the critical temperature in this case is -14°C (6°F). In fact, this point is not as sharply defined as Fig. 3 would indicate, but this is a typical outside temperature for the first signs of heat deficit, namely, surface condensation on ceilings and colder parts of walls.

Fig. 3 shows that rather large changes in the building heat loss (insulation value of the building) are required to produce much change in the critical

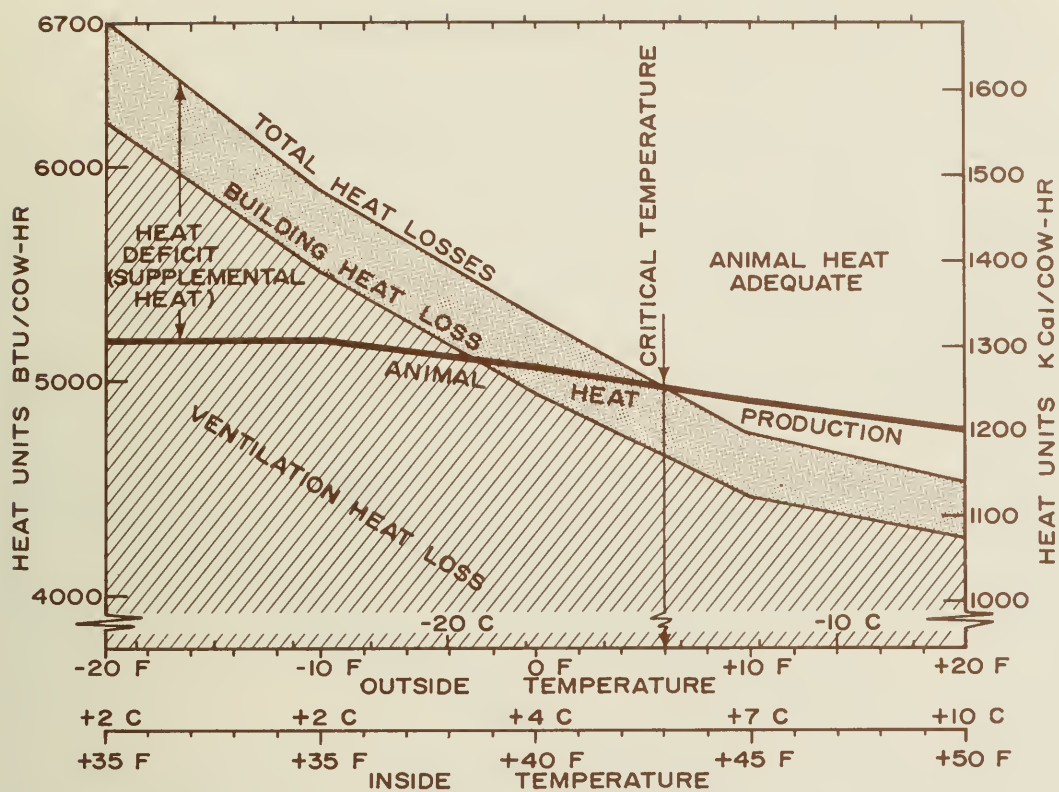


Fig. 3. Heat balance diagram for a 633-kg (1,400-lb) lactating dairy cow housed in a well-insulated barn with controlled environment. Based on 120 cows in a barn 13.4 x 61 m. (44 x 200 ft), with 10 cm (4 in.) wall insulation and 15 cm (6 in.) ceiling insulation. Inside relative humidity assumed to be 80%.

temperature. Similarly, crowding of animals to reduce building heat loss per animal has been overemphasized as a means of lowering the critical temperature and improving ventilation. And reducing building heat losses to zero (infinite insulation) in this case would only reduce the critical temperature to -19°C (-2.5°F).

On the other hand, a small percentage change in ventilation heat loss (ventilation rate) can greatly change the critical temperature. Since ventilation heat loss is directly related to the 'room latent heat' component of the total animal heat production, it is apparent that the ratio of room latent heat to animal total heat production is of extreme importance.

Fig. 4 shows calculated latent/total heat ratios for various domestic animals in relation to temperature. The sharply increasing slopes of these curves with increasing temperature result from the opposite effects of temperature on the production of sensible heat and latent heat as shown in Fig. 2. Animals with higher ratios of latent/total heat will have correspondingly higher 'critical temperatures' than those with low ratios. The low ratios for caged laying hens explains the fact that rather few Canadian poultry cage buildings use any supplementary heat, whereas additional heating is common in pig-growing units except in the warmest regions. The spread between 23-kg (50-lb) pigs and 90-kg (200-lb) pigs also points out why small pigs require more supplementary heat than larger ones, even when housed at the same temperature.

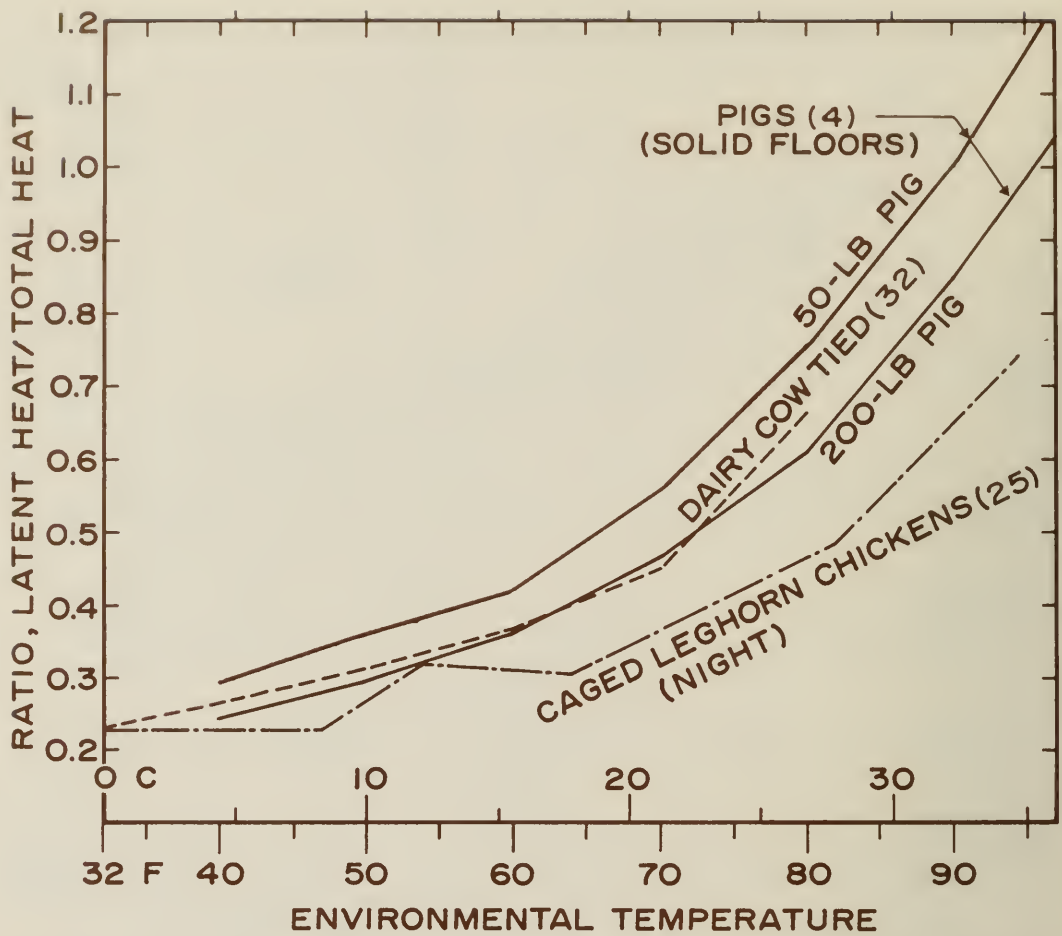


Fig. 4. Ratio, latent heat to total heat, as a function of environmental temperature, for typical farm animals.

For any given class of animals and housing design, the heat balance can be calculated to predict the critical outside temperature as well as the amount of supplementary heat required to correct the heat deficit at the lowest outside temperature to be expected. The accuracy of these calculations is, however, highly sensitive to the degree of precision of the latent and total heat production data available. Heat production data for pigs (4, 16, 17), dairy cattle (33), and laying hens (26), for example, are reasonably good. On the other hand, engineers need more information for growing turkeys, sheep, beef cattle, and veal calves in confinement; and more precise information is required on the effects of management on latent heat production.

METHODS OF CORRECTING WINTER HEAT DEFICIT

SUPPLEMENTARY HEATING

The most obvious method for correcting a heat deficit is to add dry heat, usually starting at the outside critical temperature, and increasing heat input with decreasing outside temperature (see Fig. 3). The maximum heat requirement occurs at the design winter minimum temperature, which depends on geographic location (2). Adding heat is the common method wherever large deficits occur (weanling and growing pigs, for example) or

where inside temperatures of 16 C (60 F) and higher are necessary (brooding young animals and poultry).

Supplementary heating can be very expensive, especially where too little research or experience with good design has been accumulated. In 1968 Buchanan and Fellows (6) reported supplementary heating trials in a slotted-floor total confinement beef finishing barn at Winnipeg. Based on the rather attractive rates for electric power in Manitoba, inlet-duct electric heaters were installed, capable of adding up to 0.38 kw/animal unit. At 1.1 cents/kwh this represents a peak energy cost of 10 cents/animal-day. This lowered the outside critical temperature from -1 C (30 F) without heat, to the point where acceptable environmental control could be achieved at -34 C (-30 F). Design winter minimum temperature at Winnipeg is -33 C (-28 F) on a 1% basis (2).

Buchanan's experience indicates that enough additional heat can solve a difficult heat deficit problem, but it further increases the operating costs of an already economically dubious beef housing system. Certainly a more economical solution to heat-balance problems must be found before controlled-environment beef finishing can become practical in climates as cold as in the Canadian prairies.

SOLAR HEAT

Various proposals have been made on the use of solar radiation to preheat incoming ventilation air. Many existing designs for poultry and pig buildings use a vented attic space as a plenum for winter ventilation air supply. A rise of 3 C (5 F) above winter daytime temperature is common under unpainted galvanized steel roofing. Hall (15) reported on an improved design based on a double-skinned roof, the incoming air being drawn through a 4-cm (1¹/₂-inch) space under corrugated steel roofing. The recorded temperature rise ranged from 8 C (14 F) on cloudy winter days to 24 C (44 F) in bright sun.

Obviously, solar heating is of no benefit at night when heat demand is likely to be at a maximum, so its potential value is probably limited to reducing the purchased energy requirement or to drying out a building that was wetted by condensation the previous night.

REDUCING ROOM LATENT HEAT PRODUCTION

When we consider the relative magnitude of the ventilation heat loss shown in Fig. 3, it would seem that even minor reductions in room latent heat production would be very effective in improving a ventilation heat deficit.

Harman et al. (16) showed that room latent heat production of growing pigs was much lower with slotted floors over a liquid manure pit than with solid concrete floors (see Figs. 5, 6, and 7). This is a spectacular example of a management practice that would appear to increase vaporization but, in fact, has just the opposite effect. Meiske et al. (21) similarly observed 5% to 10% lower humidities in a slotted-floor beef confinement unit, compared with solid floors.

Applying Harman's observations to ventilation calculations for pig growing-finishing units, the outside critical temperature for solid-floor pig pens is -1 C (30 F); for 35% slotted floors the critical temperature drops to -15 C (5 F). Another practical example of a management change to reduce room latent heat production is the change from deep litter poultry laying houses to wire floors or cages. This solves the wet litter problem by preventing the birds from tracking through it to spread the moisture.

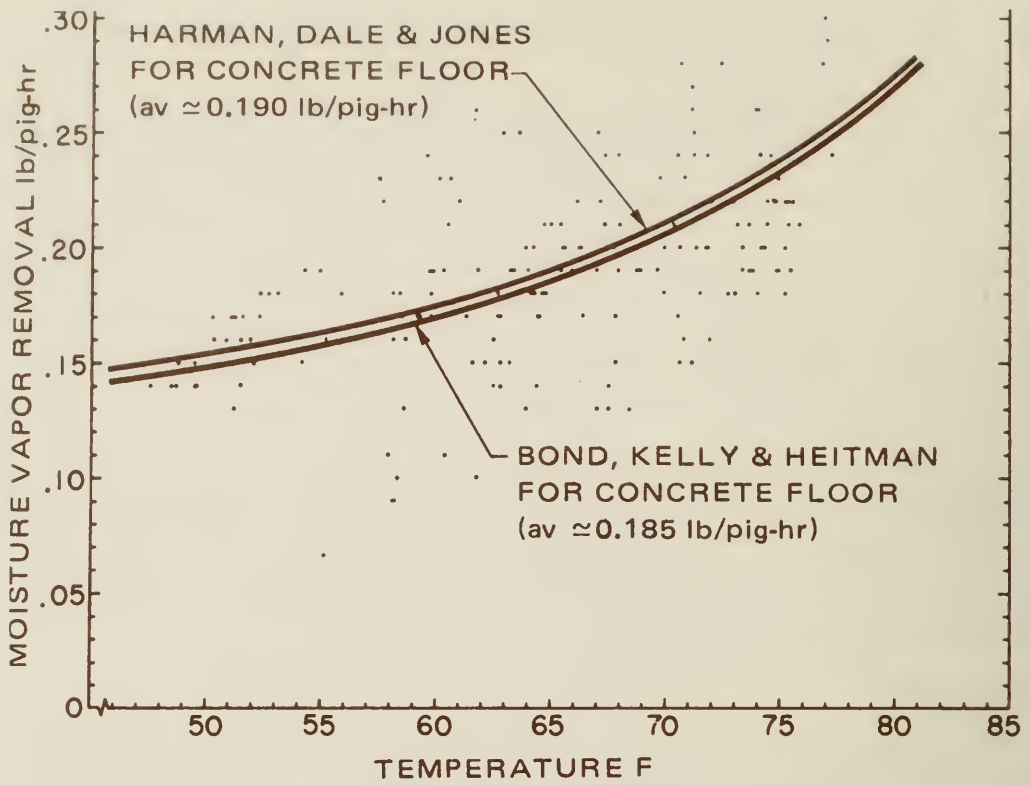


Fig. 5. Moisture vapor removal rate vs. temperature for concrete floor pen.

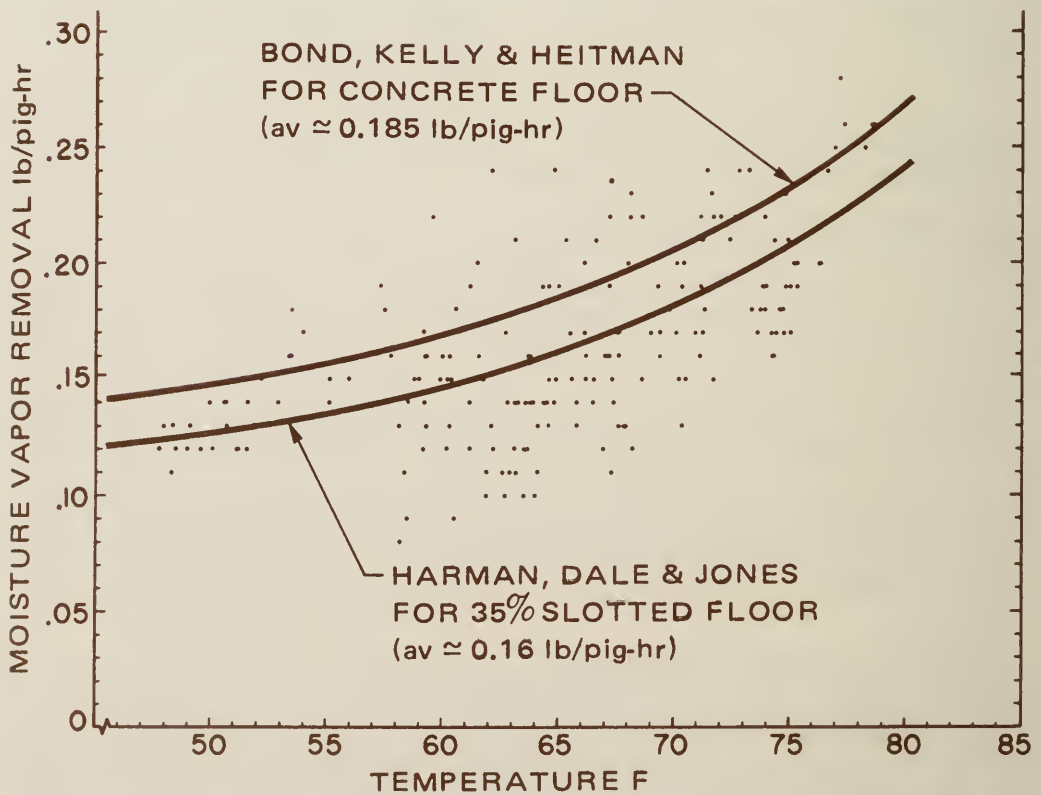


Fig. 6. Moisture vapor removal rate vs. temperature for partially slotted floor pen.

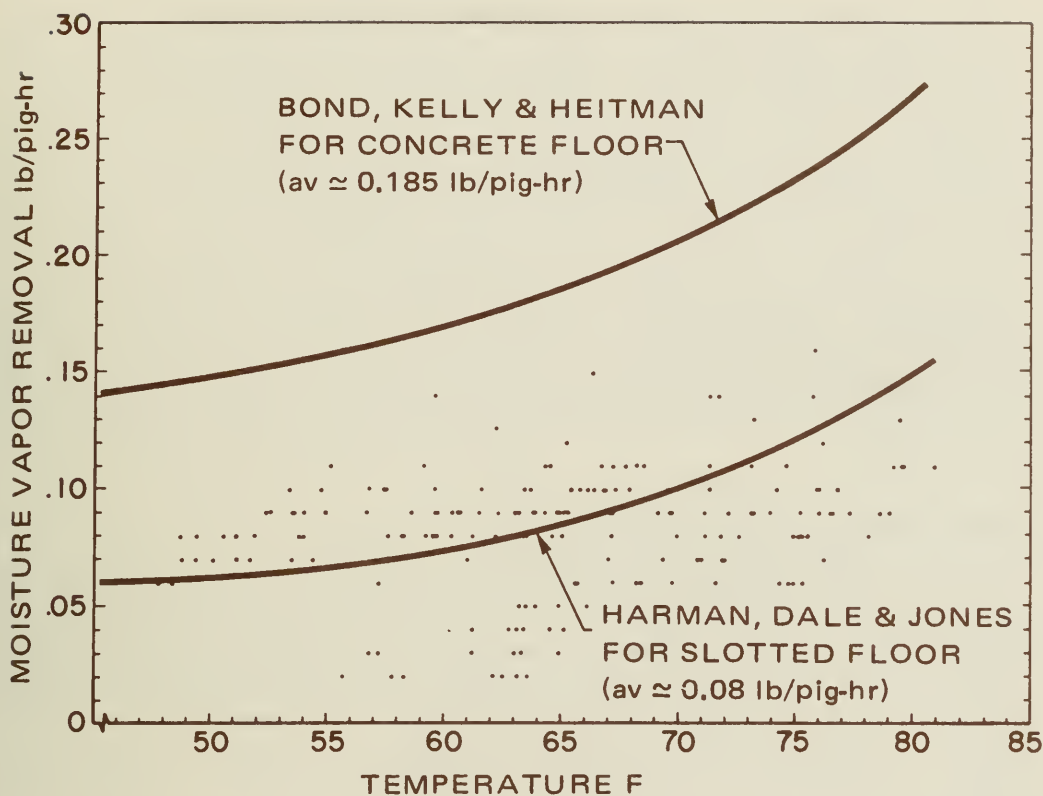


Fig. 7. Moisture vapor removal rate vs. temperature for slotted floor pen.

REMOVING WATER VAPOR BY DIFFUSION

Heat flow through insulation materials is generally in proportion to and in the direction of the temperature gradient. Published data for the insulation values of building materials are normally based on zero air movement through the insulation layer.

Pattie (27) has shown that if ventilating air can be drawn through a layer of porous insulation, such as fiberglass, in the opposite direction to the normal heat flow, this infiltrating air can pick up much of the escaping heat. This prewarms the air slightly and reduces the effective heat loss to negligible proportions. Applying this principle to a livestock building, Pattie states that the entire wall and ceiling area could act as a distributed fresh-air inlet, and 'building heat loss' could be almost eliminated.

In addition, room atmospheric pressure to draw enough ventilating air through a porous insulation would be less than 2 mm (water gauge) below the outside atmosphere. However, the partial water vapor pressure difference between the warm moist animal environment (80% relative humidity, 10 C) and the cold outside air could be as high as 100 mm water gauge; this inside-to-outside vapor pressure differential is a force potentially capable of driving water vapor out of the building against the ventilation pressure gradient causing air infiltration.

Pattie has proposed, therefore, to use a porous insulated building in which the inside is kept at a controlled negative pressure by exhaust fans, such that building heat loss is minimized by infiltration, yet some of the water vapor is allowed to escape and the ventilation heat loss is thereby reduced.

In principle, this concept is especially intriguing because it attacks two parts of the heat balance equation at the same time. However, several practical difficulties must be solved. Because a porous building would be ventilated by natural wind forces to a much greater extent than by the controlled force of the exhaust fans, a windproof, rainproof, and snowproof envelope would be needed over the walls and roof. But the protected air space between this weather envelope and the insulation material must still be well ventilated to prevent damaging condensation. Vapor barriers are normally added to the warm side of insulated construction to prevent this, but a vapor barrier defeats the principles Pattie has explored. Another practical problem is the delicate balance of air pressures required to maintain simultaneous infiltration of dry air and exfiltration of water vapor. Another complication is dust accumulation, which with time changes the porosity of the insulation.

VENTILATION HEAT EXCHANGERS

Another promising approach that also attacks the 'ventilation heat loss' part of the heat balance equation has been investigated by Giese (11, 12), Ogilvie (25), and others. This involves an air-to-air heat exchanger through which is passed simultaneously the incoming cold and the outgoing warm air. One type of heat exchanger consists of a multilayer sandwich of spaced metal sheets that separate alternating flows of warm and cold air such that heat is readily transferred from the warm to the cold air without transferring the moisture.

A heat exchanger with even a relatively low efficiency would be easily capable of correcting the heat deficit in most livestock units. Parallel-flow units are the least efficient since the temperatures of the two air flows can never cross each other but can only approach. Counter-flow units with sufficient heat-exchange surface area can bring the two air temperatures to a crossover; in other words, the final temperature of the cooled exhaust air can be below the final temperature of the warmed fresh air. Ogilvie's counter-flow laboratory heat exchanger (25) was capable of saving 65% to 70% of the sensible heat that is ordinarily wasted by ventilation.

Another heat exchanger, as yet untested for animal ventilation, uses the two-phase thermosiphon tube described by Larkin (19). Here a number of finned metal tubes with refrigerant sealed inside are banked together to transfer heat from the warm to the cold air stream. Heat is transferred rapidly across a flow divider by continuous boiling of entrapped refrigerant at the warm end and condensation of the refrigerant at the cool end of the bank of finned tubes. The advantage claimed for the thermosiphon is very rapid heat transfer, which could result in a more compact and efficient heat exchanger unit.

A potential advantage of the ventilation heat exchanger is that its theoretical effectiveness increases with decreasing outside temperature. This should permit a higher ventilation rate to reduce the concentration of problem gases and contaminants as well as water vapor.

But there are some unsolved problems. The exhaust air from a controlled animal environment is nearly saturated, and a few degrees of cooling at the plate surfaces of the heat exchanger causes condensation. If the outflow surfaces are below freezing, the condensate can collect as ice to plug the system, and wet heat exchanger surfaces collect dust, losing efficiency with time. One small perpendicular-flow heat exchanger is commercially available, but it has not been widely accepted because of low heat-exchange capacity.

REDUCING INSIDE TEMPERATURE TO CORRECT A HEAT DEFICIT

Often the simplest method for resolving a heat balance problem is to lower the inside temperature. Refer again to Fig. 2 and note that as environmental temperature falls below 10 C (50 F) the sensible heat fraction of an animal's total heat production increases rapidly, but the latent fraction declines. Thus, increasing the ventilation rate by lowering thermostat settings can sometimes overcome a heat deficit.

This method is so simple that it has potential for all well-coated livestock species capable of adjusting economically to the reduced temperature. Holstein dairy cattle (20), for example, have shown only slightly reduced milk production with temperatures down to -12 C (10 F). Similarly, growing beef cattle can tolerate low temperatures if they are suitably acclimated and the environment is comfortably dry (30).

Many new free-stall dairy barns constructed recently in milder parts of Canada and northern USA take advantage of this low-temperature tolerance of dairy cows. A very acceptable environmental system has evolved. This is a compromise between the open-front resting barns promoted 15 to 20 years ago and the mechanically ventilated controlled-environment barns. This development can be called modified environment. See Fig. 8 for details of the modified-environment concept as applied to a free-stall dairy barn.

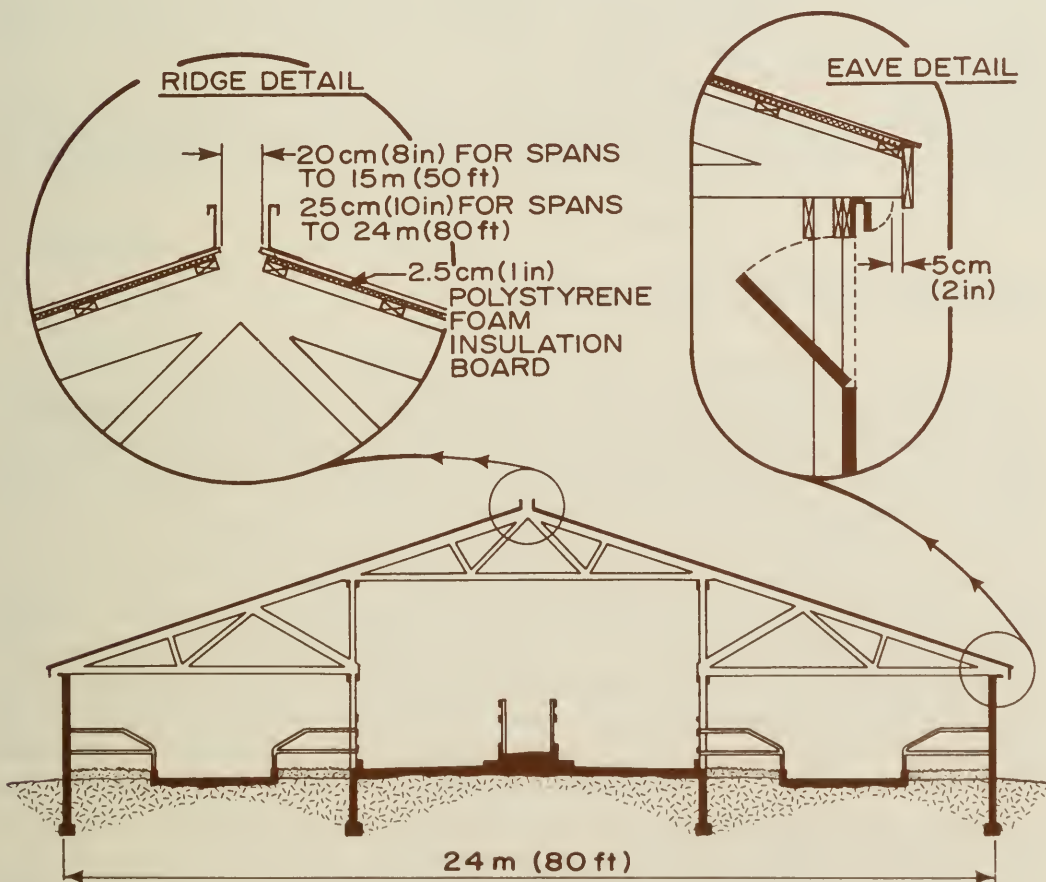


Fig. 8. Modified environment free-stall dairy barn with insulated roof and slot ventilation.

The ventilating force in this modified environment is the 'chimney effect' of the warmer air within the barn. There is no ceiling, and the sloping underside of the roof appears to contribute to the effectiveness of the inside air circulation in preventing excess condensation. Some barns of this type have been built with only a single skin of sheet metal on roof and walls. Without insulation, however, too much condensate freezes at night on the underside of the roofing. With radiation from the morning sun on the roof, this frozen layer thaws and water drips down. A layer of polystyrene foam insulation board under the roofing and siding (as shown in Fig. 8) eliminates most of the condensation. Farm experience indicates that birds will attack the polystyrene insulation wherever the interior barn framework provides a perch within reach of the insulation surface, so high-density extruded polystyrene is preferred.

The outlet ridge slot admits an insignificant amount of rain and snow, especially when guarded by vertical baffles as shown in Fig. 8. The ridge slot should terminate 2 to 3 m (6 to 10 ft) from each end of the roof to prevent back drafts. The inlet slots at the eaves are located just behind the face board to help exclude snow. Extra ventilation is obtained in mild weather by opening tilt-in flaps along two walls. For summer housing, large doors are opened all around so that the building acts mainly as a sunshade.

Since the ventilating force (neglecting wind) is the density difference between warm inside and cold outside air, this natural system tends to maintain a constant outside-to-inside temperature difference, instead of a constant inside temperature as with controlled environment.

Winter temperature surveys in uninsulated modified environment free-stall dairy barns by Boyd et al. (5) and Irish (18) indicate that winter inside temperatures follow approximately parallel to outside temperatures, but 2 C to 12 C (5 F to 22 F) higher. Until more economical methods are developed for achieving a heat balance at controlled inside temperatures, this natural ventilation system should be further exploited for sheep and beef cattle as well.

SUMMER COOLING METHODS

Summer confinement housing usually involves rapid ventilation as the only means of controlling inside temperature. Conventional engineering practice is to design mechanical ventilation for an arbitrary temperature rise (such as 2 C) based on sensible heat balance, using the sensible fraction of the livestock heat production at the design temperature. This results in ventilation rates up to 10 times the winter minimum requirements.

At such ventilation rates some evaporative cooling takes place from wet floors, litter, and drinking equipment. This can reduce or even eliminate this outside-to-inside temperature rise when outside relative humidity is low (10).

Where control of light is not required, many livestock producers use natural wind admitted through large wall openings to economize on ventilation equipment and electrical energy. This can provide improved environment for adult or well-coated livestock, but it is not practical where doors must be manually closed every night to prevent drafts on sensitive livestock such as young pigs.

Mechanical refrigeration has been evaluated for cooling controlled-environment livestock units. Stewart et al. (28), for example, studied costs and benefits of mechanically cooled dairy barns in Ohio. They concluded that

the practice of cooling the entire animal space was effective in maintaining milk yield during hot weather, but not economical in the Ohio climate (hence, Canada as well). Burnside et al. (8) in southern Illinois found that mechanically cooled pigs gained faster than those housed in an outside pen or in a fan-ventilated building, but no economic analysis was reported.

Since a major part of animal heat is dissipated by the respiratory system, *zone cooling* around the head shows promise of decreasing the cooling load, dust problems, and odors associated with total-room mechanical cooling. Hahn et al. (14) found that cows stanchioned at 29.4 C (85 F), but with heads enclosed in a compartment cooled to 15.6 C (60 F), maintained milk production at 91% of their production with 18.3 C (65 F) total cooling.

Merkel and Hazen (22) similarly found that with sows confined in farrowing crates at 32.3 C (90 F) a jet of air cooled to 18.3 C (65 F) around the nose improved nursing performance.

Zone cooling, however, is limited to tied confinement situations such as dairy tie-stalls or sow farrowing crates and would be of doubtful economic value in Canada.

Evaporative cooling for growing-finishing pigs is being investigated at Winnipeg, Man., by Buchanan (7). Results of one summer test (see Table 1) indicate spectacular advantages for intermittent spray cooling over wet-pad evaporative cooling, and uncooled environment. The outside temperature exceeded 29.4 C (85 F) on only one day of the 22-day feeding period of this test.

TABLE 1. EFFECTS OF SPRAY COOLING AND EVAPORATIVE COOLING ON 59-KG (130-LB) GROWING PIGS, SUMMER FEEDING TEST

	Control	Spray cooling	Evaporative cooling
Mean feed consumption (kg/pig-day)	3.43	3.72	3.21
Mean daily gain (kg/pig-day)	0.0607	0.834	0.549
Feed conversion (feed/gain)	5.66	4.46	5.85

Control of the water spray was by a thermostat connected in series with a cycle timer set to switch on 2 minutes out of 30. The thermostat and timer both controlled a solenoid valve in the water supply pipe. The cycle timer permitted the operator to conserve water, which could quickly overflow the manure storage if allowed to run continuously.

One explanation for the benefits of spray cooling is that a coarse spray directed on the animals' skin cools by direct conduction from skin to the evaporating film of water. This is obviously more efficient than heat transfer by conduction, convection, and radiation from dry skin to humid air, where the air has been precooled by evaporation to a temperature approaching the wet-bulb temperature. Spray cooling has a further advantage in that the loose-penned pigs can take it or leave it.

These preliminary data indicate that intake-air evaporative cooling as a method of improving hot-weather pig environment is practical only where high temperature coincides with humidities much lower than at Winnipeg. Direct spray cooling, on the other hand, is simple, inexpensive, and effective and may have application to other animals as well as pigs.

LIGHT CONTROL

Control of light is an additional environmental requirement for some animals and some stages of growth, particularly where animal reproductive functions are involved. Light stimulation typically occurs at very low lighting intensities. Complete light control requires inlets and fan openings fitted with baffles that can stop light but pass air. Two or more light bends are usually required for an effective light trap.

Fig. 9 shows a typical lightproof inlet opening built through the eave of a building. The shortest light ray is traced to show how the baffles are strategically located to stop the light. Inlets such as this distributed along the

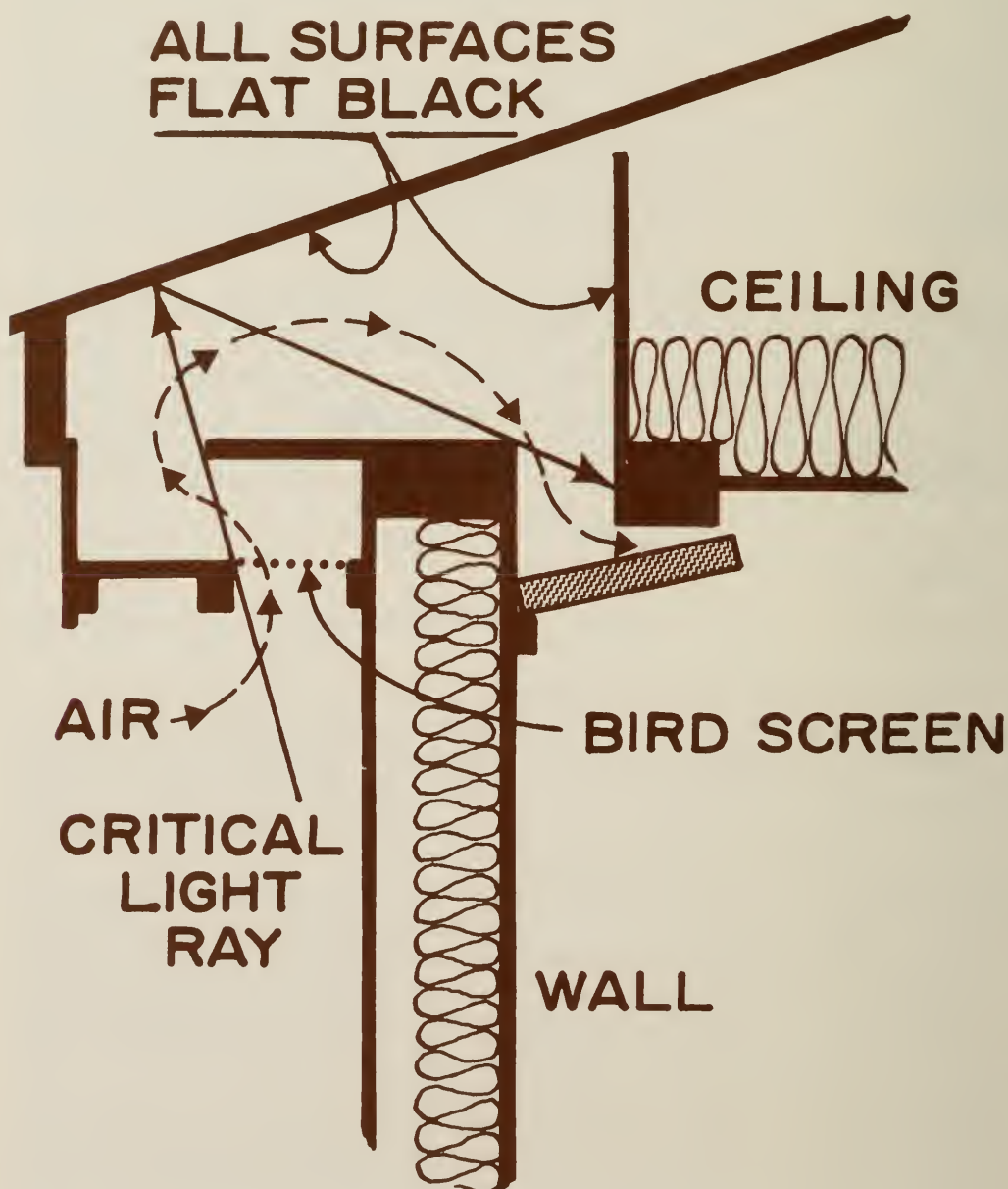


Fig. 9. Lightproof continuous-slot air inlet for controlled lighting environment.

perimeter of a building pose no great problem since the air velocities can be minimal, and the baffle surfaces remain clean and black.

Fan exhaust openings are more difficult because of higher air-flow velocities around the fans, and dust, which quickly soils the baffle surfaces. Fig. 10 shows one type of baffled light trap for an exhaust fan outlet, adapted from Turner and Davis (32). This baffle arrangement provides a minimum of only two light bends, which makes an effective light trap only if the black surfaces are cleaned daily (an impractical requirement). This light trap requires a large insulated fan house extended from the side of the building to provide enough opening to keep velocities below 120 m/min (400 ft/min). Higher velocities result in excessive energy loss and restrict ventilation.

Turnbull and Coates (30) tested a modified light trap consisting of interlocking w-folded steel strips. This provided three light bends, all within the 15-cm (6-inch) thickness of the building wall, and reduced the required depth of the fan house. This required very careful fitting of the w-folded steel strips, and a w-form with round bends instead of sharp bends was suggested to improve air-handling performance.

POLLUTION-FREE WASTE DISPOSAL AND INTENSIVE LIVESTOCK CONFINEMENT

The method of handling and disposing of livestock wastes has a major influence on the design of buildings for intensive livestock housing systems.

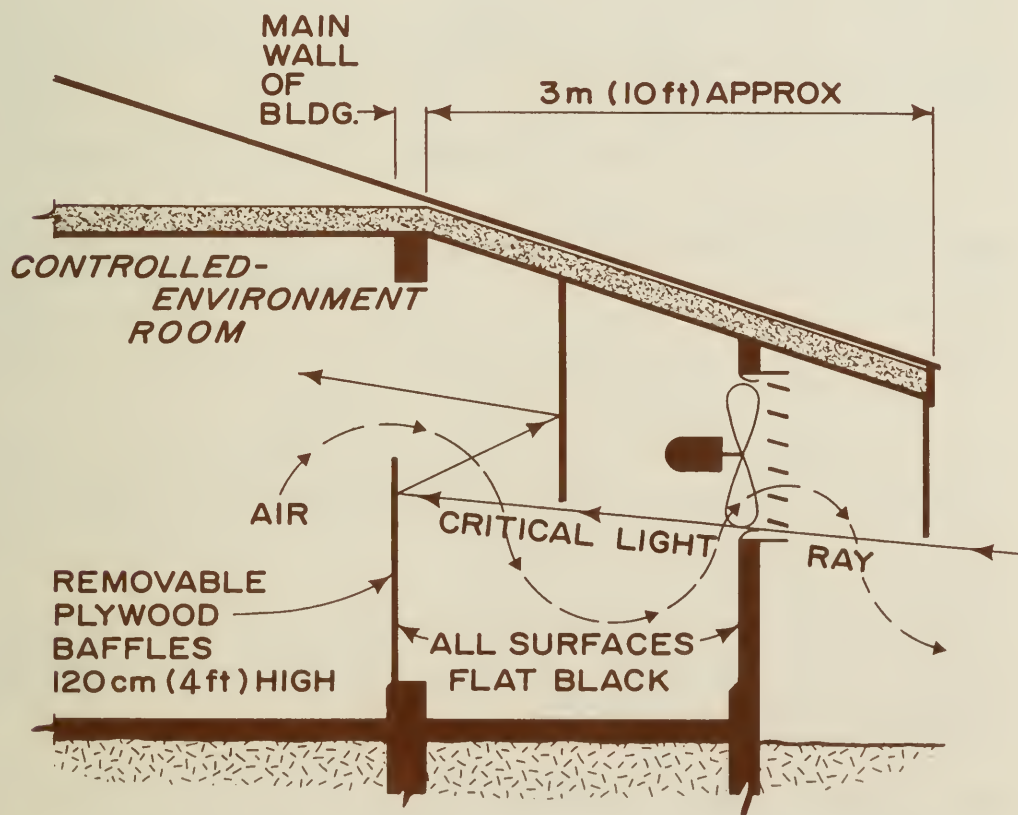


Fig. 10. Exhaust fan light trap (over and under type) for controlled-lighting environment.

The methods of storage, treatment (if any), and final disposal are strongly influenced by the economics, pollution hazards, and reliability of each phase of the operations.

Ogilvie and Hore (24) reviewed several alternatives for the treatment and final disposal of livestock wastes, including dehydration, anaerobic and aerobic stabilization ponds, septic tanks, and cropland spreading. Muehling (23) also reviewed systems for pig waste disposal, including anaerobic digesters and mechanical aeration. The important fact from these and other summaries is that each of the above disposal methods ultimately involves spreading of a raw or treated by-product onto land. This is because untreated livestock waste, unlike domestic sewage, is too concentrated to permit economical treatment leading to acceptable discharge directly into streams and rivers.

The animal production industry needs a great deal of well-informed guidance on waste disposal. One typical example of commercial information going to Canadian farmers is a plan for a 100-calf veal production system. The brochure recommends a disposal system consisting of a septic tank to hold 5.7 m³ (1,250 gal) leading to a tile 'leaching field' of unspecified size. Two things are wrong with this recommendation.

First, the 'shock load' of sanitizing wash water at the end of each batch of calves reduces the normal detention time in the septic tank from about 3.5 days (desirable) to 0.5 day or less, and therefore a slug of untreated waste is likely to plug the leaching tile.

Second, the continuous application of this concentrated effluent on the finite land area of the leaching field can lead to a dangerous groundwater pollution hazard. The waste from a 100-calf veal unit is estimated to carry about 400 kg (900 lb) of nitrogen each year. Cooper et al. (9) recommend a maximum nitrogen application rate of 347 kg/ha (310 lb/acre) per annum. This would require an unreasonably large leaching field; tank spreading from a liquid manure storage would be a more rational method.

POLLUTION REGULATIONS AND ANIMAL PRODUCTION UNITS

At present only two Canadian provinces, Alberta and New Brunswick, have regulations referring specifically to pollution from livestock production. Other provinces have generalized acts that are applicable, and more specific controls are coming. Ontario, for example, has a "Suggested Code of Practice" document for discussion, as well as the "Ontario Water Resources Commission Act," and "The Air Pollution Control Act, 1967."

Surface runoff from beef feedlots, for example, is a difficult water pollution problem because of the large surface areas involved. The State of Kansas (13) requires a downstream catch pond, sized to hold runoff based on the feedlot area times a depth factor. This does not, however, provide complete downstream protection, and the catch pond must usually be emptied by spreading on farmland.

Another approach to feedlot runoff control is to reduce the area of feeding facilities to a practical minimum. The entire animal area can then be roofed, and called 'total confinement.' The following section explores three design variations based on this principle.

BEEF CONFINEMENT HOUSING FOR WATER POLLUTION CONTROL

Figs. 11, 12, and 13 illustrate design variations for beef confinement based on different manure-handling systems. All three use the same mechanical

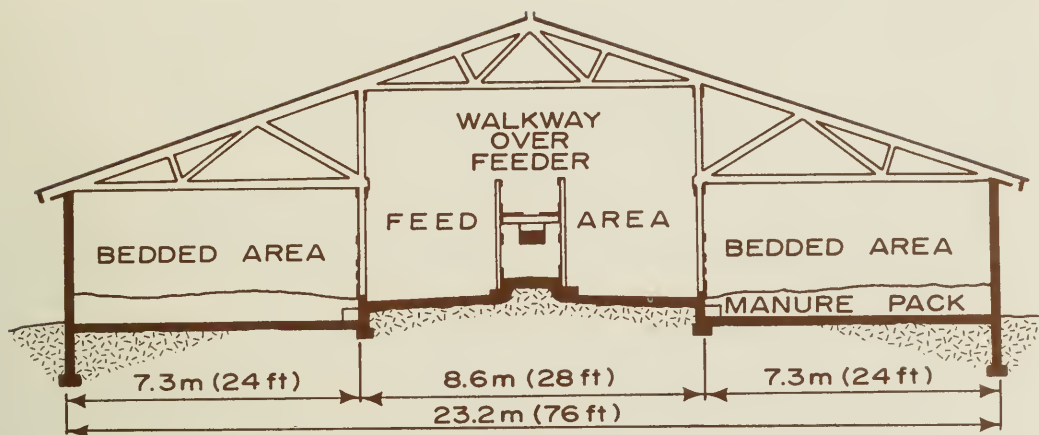


Fig. 11. Confinement beef feeder barn with solid manure handling system.

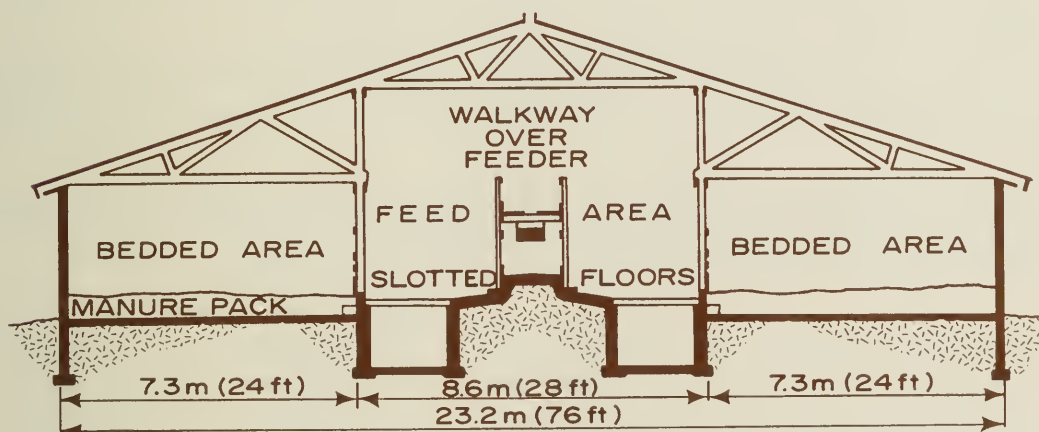


Fig. 12. Confinement beef feeder barn with liquid manure system in feed area and solid manure system in bedded area.

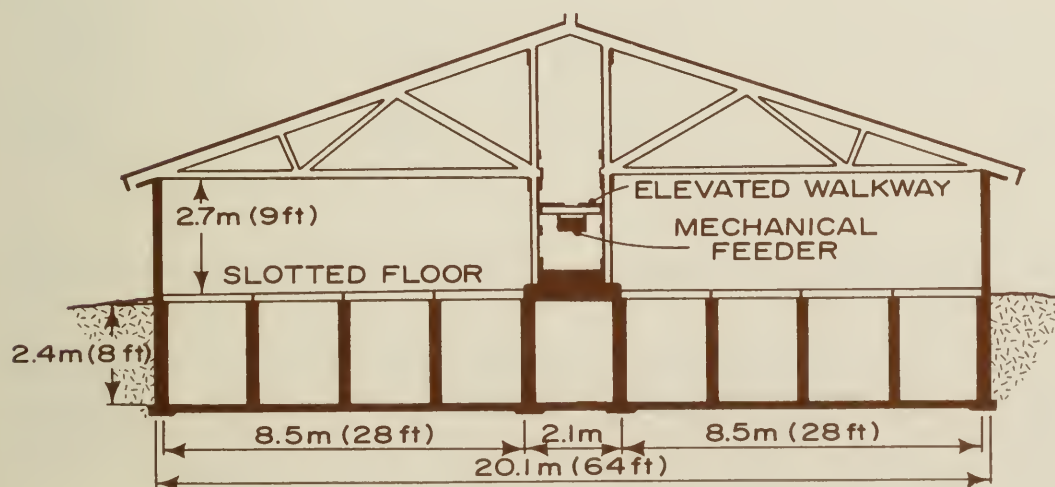


Fig. 13. Confinement beef feeder barn with totally slotted floors and underfloor liquid manure storage for 6 months.

feeding arrangement and 'modified environment' ventilation illustrated previously in Fig. 8.

Figs. 11 and 12 both show feeding areas and bedded areas separated by partial fencing for good manure pack management in the bedded area. This also provides a sorting arrangement in the feeding passages. Part of the manure storage is provided by the manure pack, but the manure from the feeding area must be removed and stored elsewhere.

The feed area of Fig. 11 is scraped frequently and loaded by tractor scoop by way of an elevated push-off into a manure spreader. Long-term storage of this part of the manure is usually on a stacking pad away from the farmstead but accessible from an all-weather farm road.

The slotted-floor feed area of Fig. 12 eliminates the daily scraping of the feed area but provides only enough storage for about 1 month. Liquid waste is then agitated and pumped by a tractor to a separate storage. This removal system could be one of several described by Turnbull (28). One disadvantage is that both solid and liquid manure handling equipment is required.

Fig. 13 shows totally slotted floor beef confinement. With slotted floors, no separate bedded area is used and bedding is not required. The underfloor storage holds the liquid manure for up to 6 months until it can be safely spread on cropland. The totally slotted floor reduces the required building span from 23.2 m (76 ft) to 20.1 m (64 ft).

These three variations in methods of storing and handling 6 months' manure production have important effects on the initial cost of the beef unit, as shown in Table 2.

TABLE 2. ESTIMATED INVESTMENT PER STEER IN BUILDING AND 6 MONTHS' MANURE STORAGE FOR BEEF CONFINEMENT UNITS

	Type of confinement unit			
	Fig. 11	Fig. 12	Fig. 13	
	solid manure (\$/steer)	solid & liquid manure (\$/steer)	liquid manure (\$/steer)	liquid manure (\$/steer)
Modified-environment building, including plumbing, electrical, and mechanical feeder	85	110	160	
Separate manure storage	Field stack	Concrete tank 35	Lined earth 10	(none)
Totals	\$85	\$145	\$120	\$160

PIG CONFINEMENT HOUSING FOR CONTROL OF WATER POLLUTION AND ODORS

Odor control is an additional requirement often imposed by complaining neighbors on animal production facilities. Ontario, as an example, is approaching this problem by establishing recommended separations between animal production units and neighboring properties, and by establishing guidelines concerning the rapid covering of manure after spreading.

But odors emanating from large animal production buildings are causing many neighbor problems, not always associated with periodic field spreading.

For example, properly designed manure aeration systems can reduce odors inside a pig confinement building to the point where only the most sensitive persons find the odor level objectionable. A well-operated aerobic system produces an odor that has often been described as 'slightly earthy.' The 'bad' odors associated with anaerobic digestion (such as hydrogen sulphide) can apparently be controlled by continuously maintaining aerobic conditions.

The oxidation ditch is one of the most promising aeration systems developed for control of odors emanating from stored animal waste. Because of the particularly bad odors from liquid pig manure, engineering design for oxidation ditch treatment of pig waste is further developed than for other livestock wastes. The Midwest Plan Service has prepared a summary of design requirements (1) for aeration of pig wastes with the oxidation ditch located directly under slatted floors. This arrangement permits year-round operation since it eliminates the freezing problems associated with treatment outdoors.

The oxidation ditch usually consists of a rectangular-sectioned concrete channel under the slotted floor. The typical channel plan is closed like a race track, and one or more toothed rotors are located along straight sections of the channel to aerate the liquid waste and keep it moving around.

The oxidation ditch was first developed in the Netherlands for economical treatment of domestic sewage from small municipalities, and first attempts to use it for processing animal wastes disclosed many problems. For example, foam has been produced overnight in sufficient quantities to completely smother animals in their pens. It is now generally agreed that excessive foam production is a symptom of insufficient aeration capacity or nonuniform loading. It is extremely important that the oxidation rotors run continuously, since even a brief interruption in the dissolved oxygen supply causes a rapid shift of the bacterial population toward the odor- and foam-producing anaerobic types.

Design criteria are now advanced to the point where oxidation ditches are reliable enough for ordinary farm use with pig waste. One manufacturer in the USA produces a 5-hp rotor for about \$1,500 US. Two of these rotors have sufficient capacity to deodorize waste from a typical 500-pig growing-finisher unit, provided the ditch liquid capacity (detention time), rotor immersion depth (aeration capacity), animal population, and liquid velocity are correctly maintained. Electrical costs for treatment of the wastes from a farrow-to-finish system are about \$1 per pig produced.

Most farm oxidation ditches are operating on continuous overflow. To start, the ditch is filled to operating depth with water. The rotor is started when the first pigs go in. Added animal wastes and spilled drinking water cause a corresponding overflow at the liquid-level control weir.

Because this overflow effluent is only partly treated, it cannot be accepted for discharge into streams and will probably go anaerobic in storage. No information appears to be available on the quantity of overflow to be stored and handled. Indications are that the rate of overflow is much less than the waste production rate, which raises the interesting question of where the liquids go. Evaporation from the splashing rotor or a leaking ditch channel could account for this loss, but neither possibility is desirable from the standpoints of winter ventilation and groundwater pollution.

REFERENCES

1. Anonymous. 1970. Oxidation ditch for treating hog wastes. Agr. Eng. Digest AED-14, Midwest Plan Service, Iowa State University, Ames, Iowa.
2. Anonymous. 1965. Climatic information for building design in Canada. Supplement No. 1 to the National Building Code of Canada.
3. Blaxter, K.L., and Wainman, F.W. 1961. Environmental temperature and the energy metabolism and heat emission of steers. J. Agr. Sci. 56:81-90.
4. Bond, T.E., Kelly, C.F., and Heitman, H., Jr. 1952. Heat and moisture loss from swine. Agr. Eng. 33(3):148-152.
5. Boyd, J.S., Hoglund, C.R., and Speicher, John A. 1969. Environmental conditions in free-stall dairy barns. Paper No. 69-401, Amer. Soc. Agr. Eng., St. Joseph, Michigan.
6. Buchanan, L.C., and Fellows, W.P. 1968. Ventilation problems in swine and beef confinement barns. Unpublished paper presented to Can. Soc. Agr. Eng.
7. Buchanan, L.C. 1969. Effect of evaporative cooling and intermittent spraying on swine performance. Unpublished paper presented to Can. Soc. Agr. Eng.
8. Burnside, J.E., Covey, E., and Reed, A. 1969. Air conditioned vs. conventional housing for growing-finishing swine. (Abstract). J. Anim. Sci. 28:140.
9. Cooper, G.S., Ketcheson, J.W., and Webber, L.R. 1969. Agriculture as a contributor to pollution. AIC Review 20(3):9-15.
10. Esmay, M.L., Saeed, M., and Wells, G.D. 1968. Psychrometrics of summer-ventilation air exchange in windowless poultry houses. Agr. Eng. Trans. 11(1):78-80, 85.
11. Giese, H., and Ibrahim, A.A. 1950. Ventilation of animal shelters by the use of heat exchangers. Agr. Eng. 31(7):329-333.
12. Giese, H., and Downing, C.G.E. 1950. Application of heat exchangers to dairy barn ventilation. Agr. Eng. 31(4):167-170, 174.
13. Gray, M.W. 1969. Status report—Kansas feedlot pollution control program. Proc. Anim. Waste Manage. Conf., Kansas City, Mo.
14. Hahn, L., Johnson, H.D., Shanklin, M., and Kibler, H.H. 1965. Inspired air cooling for lactating dairy cows in a hot environment. Agr. Eng. 46(6):332-334, 337.
15. Hall, M.D. 1966. Solar heated ventilation air for swine buildings. Unpublished paper No. 66-440. Amer. Soc. Agr. Eng., St. Joseph, Mich.
16. Harman, D.J., Dale, A.C. and Jones, H.W. 1968. Effect of floor type on the required moisture vapour removal rate from swine finishing houses. Agr. Eng. Trans. 11(1):149-152.
17. Heitman, H., Jr., and Hughes, E.H. 1949. The effects of air temperature and relative humidity on the physiological well-being of swine. J. Anim. Sci. 8:171-181.
18. Irish, W.W. 1969. A study of insulated and ventilated loose-housing systems for dairy cows. Paper No. 69-402, Amer. Soc. Agr. Eng., St. Joseph, Mich.
19. Larkin, B.S., 1971. An experimental study of the two phase thermosiphon tube. Eng. J. 14:3-6.
20. MacDonald, M.A., and Bell, J.M. 1958. Effects of low fluctuating temperatures on farm animals IV. Influence of temperature on milk yield and milk composition. Can. J. Anim. Sci. 38:160-170.
21. Meiske, J.C. et al. 1968. Finishing steers in modified environments. Research Report B-110, University of Minnesota, St. Paul, Minn.
22. Merkel, J.A., and Hazen, T.E. 1967. Zone cooling for lactating sows. Agr. Eng. Trans. 444-447.
23. Muehling, A.J. 1969. Swine housing and waste management. Research Review. AEng-873, Dep. Agr. Eng., University of Illinois, Urbana, Ill.
24. Ogilvie, J.R., and Hore, F.R. 1964. Confined livestock manure disposal. Can. Agr. Eng. 6(1):42-43.
25. Ogilvie, J.R. 1967. A heat exchanger for livestock shelters. Can. Agr. Eng. 9(1):31-32, 53.

26. Ota, H., and McNally, E.H. 1961. Poultry respiration calorimeter studies of laying hens. Agr. Research Service, USDA, 42-43.
27. Pattie, D.R. 1968. Ventilating the barn in cold weather. Agr. Eng. 49(11):668-669, 671.
28. Stewart, R.E., Notestine, J.C., Pfost, D.L., and Schnug, W.R. 1966. Field tests of summer air conditioning for dairy cattle in Ohio. ASHRAE Trans., 72:Part 1.
29. Turnbull, J.E. 1967. European experience with removal of cattle manure from slotted-floor barns. Can. Agr. Eng. 9(1):33-36.
30. Turnbull, J.E. 1967. Can we afford climate-controlled buildings for feeding beef? Engineering Specifications 6702, Engineering Research Service, Can. Dep. Agr., Ottawa.
31. Turnbull, J.E., and Coates, J.A. 1971. Temperatures and air-flow patterns in a controlled-environment cage poultry building. Agr. Eng. Trans. 14(1):109-113, 120.
32. Turner, C.N., and Davis, H.R. 1968. Ventilation with restricted light control for poultry houses. Agr. Eng. Ext. Bull. 319, Cornell University, Ithaca, N.Y.
33. Yeck, R.G., and Stewart, R.E. 1959. A ten-year summary of the psychroenergetic laboratory dairy cattle research at the University of Missouri. Trans. Amer. Soc. Agr. Eng. 2(1):71-77.

METRIC EQUIVALENTS

LENGTH

inch	= 2.54 cm	millimetre	= 0.039 in.
foot	= 0.3048 m	centimetre	= 0.394 in.
yard	= 0.914 m	decimetre	= 3.937 in.
mile	= 1.609 km	metre	= 3.28 ft
		kilometre	= 0.621 mile

AREA

square inch	= 6.452 cm ²	cm ²	= 0.155 sq in.
square foot	= 0.093 m ²	m ²	= 1.196 sq yd
square yard	= 0.836 m ²	km ²	= 0.386 sq mile
square mile	= 2.59 km ²	ha	= 2.471 ac
acre	= 0.405 ha		

VOLUME (DRY)

cubic inch	= 16.387 cm ³	cm ³	= 0.061 cu in.
cubic foot	= 0.028 m ³	m ³	= 31.338 cu ft
cubic yard	= 0.765 m ³	hectolitre	= 2.8 bu
bushel	= 36.368 litres	m ³	= 1.308 cu yd
board foot	= 0.0024 m ³		

VOLUME (LIQUID)

fluid ounce (Imp)	= 28.412 ml	litre	= 35.2 fluid oz
pint	= 0.568 litre	hectolitre	= 26.418 gal
gallon	= 4.546 litres		

WEIGHT

ounce	= 28.349 g	gram	= 0.035 oz avdp
pound	= 453.592 g	kilogram	= 2.205 lb avdp
hundredweight (Imp)	= 45.359 kg	tonne	= 1.102 short ton
ton	= 0.907 tonne		

PROPORTION

1 gal/acre	= 11.232 litres/ha	1 litre/ha	= 14.24 fluid oz/acre
1 lb/acre	= 1.120 kg/ha	1 kg/ha	= 14.5 oz avdp/acre
1 lb/sq in.	= 0.0702 kg/cm ²	1 kg/cm ²	= 14.227 lb/sq in.
1 bu/acre	= 0.898 hl/ha	1 hl/ha	= 1.112 bu/acre

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